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COVER PHOTOS :

Left: *Citripestis eutraphera* infestation on mango (**Photo Credit:** S. M. Chavan, Navsari Agricultural University, Valsad, Gujarat)

Right: Powdery mildew symptoms during flowering and fruit set of mangoes (**Photo Credit:** Sriram S., ICAR– IIHR, Bengaluru, Karnataka)

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Pest Management in Horticultural Ecosystems
Vol. 32, No.1 pp i (June 2026)

Editorial

It gives me immense pleasure to present **Volume 32, Issue 1** of Pest Management in Horticultural Ecosystems, featuring a diverse collection of research contributions and a review article addressing contemporary challenges in horticultural crop protection. The issue encompasses a wide range of topics, including mango powdery mildew and its integrated management; important insect pests and their management; pest population dynamics and their association with weather parameters; pollinator diversity and enhancement of pollination services; molecular identification and phylogenetic analysis of fruit flies; insect–microbe interactions; insect biology and laboratory rearing; and the management of major pests of horticultural crops. The research notes further highlight emerging and invasive pest concerns, including an outbreak of the mango looper, the first report of the invasive soft scale *Fistulococcus pokfulamensis* in Kerala, new host plant records, and the evaluation of management options against *Sciothrips cardamomi*. Collectively, these contributions underscore the importance of integrating ecological understanding, biological control, molecular tools, pollinator conservation, and the judicious use of pesticides to develop sustainable and effective pest management strategies. I hope that the findings presented in this issue will be valuable to researchers, academicians, students, extension professionals, and practitioners, and will stimulate further research towards resilient, environmentally sound, and economically viable horticultural production systems. I sincerely thank all the authors, reviewers, editorial board members, and contributors for their valuable support in bringing out this issue of the journal.

N. R. PRASANNAKUMAR
Chief Editor

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REVIEW ARTICLE

Powdery mildew of mango: Etiology, epidemiology and integrated management strategies

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ABSTRACT: Mango flower and fruit drop in early developmental stage is one of the key reasons for low fruit set which is largely attributed to diseases and pest incidence. Powdery mildew of mango, incited by the fungus *Pseudoidium anacardii* formerly known as *Oidium mangiferae* Berthet, is one of the most widespread diseases of mango world over that can cause up to 80–90% crop loss. The fungus attacks the young tissues of inflorescences, young fruits and leaves. The affected flowers and fruits drop pre–maturely reducing fruit set. High costs of fungicides and their application for its management have further amplified economic importance of this disease. Hence, extensive information on symptomatology, disease cycle, perpetuation and management has been generated worldwide in recent years. There has been a tectonic shift in powdery mildew management strategies which were so far dominated by a couple of sulphur-based fungicides. More effective molecules and non–chemical sustainable strategies have been devised in recent past. There has also been more acceptance of integrated disease management (IDM) strategy for powdery mildew on mango involving disease surveillance-based forewarning, cultural methods, biological control, application of safer and more effective fungicides and some salts. This review discusses the recent worldwide information generated especially on pathogen, disease progress, management strategies and role of nanotechnology in respect of powdery mildew of mango.

Keywords: *Mangifera indica,* Powdery mildew, *Pseudoidium anacardii*, Integrated disease management, Nanotechnology

INTRODUCTION

Mango (*Mangifera indica* L.) produces profuse inflorescences bearing hundreds of ovule-bearing flowers; however, only a small proportion of the initially set fruits reach maturity, making fruit retention a critical determinant of yield. Among the multiple biotic and abiotic factors influencing fruit drop, diseases affecting flowers, leaves, and young fruits play a decisive role, particularly during the flowering to early fruit set stages (Chadha, 1993; Palti *et al*., 1974). Mango is affected by numerous diseases throughout its growth cycle, from nursery to postharvest, many of which significantly limit productivity (Prakash, 1998; Prakash and Raoof, 1994; Iqbal *et al*., 2024). The major diseases affecting mango during the flowering stage include powdery mildew, blossom blight, blossom malformation, and blossom spot. Among these, powdery mildew and blossom blight are particularly damaging, as they directly infect floral tissues on the panicle and markedly increase flower and young fruit abscission (Palti *et al*., 1974; Prakash and Raoof, 1994). Powdery mildew is the most widespread, economically important, and destructive disease of mango, occurring in nearly all mango-growing regions of the world (Hewitt, 1998; Nasir *et al*., 2017; Iqbal *et al*., 2024). It infects multiple aerial parts of the host, including young leaves, inflorescences, flowers, and developing fruits. On young leaves, infection appears as white powdery growth on both surfaces, leading to curling, distortion, and reduced photosynthetic efficiency. On inflorescences, the pathogen colonizes panicle branches, flowers, and pedicels, causing flower necrosis, failure of anthesis, and extensive blossom shedding. Infection of flowers and peduncles directly interferes with pollination and fertilization, thereby exacerbating early fruit drop. Young fruits, when infected, often become completely covered with fungal growth, resulting in epidermal damage, cracking, and premature abscission (Sridhar and Sohi, 1973; Prakash and Mishra, 1986; Lonsdale and Kotze, 1993; Sinha *et al*., 2001; Iqbal *et al*., 2024).

Powdery mildew of mango is caused by the obligate fungal pathogen *Pseudoidium anacardii* (syn. *Oidium mangiferae*) and is one of the most destructive diseases

affecting mango production. The disease is particularly severe under cool, dry, and humid conditions prevailing during flowering, when infection coincides with the most susceptible phenological stage of the crop. Epidemics during this critical stage can markedly reduce fruit set and fruit retention, resulting in substantial yield losses. Depending on disease severity and prevailing environmental conditions, yield losses have been reported to range from 20–25% under moderate infection to as high as 90% during severe epidemic years (Reuveni and Reuveni, 1995; Nasir *et al*., 2014; Reuveni *et al*., 2018; Iqbal *et al*., 2024; Abou El-Nasr *et al*., 2025). Powdery mildew diseases, in general, represent one of the most important groups of plant pathological problems worldwide, infecting nearly 10,000 species of angiosperms and accounting for a substantial proportion of fungicide use in agriculture (Briton, 1923; Hewitt, 1998; McGrath, 2021). In mango, the disease has emerged as a major limiting factor in recent years, particularly in tropical and subtropical regions where favourable climatic conditions during flowering frequently lead to epidemics (Raut *et al*., 2020; Deshmukh *et al*., 2021; Iqbal *et al*., 2024). Despite its significant economic impact, management of mango powdery mildew remains challenging due to its strong dependence on weather conditions during flowering, limited availability of stable host resistance, and increasing concerns over fungicide resistance and residue accumulation (Reuveni *et al*., 2000; McGrath, 2021). Accordingly, this review summarizes recent advances in symptomatology, epidemiology, host response, and chemical, biological, and nanotechnology-based management strategies, to support the development of sustainable disease management strategies.

Distribution and economic importance

Powdery mildew, one of the earliest identified diseases on mango, was first recorded in Brazil in 1914, where the pathogen was illustrated by Berthet (Briton, 1923). In India, it was reported very early by Wagle (1928), Galloway (1935) and Uppal (1937). According to Johnson (1994), the disease was most likely present throughout the Indian Subcontinent since late 1980s. In India, this disease continues to be one of the major limiting factors in mango cultivation, despite having been reported nearly a century ago. In the past, this disease was sporadic, but now it has become a disease of regular occurrence not only in India but also in other mango growing countries worldwide (Prakash, 2004; Nasir *et al.,* 2014).

In general, losses caused by powdery mildew of mango depend upon several factors like agroclimatic region, cultivar, weather conditions during flowering and disease management practices. Because of the variation in these factors and their interaction, losses caused by the disease are highly fluctuating and often lead to inaccurate estimation of losses. Blossom infection is the major cause of losses rather than leaf infection in the most susceptible mango cultivars (Ruehle and Ledin, 1956; Gupta and Dang, 1980; Lonsdale and Kotze, 1993; Ploetz, 2003). In the major mango growing countries, loss estimates up to 70% have been reported (Ihsan *et al.,* 1999), but on an average basis 15– 20% losses have been estimated worldwide (Nasir *et al.,* 2014). In normal infection conditions, 20– 40% of flowers and fruits are destroyed but during epidemics, which may result in complete failure of the mango crop (Prakash and Srivastava, 1987). This disease can cause up to 80% yield losses when outbreaks occur during early flowering (Johnson, 1994). Prakash and Srivastava (1987) reported 30– 90% losses in India and 80– 90 % in South Africa (Kotze, 1985), while it can cause up to 80–90% crop loss under favourable conditions (Schoeman *et al.,* 1995). Powdery mildew incidence of 97% was recorded with 88% severity in Uttar Pradesh, India during the last week of March (CISH, 2014). Even complete crop failure was observed in South Africa by Joubert *et al*. (1993). Another estimate in India reported losses ranging from 22.35 to 90.41% (Prakash and Mishra, 1993; Prakash and Raoof, 1994).

Recent evidence confirms that powdery mildew remains a major constraint to mango production across all major growing regions, with disease incidence approaching 100% under favourable conditions and average yield losses of 20–25%, occasionally resulting in near-complete crop failure (Iqbal *et al*., 2024). Increasing climate variability is further influencing disease epidemiology, as cool and dry conditions during flowering continue to favour infection, while altered rainfall and temperature patterns intensify disease severity and unpredictability. Consequently, losses associated with powdery mildew are becoming more variable and severe, driven not only by cultivar and agronomic factors but also by climate-driven shifts that exacerbate disease pressure and economic impact on mango production (Singh and Singh, 2023).

Pathogen

The use of molecular tools has greatly improved our knowledge in recent years regarding taxonomy of

pathogens inciting powdery mildews (Takamatsu *et al.,* 2007). A major limitation in the study of powdery mildew pathogens lies in their obligate biotrophic lifestyle as they cannot be cultured on artificial media. Due to their obligate biotrophic nature, the relationship between powdery mildews and their host plant is highly conserved. Recently, an updated taxonomic monograph of the powdery mildews has been published (Braun and Cook, 2012). Erysiphales in its current circumscription encompass 873 known species. The taxonomy and nomenclature of the Erysiphales follows Braun (1987). Further, it was updated and supplemented by Braun and Takamatsu (2000). Major changes have recently occurred in the taxonomy and nomenclature of the family Erysiphaceae. In 1914, Berthet first described as *Oidium mangiferae* Berthet (Briton, 1923). On the basis of conidial germination and histological studies (globular haustoria), the pathogen was later kept in the *Erysiphe polygoni* group. As the perfect stage of the pathogen was not described by Uppal (1937), the name of the conidial stage *O. mangiferae* Berthet was preferred. The *Oidium* sp. infecting mango was suspected to also infect oak and other trees (Gorter, 1984; Joubert *et al*., 1993) because the characters of the two species were similar however the evidence was insufficient. Joubert *et al*. (1993) differentiated two powdery mildew fungi based on their conidiophore characters and several workers characterized the morphological features of *O. mangiferae* (Akhtar *et al.,* 1999; Palti *et al.,* 1974). It was subsequently established as the causal agent of mango powdery mildew worldwide, with mango recognised as its only known host (Palti *et al.,* 1974). The pathogen was subsequently renamed as *Pseudoidium anacardii* (F. Noack) (Braun and Cook, 2012). The conidia are produced in a basipetal fashion and are sometimes seen singly or in pairs. Conidia measure 25 to 48.9 μm in length and 16 to 23.9 μm in width, mostly 33 to 42.9 x 18 to 21.9 μm and germinate by a germ tube. A survey of conidial characters useful for powdery mildew species identification has been provided by Braun and Cook (Braun and Cook, 2012).

The telemorph of the pathogen is not known in many locations (Nasir *et al.,* 2014). According to Limkaisang *et al.* (2006) and (Takamatsu *et al.*, 2007), the anamorphic powdery mildews occurring on several tropical trees*, viz. Acacia, Anacardium, Bixa, Citrus* and *Mangifera* spp. relate to the oak powdery mildew *Erysiphe quercicola. E. quercicola* was first described on oak in Japan by Takamatsu *et al.* (2007). The species name *Quercicola* refers to the host genus Oak (*Quercus*). Cunnington *et al*. (2003) reported that the ITS sequence of *O. mangiferae* on mango was identical to that of *E. alphitoides* from *Q. robur*. This report also suggests a close relationship between *E. alphitoides* and anamorphic powdery mildews distributed in tropical and subtropical areas, hence these molecular studies of the ITS- ribosomal DNA region have provided useful links between anamorphic Erysiphales and their respective teleomorphs. Differences in the nucleotide sequences of ITS regions of rDNA and PCR using species-specific primers have been used very effectively for detection or identification of powdery mildew pathogens (Takamatsu and Kano, 2001). The powdery mildew pathogen associated with mango inflorescences, collected during 2011-2012 from the Kent and Keith varieties in northern Sinaloa, Mexico, were analysed by molecular and phylogenetic analysis of the ITS rDNA region (Felix *et al.,* 2013). These samples were found to be closely related to *P. anacardii* specimens collected from mango trees in various countries. However, the teleomorph was not found. Studies on ecology and classification of the powdery mildew fungi of mango in tropical region are limited due to limited number of researcher groups and lack of teleomorphs in these regions necessary for species identification. Hence, the names of powdery mildew fungi used in this review are identical with those used in the corresponding references to avoid confusion.

Host plant resistance

Host plant resistance is one of the most desirable and sustainable approaches for managing powdery mildew in mango. However, studies conducted across different mango-growing regions consistently report wide variation in cultivar responses, with disease expression strongly influenced by prevailing weather conditions during susceptible phenological stages, particularly flowering. Consequently, the literature often presents contradictory assessments of cultivar performance. In highly susceptible cultivars, powdery mildew may infect flowers, fruits, and leaves simultaneously, resulting in severe yield losses (Ploetz and Ploetz, 2003). Early screening studies identified limited variability in disease incidence among mango cultivars, with only a few cultivars such as Neelum, Zardalu, Banglora, and Totapuri exhibiting comparatively lower incidence (Gupta, 1976). Subsequent evaluations confirmed that most commercially important mango cultivars exhibit variable to moderate levels of powdery mildew incidence depending on agro-climatic conditions, rather than stable

resistance (Palti *et al*., 1974; Datar, 1983; Prakash and Raoof, 1994; Akhtar *et al*., 1999).

Marked variation in powdery mildew incidence among mango cultivars has been reported across different agro-climatic regions, highlighting strong genotype × environment interactions. In southern India, the disease has been observed to persist for most of the year on cultivars such as Pairie and Alphonso, indicating sustained susceptibility under favourable climatic conditions (Rawal, 1998). In contrast, field evaluations in Bihar recorded comparatively low disease incidence in cultivars Totapuri, Totapuri Red Small, Vashi Badami, and Ladavio, whereas cultivars such as Mahmood Bahar, Kesar, Neelum, Samar Bahisht Chaunsa, Sensation, and Bangalora exhibited low to moderate disease incidence (1–15%), suggesting partial tolerance rather than complete resistance (CISH database; http: www.cishlko.org/pccell.php).

Similarly, varietal screening conducted in Andhra Pradesh during 2008 revealed low disease incidence in Totapuri and Kesar (≈10%), intermediate incidence (11–20%) in Beneshan, Peddarasam, Chinnarasam, and Cherukurasam, and high incidence (>40%) in Neeluddin, Surya Amrutham, and Nuzivid Thiyamamidi (APHU Annual Report, 2008–09). Earlier studies also indicated that Totapuri consistently exhibits comparatively lower disease incidence across locations, although its response is influenced by environmental conditions (Datar, 1983). Comparative analyses synthesizing quantitative disease data from multiple studies have further classified mango cultivars according to severity scales. Using such approaches, cultivars such as Ghanya, Jahangir, Yellamondela Thiamandi, Bablipunasa, Kharbuja, and K.O.7 have been reported to exhibit relatively low disease incidence, while Zill, Kent, Alphonso, and Nam Dok Mai were categorized as highly susceptible. Intermediate incidence levels were observed in cultivars including Haden, Glenn, Carrie, Keitt, Sensation, Tommy Atkins, and Kensington (Johnson, 1994; Prakash and Raoof, 1994).

Recent multi-location field evaluations across India and Pakistan have consistently demonstrated wide variability in powdery mildew incidence among mango cultivars, reinforcing the strong influence of genotype × environment interactions. In Rajasthan, high disease incidence was recorded in Bombay Green and Dashehari (57.3%), moderate incidence in Amrapali (50.2%), and comparatively lower incidence in Mallika (23.7%), Chaunsa (19.2%), Kesar (19.2%), and Langra (15.6%) (Yadav *et al*., 2014). Comparable variability has also been reported in Pakistan, where among 25 mango cultivars evaluated in 2011, the lowest disease incidence (3.66%) was observed in Almas and Sensation, while high incidence occurred in cultivars such as Dashehari, Chaunsa Samar Bahisht, Malda, and Ratole No. 12 (Naqvi *et al*., 2014). Notably, despite relatively high disease incidence, some cultivars maintained satisfactory yields and were therefore classified as tolerant rather than resistant.

Further field-based screening under natural epiphytotic conditions at Dhaulakuan and Jachh (Nurpur) showed that cv. Totapuri consistently exhibited comparatively low disease incidence (14.15–16.33%), along with the lowest apparent infection rate (0.02–0.04 day^{-1}) and AUDPC values (1.08–1.39), indicating relatively stable performance across environments (Kaur *et al*., 2020). Similarly, multi-season evaluations conducted under western Vidarbha conditions of Maharashtra (2016–2019) revealed disease incidence ranging from 31.9% to 47.9%, with cv. Dashehari recording the lowest pooled incidence and cv. Vanraj the highest, highlighting the limited availability of strong resistance among commercial cultivars (Deshmukh *et al*., 2021). Collectively, these studies confirm that powdery mildew incidence in mango is highly variable across cultivars and environments, and that no cultivar consistently expresses complete immunity, emphasizing the need for continued multi-location screening and integration of host response data into disease management strategies.

Susceptibility of host parts

More precise knowledge of when to expect the first appearance of the disease, based on prevailing weather conditions and the susceptible host part, would govern correct timing of fungicide applications. Young leaves and panicles are attacked more frequently. On young leaves, both sides of the leaf are attacked, and the upper side may even be affected more severely (Burnett, 1975). Mildew on the undersurface is frequently restricted to the area of the central rib and such leaves are often twisted, curled and distorted (Romero *et al.,* 2003; Palti *et al.,* 1974; Cook, 1975). Infection is frequently noticed on young leaves, when their colour changes from brown to light green and distortion of leaves is more common in plains (Mishra and Prakash, 1995). However, this fungus predominantly infects and colonizes all parts of the panicle, including flowers and young fruits (Fig. 1). The

sepals are relatively more susceptible than the petals. The main branches of the inflorescence are affected partially on the less susceptible cultivars (Prakash, 2004).

Powdery mildew severity in relation to developmental stages was studied in detail by Schoeman *et al.* (1995). The mango inflorescences were classified into a number of developmental stages and among the various stages, from the protected stage (elongation of inflorescence still protected by bracts) susceptibility increased with inflorescence development to the full- bloom stage. On normal flowering inflorescences, the first symptoms were detected 2 weeks after 20% of the inflorescences were between the red– coloured and fruit-set stages. The green-coloured and red-coloured stages of inflorescence were only slightly susceptible and full-bloom stage appeared to be the most susceptible stage. Inflorescence developmental stages before the protected stage were immune to infection, even when disease levels had reached a peak on other inflorescences in the field (Schepers, 1983). The powdery mildew affected flowers turn brown, grey and brittle and can be easily crumbled. Infection often causes flowers and small fruits to abort and fall off. When infection occurs on the flower stalks and flowers of mango, the flowers usually cease to grow, fail to open, and shed; however, they sometimes persist and set fruit (Palti *et al.,* 1974). In highly susceptible varieties, all branches, including the central axis of the inflorescence, may be completely covered with mildew and eventually blacken. On less susceptible varieties, only portions of the branches are affected; the upper part of the stalk is more often mildewed; however, the centre stalk is not severely affected at its base. Acute blossom infection may cause complete damage to fruit; the flower remains closed and drops from the inflorescence. Almost all the inflorescence showed a pattern of disease from tip to downward (Singh, 1960; Palti *et al.,* 1974). Fungal development stops when infected tissues become necrotic (Palti *et al.,* 1974). Recent reviews emphasize that panicles and young fruits remain the highest-risk host parts under favourable weather conditions, particularly during cool and dry flowering periods, while also highlighting the lack of comprehensive field-based data across diverse climatic regimes and developmental stages, underscoring the need for further research on temporal susceptibility windows and tissue-age-dependent infection dynamics (Iqbal *et al*., 2024).

Similarly, in peach, only certain developmental stages were susceptible to powdery mildew caused by *Sphaerotheca pannosa* var. *persicae*, and infection appeared only one month after flowering. Fruits were susceptible during the early stages of their development and became completely resistant two months after flowering (Weinhold, 1961). A study on the biochemical changes in powdery mildew infected panicles revealed that there is a continuous decrease in the percentage of moisture according to infection level. Further, pH increases with increasing infection in affected host tissue and contents of total sugars and tannins decrease with the severity of the disease (Prakash *et al.,* 1989). Researchers have hypothesized that metabolites, phytoalexins, phenolic compounds, inhibitors, and calcium/ phosphate ions may play a role in such host pathogen interactions (Nasir *et al.,* 2014). However, the main reasons for the susceptibility of certain host tissues at specific developmental stages are not known and need to be studied further.

In India, the disease has been noticed on young mango fruits in varieties such as Dashehari, Kishan Bhog. In such varieties, fruits may remain on the tree until they reach pea size and then drop prematurely. As infected newly– set fruit develop, the epidermis of the infected area cracks and corky tissue is formed (Palti *et al.,* 1974; Joubert *et al.,* 1993). In Mexico, along with powdery mildew infection on inflorescences, a scabby appearance was also observed on a high percentage

Fig. 1. Powdery mildew symptoms during flowering and fruit set of mangoes

of fruits (Felix *et al*., 2013). Such discolouration and distortion of fruits have serious bearing on the fruit quality. These symptoms and the factors leading to such infections need to be investigated further.

Disease cycle and perpetuation

The fungus produces spores abundantly all over the surface of affected tissues. The fungal spores disseminate through wind and produce germ tubes on susceptible host tissues to initiate infection. Wagle (1928) had elaborated on the life cycle of mango powdery mildew pathogen. The life cycle from conidia to conidia is completed in about five days. No teleomorph of the pathogen is known from mango (Fig. 2) (Nasir *et al.,* 2014). Studies have revealed that the powdery mildew pathogen of mango perpetuates in older infected mango leaves and intact green malformed inflorescences in the form of mycelium, conidia or dormant mycelium (Prakash and Raoof, 1985; Gupta, 1988). Under Indian conditions, pathogen survives in the form of mycelium, conidiophores and conidia from April to August and only in mycelial stage from September to December on older infected leaves during off-season. It also perpetuates on infected green inflorescences which remain hidden under dense foliage of mango tree during off– season in mycelial form (Singh, 2000). During favourable weather conditions, the dormant mycelium is activated and profuse spores are produced and blown on to new susceptible tissues leading to initiation of fresh infection (Mougy *et al.,* 2014).

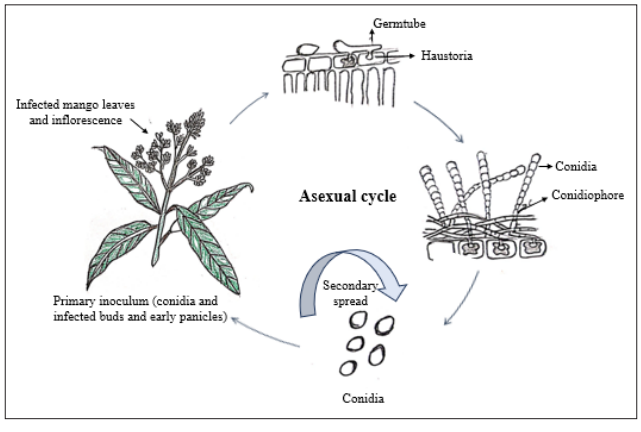

Fig. 2. The life cycle of a powdery mildew fungus on mango

Role of epidemiological factors

For a powdery mildew epidemic to occur, weather conditions favourable for conidia release are necessary and susceptible tissue must be available at the same time (Schoeman *et al.,* 1995) Powdery mildew epidemics exhibit distinct temporal and spatial patterns and are influenced by a complex interplay of factors, including weather conditions, host susceptibility, pathogen virulence, and crop management practices (Sinha *et al.,* 2004). For forewarning, information on these factors is used as input. Development of powdery mildew is characterized by an initial slow growth when favourable conditions just set in during susceptible stage of the host. But suddenly epidemic starts in a devastating appearance leaving no time for taking any appropriate control measure. The pathogen grows very fast (4 to 5 days latent period) and therefore, timely decisions are vital for its management. Spores blown from infected areas readily adhere to hairy, un-opened flowers near tip of the inflorescence and germinate within 5 to 7 hrs (Weinhold, 1961). Overall disease development is favoured by high humidity (Palti *et al.,* 1974). The released spores of powdery mildew germinate and cause infection even if there is no film of water on plant surface as long as the relative humidity in the air is fairly high and once the infection starts the mycelium continues to spread on host regardless of the moisture condition of the atmosphere (Agrios, 2005). Butt (1978) reported that free water generally causes damage to superficial mycelium of powdery mildews and that spore number is low for several days after rain though the rains can also stimulate the pathogen by raising the atmospheric humidity. According to Kotze (1985), outbreaks of powdery mildew do not have to be preceded by rain or dew. The disease appearance and incidence are greatly influenced by the sunshine (hours) per day and it is inversely proportional to the disease having a correlation coefficient of r =0.5943. The pathogen causes maximum infection on the host plant at 26°C and 100% relative humidity (Gupta, 1989). A similar kind of study revealed that consecutive occurrence of high RH (>80%) and minimum temperature above 10°C for 4– 5 days is conducive for powdery mildew development on floral parts (Jones, 1923).

The disease symptoms appear in February and March in India, on flower scales, flower heads, young leaves, stalks and fruits (Singh, 1960). During flowering, periodical monitoring of mildew severity was carried out using the standard meteorological week (SMW) as the time scale, starting with January 1-7 as first SMW of the year. The mean maximum (32.6^{o}C) and minimum (10.84 to 11.19^{o}C) temperature and relative humidity (50 to 60%) recorded between 5th to 8th SMWs were

found very congenial for the appearance and spread of powdery mildew in Maharashtra state. In Uttar Pradesh, first incidence of powdery mildew was observed on Dashehari during the last week of January and maximum incidence (97%) with severity (88%) was recorded in the last week of March. At Central Institute for Subtropical Horticulture (CISH) farm, powdery mildew was observed with moderate incidence (37.6%) with severity of 34.1 per cent during end of March (13th SMW) (CISH Annual Report, 2013-14). In Andhra Pradesh, disease incidence was first noticed during last week of January (4th SMW), 2014 in mango cv. Dashehari (susceptible) and Baneshan (moderately susceptible) cultivars and continued up to February last week (8th SMW). In both the varieties the maximum disease severity was observed during 2nd week of February (6th SMW). Appearance of powdery mildew was first noticed on panicles during 4th week of February and on leaf and twigs during second week of February at FRS, Sangareddy (https://drysrhu.ap.gov.in/). Sinha *et al.* (1960, 2000) studied in detail about the statistical modelling and forecasting methods for mango powdery mildew and analysed the critical weather factors for the development of powdery mildew to develop a forewarning model. CISH, Lucknow has also developed an expert system (mango decision support system) for weather based forewarning of powdery mildew disease. It takes into account four weather parameters viz., max. and min. temperature, relative humidity and wind speed which favours the development of powdery mildew and also recommends a fungicide spray schedule for its effective management (CISH, 2014). Since this disease is weather sensitive and necessitates regular monitoring of weather factors and trapping of conidia in the area to apply control measures (Mishra and Prakash, 1995; Mishra, 2001).

Powdery mildew development in mango is strongly governed by weather conditions prevailing during flowering and early fruit set, with epidemics closely linked to temperature, relative humidity, and airborne inoculum levels. In Mexico, disease outbreaks were associated with high temperatures (>30 °C), elevated relative humidity (≥90%), and increased conidial density, with full bloom and early fruit set (8–15 mm fruits) identified as the most susceptible stages (Pérez-Rodríguez *et al*., 2017). Similarly, in the Konkan region of Maharashtra, disease onset typically occurs in January and peaks by the second fortnight of March, reaching up to 85.6% severity, with incidence showing a significant positive correlation with minimum temperature (Raut *et al*., 2017). Complementary regression analyses indicate that temperature, relative humidity, and rainfall together explain 85–94% of disease variability, identifying moderate temperatures (≈16–26 °C) combined with high but fluctuating relative humidity (61–95%) as most conducive for epidemics and underscoring the value of weather-based forecasting models for timely disease management (Mamta *et al*., 2021).

Epidemiological studies have demonstrated that mango powdery mildew epidemics are strongly governed by short-term weather fluctuations during flowering. A seven-year field study (2012–2018) showed that disease initiation coincided with panicle emergence, with peak incidence and severity occurring between the 11th and 13th standard meteorological weeks, and that disease incidence and severity were negatively correlated with average relative humidity ($r = -0.766$ to -0.787) but positively correlated with maximum temperature ($r \approx 0.71$–0.75); stepwise regression analysis further indicated that average relative humidity alone explained 59–62% of the variability in disease development, highlighting its dominant role in epidemic progression (Bana *et al*., 2020). Complementary findings from a three-year study (2016–2019) under western Vidarbha conditions reported 31.9–47.9% disease incidence during flowering, with positive correlations with rainfall and relative humidity and a significant negative correlation with bright sunshine hours, confirming that humid, low-radiation conditions during flowering are the principal drivers of mango powdery mildew epidemics (Deshmukh *et al*., 2021).

Management of powdery mildew of mango

Fungicides in the management of mango powdery mildew

Chemical control has played a crucial role in the management of mango powdery mildew, particularly during flowering and early fruit-set stages when the crop is most vulnerable. Earlier disease management relied on inorganic fungicides such as copper compounds and sulphur, which provided limited and inconsistent control and were constrained by phytotoxicity under high temperature conditions (Palti *et al*., 1974; Prakash and Raoof, 1994). The introduction of contact fungicides such as dinocap and systemic fungicides including morpholines and benzimidazoles improved disease suppression, though their efficacy declined under high disease

Table 1: Fungicide-based management strategies for powdery mildew of mango

Fungicide group / strategy	Active ingredient(s)	Dose / formulation	Crop stage / timing	Key Findings	Location / cultivar	Reference
Systemic fungicide (Morpholine)	Tridemorph	–	Flowering	Effective disease control	India	Gupta and Yadav (1984)
Triazole (DMI)	Difenoconazole	0.05%	Flowering	97.9% disease reduction over control	–	Peterson *et al*. (1991)
Inorganic contact fungicide	Bordeaux mixture, Copper oxychloride	–	Flowering	Limited control; historical use	India	Prakash and Raoof (1994)
Contact fungicide (multisite)	Sulphur (wettable / dust)	0.2%	Flower cluster expansion to fruit set	Preventive control; inexpensive; phytotoxic above 30 °C; frequent sprays required	India, Israel	Palti *et al*. (1974); Peterson *et al*. (1991); Nelson (2008)
QoI (Strobilurin)	Trifloxystrobin	–	Bloom clusters	Best control of powdery mildew on bloom clusters	Israel	Reuveni (2000)
Contact fungicide (nitrophenol)	Dinocap	0.05%	Flower initiation to fruit set (fortnightly)	Effective in disease control under low–moderate disease pressure	Andhra Pradesh, India	Vijay and Satyanarayana (2002)
Triazole (DMI)	Penconazole	–	Pre-flowering to fruit set	Superior to non-triazoles	Punjab, cv. Dashehari	Thind *et al*. (2005)
Triazole (DMI)	Hexaconazole	0.05%	Flowering	Lowest disease incidence (21.2%); highest fruit retention	Maharashtra, cv. Kesar	Chavan *et al*. (2009)
Integrated spray schedule	Sulphur → Hexaconazole + Zineb	Sulphur 0.2%; Hexaconazole 0.1%	15–20 days interval	Disease maintained below Economic threshold	India	Shukla and Adak (2016)
Premix (DMI + QoI)	Tebuconazole + Trifloxystrob	3 bloom sprays	Flowering	>90% disease control	Pakistan	Nasir *et al*. (2017)

Premix (SDHI + DMI)	Fluopyram + Tebuconazole	750 ml ha^{-1}	Flowering	Powdery mildew incidence reduced to 25.10%	Maharashtra (Konkan)	Patil *et al*. (2017)
Fungicide strategy	Systemic + contact multisite	Rotational sprays	Flowering	Improved disease suppression; reduced resistance risk	Mexico	Pérez-Rodríguez *et al*. (2017)
QoI (Strobilurin)	Azoxystrobin 23% SC	2 ml L^{-1}	Flowering–fruit set	≈67% disease reduction; highest yield (28.63 t ha^{-1}); non-phytotoxic	Karnataka	Ravikumar *et al*. (2017)
Timing-based fungicide strategy	Sulphur / mineral oil + DMI fungicides	10-day interval	Panicles 5–10 cm	70–90% disease suppression; better than 14-day schedule	Israel	Reuveni *et al*. (2018)
Mineral oil–based fungicide	Mineral oil + D-limonene + Penconazole + Myclobutanil + Tetraconazole + Difenconazole	–	Flowering	71–86% disease reduction; Addition of D-limonene to mineral oil has improved efficacy compared to commercially available mineral oil	Israel	Reuveni *et al*. (2018)
Premix (DMI + DMI)	Pydiflumetofen + Difenoconazole	0.6 ml L^{-1}	Flowering	Minimum PDI (8.88%); 82.88% disease control	Maharashtra, cv. Alphonso	Raut *et al*. (2020)
Triazole (DMI)	Hexaconazole 5% EC	1 ml L^{-1}	Flowering	low per cent disease index (≈9–10%) and ≈83% disease control, highest fruit yield	Punjab, India	Arora *et al*. (2021)
Systemic fungicides	Tebuconazole + Trifloxystrobin, propiconazole	-	Flowering	62–63% disease reduction	Pakistan	Majeedano *et al*. (2021)
Premix (DMI + QoI)	Tebuconazole + Trifloxystrobin	0.5–0.75 g L^{-1}	Flowering	Lowest PDI (3.33–3.84%); 85.7–87.5% reduction	India	Basha *et al*. (2024)

pressure. Over the last two decades, triazole (DMI) fungicides have become central to powdery mildew management due to their protectant, curative, and eradicant properties (Thind *et al*., 2005; Chavan *et al*., 2009). More recently, strobilurins (QoIs) and premix formulations combining multiple modes of action have been evaluated to enhance control and delay resistance development, highlighting the importance of fungicide rotation and integrated disease management strategies (Reuveni et al., 2018; Arora *et al*., 2021). Key studies on fungicide-based management of mango powdery mildew are presented in Table 1.

Timing of fungicide application

Precise knowledge of the first appearance of the disease and its subsequent development, based on weather conditions and susceptibility of different developmental stages, would aid growers in ascertaining optimum timing of fungicide applications (Schoeman *et al.,* 1995). Quick identification and diagnosis of powdery mildew especially on inflorescence is very important. Unfortunately, as powdery mildew can quickly colonize the entire inflorescence, the most effective way to counter the disease is to use prophylactic control measures to prevent any losses in the forthcoming season. First disease symptoms were detected 2-3 week after 20% of the inflorescences attained the red–coloured to red–open stages. Therefore, fungicide application is necessary before 50% of the inflorescences attain the full-bloom stage. The red-coloured and red-open stages are well–defined stages in the mango and make it easier for the grower to determine when spraying should start. Further, growers should monitor the development of the inflorescences and apply the first fungicidal spray as soon as axes of inflorescences change colour (Schoeman *et al.,* 1995). According to Nelson (2008) the first spray application should be done not later than at 50% of full flowering, and spraying should continue every 7-14 days thereafter until fruit set. Cultural practices and phytosanitation can also minimize disease to certain extent, but time of application of fungicides remains the mainstay of powdery mildew disease management (Nasir *et al.,* 2014, Schoeman *et al.,* 1995).

Importantly, recent field studies from Mexico reinforce and refine these recommendations, demonstrating that fungicide applications precisely timed to the period of full bloom and early fruit set (8–15 mm) provide significantly superior disease control compared with sprays applied outside this window. Moreover, scheduling applications *in* anticipation of conducive weather conditions, rather than after disease establishment, markedly enhances fungicide efficacy, underscoring the value of epidemiology-driven, time-sensitive spray programs for effective mango powdery mildew management (Pérez-Rodríguez *et al*., 2017).

Effect of fungicide application on flowers

Several studies have documented the adverse effects of agrochemical sprays on pollen germination, fruit set, and yield in different crops. In most fruit crops, early-season fungicide applications are essential to protect susceptible floral tissues and foliage; however, the timing of these sprays often coincides with the full-bloom stage, when pollination occurs. Successful pollination in higher plants involves a sequence of critical events, including stigma receptivity, pollen transfer and adhesion, pollen germination, pollen tube growth, and subsequent fertilization leading to fruit set (Raghavan, 1978; Wetzstein and Sparks, 1989). Disruption of any of these processes can negatively affect fertilization and yield, and several fungicides have been reported to interfere with one or more of these steps. In mango, information on the effects of fungicides on pollen viability and fertilization is extremely limited, with only a single study by Dag *et al*. (2002) addressing the impact of fungicides on pollen germination. In contrast, extensive research has been conducted in apple and other temperate fruit crops. Kovach *et al*. (2000) reported that fungicides such as benomyl, captan, vinclozolin, and iprodione, when applied at bloom, significantly reduced seed number per berry and berry weight in strawberry. Similarly, Church *et al.,* (1983) demonstrated that captan and dinocap significantly inhibited pollen germination and pollen tube growth in apple flowers under orchard conditions when applied two hours after pollination.

Mechanistic studies have shown that several fungicides can inhibit pollen germination and pollen tube growth through different mechanisms. Benomyl and triazole fungicides inhibit pollen tube elongation by disrupting microtubule organization, as demonstrated in *Tradescantia* (He et al., 1995, 1996). Similarly, in cranberry, captafol and cupric hydroxide reduced pollen germination by more than 50% when applied to stigmatic surfaces one hour prior to pollination. Numerous *in vitro* studies on apple pollen have also reported inhibitory effects of fungicides such as benomyl,

Table 2: Non-chemical and integrated approaches for management of powdery mildew in mango

Category	Control agent / approach	Mode of action	Effectiveness reported	Key advantage	Limitation	Reference
Integrated disease management	Cultural practices (sanitation, removal of infected leaves and panicles)	Reduction of primary inoculum	Reduced disease severity; improved fungicide efficacy	Environmentally safe; preventive	Labour-intensive; not curative	Joubert (1991); Prakash and Mishra (1993a); Prakash and Raoof (1994)
Inorganic salts	Phosphate and potassium salts (KH_2PO_4, K_2HPO_4)	Direct antifungal action; host resistance induction	Significant reduction in powdery mildew severity	Eco-friendly; residue-free	Requires repeated sprays	Reuveni *et al*. (1994); Reuveni (1996); Mahrous (2003)
Salt–fungicide integration	Phosphate salts + DMI fungicides (penconazole, myclobutanil, diniconazole)	Contact + systemic protection	Comparable or superior control vs full-dose fungicide sprays	Resistance management; reduced residues	Requires optimized scheduling	Reuveni and Reuveni (1995); Reuveni (2000)
Commercial biofungicide	*A. quisqualis*	Hyperparasitism	Moderate to good disease control	Registered product	Limited standalone efficacy	Hofstein *et al*. (1996)
Inorganic salts	Mono-potassium phosphate (KH_2PO_4 / MKP)	Host defense induction	Effective disease suppression; allowed 50% reduction in fungicide use	Reduces fungicide load; improves nutrition	Preventive; timing dependent	Napier and Ooshyes (2000)
Biological control	*Ampelomyces quisqualis*	Hyperparasitism of powdery mildew	Reduced disease severity; increased yield	Target-specific; eco-friendly	Slow action; variable field efficacy	Sztejnberg *et al*. (1989); Kiss (2003)
Integrated bio-based approach	BCAs + KH_2PO_4 (0.5%)+ kaolin (0.5%) + antioxidants (l mM, ascorbic acid)	Multiple modes: antagonism, physical barrier, resistance induction	Strong reduction in disease severity and conidial germination	IPM-compatible	Complex mixtures; field validation needed	Nofal and Haggag (2006)
Inorganic salts	Mono-basic potassium phosphate	Host defense induction	Significant reduction in powdery mildew severity	Eco-friendly	Requires repeated applications	Azmy (2014)

Salt–fungicide integration	Sulphur / mineral oil + DMI fungicides	Contact + systemic protection	70–90% disease suppression with 10-day spray interval	Reduced fungicide dose	Timing critical	Reuveni *et al*. (2018)
Commercial BCA	*A. quisqualis*	Hyperparasitism	Moderate to good disease control	Registered biofungicide	Limited standalone efficacy	Azmy (2014)
Biological control	*Bacillus subtilis* / *Ampelomyces quisqualis*	Antagonism & hyperparasitism	>90% disease reduction under field conditions	Eco-friendly	Repeated sprays required	Kaur *et al*. (2018)
Botanicals / natural fungicide	garlic oil + chili oil + sulphur + copper	Antifungal activity of essential oils + micronutrients	Very low disease severity (≈2–15%); 70–94% efficacy; increased yield	Eco-friendly, cost-effective	Multi-component formulation; needs validation across regions	Alkolaly *et al*. (2022)
Botanicals	Neem leaf extract (10%)	Antifungal & growth-regulating effects	Lowest disease severity (≈10.83%); 76.67% disease reduction	Organic alternative	Reduced efficacy under high disease pressure	Patel and Mahatma, (2024)
Integrated bio-nutrient approach	Organic inputs (panchagavya, vermiwash, jeevamrut)	Nutrition-mediated resistance	Reduced powdery mildew severity; improved yield and fruit quality	Suitable for organic farming	Lower efficacy than fungicides	Kulkarni *et al*. (2023); Dalvi *et al*. (2021)
Eco-friendly chemical alternatives	Acetic acid, sulphur, salicylic acid	Direct antifungal action + induction of host resistance	Acetic acid (16.5 ml L^{-1}) comparable to propiconazole; enhanced phenols, proline, PPO & POD	Residue-free; induces systemic resistance	Phytotoxicity risk at higher doses	El-Meslamany *et al*. (2020)

Table 3: Nanoparticle-based formulations for the management of powdery mildew

Nanoparticle	Particle size	Crop	Dose / application	Key outcome	Reference
Silica–silver nanoparticles	–	Cucurbits	Field application	Complete disease control within 3 weeks; phytotoxic only at very high dose	Park *et al.* (2006)
Nanosilica	–	Rose	500 mg L^{-1}	Comparable efficacy to penconazole; improved vegetative growth, floral traits, and vase life; hyphal ultrastructural damage and PAL upregulation	Elsharkawy *et al.* (2015)
Nano-silver colloids	~1.5 nm	Rose	Field spray	>95% disease suppression within 2 days; no recurrence for one week	Kim *et al.* (2008)
Silver (AgNPs)	–	Cucumber & pumpkin	100 ppm (field spray)	Strong inhibition of mycelial growth and conidial germination under field conditions	Lamsal *et al.* (2011)
	~17–23 nm	Grapevine	Foliar spray	Improved control of *Erysiphe necator*; enhanced leaf adhesion, sugar accumulation, and grape yield	Vizitiu *et al.* (2022)
	50–90 nm	General	–	Developed stable nanoformulation and standardized sulphur estimation method	Choudhury *et al.* (2010); Kumar *et al.* (2011)
	–	Okra	1000 ppm (in vitro)	Minimum conidial germination (2.95%); disruption of cleistothecia; superior to commercial sulphur	Gogoi *et al.* (2013)
Sulphur (SNPs)	~85 nm	Mango (*Mangifera indica* cv. Keitt)	100 ppm (foliar spray)	Reduced powdery mildew incidence (14.6%); markedly increased productivity (342%) and fruit quality; higher doses caused phytotoxicity	Abou El-Nasr *et al.* (2025)
	12.2–23.5 nm	Cucumber	Foliar spray	Superior disease suppression vs. bulk sulphur; efficacy comparable to systemic fungicides; highest yield and fruit quality; safe residue levels within 2 days	Abdel-Rahman and Alkolaly (2020)
Copper oxide (CuO-NPs)	–	Rose	Greenhouse application	81.71% disease control; effective in non-encapsulated form under controlled conditions	Adnan and Waleed (2025)
Chitosan (nano/ biopolymer)	Oligomer-based	Grapevine	Field & laboratory	Significant reduction of powdery mildew	Ruano-Rosa *et al.* (2022)
	–	Jalapeño pepper (*Capsicum annuum*)	0.1–0.2%	Highest control efficacy (up to 70%); disrupted spore and mycelial cell walls; effective alternative to fungicides	Jiménez-Pérez *et al.* (2024)

sulphur, thiophanate-methyl, binapacryl, bupirimate, triforine, captan, dithianon, mancozeb, zineb, and dinocap on pollen germination and tube growth (Church and Williams, 1977, 1978; Marcucci and Filiti, 1984). However, field and greenhouse studies have yielded contradictory results, with some reports indicating no significant effects of fungicides such as captan, binapacryl, dinocap, dithianon, thiophanate-methyl, and benomyl on fruit set under orchard conditions (Church and Williams, 1977). These inconsistencies may be attributed to environmental factors that modulate fungicide activity under field conditions. Despite widespread fungicide use during mango flowering, conclusive studies evaluating the effects of commonly used fungicides on pollen germination, floral fertility, and fruit set in mango are lacking, highlighting a critical gap that warrants systematic investigation.

Alternative methods of control

Alternative and integrated approaches for the management of mango powdery mildew have gained importance due to concerns over fungicide resistance, environmental safety, and negative effects on pollination and fruit set. Cultural practices such as orchard sanitation and removal of infected panicles reduce primary inoculum and enhance the effectiveness of other control measures (Joubert, 1991; Prakash and Mishra, 1993a). Among non-chemical options, inorganic salts particularly potassium and phosphate salts have shown promising results by suppressing pathogen development and inducing host resistance, either alone or in combination with reduced doses of fungicides, thereby lowering chemical inputs by up to 50% (Reuveni and Reuveni, 1995; Napier and Ooshyes, 2000). Biological control agents, especially mycoparasites such as *Ampelomyces quisqualis*, have demonstrated the ability to parasitize powdery mildew fungi and reduce disease severity across several crops, including mango, although field performance can be variable (Sztejnberg *et al*., 1989; Kiss *et al*., 2004). More recent studies indicate that integrated use of biological agents, mineral salts, and protective materials such as kaolin can significantly reduce conidial germination and disease severity under field conditions, supporting their inclusion in environmentally safe integrated disease management programs for mango powdery mildew (Table 2).

Role of nanotechnology in the management of powdery mildew

Recent advances in nanotechnology have led to the development of nanoformulations (<100 nm) with enhanced chemical reactivity and bioactivity, enabling effective disease control at very low doses (Gogoi *et al.*, 2009). Several studies have explored the formulation, characterization, and application of nanoparticles such as nanosilver, nano-sulphur, and silica–silver composites for plant disease management (Al-Samarrai, 2012; Soni and Prakash, 2012). Although relatively few studies have focused specifically on powdery mildew, available evidence indicates that nanoparticles can significantly inhibit mycelial growth, conidial germination, and pathogen development under both in vitro and field conditions. Key studies evaluating nanoparticle-based interventions against powdery mildew are summarized in Table 3.

CONCLUSION

Mango powdery mildew is one of the most serious diseases of mango affecting almost all the cultivars, causes poor fruit setting and up to 90 percent crop loss occurs during flowering time every year and the severity depends on prevailing weather conditions. The critical flowering stage particularly full bloom and fruit set stages are most susceptible for infection; therefore, all management efforts have to be concerted to protect these stages from pathogen. With advent of new safer and effective molecules, chemical management still remains the mainstay of powdery mildew management in mango. Apprehensions about using fungicides is growing based on the evidence that the powdery mildew pathogen is developing resistance against some systemic fungicides and application of fungicides during full blooms may hinder pollination and fruit set. Further, risks associated with fungicide residues on fruits have highlighted the need for more effective and safer alternative control measures. Biocontrol of powdery mildew pathogen by *A. quisqualis* has been established on several crops. Though efficacy of *Ampelomyces* mycoparasites is reported to be different on different crops, it's applicability on mango has not yet been evaluated under Indian conditions. This mycoparasite is known to have problems with the efficacy at lower humidity levels and due to their slow development on powdery mildew colonies. However, as Indian mangoes are normally cultivated in high humid areas, *Ampelomyces* might still be an appropriate candidate for management strategy against mango powdery mildew in India. While there is ample of information pertaining to the characterisation of the pathogen, there is still a need to develop integrated management module to manage powdery mildew of mango with more of non– chemical components.

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AUTHOR'S CONTRIBUTION

SG, SML, SS- conceptualisation, writing the original draft, SG and SS final draft correction.

CONFLICT OF INTEREST

Authors do not have conflicts of interest to express

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Efficacy of entomopathogens against marigold thrips, *Neohydatothrips samayunkur* Kudo (Thysanoptera: Thripidae), on *Tagetes erecta* L.

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ABSTRACT: The present investigation evaluated the efficacy of three entomopathogenic biocontrol agents against marigold thrips, *Neohydatothrips samayunkur* Kudo (Thysanoptera: Thripidae) on marigold (*Tagetes erecta* L.) during 2024 and 2025. Three entomopathogenic formulations viz., *Beauveria bassiana* (Bals.) Vuill. NBAIR Bb5a (Bb WP), *Metarhizium anisopliae* (Metschn.) Sorokin NBAIR Ma4 (Ma WP) and *Bacillus albus* NBAIR BATP (Ba WP), each formulated as wettable powder (WP) at 5 g/L, were evaluated against an untreated control in a Randomized Complete Block Design with five replications. Thrips populations were assessed by tap sampling at pre-treatment, and at 3, 7, and 14 days after spray (DAS). Results of both the years consistently demonstrated that *B. bassiana* (NBAIR Bb5a (Bb WP)) was the most effective treatment, reducing thrips counts to 10.4 thrips/tap at 14 DAS (2024) and to 7.2 ± 1.92 thrips/tap at 14 DAS (2025), compared to 22.6 and 25.6 thrips/tap in untreated controls, respectively. All three entomopathogens recorded significantly ($p<0.01$) lower thrips populations than the untreated control from 3 DAS onwards. These results demonstrate the potential of NBAIR entomopathogen formulations as effective and eco-friendly components of integrated pest management (IPM) programmes for marigold thrips.

Keywords: *Beauveria bassiana*, biocontrol, entomopathogens, thrips

INTRODUCTION

Marigold (*Tagetes erecta* L., Asteraceae) is one of the most economically important ornamental and medicinal crops in tropical and subtropical regions. In India, marigold cultivation spans an estimated 200,000 hectares and contributes substantially to floricultural trade, religious markets, and the natural colourant industry, as petals are a rich source of lutein, xanthophylls and other carotenoids. Among the various biotic stresses limiting marigold productivity, thrips infestations are of paramount concern.

Neohydatothrips samayunkur Kudo (Thysanoptera: Thripidae), is an emerging pest of considerable significance on marigold in South and Southeast Asia. Adults and larvae rasp and imbibe sap from flowers, buds and tender foliage, producing characteristic silvering, distortion and necrosis that directly reduce market value and render the crop susceptible to secondary infections (Rao *et al.,* 2018). The indiscriminate use of synthetic insecticides in marigold cultivation has led to resistance development, disruption of natural enemy communities, and environmental contamination (Lacey *et al.,* 2015).

Entomopathogens offer a biologically sound alternative. The entomopathogenic fungi, *Beauveria bassiana* (Bals.) Vuill. and *Metarhizium anisopliae* (Metschn.) Sorokin infects insect hosts through cuticle penetration and produces mycotoxins that are lethal to the host (Chandler *et al.,* 2000). Bacterial agents such as *Bacillus albus* suppress pests through lipopeptide toxins and induction of systemic plant resistance. The National Bureau of Agriculturally Important Insects (NBAIR), Bengaluru, has developed indigenous strains suited to Indian agroclimatic conditions. However, field validation against *N. samayunkur* on marigold remains limited. The present study was therefore undertaken to evaluate the field efficacy of *B. bassiana* NBAIR Bb5a, *M. anisopliae* NBAIR Ma4 and *B. albus* NBAIR BATP against *N. samayunkur* on marigold during 2024 and 2025.

MATERIALS AND METHODS

Experimental site and crop management

Field experiments were conducted during two consecutive *kharif* seasons (2024 and 2025) at the

research farm of ICAR-NBAIR, Bengaluru (13°N, 77°E; altitude 920 m asl), Karnataka, India. Marigold (*T. erecta* cv. African Marigold) was transplanted at 30 × 30 cm spacing following recommended agronomic practices. No synthetic pesticides were applied throughout the experimental period.

Treatments and application

Four treatments were evaluated in a Randomized Complete Block Design (RCBD) with five replications: T1 – *Beauveria bassiana* NBAIR Bb5a WP (1×10^8 cfu/g) @ 5 g/L; T2 – *Metarhizium anisopliae* NBAIR Ma4 WP (1×10^8 cfu/g) @ 5 g/L; T3 – *Bacillus albus* NBAIR BATP WP (1×10^8 cfu/g) @ 5 g/L; and T4 – Untreated Control (UC). Sprays were applied during early morning hours (06:00–08:00 h) using a hand-operated compression sprayer to ensure uniform coverage of all plant parts.

Thrips population assessment and statistical analysis

Thrips, *N. samayunkur* populations were assessed by the standard tap sampling method. Ten randomly selected plants per plot were gently tapped over a white tray, and dislodged thrips were counted immediately. Observations were recorded one day before spray (pre-treatment) and at 3, 7, and 14 days after spray (DAS). Data from 2024 are presented as means ± SD with square root transformed values in parentheses; data from 2025 are expressed as means ± SD. Statistical analyses were performed using ANOVA, followed by Tukey's Honest Significant Difference (HSD) test at 1% level.

RESULTS AND DISCUSSION

Pre-treatment thrips populations

Pre-treatment thrips counts were statistically homogeneous across all treatment groups in both years, confirming comparability of experimental plots. In 2024, pre-treatment counts ranged from 17.8 (T1- *B. bassiana* to 22.2 (T3- *B. albus*) thrips/tap (F = 1.586, NS); in 2025, from 18.6 ± 3.84 (T1) to 23.0 ± 2.00 (T3- *B. albus*) thrips/tap (F = 1.55, NS), validating the RCBD (Table 1 and 2).

Efficacy at 3 DAS

Three days after spray, all entomopathogenic treatments recorded significantly ($p<0.01$) lower thrips populations than the untreated control. In 2024, *B. bassiana* (T1-) recorded the lowest count (9.8 thrips/tap), followed by *M. anisopliae* (T2, 14.4*b*) and *B.*

Table 1: Effect of entomopathogenic formulations on the population of marigold thrips, *Neohydatothrips samayunkur*, at different intervals after treatment during 2024.

Treatment	Pre-Treatment	3 DAS	7 DAS	14 DAS
		Mean number of thrips/tap±SD		
T1 – Bb WP	17.80±2.20 (4.20)	9.80±0.77^{c} (3.12)	8.60±1.47^{c} (2.88)	10.40±1.25^{b} (3.17)
T2 – Ma WP	21.00±2.59 (4.56)	14.40±1.13^{b} (3.79)	12.80±2.18^{bc} (3.55)	18.00±2.17^{a} (4.22)
T3 – Ba WP	22.20±2.74 (4.71)	19.40±1.52^{a} (4.39)	19.60±3.35^{ab} (4.39)	18.80±2.26^{a} (4.30)
T4 – UC	19.80±2.44 (4.43)	22.40±1.76^{a} (4.72)	22.40±3.82^{a} (4.66)	22.60±2.72^{a} (4.74)
F value	1.586 (NS)	25.03**	7.588**	9.035**
LSD (0.01)	NS	0.609	1.278	0.956
CV (%)	–	7.86	17.07	12.03

Values in parentheses are square root transformed data. Means in a column followed by the same superscript letter are not significantly different at Tukey's HSD (p=0.01). **: Significant at 1% level; NS: Not significant. Bb WP – *Beauveria bassiana* ICAR-NBAIR Bb5a; Ma WP – *Metarhizium anisopliae* ICAR-NBAIR Ma4; Ba WP – *Bacillus albus* ICAR-NBAIR BATP; UC – Untreated control; DAS – Days after spray.

albus (T3, 19.4), while the untreated control recorded 22.4 (F = 25.03; p<0.001). In 2025, *B. bassiana* again recorded the lowest count (11.0 ± 3.00/tap) against an untreated control of 19.0 ± 3.53 (F = 5.48; p<0.001). *B. albus* and *M. anisopliae* were statistically comparable to *B. bassiana* at 3 DAS in 2025, suggesting similar initial infectivity rates. Comparable early efficacy of fungal entomopathogens against thrips species on horticultural crops has been documented by Sundar *et al.* (2020).

Efficacy at 7 DAS

At 7 DAS, differences among the entomopathogenic treatments became more pronounced. In 2024, *B. bassiana* maintained the lowest count (8.6), while *M. anisopliae* recorded 12.8 and *B. albus* 19.6; the control rose to 22.4. In 2025, the untreated control increased sharply to 27.6 ± 4.39, while *B. bassiana* maintained suppression at 10.6 ± 2.07. *M. anisopliae* and *B. albus* recorded 13.2 ± 3.11 and 19.4 ± 7.63, respectively (F = 12.48; p<0.001). The progressive efficacy of *B. bassiana* over time reflects autocidal amplification, wherein conidia produced on cadavers initiate secondary infections within the thrips population (Maniania *et al.,* 2008).

Efficacy at 14 DAS

At 14 DAS, the contrast between treated and untreated plots was most pronounced. In 2024, *B. bassiana* recorded 10.4 thrips/tap and was statistically distinct from *M. anisopliae* (18.0) and *B. albus* (18.8), both of which were not significantly different from the control (22.6) at this time point (F = 9.035; p<0.001). In 2025, *B. bassiana* achieved a reduction to 7.2 ± 1.92, approximately 72 per cent suppression relative to the untreated control (25.6 ± 2.40). Both *M. anisopliae* (15.6 ± 1.94) and *B. albus* (14.4 ± 1.51) achieved significant suppression relative to controls (F = 73.487; p<0.001). The superior performance of *B. bassiana* is consistent with earlier reports of its virulence against *Frankliniella occidentalis* and *Thrips palmi* on horticultural crops (Bhanu *et al.,* 2010; Shinde *et al.,* 2012). The performance of *B. albus*, particularly at 14 DAS in 2025, likely reflects its multifactorial mode of action through lipopeptide toxins (iturin, surfactin, fengycin) and induction of systemic plant resistance, which accumulate over time (Ekesi *et al.,* 2002). The between-year variation in the relative ranking of T2 and T3 underscores the influence of agroclimatic conditions on entomopathogen field performance and emphasises the importance of multi-season validation in biocontrol research.

CONCLUSION

All three ICAR-NBAIR entomopathogen formulations *B. bassiana* Bb5a WP, *M. anisopliae* Ma4 WP, and *B. albus* BATP WP at 5 g/L recorded significantly lower *N. samayunkur* populations than the untreated control from 3 DAS onwards across both seasons. *B. bassiana* ICAR-NBAIR Bb5a consistently

Table 2: Effect of entomopathogenic formulations on the population of marigold thrips, *Neohydatothrips samayunkur* at different intervals after treatment during 2025.

Treatment	Pre-Treatment	3 DAS	7 DAS	14 DAS
		Mean number of thrips/tap±SD		
T1 – Bb WP	18.6±3.84 (4.36)	11.0±3.00^{a} (3.39)	10.6±2.07^{a} (3.33)	7.2±1.92^{a} (2.77)
T2 – Ma WP	20.6±3.04 (4.59)	13.8±3.03^{a} (3.78)	13.2±3.11^{ab} (3.70)	15.6±1.94^{b} (4.01)
T3 – Ba WP	23.0±2.00 (4.85)	15.8±3.27^{a} (4.03)	19.4±7.63^{bc} (4.46)	14.4±1.51^{b} (3.87)
T4 – UC	21.8±4.14 (4.73)	19.0±3.53^{b} (4.42)	27.6±4.39^{c} (5.30)	25.6±2.40^{c} (5.11)
F (df=3,16)	1.55 NS	5.48**	12.48**	73.487**
LSD (p=0.01)	–	2.07	3.08	1.27

Values in parentheses are square root transformed data.

Means in a column followed by the same superscript letter are not significantly different at Tukey's HSD (p=0.01). **: Significant at 1% level; NS: Not significant. Bb WP – *Beauveria bassiana* ICAR-NBAIR Bb5a; Ma WP – *Metarhizium anisopliae* NBAIR Ma4; Ba WP – *Bacillus albus* ICAR-NBAIR BATP; UC – Untreated control; DAS – Days after spray.

exhibited the highest and most sustained efficacy, reducing the thrips population by approximately 72 per cent at 14 DAS compared to untreated control during 2025. These results validate the potential of ICAR-NBAIR entomopathogen formulations as effective and ecologically safe components of IPM programmes for marigold thrips management.

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AUTHORS CONTRIBUTION

GB – Conceptualization, carrying out research experiments, data Analysis, and writing the manuscript; RRR – Identification of thrips species and assisted in taking observations; BSG: Data compilation and proofreading; AK: Preparation of fungal formulation and assisted in carrying out research experiments; MSY: Manuscript writing and proofreading

CONFLICT OF INTEREST

Authors don't have conflict of interest to express

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Diversity, abundance and pollination efficiency of native bees on teasel gourd (*Momordica subangulata* Blume ssp. *renigera*) in Western Ghats region of Karnataka

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ABSTRACT: The study was conducted during 2022–2024 at the research farm of ICAR-Indian Institute of Horticultural Research (ICAR-IIHR), Central Horticultural Experiment Station, Chettalli, Kodagu, India, to investigate the diversity of bee visitors, their foraging behaviour, and their pollination efficiency in teasel gourd. Six groups of native bees belonging to the families Apidae and Halictidae were observed visiting the male flowers of teasel gourd. Among them, *Apis cerana indica* was the predominant visitor, accounting for nearly 89% of the total bee visits, followed by *Halictus* spp. (8%) and *Tetragonula* spp. (3%). Natural visitation to female flowers was very limited; however, occasional visits by *A. cerana indica* and *Tetragonula* spp. were recorded following hand pollination. The highest foraging activity of *A. cerana* was recorded between 07:00 and 08:00 h, which coincided with peak floral receptivity. Different pollination methods had a significant effect on fruit yield and quality during both years of the study. Hand pollination and pollen augmentation significantly enhanced fruit set, fruit weight, fruit length, and fruit diameter compared with open pollination. Conversely, exclusion of bee visitors led to negligible fruit development, underscoring the critical role of insect pollinators in supplementing hand pollination for improved yield and fruit quality. This finding suggests that conserving and maintaining native bee populations, particularly *A. cerana*, together with appropriate pollination management practices, could substantially improve teasel gourd production.

Key words: Teasel gourd, diversity, abundance, pollination efficiency, native bee visitors

INTRODUCTION

Pollination is a fundamental ecological process that ensures sexual reproduction, fruit set, and seed production in flowering plants. Approximately 95% of flowering plant species are cross-pollinated, with nearly 85% relying on animals for pollen transfer, of which insect pollination (entomophily) accounts for about 90% of animal-mediated pollination (Tewari and Singh, 1983; Richards, 1986; Buchmann and Nabhan, 1996). In agriculture, animal-mediated pollination is indispensable, with 87 of the world's 124 leading food crops benefiting from or depending on visitors (Klein *et al*., 2007). Among insect visitors, species of the orders Hymenoptera, Lepidoptera, and Diptera play a dominant role in crop pollination (Jadhav *et al*., 2011). In cucurbits, pollination is primarily arbitrated by insects, with honey bees (*Apis mellifera* Linn), squash bees (*Peponapis* and *Xenoglossa* spp.) and bumble bees (*Bombus* spp.) recognised as the most effective pollinators (Klein *et al*., 2007; Artz *et al*., 2011). Pollination services are estimated to contribute more than US$ 800 billion annually to global agriculture through enhanced crop productivity and nutritional security (Devkota *et al.,* 2024). Cucurbit crops are particularly dependent on insect pollination because their large, sticky pollen grains cannot be effectively dispersed by wind. Also, most of the cucurbits are monoecious, few exceptions like pointed gourd, spine gourd, teasel gourd and Ivy gourds are dioecious in nature. Efficient transfer of pollen between male and female flowers is therefore essential not only for successful fruit and seed set but also for improving fruit quality and yield (Free, 1970; McGregor, 1976).

Teasel gourd (*Momordica subangulata* Blume ssp. *renigera*) is an underutilized, high-value indigenous cucurbit cultivated in South and Southeast Asia, particularly by tribal and smallholder farmers. It is a perennial, dioecious, cross-pollinated climber with tuberous roots belonging to the family Cucurbitaceae and is cultivated across diverse agro-climatic regions ranging from plains to mid-hills in Assam, Tripura, West Bengal, Odisha, and the Andaman Islands. This climbing creeper is also grown in Pakistan, Bangladesh, and Sri Lanka

(Ashoka *et al*., 2024; Verma *et al*., 2025; Koundinya *et al*., 2025). The crop is valued for its high nutritional and medicinal properties, including antioxidant, antimicrobial, antidiabetic, hepatoprotective, and anticancer activities (Bhagat *et al*., 2017). However, its productivity is often constrained by poor natural pollination of female flowers and susceptibility to biotic stresses (Sudhakar Pandey *et al*., 2020). Since the flowers remain receptive for only a single day, this period is very important for pollination of this crop for successful fertilization and fruit set. Despite the economic and nutritional importance of teasel gourd, information on the diversity, abundance, and pollination efficiency of native insect visitors remains limited. Therefore, the present study was undertaken to (i) document the diversity and abundance of native insect species visiting teasel gourd flowers and (ii) evaluate the pollination efficiency of the native insect species on Teasel gourd flowers.

MATERIAL AND METHODS

Field experiments were conducted during 2022–23 and 2023-24 at the ICAR-Indian Institute of Horticultural Research (ICAR-IIHR), Central Horticultural Experiment Station (CHES), Chettalli, Kodagu, Karnataka, India (12°26'N, 75°47'E; 1050 m msl) to study native bee species diversity and foraging behaviour in teasel gourd, *M. subangulata ssp. renigera*. Observations were made during the cropping seasons from June to August in both years. The experimental field was located near the CHES apiary containing Indian honey bees, *Apis cerana indica* F., along with naturally occurring bee population. Hand-pollinated teasel gourd plants were maintained at a spacing of 1.8 × 2 m with a male to female plant ratio of 1:5.

Flower visitors were observed from 06:00 to 18:00 h during the peak flowering period. Data on the number and type of insect visitors were recorded hourly from 15 each randomly selected male and female flowers for seven consecutive days. The diurnal foraging activity of different insect visitors on male flowers of teasel gourd were recorded at different hours of the day. Their visitation frequency was recorded as the mean number of insects visited per flower in 10 min. Diurnal foraging activity on female flowers was not recorded because no insect visitors were observed on female flowers during the study period. To assess the influence of pollination on yield parameters, four treatments were imposed: open pollination (Female flowers left open without bagging), pollinators/bee visitors exclusion (Female flowers were bagged with nylon net), hand pollination (Female flowers after hand pollination were again bagged with butter paper), and pollen augmentation (Female flowers after hand pollination were left open for insect visitation). Final fruit set was recorded 10 days after treatment, and fruits were harvested to record fruit weight, length, and diameter. Fifteen flowers per treatment were selected randomly and labelled. The data were subjected to Analysis of Variance (ANOVA), and treatment means were compared using Critical Difference at 5% significance level under 95% confidence interval.

RESULTS AND DISCUSSION

Bee visitor diversity, abundance and foraging activity on teasel gourd

A total of six bee species belonging to two families, Apidae and Halictidae (Order: Hymenoptera), were recorded visiting the flowers of teasel gourd during June–July 2022 (Fig. 1). Members of the family Apidae dominated among the native bee population and included *A. cerana indica* Fabricius (Indian honey bee), *Apis florea* (little bee), *Tetragonula* spp. (stingless bees), *Amegilla* spp. (blue-banded bees) and *Xylocopa* spp. (carpenter bees), representing the tribes Apini, Meliponini, Anthophorini and Xylocopini, respectively. The only representative from the family Halictidae was *Halictus* spp. (tribe Halictini). Female flowers received negligible or no insect visitation under natural conditions. However, after hand pollination, *A. cerana* and *Tetragonula* spp. were occasionally observed visiting female flowers (Fig. 2), indicating that the rewardless nature of pistillate flowers discourages bees visitation.

The predominance of bee visitors observed in the present study agrees with earlier reports that Hymenopteran bees are the principal pollinators of cucurbit crops (Dorjay and Abrol, 2022). Honey bees and halictid bees have been recognized as major visitors of cucurbits in tropical regions (Grewal and Sidhu, 1978; Chaudhary *et al*., 2024). Similar visitor assemblages comprising *A. cerana*, *A. florea*, *Tetragonula* spp. and *Halictus* spp. have been reported in bitter gourd (Deyto and Cervancia, 2009; Yogapriya et al., 2019). Although Balina *et al*. (2012) documented nine bee species belonging to three families on bitter gourd flowers, the present study recorded fewer species, possibly reflecting differences in crop species, dioecious, plant nature and type of reward provided by the plants to the insect visitors. Nevertheless, the dominance of native bee

Indian honey bee, *Apis cerana* | Little bee, *Apis florea* | Sweat bee, *Halictus spp.*

Stingless bees, *Tetragonula spp.* | Blue banded bee, *Amegilla spp.* | Carpenter bee, *Xylocopa spp.*

Fig. 1. Insect visitors on male flowers of teasel gourd

Indian honey bee, *Apis cerana* | Stingless bee, *Tetragonula spp.*

Fig. 2. Insect visitors on female flowers of teasel gourd

species highlights the ecological importance of teasel gourd as a resource for native bee fauna in the Western Ghats.

Among all bee species, *A. cerana* was the predominant visitor, accounting for approximately 89% of the total bee population on male flowers, followed by *Halictus* spp. (8%) and *Tetragonula* spp. (3%) (Fig. 3). The overwhelming dominance of *A. cerana* indicates its primary role as the effective pollen vector under the study conditions. Similar dominance of honey bees has been reported in muskmelon (Belavadi, 2019) and several cucurbit crops where *Apis* species constitute the major proportion of floral visitors (Dorjay and Abrol, 2022; Ikram *et al*., 2025). Although *Halictus* spp. were less abundant, previous studies have demonstrated their importance as efficient pollinators of bitter gourd (Grewal and Sidhu, 1978; Balina *et al*., 2012), suggesting that even less abundant native bees may contribute significantly to pollen transfer.

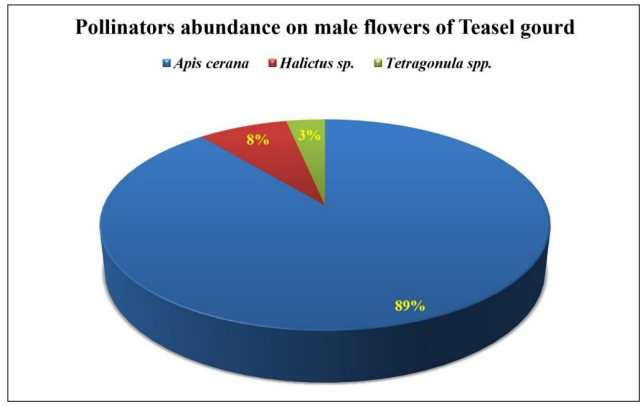

Fig. 3. Relative abundance of major *Apis* and non-*Apis* bee visitors on male flowers of teasel gourd

Distinct temporal differences were observed in the foraging activity of different bee species. *Apis cerana* commenced foraging during 06:00–07:00 h with approximately 4.5 visits per flower/10 min and reached peak activity during 07:00–08:00 h (about 7.1 visits per flower/10 min), after which visitation gradually declined with slight fluctuations during mid-morning (10:00–11:00 h, 5.4 visits/flower/10 min) and afternoon hours, reaching the lowest level during 17:00–18:00 h (1 visit/flower/10 min) (Fig. 4). This indicates that *A. cerana* prefers cooler morning hours for active foraging. In contrast, *Halictus* spp. exhibited comparatively low activity during the early morning but attained maximum visitation around 12:00–14:00 h (one visit per flower/10 min), whereas *Tetragonula* spp. showed consistently low activity with slight increases during 10:00–11:00 h and 14:00–15:00 h (0.3–0.7 visits per flower/10 min), while activity remained almost absent during the remaining hours. Overall, *A. cerana* remained as the principal visitor of teasel gourd male flowers throughout the flowering period, whereas *Halictus* spp. and *Tetragonula* spp. showed minimum foraging activity (Fig. 4).

The early morning peak in bees activity corresponds well with the flowering biology of cucurbits, where anthesis, maximum pollen viability, nectar secretion and stigma receptivity occur during the morning hours. Similar peak foraging activity between 06:00 and 10:00 h has been reported in several cucurbit crops (Hanh, 2008; Taha and Bayoumi, 2009; Dan *et al.,* 2019; Knapp and Osborne, 2019). Dalio (2021) further reported that insects visitation coincides with maximum floral rewards shortly after anthesis, while visitation declines later in the day as nectar availability decreases and flowers begin to senesce. Therefore, synchronization between floral phenology and insect activity appears to maximize pollination efficiency in cucurbits.

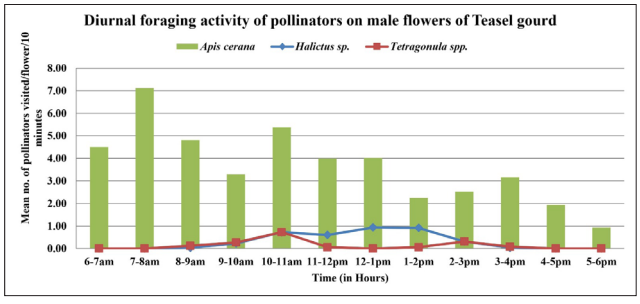

Fig. 4. Diurnal foraging activity of bee visitors on male flowers of teasel gourd

Pollination efficiency

Pollination efficiency experiment was conducted to record the effect of different pollination treatments on the yield parameters of teasel gourd during the years 2022–23 and 2023–24. Significant differences among pollination treatments were observed for all fruit yield parameters during both years of experimentation. During 2022–23, pollen augmentation and hand pollination produced significantly greater fruit weight ($F_{3, 39}$ = 83.727, P = <0.001; Mean=62.66 and 52.94 g), fruit length ($F_{3, 39}$ = 93.446, P = <0.001; Mean=8.69 and 7.56 cm) and fruit diameter ($F_{3, 39}$ = 109.112, P = <0.001; Mean=3.99 and 3.50 cm), respectively, compared with open pollination and pollinators exclusion treatments (Fig. 5; Table 1). Both pollen augmentation and hand pollination treatments performed comparably, with no significant differences observed between them for most fruit quality parameters. However, pollen augmentation showed a slight improvement in fruit quality attributes, which may be attributed to the activity of naturally occurring bee pollinators, particularly *A. cerana* and *Tetragonula* spp. These bees likely utilized the pollen manually deposited on the stigmas and facilitated additional pollen transfer among previously pollinated female flowers, thereby enhancing pollen deposition, improving fertilization efficiency, and minimizing the limitations associated with hand pollination. Consequently, pollen augmentation achieved the highest fruit set (100%), compared with 86.67% under hand pollination.

In contrast, exclusion of bee visitors resulted in complete failure of fruit set at 10 days after treatment, with the female ovaries undergoing degeneration due to the absence of effective pollination. This was reflected in the extremely poor ovary development, with mean fruit weight, length, and diameter of only 0.88 g, 2.04 cm, and 0.81 cm, respectively. Open pollination recorded only 6.67% fruit set, indicating that under natural field conditions, pollinator visitation to female flowers was insufficient to achieve satisfactory pollination and fruit development (Table 1).

A similar trend was observed during 2023–24. The fruit set recorded under open pollination, hand pollination, and pollen augmentation was 13.33%, 86.67%, and 100.00%, respectively. Hand pollination was recorded the highest fruit weight ($F_{3, 42}$ = 54.881, P = <0.001; Mean = 61.36 g) and fruit length ($F_{3, 42}$ = 53.850, P = <0.001; Mean = 7.16 cm), whereas pollen augmentation produced the maximum fruit diameter

(F3, 42 = 55.429, P = <0.001; Mean = 4.01 cm). Both treatments were statistically superior and remained at par with each other for most parameters. Bee visitor exclusion again resulted in negligible fruit development, confirming the necessity of hand pollination supported by the insects visits to the pollinated flowers for effective pollination and successful fruit set in teasel gourd (Table 2). Across both years, the results clearly demonstrated the importance of hand pollination accompanied by the insect-mediated supplementary pollination substantially enhances fruit size and quality attributes in teasel gourd. The poor performance under bee visitor exclusion treatments further emphasizes, there is some role of insect visitors in pollination, fruit development, and productivity of the crop to some extent in natural condition for the future perpetuation of crop in wild.

Pollinators exclusion

Open pollination

Hand pollination

Hand cum open pollination

Fig. 5. Effect of different pollination treatments on fruits of teasel gourd

Table 1: Means of yield parameters for the different pollination treatment in teasel gourd *Momordica subangulata* ssp. *renigera* in Research farm of CHES Chettalli, Kodagu (2022-23)

Treatments/Yield parameter	Fruit set (%)	Fruit weight (g) ± S.E	Fruit length (cm) ± S.E	Fruit diameter (cm) ± S.E
Open pollination	6.67	2.18±0.96^{b} (1.251)	2.49±0.28^{b} (1.554)	0.99±0.13^{b} (0.973)
Pollinators exclusion	0.00	0.88±0.04^{b} (0.936)	2.04±0.04^{b} (1.428)	0.81±0.02^{b} (0.898)
Hand Pollination	86.67	52.94±7.28^{a} (6.817)	7.56±0.61^{a} (2.708)	3.50±0.29^{a} (1.840)
Pollen augmentation	100.00	62.66±3.34^{a} (7.881)	8.69±0.23^{a} (2.944)	3.99±0.05^{a} (1.999)
F value		83.727	93.446	109.112
df		3, 39	3, 39	3, 39
p		<0.001	<0.001	<0.001
CV		35.260	13.960	14.358
CD (0.05)		1.138	0.230	0.157

Means followed by the same letter in superscript within column are not significantly different based on Treatment Means comparison at 95% significant level. N=15; Figures in parentheses are √(x) transformed values.

Table 2: Means of yield parameters for the different pollination treatment in teasel gourd *Momordica subangulata* ssp. *renigera* in Research farm of CHES Chettalli, Kodagu (2023-24)

Treatments/Yield parameter	Fruit set (%)	Fruit weight (g) ± S.E	Fruit length (cm) ± S.E	Fruit diameter (cm) ± S.E
Open pollination	13.33	11.56±5.93[b] (2.273)	1.83±0.72[b] (1.298)	1.11±0.44[b] (1.126)
Pollinators exclusion	0.00	0.27±0.06[b] (0.871)b	1.18±0.19[b] (1.260)	0.43±0.07[b] (0.953)
Hand Pollination	86.67	61.36±7.38[a] (7.499)a	7.16±0.52[a] (2.738)	3.72±0.27[a] (2.034)
Pollen augmentation	100.00	57.86±4.29[a] (7.563)	7.05±0.26[a] (2.741)	4.01±0.09[a] (2.121)
F value		54.881	53.850	55.429
df		3, 42	3, 42	3, 42
p		<0.001	<0.001	<0.001
CV		40.059	22.155	20.182
CD(0.05)		1.344	0.328	0.232

Means followed by the same letter in superscript within column are not significantly different based on Treatment Means comparison at 95% significant level. N=15; Figures in parentheses are √(x+0.5) transformed values.

The superior performance of hand pollination and pollen augmentation clearly demonstrates that fruit production in teasel gourd is strongly pollen-limited under natural conditions. Being a dioecious species, successful fertilization depends entirely on the transfer of pollen from male to female flowers. The negligible visitation observed on female flowers further limits natural fruit set because pistillate flowers do not provide nectar or pollen rewards to attract insect visitors. Similar observations have been reported in bitter gourd, where rewardless pistillate flowers receive fewer and shorter insect visits than staminate flowers (Oronje *et al*., 2012). Consequently, fruit set under open pollination remains poor, and manual pollination has long been recommended to improve productivity (Mishra and Sahoo, 1983; Joseph, 2005; Behera *et al*., 2010).

The results are also consistent with recent findings of Koundinya *et al*. (2025), who reported that natural fruit set in teasel gourd generally ranges from negligible levels to only 15–20% because of inadequate visitor activity. Similar responses have been documented in cucumber, where honey bee pollination produced fruit yield and quality comparable with hand pollination and significantly superior to open pollination (Thakur and Rana, 2008). Earlier studies have also reported that, pollination efficiency is influenced by factors such as floral phenology, nectar and pollen rewards, insect foraging behaviour and environmental conditions, including temperature, humidity and wind (Nepi and Pacini, 1993; Winfree *et al*., 2008).

The present study further demonstrates that pollen augmentation, which combines manual pollen transfer with continued insect visitation, can produce fruit quality equivalent to hand pollination while allowing naturally occurring insect visitors to contribute to pollen deposition. This finding suggests that conserving and maintaining native bee populations, particularly *A. cerana*, together with appropriate pollination management practices, could substantially improve commercial production of teasel gourd.

Overall, the present investigation identifies *A. cerana* as the principal visitor of teasel gourd, exhibiting the highest abundance and foraging activity during the early morning hours when floral receptivity is greatest. The comparable performance of pollen augmentation and hand pollination highlights the importance of conserving native bee populations and integrating managed pollination strategies to enhance fruit yield and quality

in teasel gourd cultivation. Future research should focus on evaluating different bee attractants for increasing pollinator visitation to female flowers and assessing their effectiveness in enhancing pollination efficiency, fruit set, and overall productivity under field conditions.

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AUTHORS CONTRIBUTION

ATR, MGS: Manuscript writing, Carrying research experiment; GN: Assisted in taking observation, Carrying research experiment; MBM: Data compilation and analysis; RS, PVR: Proof reading.

CONFLICT OF INTEREST

Authors don't have conflict of interest to express

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Field efficacy of novel insecticide molecules against the thrips complex in grapevine cv. Bangalore blue

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ABSTRACT: Field evaluation of new-generation insecticides against grape thrips on cv. Bangalore Blue was conducted during 2025 at Budigere (Devanahalli taluk) and Konaghatta (Doddaballapur taluk). Among the insecticides tested, broflanilide 30 SC exhibited the highest efficacy, resulting in the greatest reduction in thrips population and the lowest berry damage. Spinetoram 11.70 SC and spinosad 45 SC were also highly effective and provided significantly better control than the untreated check, whereas fluxametamide 10 EC and dimpropyridaz 120 g/L SL showed moderate efficacy. Economic analysis revealed that broflanilide 30 SC recorded the highest incremental cost-benefit ratio (ICBR) of 25.22, followed by spinosad 45 SC (17.32). The results indicate that broflanilide 30 SC is a promising option for the effective and economical management of grape thrips in Bangalore Blue vineyards.

Keywords: Bio-efficacy, *Vitis vinifera*, *Scirtothrips dorsalis*, Broflanilide, Bangalore Blue.

INTRODUCTION

Grape (*Vitis vinifera* L.) is considered one of the most significant fruit crops in temperate zones and has been successfully cultivated in the tropical and subtropical climates of the Indian subcontinent (Bose *et al*., 1999). In India, grapes are cultivated on roughly 1.63 lakh ha, producing 34.01 lakh tonnes annually (Patel *et al.,* 2024). Karnataka ranks among the leading grape-producing states, where varieties like 'Bangalore Blue' are popular for their juice and wine potential. The berries are typically medium in size, with a bluish black to dark purple hue. They are seeded, spherical in shape and contain a juicy pulp. The pulp is green and succulent, while the juice exhibits a rich purple colour with a distinct foxy flavour. It has total soluble solids ranging from 16-18% and an acidity level of approximately 0.8-1.0% (Winkler and Cook, 1974).

However, the climatic conditions conducive to grape growing also support the rapid multiplication of insect pests. Among these, thrips (*Scirtothrips dorsalis* Hood, *Thrips parvispinus* (Karny), *Thrips palmi* Karny, *Thrips florum* Schmutz and *Megalurothrips typicus* Bagnall have been identified as major contributors to both qualitative and quantitative yield reductions (Abhijna, 2025). Thrips damage results in whitish discoloration of leaves, corky surfaces on berries (scab formation), and reduced market appeal (Kulkarni, 2020).

Infestation by thrips, particularly *Rhipiphorothrips cruentatus* Hood, results in distinct damage to grape leaves. Affected leaves develop a whitish discoloration, appear withered, and eventually turn brown. As the infestation progresses, the leaves curl and fall off prematurely. Such affected vines often fail to bear fruit, or the developing fruits drop off before maturity. Even when fruits reach maturity, their quality remains substandard. Another species, *Scirtothrips dorsalis* Hood, causes damage by lacerating and sucking sap from grape berries at all developmental stages. This feeding activity results in corky surface on the berries, leading to scab formation (Reddy, 1957). These symptoms significantly reduce the fruit's market appeal and export quality. In recent years, thrips-related damage has been increasingly observed, with particularly severe effects noted on the Bangalore Blue cultivar.

In recent years, thrips-related damage has been increasingly observed on the Bangalore Blue cultivar and the foregoing review has provided ample evidence that the occurrence, abundance and diversity of thrips infesting grapes differ across regions, cultivars and growth stages. Further, it was also found that the performance of different insecticides and biorationals evaluated under varied vineyard conditions has also been inconsistent. Since chemical control remains a primary method for pest management, identifying molecules

with high efficacy and economic returns is crucial. Thus, efficacy trials were conducted to know the relative bio-efficacy of different new generation chemicals against grape thrips.

MATERIALS AND METHODS

The efficacy trials were conducted against grape thrips in farmers' orchards at Budigere and Konaghatta of Devanahalli and Doddaballapur taluks, respectively during 2025. Two field trials were conducted during 2025 in a Randomized Block Design (RBD) with eight treatments, *viz*., cyantraniliprole 10.26 OD @ 1.4 ml/ L, fluxametamide 10 EC @ 0.8 ml/ L, spinetoram 11.70 SC @ 0.6 ml/ L, spinosad 45 SC @ 0.25 ml/ L, dimpropyridaz 120 g/L SL @ 1.0 ml/ L, broflanilide 30 SC @ 0.08 ml/ L, lambda-cyhalothrin 4.9 CS @ 0.5 ml/ L, and an untreated control. Each treatment was replicated thrice, and each vine was considered one replication. The treatments included chemicals selected based on their safety and efficacy profile on the basis of earlier literature. Inclusion of lambda-cyhalothrin as a standard check was based on farmers feedback and usage. The study evaluated the efficacy of broflanilide, dimpropyridaz, and fluxametamide against grape thrips to explore their potential as novel management options. This investigation was particularly relevant as grape growers often resort to insecticide applications at intervals of 3-4 days during the flowering and berry formation stages due to severe thrips infestation.

Before the treatment imposition, the vines were selected for the experiment carefully and labelled. Each vine representing single replication of each treatment was tagged properly for taking observations on thrips and totally three vines were selected from each treatment. From each labelled vine, five shoots were randomly selected and tagged. Later the number of thrips present before spray was taken as pre-count. The treatments were imposed by using high volume knapsack sprayer. Sprays were imposed at the inflorescence and fruit setting stages at an interval of 10 days. Observations were recorded on the number of thrips per shoot (using the tapping method) and berry damage on five randomly selected bunches per vine. The observations on number of thrips per tap were recorded at pre-treatment and at 3, 7 and 10 days after spraying (DAS). Later the values were square root transformed and subjected to Two way Analysis of Variance (ANOVA).

Per cent bunch damage

The percentage of bunch damage was estimated by recording the number bunches damaged by thrips per vine and total number of bunches per vine in each treatment. Each vine is represented as one replication. The observations were used to calculate the extent of bunch damage based on the proportion of damaged bunches to the total number of bunches per vine, using the following formula:

$$\text{Bunch damage (\%)} = \frac{\text{Number of damaged bunches}}{\text{Total number of bunches per vine}} \text{ X100}$$

Per cent berries damage

The percentage of berry damage was assessed by randomly selecting five bunches from each individual vine in all replications of each treatment. The number of healthy and damaged berries in each selected bunch was recorded and the extent of berry damage was calculated as the proportion of damaged berries to the total number of berries observed, using the following formula:

$$\text{Berry damage (\%)} = \frac{\text{Number of damaged berries}}{\text{Total number of berries observed}} \text{ X100}$$

RESULTS AND DISCUSSION

Budigere (Trial I)

The data on the efficacy of selected insecticides against thrips on grapes cv. Bangalore Blue are presented in Table 1. The pre-treatment population count of thrips were taken one day prior to the imposition of the treatments and the count ranged from 9.89 to 11.56 thrips per shoot, with no significant variation among treatments, confirming uniform initial infestation. These pre-count values were used to work out the per cent reduction in the thrips damage after imposition of treatments. The observations were recorded at three, seven and ten days after spraying.

At three days after treatment, broflanilide 30 SC recorded the lowest thrips population (4.00 thrips/shoot per shoot) and was significantly superior to all other treatments. This was followed by spinetoram 11.70 SC and spinosad 45 SC, which recorded 5.33 and 5.56 thrips per shoot, respectively, and were statistically on par with each other. Fluxametamide 10 EC and dimpropyridaz 120 g/L SL provided moderate control, recording

6.89 and 7.56 thrips per shoot, respectively, and did not differ significantly from one another. In contrast, cyantraniliprole 10.26 OD and lambda-cyhalothrin 4.9 CS were comparatively less effective in reducing thrips populations three days after treatment application.

The observations recorded at seven days post-treatment, the least thrips incidence was observed in broflanilide 30 SC (2.44 thrips per shoot), which was significantly superior to all other treatments. It was followed by spinetoram 11.70 SC (3.33) and spinosad 45 SC (3.56 thrips per shoot), which were statistically on par. Fluxametamide 10 EC (5.44) and dimpropyridaz 120 g/L SL (5.56 thrips per shoot) showed moderate reduction in thrips population, whereas cyantraniliprole 10.26 OD (6.44 thrips per shoot) and lambda-cyhalothrin 4.9 CS (6.56 thrips per shoot) were found least effective among the chemical treatments. The untreated control recorded the highest thrips population (13.67 thrips per shoot).

At ten days after the first spray, broflanilide 30 SC recorded the lowest thrips population (2.33 thrips per shoot) and was significantly superior to all other treatments. Spinetoram 11.70 SC and spinosad 45 SC were the next most effective treatments, recording 3.22 and 3.44 thrips thrips per shoot, respectively, and were statistically on par with each other. Fluxametamide 10 EC (5.33 thrips per shoot) and dimpropyridaz 120 g/L SL (5.44 thrips per shoot) exhibited moderate efficacy in suppressing thrips populations. In contrast, cyantraniliprole 10.26 OD (6.33 thrips per shoot) and lambda-cyhalothrin 4.9 CS (6.67 thrips per shoot) were comparatively less effective among the insecticidal treatments. The untreated control harboured the highest thrips population, with 13.89 thrips per shoot.

A similar efficacy trend was also observed after the second spray. On the third day after the second spray, broflanilide 30 SC recorded the lowest mean number of population (1.33 thrips per shoot), followed by spinetoram 11.70 SC (2.89) and spinosad 45 SC (3.11). Fluxametamide 10 EC (5.00) and dimpropyridaz 120 g/L SL (5.11) maintained moderate suppression, whereas cyantraniliprole 10.26 OD (5.89) and lambda-cyhalothrin 4.9 CS (5.44) were found less effective. The untreated control recorded the highest mean number of population (13.78 thrips per shoot).

On the seventh day after the second spray, broflanilide 30 SC continued to record the lowest thrips population (0.89 thrips per shoot). This was followed by spinetoram 11.70 SC (1.67) and spinosad 45 SC (1.78) and found statistically on par with each other. Fluxametamide 10 EC (3.44) and dimpropyridaz 120 g/L SL (3.89) recorded moderate counts, while cyantraniliprole 10.26 OD (4.22) and lambda-cyhalothrin 4.9 CS (4.78) recorded relatively higher mean number of thrips per shoot among chemical treatments. The untreated control showed the maximum mean number of thrips per shoot (13.22).

At the tenth day after the second spray, broflanilide 30 SC recorded the lowest mean number of thrips per shoot (0.22) with the highest per cent reduction (98.11%) over untreated control, followed by spinetoram 11.70 SC and spinosad 45 SC, which were recorded 0.56 and 0.67 thrips per shoot, achieving 95.19% and 94.31% reduction over untreated control, respectively. Fluxametamide 10 EC and dimpropyridaz 120 g/L SL recorded moderate reductions of 78.92% and 75.54%, respectively. Whereas cyantraniliprole 10.26 OD and lambda-cyhalothrin 4.9 CS were least effective with 67.72% and 66.82% reduction, respectively.

With respect to bunch damage at harvest, broflanilide 30 SC proved most effective treatment with least per cent bunch damage (4.43% per vine) and was statistically on par with spinetoram 11.70 SC (5.09%). This was followed by spinosad 45 SC (7.90%). Moderately high per cent bunch damage was observed with fluxametamide 10 EC (11.68%) and dimpropyridaz 120 g/L SL (12.60%) treatments. Whereas lambda-cyhalothrin 4.9 CS (19.78%) and cyantraniliprole 10.26 OD (25.37%) were found least effective in reducing per cent bunch damage among chemical treatments. The untreated control recorded the maximum per cent bunch damage (42.55%).

A similar trend was observed with respect to berry damage, the lowest per cent berry damage was recorded in broflanilide 30 SC (7.97%), which was statistically on par with spinetoram 11.70 SC (10.75%) and spinosad 45 SC (12.27%). Moderately high per cent berry damage was observed in fluxametamide 10 EC (20.36%) and dimpropyridaz 120 g/L SL (27.97%). Cyantraniliprole 10.26 OD (47.05%) and lambda-cyhalothrin 4.9 CS (44.56%) treatments recorded relatively high per cent berry damage with 47.05% and 44.56%, respectively. The maximum per cent berry damage was observed in the untreated control (52.49%).

Overall, the results clearly revealed that broflanilide 30 SC, spinetoram 11.70 SC, and spinosad 45 SC

Table 1: Efficacy of insecticides against thrips on cv. Bangalore Blue grapes (Budigere)

Treatments	Dosage formulation ml/L	Pre-count	Mean number of thrips per shoot*						Reduction over control (%)	Bunch damage (%)**	Berry damage (%)**
			First spray			Second spray					
			3 DAS	7 DAS	10 DAS	3 DAS	7 DAS	10 DAS			
Cyantraniliprole 10.26 OD	1.4	9.89 (3.22)	8.44 (2.99)^{d}	6.44 (2.64)^{d}	6.33 (2.61)^{d}	5.89 (2.53)^{d}	4.22 (2.17)^{d}	3.56 (2.01)^{d}	67.72	25.37 (30.25)^{e}	47.05 (43.31)^{d}
Fluxametamide 10 w/w EC	0.8	10.89 (3.37)	6.89 (2.72)^{c}	5.44 (2.44)^{c}	5.33 (2.42)^{c}	5.00 (2.35)^{c}	3.44 (1.98)^{c}	2.56 (1.75)^{c}	78.92	11.68 (19.99)^{c}	20.36 (26.82)^{b}
Spinetoram 11.70 SC	0.6	10.44 (3.31)	5.33 (2.41)^{b}	3.33 (1.96)^{b}	3.22 (1.93)^{b}	2.89 (1.84)^{b}	1.67 (1.47)^{b}	0.56 (1.02)^{b}	95.19	5.09 (13.04)^{a}	10.75 (19.14)^{a}
Spinosad 45 SC	0.25	10.56 (3.32)	5.56 (2.46)^{b}	3.56 (2.01)^{b}	3.44 (1.99)^{b}	3.11 (1.90)^{b}	1.78 (1.51)^{b}	0.67 (1.08)^{b}	94.31	7.90 (16.32)^{b}	12.27 (20.50)^{a}
Dimpropyridaz 120g/L SL	1.0	11.00 (3.39)	7.56 (2.84)^{c}	5.56 (2.46)^{c}	5.44 (2.44)^{c}	5.11 (2.37)^{c}	3.89 (2.09)^{c}	3.00 (1.87)^{c}	75.54	12.60 (20.79)^{c}	27.97 (31.93)^{c}
Broflanilide 30 SC	0.08	10.44 (3.31)	4.00 (2.12)^{a}	2.44 (1.72)^{a}	2.33 (1.68)^{a}	1.33 (1.35)^{a}	0.89 (1.17)^{a}	0.22 (0.84)^{a}	98.11	4.43 (12.15)^{a}	7.97 (16.40)^{a}
Lambda-cyhalothrin 4.9 CS	0.5	11.11 (3.41)	9.00 (3.08)^{d}	6.56 (2.66)^{d}	6.67 (2.68)^{d}	5.44 (2.44)^{d}	4.78 (2.30)^{d}	4.11 (2.15)^{e}	66.82	19.78 (26.41)^{d}	44.56 (41.88)^{d}
Untreated control	-	11.56 (3.47)	12.11 (3.55)^{e}	13.67 (3.76)^{e}	13.89 (3.79)^{e}	13.78 (3.78)^{e}	13.22 (3.70)^{e}	12.89 (3.66)^{f}	-	42.55 (40.72)^{f}	52.49 (46.43)^{e}
Sem	-	**0.07**	**0.04**	**0.03**	**0.03**	**0.04**	**0.06**	**0.04**	**-**	**0.49**	**1.91**
CD at 5%	-	**0.23**	**0.13**	**0.10**	**0.10**	**0.13**	**0.17**	**0.13**	**-**	**1.49**	**5.80**

*indicates significant; values in the parenthesis are as SQRT (√x +0.5) transformation values; DAP – days after pruning, ** Values arc sign transformation

were the most effective treatments in suppressing thrips populations and minimizing per cent bunch and berry damage at Budigere. Fluxametamide 10 EC and dimpropyridaz 120 g/L SL were moderately effective, while cyantraniliprole 10.26 OD and lambda-cyhalothrin 4.9 CS were comparatively less effective. The untreated control recorded the highest thrips population and highest per cent bunch and berry damage during efficacy study period.

Konaghatta (Trial II)

The data on the efficacy of various insecticidal treatments against thrips on grape cv. Bangalore Blue at Konaghatta are presented in Table 2. The pre-treatment thrips population varied from 10.22 to 11.89 thrips per shoot, with no significant difference among treatments.

At three days post-treatment, all the treatments were found significantly superior over untreated control, but the lowest mean number of thrips population was observed in broflanilide 30 SC (T_6) with 4.33 thrips per shoot, which was statistically superior to all other treatments. This was followed by spinetoram 11.70 SC and spinosad 45 SC, recording 5.67 and 5.89 thrips per shoot, respectively and was statistically on par with each other. Moderate suppression of thrips population was noted in fluxametamide 10 EC (T_2) and dimpropyridaz 120 g/L SL with 7.22 and 7.67 thrips per shoot, whereas cyantraniliprole 10.26 OD and lambda-cyhalothrin 4.9 CS were found less effective with 8.78 and 9.33 thrips per shoot, respectively. The untreated control recorded the highest thrips population with 12.44 thrips per shoot.

The observations recorded at seven days after the first spray revealed that broflanilide 30 SC continued to show the highest efficacy against thrips with 2.78 thrips per shoot and significantly superior to all other treatments. It was followed by spinetoram 11.70 SC, spinosad 45 SC with 3.67 and 3.89 mean number of thrips per shoot, respectively. Moderate suppression was seen in fluxametamide 10 EC and dimpropyridaz 120 g/L SL with 5.78 and 5.89 thrips per shoot, respectively and were on par with each other. Cyantraniliprole 10.26 OD and lambda-cyhalothrin 4.9 CS were found relatively less effective in controlling thrips, while the untreated control remained with highest mean number of thrips (14.00 thrips per shoot).

At ten days after post-treatments, broflanilide 30 SC recorded the lowest mean population (1.89 thrips per shoot), followed by spinetoram 11.70 SC (3.56) and spinosad 45 SC (3.78). These treatments were statistically on par and significantly superior to the rest of the treatments. Fluxametamide 10 EC (5.22) and dimpropyridaz 120 g/L SL (5.89) were found moderately effective, whereas cyantraniliprole 10.26 OD (6.67) and lambda-cyhalothrin 4.9 CS (7.00) were found least effective among chemical treatments. The untreated control recorded the highest thrips population with14.22 per shoot.

A similar trend was also observed after the second spray. At three days after post-treatments, it was found that broflanilide 30 SC with 1.56 thrips per shoot showed highest efficacy against thrips and significantly superior over all other treatments. This was followed by spinetoram 11.70 SC (2.89) and spinosad 45 SC (3.00) and equally effective in reducing the thrips population. Fluxametamide 10 EC (4.78) and dimpropyridaz 120 g/L SL (4.89) were found moderately effective against thrips. Cyantraniliprole 10.26 OD (6.22) and lambda-cyhalothrin 4.9 CS (6.67) were found comparatively less effective. The untreated control recorded highest mean number of thrips with 14.11 per shoot.

At seven days after post treatments, broflanilide 30 SC found significantly superior to all other treatments with 1.11 thrips per shoot. It was followed by spinetoram (2.00) and spinosad (2.11) treatments which were found equally effective in reduction of mean number of thrips per shoot. Fluxametamide (3.33) and dimpropyridaz (4.22) were found moderately effective. These were followed by cyantraniliprole (4.56), and lambda-cyhalothrin (5.11) which were observed to be relatively less effective.

At the tenth day after the second spray, broflanilide 30 SC recorded the lowest mean number of thrips (0.33 thrips per shoot) and achieved the highest per cent reduction over control (97.25%). This was followed by spinetoram 11.70 SC and spinosad 45 SC with 0.78 and 0.89 thrips per shoot, achieved 93.49% and 92.65% reduction over untreated control, respectively and were on par with each other. Fluxametamide 10 EC (2.11 thrips/shoot) and dimpropyridaz 120 g/L SL (3.33 thrips/shoot) showed moderate efficacy with 83.09% and 73.57% reduction, respectively. Cyantraniliprole 10.26 OD (3.89 thrips/ shoot) and lambda-cyhalothrin 4.9 CS (4.44 thrips/ shoot) were not effective enough to be superior over the above treatments with 65-66% reduction over untreated control.

Table 2: Efficacy of insecticides against thrips on cv. Bangalore Blue grapes (Konaghatta)

Treatments	Dosage formulation ml/L	Pre-count	Mean number of thrips per shoot*						Reduction over control (%)	Bunch damage (%)**	Berry damage (%)**
			First spray			Second spray					
			3 DAS	7 DAS	10 DAS	3 DAS	7 DAS	10 DAS			
Cyantraniliprole 10.26 OD	1.4	10.22 (3.27)	8.78 (3.05)^{d}	6.78 (2.70)^{d}	6.67 (2.68)^{d}	6.22 (2.59)^{d}	4.56 (2.25)^{de}	3.89 (2.09)^{de}	65.77	27.07 (31.35)^{e}	43.89 (41.49)^{e}
Fluxametamide 10 w/w EC	0.8	11.22 (3.42)	7.22 (2.78)^{c}	5.78 (2.51)^{c}	5.22 (2.39)^{b}	4.78 (2.30)^{c}	3.33 (1.96)^{c}	2.11 (1.61)^{c}	83.09	13.05 (21.17)^{c}	17.42 (24.67)^{c}
Spinetoram 11.70 SC	0.6	10.78 (3.36)	5.67 (2.48)^{b}	3.67 (2.04)^{b}	3.56 (2.01)^{b}	2.89 (1.84)^{b}	2.00 (1.58)^{b}	0.78 (1.13)^{b}	93.49	7.06 (15.40)^{a}	9.92 (18.36)^{ab}
Spinosad 45 SC	0.25	10.89 (3.37)	5.89 (2.53)^{b}	3.89 (2.09)^{b}	3.78 (2.07)^{b}	3.00 (1.87)^{b}	2.11 (1.62)^{b}	0.89 (1.18)^{b}	92.65	10.11 (18.54)^{b}	12.38 (20.60)^{bc}
Dimpropyridaz 120g/L SL	1.0	11.33 (3.44)	7.67 (2.86)^{c}	5.89 (2.53)^{c}	5.78 (2.51)^{c}	4.89 (2.32)^{c}	4.22 (2.17)^{d}	3.33 (1.96)^{d}	73.57	14.59 (22.46)^{c}	27.57 (31.68)^{d}
Broflanilide 30 SC	0.08	10.78 (3.36)	4.33 (2.20)^{a}	2.78 (1.81)^{a}	1.89 (1.55)^{a}	1.56 (1.43)^{a}	1.11 (1.26)^{a}	0.33 (0.90)^{a}	97.25	6.19 (14.41)^{a}	5.95 (14.12)^{a}
Lambda-cyhalothrin 4.9 CS	0.5	11.44 (3.45)	9.33 (3.14)^{d}	6.89 (2.72)^{d}	7.00 (2.74)^{d}	6.67 (2.68)^{d}	5.11 (2.37)^{e}	4.44 (2.22)^{e}	65.09	21.29 (27.48)^{d}	46.00 (42.70)^{e}
Untreated control	-	11.89 (3.52)	12.44 (3.60)^{e}	14.00 (3.81)^{e}	14.22 (3.84)^{e}	14.11 (3.82)^{e}	13.56 (3.75)^{f}	13.22 (3.70)^{f}	-	44.51 (41.85)^{f}	52.62 (46.50)^{f}
Sem		**0.07**	**0.04**	**0.03**	**0.03**	**0.05**	**0.06**	**0.05**	-	**0.74**	**0.68**
CD at 5%		**0.22**	**0.13**	**0.10**	**0.08**	**0.15**	**0.18**	**0.15**	-	**2.24**	**2.12**

*indicates significant; values in the parenthesis are as SQRT (√x +0.5) transformation values; DAP – days after pruning, **Values arc sign transformation

At the harvest, broflanilide 30 SC (6.19%) and spinetoram 11.70 SC (7.06%) found significantly superior over all other treatments with respect to per cent bunch damage. These were followed by spinosad 45 SC (10.11%) which performed significantly better than the rest of the treatments. Moderate protection to grape bunches was noted in fluxametamide 10 EC (13.05%) and dimpropyridaz 120 g/L SL (14.59%), while lambda-cyhalothrin 4.9 CS (21.29%) and cyantraniliprole 10.26 OD (27.07%) were found least effective. The untreated control recorded the highest per cent bunch damage (44.51%).

A similar pattern was also evident for per cent berry damage. The lowest per cent berry damage was observed in broflanilide 30 SC (5.95%), which was statistically on par with spinetoram 11.70 SC (9.92%). This was followed by spinosad 45 SC (12.38%). Moderate reduction with per cent berry damage was achieved with fluxametamide 10 EC (17.42%) and dimpropyridaz 120 g/L SL (27.57%), whereas cyantraniliprole 10.26 OD (43.89%) and lambda-cyhalothrin 4.9 CS (46.00%) were found least effective in reducing per cent berry damage. The highest per cent berry damage was observed in the untreated control (52.62%).

Overall, at Konaghatta, the efficacy results clearly revealed that broflanilide 30 SC, spinetoram 11.70 SC, and spinosad 45 SC were found the most effective treatments, consistently reducing thrips incidence and fruit damage after two sprays at 10 days interval. Fluxametamide 10 EC and dimpropyridaz 120 g/L SL provided moderate protection against thrips. Whereas cyantraniliprole 10.26 OD and lambda-cyhalothrin 4.9 CS was found comparatively less effective.

Pooled data

The pooled data on the efficacy of different insecticidal treatments against thrips on grape cv. Bangalore Blue is given in Table 3. The pre-treatment population ranged from 10.06 to 11.72 thrips per shoot.

Three days post treatments, all the treatments were significantly superior over control, but the lowest mean number of thrips (4.17 thrips per shoot) was observed in broflanilide 30 SC after first spray. This was followed by spinetoram 11.70 SC (5.50 thrips/shoot) and spinosad 45 SC (5.72 thrips/shoot), which were found statistically at par with each other. Further, these were also found significantly superior over fluxametamide 10 EC (7.06 thrips/shoot) and dimpropyridaz 120 g/L SL (7.61 thrips/shoot). Relatively the highest thrips population was observed in lambda-cyhalothrin 4.9 CS and cyantraniliprole 10.26 OD with 9.17 and 8.61 thrips/shoot, respectively, which were least effective but still significantly superior to the untreated control (12.28 thrips/shoot).

At seven days post treatments of the first spray, broflanilide 30 SC recorded the minimum thrips population of 2.61 thrips per shoot, which was significantly superior over all other treatments. Spinetoram 11.70 SC (3.50 thrips/shoot) and spinosad 45 SC (3.72 thrips/shoot) were found equally effective in reducing thrips population and these were significantly superior to fluxametamide 10 EC (5.61 thrips/shoot), dimpropyridaz 120 g/L SL (5.72 thrips/shoot), cyantraniliprole 10.26 OD (6.61 thrips/shoot) and lambda-cyhalothrin 4.9 CS (6.72 thrips/shoot). Similar trend was also observed at ten days post treatments after first spray, where broflanilide 30 SC continued to register the least thrips population (2.11 thrips/shoot) and this was followed by spinetoram 11.70 SC (3.39 thrips/shoot) and spinosad 45 SC (3.61 thrips/shoot), all of which were significantly superior to the rest of the treatments.

Similar trend was also observed at three days post treatments after second spray. Broflanilide 30 SC (1.44 thrips/shoot) recorded the lowest thrips population and found significantly superior over all other treatments. Spinetoram 11.70 SC (2.89 thrips/shoot) and spinosad 45 SC (3.06 thrips/shoot) were found equally effective in reduction of thrips populations, followed by fluxametamide 10 EC (4.89 thrips/shoot) and dimpropyridaz 120 g/L SL (5.00 thrips/shoot). Cyantraniliprole 10.26 OD (6.06 thrips/shoot) and Lambda-cyhalothrin 4.9 CS (6.05 thrips/shoot) were least effective but significantly superior over the untreated control (13.94 thrips/shoot). Similar trends were also noticed at seven days and ten days post treatments, where broflanilide 30 SC with 1.00 and 0.28 thrips/shoot, respectively was found significantly superior to all other treatments, followed by spinetoram 11.70 % SC (1.83 and 0.67 thrips/shoot) and spinosad 45 SC (1.94 and 0.78 thrips/shoot). Fluxametamide 10 EC (3.39 and 2.33 thrips/shoot) and dimpropyridaz 120 g/L SL (4.06 and 3.17 thrips/shoot) were found moderately effective against thrips. Cyantraniliprole 10.26 OD (4.39 and 3.72 thrips/shoot) and lambda-cyhalothrin 4.9 CS (4.94 and 4.28 thrips/shoot) were not effective enough to be superior over the above treatments.

Table 3: Efficacy of insecticides against thrips on cv. Bangalore Blue grapes (pooled)

Treatments	Dosage formulation ml/L	Pre-count	Mean number of thrips per shoot						Reduction over control (%)	Bunch damage (%)**	Berry damage (%)**
			First spray			Second spray					
			3 DAS	7 DAS	10 DAS	3 DAS	7 DAS	10 DAS			
Cyantraniliprole 10.26 OD	1.4	10.06 (3.25)	8.61 (3.02)^{d}	6.61 (2.67)^{d}	6.50 (2.65)^{e}	6.06 (2.56)^{d}	4.39 (2.21)^{de}	3.72 (2.05)^{e}	66.82	26.22 (30.80)^{e}	45.44 (42.38)^{e}
Fluxametamide 10 w/w EC	0.8	11.06 (3.40)	7.06 (2.75)^{c}	5.61 (2.47)^{c}	5.28 (2.40)^{c}	4.89 (2.32)^{c}	3.39 (1.97)^{c}	2.33 (1.68)^{c}	81.09	12.89 (21.04)^{c}	18.34 (25.76)^{c}
Spinetoram 11.70 SC	0.6	10.61 (3.33)	5.50 (2.45)^{b}	3.50 (2.00)^{b}	3.39 (1.97)^{b}	2.89 (1.84)^{b}	1.83 (1.53)^{b}	0.67 (1.08)^{b}	94.33	6.07 (14.26)^{a}	10.33 (18.75)^{ab}
Spinosad 45 SC	0.25	10.72 (3.35)	5.72 (2.49)^{b}	3.72 (2.05)^{b}	3.61 (2.03)^{b}	3.06 (1.89)^{b}	1.94 (1.56)^{b}	0.78 (1.13)^{b}	93.47	8.99 (17.45)^{b}	12.79 (20.55)^{b}
Dimpropyridaz 120g/L SL	1.0	11.17 (3.41)	7.61 (2.85)^{c}	5.72 (2.49)^{c}	5.67 (2.48)^{d}	5.00 (2.35)^{c}	4.06 (2.13)^{d}	3.17 (1.91)^{d}	74.53	13.59 (21.63)^{c}	27.77 (31.80)^{d}
Broflanilide 30 SC	0.08	10.61 (3.33)	4.17 (2.16)^{a}	2.61 (1.76)^{a}	2.11 (1.62)^{a}	1.44 (1.39)^{a}	1.00 (1.22)^{a}	0.28 (0.88)^{a}	97.63	5.31 (13.32)^{a}	6.96 (15.30)^{a}
Lambda-cyhalothrin 4.9 CS	0.5	11.28 (3.43)	9.17 (3.11)^{d}	6.72 (2.69)^{d}	6.83 (2.71)^{e}	6.05 (2.54)^{d}	4.94 (2.33)^{e}	4.28 (2.19)^{f}	65.95	20.53 (26.94)^{d}	45.28 (42.29)^{e}
Untreated control	-	11.72 (3.50)	12.28 (3.57)^{e}	13.83 (3.79)^{e}	14.06 (3.82)^{f}	13.94 (2.80)^{e}	13.39 (3.73)^{f}	13.06 (3.68)^{g}	-	43.52 (41.28)^{f}	52.55 (46.46)^{f}
F-test		**NS**	*	*	*	*	*	*	-	*	*
Sem		**0.07**	**0.04**	**0.03**	**0.03**	**0.04**	**0.05**	**0.03**	-	**0.71**	**0.89**
CD at 5%		**0.22**	**0.13**	**0.10**	**0.09**	**0.12**	**0.16**	**0.09**	-	**2.16**	**2.56**

*indicates significant; values in the parenthesis are as SQRT (√x +0.5) transformation values; DAP – days after pruning, **Values arc sign transformation

Among all the treatments, broflanilide 30 SC recorded the lowest per cent bunch damage (5.31 %) and berry damage (6.96 %) (Table 3), which was on par with spinetoram 11.70 SC (10.33 % and 6.07 %). These were followed by spinosad 45 SC (8.99% bunch and 12.79 % berry damage, respectively) significantly superior to fluxametamide 10 EC (12.89% bunch and 18.34 % berry damage, respectively), and dimpropyridaz 120 g/L SL (13.59% bunch and 27.77 % berry damage, respectively), whereas the highest per cent bunch (43.52 %) and berry (52.55 %) damage was observed in the untreated control.

The per cent reduction of thrips population over control was highest in Broflanilide 30 SC (97.63 %) followed by spinetoram 11.70 SC (94.33 %) and spinosad 45 SC (93.47 %). Moderate efficacy was observed with fluxametamide 10 EC (81.09 %) and dimpropyridaz 120 g/L SL (74.53 %), whereas cyantraniliprole 10.26 OD and lambda-cyhalothrin 4.9 CS with 66.82 % and 65.95 % reduction respectively were found relatively less effective.

Overall, pooled results across both locations revealed that broflanilide 30 SC, spinetoram 11.70 SC, and spinosad 45 SC were the most effective insecticidal treatments in suppressing thrips population and minimizing berry and bunch damage, followed by fluxametamide 10 EC and dimpropyridaz 120 g/L SL. The least effective treatments were cyantraniliprole 10.26 OD and lambda-cyhalothrin 4.9 CS, although they performed significantly better than the untreated control.

As thrips is one of the major sucking pests on Bangalore Blue causing huge economic loss to farmers by damaging inflorescence and berries, it is very essential to take up the management practices to control the pest. In the present study among the seven tested chemicals, broflanilide 30 SC @ 0.08 ml/L was found to be most effective and superior over all other treatments. This agrees with the observations of Samreen and Pavana. (2025) who demonstrated that broflanilide 30 SC provided consistently high levels of control (93.61% efficacy) in the field against the invasive thrips species, *T. parvispinus*, on chilli followed by fluxametamide 10 EC with a 90.72% reduction and cyantraniliprole 10.26 OD (60.54%). The present findings are also in line with the observations of Chen *et al.* (2022), who demonstrated that broflanilide provided consistently high levels of control (90-93 per cent efficacy) against *Thrips palmi* up to 14 days and >90 per cent egg mortality.

The next best chemicals were spinetoram 11.7 SC @ 0.6 ml/L and spinosad 45 SC @ 0.25 ml/L. The present findings further align with findings of Guruprasad *et al*. (2019), who reported that spinetoram 11.7 SC significantly suppressed thrips incidence in grapes and the field evaluations highlighting the strong efficacy and selectivity of spinosyn compounds. Ghosh and Karmakar (2021) also reported that spinetoram + sulfoxaflor recorded the lowest thrips population (2.37 thrips/shoot) and highest per cenet reduction (84.55%) over the untreated control from the bio-efficacy insecticides trials against *T. palmi* on grapes. Current findings were also corroborated by National Research Centre for Grapes (ICAR-NRCG) field trials, which demonstrated that spinosad 45 SC achieved remarkable control of vineyard thrips (*S. dorsalis*), recording 65-92 per cent reduction in field populations and 85-98 per cent mortality in laboratory tests, clearly underscoring its strong performance in managing grape thrips (Yadav *et al.,* 2016). This also aligns with Kulkarni (2012), who reported that spinosad 45 SC (0.25 ml/l) significantly reduced thrips population in grapes was the highest among treatments.

In the present study, it was found that fluxametamide 10 EC consistently reduced thrips incidence to moderate levels, though its efficacy was slightly inferior to broflanilide and spinetoram, which showed near-complete suppression. However, laboratory bioassay studies by Kamakshi *et al.* (2024) demonstrated that fluxametamide 10 EC @ 400 ml/ha caused very high mortality of *T. parvispinus*, with efficacy statistically on par with broflanilide and superior to spinetoram and spinosad. These results are slightly in contradictory to current findings.

On the other hand, cyantraniliprole 10.26 OD and lambda-cyhalothrin 4.9 CS were the found least effective among chemical treatments, recording higher thrips counts throughout the trial. This sub optimal performance of lambda-cyhalothrin is consistent with the findings of Sun *et al.* (2024) who reported a LC_{50} value of 130.44 mg/L indicating a relatively low toxicity in practical applications. This aligns with findings from recent studies on chilli thrips (*S. dorsalis*), where spinetoram (11.7 SC at 60 g a.i./ha) achieved the highest mean reduction (93.35 per cent), while cyantraniliprole 10.26 OD at 60 g a.i./ha exhibited comparatively lower efficacy of 90.78 per cent from that of spinetoram (Poornima *et al*., 2024). Further, Mavridis *et al.* (2023) also reported high LC_{50} values and significantly lower

field efficacy for cyantraniliprole against *Frankliniella occidentalis* compared to spinosyns. This is likely due to the systemic but slow action of diamide insecticides, which may not adequately control highly mobile and rapidly reproducing pests like thrips, combined with potential cross-resistance issues. However, these findings were slight contradictory to Priyanka *et al.* (2023) who reported that cyantraniliprole 300 g/L (90 g a.i./ha) provided highly effective in managing thrips population in grapes with higher yields and no phytotoxicity, it may be due to differences in local thrips susceptibility, environmental conditions, and application practices, which strongly influence cyantraniliprole performance. The untreated control naturally harboured the highest infestations at all intervals, confirming the effectiveness of applied insecticidal treatments in suppressing the thrips complex on grapes.

CONCLUSION

Based on the findings of the present study, broflanilide 30 SC @ 0.08 ml/ L, spinetoram 11.70 SC @ 0.6 ml/L, and spinosad 45 SC @ 0.25 ml/L were identified as the most effective insecticides for the management of grape thrips. Among these, broflanilide 30 SC not only provided superior suppression of thrips infestation and berry damage but also recorded the highest incremental cost–benefit ratio, making it the most economically viable option for grape growers. Fluxametamide 10 EC and dimpropyridaz 120 g/L SL exhibited moderate efficacy and may be incorporated into insecticide rotation programmes to diversify modes of action and delay the development of resistance in thrips populations.

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AUTHOR CONTRIBUTION

AAN- Investigation, data analysis and Manuscript writing; GK-Conceptualization, framing research, Supervision and Manuscript editing. AM and BM-Manuscript correction, feed back and members of advisory committee.

CONFLICT OF INTEREST

Authors don't have conflict of interest to express

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DNA barcoding and phylogenetic analysis of major fruit fly pests occurring in New Delhi

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ABSTRACT: Accurate and rapid species identification of tephritid fruit flies is critical for effective pest management, particularly where morphologically similar species coexist. The present study aimed to document economically important fruit fly pests in Delhi and to establish DNA barcode-based identification using mitochondrial cytochrome c oxidase subunit I (mtCOI) gene. Adult flies were collected using cue lure and methyl eugenol traps and also through laboratory rearing of infested fruit and vegetables. All samples were morphologically identified and representative samples were subjected to COI gene amplification and Sanger sequencing. A total of 264 specimens representing five species, *Zeugodacus cucurbitae* (Coquillett, 1899); *Z. tau* Walker, 1849; *Bactrocera dorsalis* (Hendel, 1912); *B. zonata* (Saunders, 1842) and *B. divenderi* Maneesh, Hancock & Prabhakar, 2022 were recorded from cucurbitaceous vegetables and fruit crops including mango, guava and pomegranate. Twelve barcodes, showing high sequence similarity (98.06-100%) were generated using the universal primer pair (LCO1490 and HCO2198) and deposited in GenBank. Phylogenetic analyses using the Neighbor-Joining (NJ) method recovered distinct clusters corresponding to the morphologically identified species and clearly separated the genera *Zeugodacus* and *Bactrocera*. The generated DNA barcodes provide a valuable molecular reference for fruit fly identification in Delhi and demonstrate the usefulness of COI barcoding as a tool for surveillance, diagnostics and integrated management.

Keywords: COI, Dacinae, Fruit fly surveillance, Molecular identification, Tephritidae

INTRODUCTION

Tephritidae, commonly known as fruit flies, constitute one of the largest and most diverse families within the order Diptera. Globally, this family encompasses more than 5000 species (Bragard *et al.,* 2020), of which nearly 200 are economically important (Papadopoulos *et al.,* 2024). In the Indian subcontinent, 335 species of fruit flies have been recorded, belonging to 97 genera, 22 tribes and 5 subfamilies (Singh *et al*., 2025). Fruit flies cause major losses in fruit and vegetable production by laying eggs in ripening fruits, leading to spoilage and reducing their market value (Dias *et al.,* 2022; He *et al.,* 2023). These pests pose serious challenges to the agricultural sector by inflicting direct damage, making fruits unmarketable and contributing to considerable post-harvest losses (Ekesi *et al.,* 2016). Their high reproductive capacity, broad larval host range, rapid dispersal, extreme polyphagy and wide climatic tolerance enable them to multiply quickly under favourable conditions, further intensifying their destructive impact on fruits and vegetables (Vasudha and Agarwal, 2019; He *et al.,* 2023). Rapid and fast identification of fruit fliesis crucial in effective pest management and decision making (Armstrong and Ball, 2005; Kunprom and Pramual, 2016). The taxonomy of the fruit flies mostly relies on the morphological characters of the adults (Frias *et al.,* 2008); however, it becomes challenging when there is high variation within a species or when closely related species exhibit strong morphological similarity and the immature stages (Armstrong *et al.,* 1997; Mitra *et al.,* 2025). Accurate identification is particularly challenging within the *Bactrocera dorsalis* species complex, which comprises approximately 90 closely related species, including nearly 30 species attracted to methyl eugenol (ME). Morphological identification of *B. dorsalis* is often complicated by overlapping diagnostic characters with closely related species, particularly *B. carambolae* and *B. occipitalis*, resulting in potential misidentification (Leblanc *et al.,* 2015; Pieterse *et al.,* 2017; Taddei *et al.,* 2023). Compared to traditional taxonomic identification molecular detection methods are rapid, highly specific and also useful in identifying immature stages, cryptic

taxa as well as degraded and specimens with lost body parts (Avise, 1994; Hebert *et al.,* 2003; Hillary and Ceasar, 2023; Kumar *et al*., 2025; Barman *et al*., 2025). Several molecular approaches have been developed to support fruit fly identification, including PCR-based techniques such as restriction length polymorphism (RFLP) (Armstrong *et al*., 1997; Barr *et al*., 2006), amplified fragment length polymorphism (AFLP) (Kakouli-Duarte *et al*., 2001), and oligonucleotide array-based assays (Naeole and Haymer 2003).Among these, DNA barcoding based on mtCOI has become one of the most widely used methods for tephritid identification because of its high discriminatory power and ability to complement morphological identification. (Armstrong and Ball, 2005; Black *et al.,* 2012).

This study aimed to document the economically important tephritid pests occurring in Delhi and establish a DNA barcode reference library based on mtCOI gene. Despite the economic importance of fruit flies, comprehensive information on molecular characterization of tephritid species is lacking.Fruit fly specimens were collected from various agricultural fields and orchards and identified morphologically using standard taxonomic keys and validated through COI DNA barcoding. Molecular phylogenetic analysis was subsequently carried out to assess genetic relationships among the recorded species.

MATERIALS AND METHODS

Insect collection and rearing

Adult male fruit flies were collected at weekly intervals from October 2024 to June 2025 covering the winter and summer seasons using pheromone traps developed by the Division of Entomology, ICAR - Indian Agricultural Research Institute (ICAR-IARI), New Delhi. Traps provided with cuelure and methyl eugenol were installed at a density of one trap per acre in experimental vegetable fields and orchards following developer's recommendations. In addition to trap collections, infested fruits and vegetables were collected from the same field and orchards for laboratory rearing. Each infested fruit or vegetable sample was placed individually in a 3 litre glass jar half filled with sterile sands to allow pupation followed by adult emergence, enabling the host association of each emerged adult to be recorded. Emerged adults were reared with honey solution and sugar cube at Division of Entomology. The culture was maintained at 28±2°C and 75% relative humidity. Adult specimens collected from traps were stored in absolute alcohol for further molecular study.

Morphological identification

Adult fruit flies collected from pheromone traps and those reared from infested fruits and vegetables were identified morphologically using the taxonomic keys of White and Elson-Harris (1992), Ramani (1997), David and Ramani (2011), Leblanc *et al.* (2021), Leblanc (2022), and Singh *et al*. (2022). Species identification was based on diagnostic morphological characters, including facial markings, scutal vittae, wing banding pattern, leg coloration, abdominal markings, and the presence or absence of a male pecten. The principal diagnostic characters used were as follows: *Zeugodacus cucurbitae* – orange-brown body with a fulvous face bearing two black spots, yellow medial and lateral scutal vittae, and a broad costal band expanded into an apical spot with radial-medial and subapical bands; *Z. tau* – dark brown scutum with yellow vittae, oval facial spots, an apically expanded costal band, and a male pecten on tergite III; *Bactrocera dorsalis* – yellowish face with two black facial spots, black to reddish-brown scutum with yellow lateral vittae, entirely yellow fore and mid femora, a continuous costal band, and an orange-red abdomen with a distinct T-shaped marking; *B. zonata* – pale orange-brown body with oval facial spots, a discontinuous costal band forming an apical spot, reddish-brown abdomen, and a male pecten on tergite III; and *B. divenderi* – entirely black face without facial spots, narrow postsutural lateral yellow vittae extending to the intra-alar seta, predominantly black fore and mid femora, a narrow non-expanded costal band and a predominantly black abdomen with a narrow pale transverse band on tergite II. Representative specimens were photographed dorsally using a Leica EC4 digital camera mounted on a Leica M205FA stereo zoom auto-montage microscope (Leica Microsystems, Germany), and the images were processed using Adobe Photoshop (Version 23.1.0). All voucher specimens were deposited in the National Pusa Collection (NPC), Division of Entomology, ICAR–Indian Agricultural Research Institute, New Delhi (INPC: http://grbio.org/cool/nwky-2b63).

DNA extraction

DNA was extracted from three legs of one side from adults and half body parts of maggots using CTAB

protocol. The lysis buffer of total 10 ml was prepared by 3.5 ml of 10% CTAB detergent, 2.8 ml of 5M NaCl, 1.0 ml of 1M Tris-HCl, 0.4 ml of 0.5M EDTA (pH 8.0), 20 µl of β-mercaptoethanol and 2.3 ml of sterile distilled water. Each insect tissue was put in a 1.5 ml microcentrifuge tube and homogenized in 500 µl of the extraction buffer with the help of a micro-pestle. The homogenate was incubated at 65°C for 2 hrs with gentle mixing every 10 mins. Following incubation, an equal volume (500µl) of chloroform:isoamyl alcohol (24:1) was added to each tube, mixed thoroughly and centrifuged at 6000 rpm for 15 min. The aqueous phase was carefully transferred to a new tube and 400µlof chilled isopropanol were added to precipitate the DNA. The mixture was kept at -20°C for 2 hrs. DNA was pelleted by centrifugation at 12000 rpm for 20 mins at 4°C. The supernatant was gently discarded and the pellet was washed with 70% ethanol. After removing residual ethanol by air drying at room temperature the DNA pellet was dissolved in 50 µl of TE buffer. The quality of the isolated DNA was assessed through 1% agarose gel electrophoresis and the purity and concentration were assessed using NanoDrop™ One Spectrophotometer (Thermo Scientific™). All the extracted DNA was stored at - 20°C for further molecular study.

PCR amplification of COI gene

The standard barcoding region of COI gene was amplified using universal barcoding primers LCO 1490 (Forward): GGTCAAATCATAAAGATATTGG and HCO2198 (Reverse): TAAACTTCAGGGTGACCAAAAAATCA (Folmer *et al.,* 1994). The PCR reaction of total 25 µl, consist of 12.5 µl of EmeraldAmp® MAX PCR Master Mix, 1 µl of forward and reverse primers, 8.5 µl of nuclease free water and 2 µl of template DNA. The PCR parameters for *Z. cucurbitae* is as follows: Initial denaturing at 95°C for 4 min followed by 35 cycles of 1 min denaturing at 95°C, 1 min annealing at 52°C and 1.30 min extension at 72°C followed by final extension for 7 min at 72°C. The PCR parameters for other species was as follows: initial denaturation at 94°C for 1 min, followed by 4 cycles of 94°C for 30 sec, 45°C for 40 sec and 72°C for 1 min, followed by 34 cycles of 94°C for 30 sec 51°C for 40 sec and 72°C for 1 min, followed by final extension at 72°C for 5 min. The reaction was stopped by an indefinite hold at 4 °C. The resulting products of PCR were separated using 1.6% agarose gel electrophoresis stained with ethidium bromide and visualized with a gel documentation system (BioRad Lab.).

Sequencing and characterization

The PCR amplified region of the COI gene from different fruit fly species was sequenced using Sanger dideoxy sequencing from Barcode Bioscience (Bengaluru, India). The sequences were then manually assembled using two or more forward and reverse sequence with the help of BioEdit software Version 7.2.5. The noisy sequences were trimmed from both ends of forward and reverse sequences. Subsequently, the sequences were aligned and consensus sequences were created for each species. The resulting consensus sequences were then compared in NCBI through BLASTN software to assess the quality and percentage similarity of the sequences with already submitted sequences. The assembled sequence was submitted to NCBI GenBank and accession number was obtained.

Phylogenetic analysis:

For phylogenetic analysis,COI gene sequence of respective fruit fly species generated in this study, along with sequences retrieved from NCBI database, were used.COI gene sequences submitted from different geographic locations worldwide (Supplementary Table 1) were collected from NCBI. For species lacking global representation, the available sequence entries in the database were used for the evaluation. A total of ten sequences per species were retrieved for phylogenetic analysis (Supplementary Table 1). Additionally, three sequences of *Culex quinquefasciatus* from three different geographic locations were retrieved from NCBI to serve as the out-group (Supplementary Table 1). The phylogenetic tree was constructed following the Neighbor-Joining (NJ) (Saitou and Nei, 1987) and Maximum Composite Likelihood methods (Tamura *et al.,* 2004) with 1000 bootstrap replicates in MEGA12 (Kumar *et al.,* 2024). The NJ tree was further refined and visually improved using the web-based iTOL tool (https://itol.embl.de/).

RESULTS AND DISCUSSION

A total number of 264 fruit fly specimens representing five species of fruit flies (*Zeugodacus cucurbitae, Z. tau, Bactrocera dorsalis, B. zonata* and *B. divenderi*) from the subfamily Dacinae were found in the selected vegetable fields and orchards of the already known hosts. The details of recorded species and the host plant from which they were collected are given in Table 1. The photographic illustrations of the representatives from the collected species were shown in Fig. 1.

Table 1: Details of the fruit fly species along with their recorded host plant and attractants

Sl. No	Insect Species	Host Plant (Collected from)	Attractants	Total no. of specimens
1.	*Zeugodacus cucurbitae* (Coquillett, 1899)	*Luffa aegyptiaca* (Sponge gourd), *Cucurbita pepo* (Summer squash) and *Cucumis sativus* (Cucumber)	Cue lure	66
2.	*Zeugodacus tau* Walker, 1849	*Luffa aegyptiaca* (Sponge gourd), *Cucurbita pepo* (Summer squash) and *Cucumis sativus* (Cucumber)	Cue lure	52
3.	*Bactrocera dorsalis* (Hendel, 1912)	*Mangifera indica* (Mango), *Punica granatum* (Pomegranate) and *Psidium guajava* (Guava)	Methyl eugenol	56
4.	*Bactrocera zonata* (Saunders, 1842)	*Mangifera indica* (Mango), and *Psidium guajava* (Guava)	Methyl eugenol	58
5.	*Bactrocera divenderi* Maneesh, Hancock & Prabhakar, 2022	*Luffa aegyptiaca* (Sponge gourd)	Cue lure	32

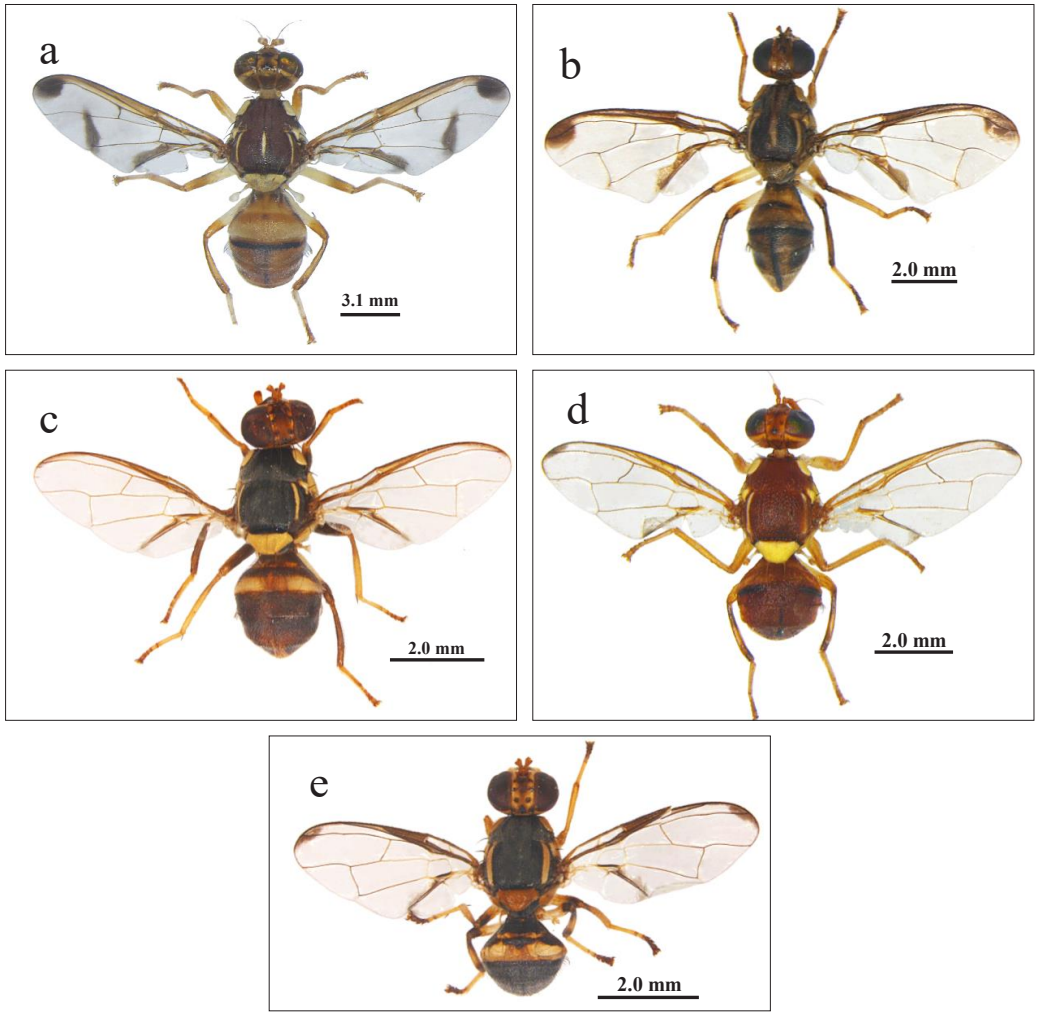

Fig. 1. Fruit fly species recorded in the present study (a) *Zeugodacus cucurbitae*, (b) *Z. tau*, (c) *Bactrocera dorsalis*, (d) *B. zonata*, (e) *B. divenderi*.

Table 2: List of accession numbers along with their % similarity with already submitted sequences in NCBI database, compared through BLASTN software.

Sl. No	Insect Species	Accession No	% Similarity
1.	*Zeugodacus cucurbitae*	PX672281, PX672755, PX699579	99.82-100.00%
2.	*Zeugodacus tau*	PX671287, PX701743	99.27-99.47%
3.	*Bactrocera dorsalis*	PX672976, PX699589	99.79-100.00%
4.	*Bactrocera zonata*	PX671429, PX672856, PX699593	99.50-100.00%
5.	*Bactrocera divenderi*	PX671250, PX699590	98.06-100.00%

Barcode generations

The consensus COI gene sequences made through bioinformatic software using forward and reverse sequences obtained from sanger sequencing of the PCR amplified product, assessed through NCBI BLASTN software. The BLASTN comparison of the submitted sequences showed very high degree of similarity with the NCBI database sequence of the same species (Table 2). A total number of twelve barcodes were generated in this study and accession numbers were obtained for all the species studied (Table 2). Two new barcodes were generated for *Z. tau*, *B. dorsalis* and *B. divenderi* and three new barcodes were generated for *Z. cucurbitae* and *B. zonata*, collected from various locations of ICAR-IARI, New Delhi. The relatively low sequence similarity (98.06%) observed for one *B. divenderi* sequence may be attributed to the limited molecular data currently available for this recently described species. *B. divenderi* was previously misidentified as *B. nigrofemoralis* White & Tsuruta and its economic importance as a pest remained unrecognizeduntil its formal description (Singh *et al*., 2022). Consequently, the limited representation of *B. divenderi* sequences in public databases may have contributed to the lower BLAST similarity observed in the present study.

Phylogenetic analysis

The results of phylogenetic analyses are summarized in Fig. 2. and reveal clear and consistent evolutionary relationships among the studied species. The topology of tree indicates that the positions of most species are highly stable in the Neighbor-Joining (NJ) analyses, reflecting strong phylogenetic signals in the dataset. *B. zonata* clusters closely with *B. divenderi* and both species are grouped under a single well-supported node, indicating a close evolutionary relationship. *B. dorsalis* also shows close affinity with these two species and together *B. zonata*, *B. divenderi* and *B. dorsalis* form a single monophyletic clade, suggesting a shared common ancestor. In contrast, *Z. cucurbitae* and *Z. tau* cluster together to form a distinct monophyletic group. This group is clearly separated from *Bactrocera* clade, highlighting the genetic divergence between the two genera and confirming their distinct evolutionary lineages.

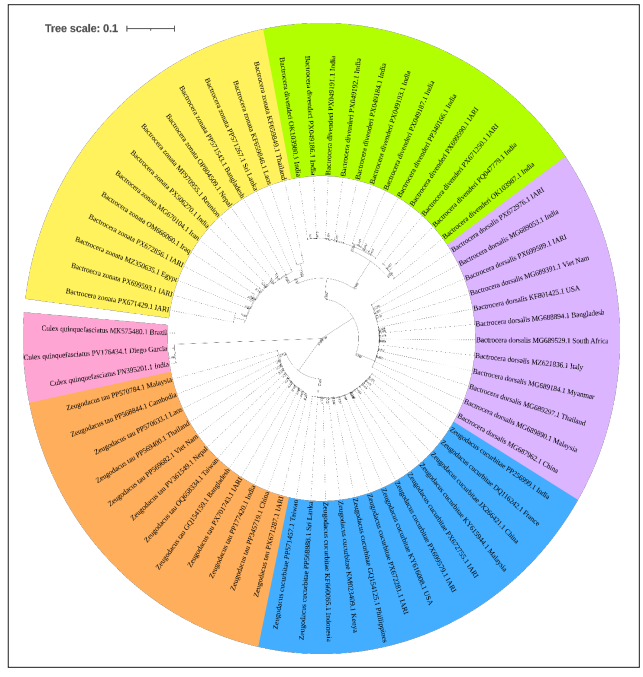

Fig. 2. Phylogenetic tree of recorded fruit fly species, constructed using the Neighbor-Joining (NJ) method taking *Culex quinquefasciatusas* an outgroup. Bootstrap values were calculated from 1000 replicates and are shown on the branches. Accession numbers of the sequences along with the country names from where they were submitted, shown in the tree and the de novo sequences were mentioned with the names of IARI after their individual accession numbers.

DNA barcoding based on the mitochondrial cytochrome c oxidase subunit I (COI) gene has become a widely accepted tool for the identification of tephritid

fruit flies and complements conventional morphology, particularly for closely related species and immature stages (Armstrong and Ball, 2005; Black *et al.*, 2012). A comprehensive COI reference library developed for 265 species of the tribe Dacini demonstrated that COI barcodes provide reliable species identification for most fruit flies, although species complexes such as the *Bactrocera dorsalis* complex may require additional molecular markers because approximately 11.3% of species were found to be non-monophyletic (Doorenweerd *et al*., 2022). In the present study, five economically important tephritid species infesting fruit and vegetable crops in Delhi were identified using both morphological characters and COI barcodes. A total of 264 specimens were collected, and representative specimens generated 12 COI barcode sequences showing 98.06–100% similarity with existing GenBank sequences. Neighbor-Joining phylogenetic analysis recovered distinct genetic clusters corresponding to the morphologically identified species and clearly separated the genera *Zeugodacus* and *Bactrocera*, consistent with previous studies (Kunprom and Pramual, 2016; Shashank *et al*., 2022). The relatively lower similarity (98.06%) observed for one *Bactrocera divenderi* sequence is likely due to the limited availability of reference sequences for this recently described species, which was previously misidentified as *B. nigrofemoralis* (Singh *et al*., 2022). The COI barcode sequences generated in this study provide valuable molecular reference data for the fruit fly fauna of Delhi and will support future surveillance, molecular diagnostics, and integrated pest management programs.

CONCLUSION

Accurate identification of fruit fly species infesting fruit and vegetable crops is essential for effective pest management and quarantine enforcement. In the present study, five fruit fly species were recorded from the New Delhi. Emergence studies from infested fruits confirmed that *Z. cucurbitae*, *Z. tau* and *B. divenderi* are the recorded species infesting cucurbits, whereas *B. dorsalis* and *B. zonata* are the major species infesting mango and guava. In pomegranate, *B. dorsalis* was identified as the sole recorded fruit fly species at the study location. DNA barcoding proved to be a reliable and powerful tool for the rapid and precise identification of fruit fly species occurring in New Delhi.

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AUTHOR CONTRIBUTION

Suman Barman: Writing – original draft, Visualization, Validation, Investigation, Formal analysis.

Pathour Rajendra Shashank: Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Formal analysis, Conceptualization.

Susheel Kumar Sharma: Supervision, resources, editing & review.

Godavari H: Data collection and identification.

Mukesh Kumar Dhillon: Supervision, resources, editing & review

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DATA AVAILABILITY

The sequence data used in this study are submitted to NCBI, and details of the data is provided within the manuscript.

DECLARATIONS

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests: The authors declare no competing interests.

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Pest–weather dynamics in tomato: a study from North-Western Punjab

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ABSTRACT: Seasonal incidence of insect pests of tomato was monitored weekly and analysed in relation to key meteorological parameters such as maximum and minimum temperatures, relative humidity, and rainfall. Sucking pests such as *Aphis gossypii* and *Bemisia tabaci*, along with lepidopteran pests viz., the leaf miner *Tuta absoluta* and the fruit borer *Helicoverpa armigera* were first observed during the 41st and 43rd Standard Meteorological Weeks (SMW), respectively. The peak populations of pest were recorded during the 48th SMW, with peak densities of *A. gossypii* (17.78 nymphs/plant), *B. tabaci* (21.8 nymphs/plant), *T. absoluta* (5.2 larvae/plant), and *H. armigera* (4.2 larvae/plant). Correlation analysis showed that maximum temperature had a strong positive association with pest incidence, with correlation coefficient values of 0.719, 0.658, 0.622, and 0.689 for *A. gossypii*, *B. tabaci*, *T. absoluta*, and *H. armigera*, respectively. Minimum temperature exhibited weak, non-significant negative correlations (–0.290 to –0.216). Relative humidity showed negative non-significant correlation for *A. gossypii* (–0.523), *B. tabaci* (–0.565), and *H. armigera* (–0.411), while *T. absoluta* showed a significant negative correlation (–0.580). Rainfall showed significant negative correlations with all four pests. Understanding the seasonal occurrence of insect pests in tomatoes identified the dynamic nature of pest challenges throughout the crop. This awareness may be useful in establishing early and effective control measures and reducing the environmental impact associated with pest management techniques.

Keywords: Tomato, Correlation, Seasonal incidence, Meteorological parameters

INTRODUCTION

Tomato (*Solanum lycopersicum* L.), a prominent member of the Solanaceae family, is among the most widely cultivated and economically significant vegetable crops worldwide. It ranks second after potato in global vegetable production, with an estimated annual output of 213.20 million tonnes (FAOSTAT, 2024). Asia is the leading producer, contributing 60-70 per cent of global output and achieving an average yield of 27 tonnes per hectare. India plays a key role, accounting for approximately 11 per cent of global production. During 2023–2024, tomato was cultivated in India on 870.96 thousand hectares, with a total production of 21.32 thousand metric tonnes and an average yield of 24.48 t ha^{-1}. The principal tomato-producing states- Andhra Pradesh, Tamil Nadu, Karnataka, Madhya Pradesh, among others together account for nearly 90% of national production (NHB, 2020). In Punjab, cultivation covered 11.17 thousand hectares, yielding 291.00 thousand metric tonnes, with a productivity of 26.06 t ha^{-1} (Anonymous, 2024). Meteorological conditions play a pivotal role in shaping the growth, development, and population dynamics of insect pests in tomato crops. Among the most influential factors are maximum and minimum temperatures, relative humidity, and rainfall, all of which affect the life cycles, reproduction, and survival rates of key pest species. Changes in these climatic parameters can either favour or suppress pest incidence and intensity, thereby impacting crop health and productivity (George *et al*., 2019).

Bemisia tabaci (Gennadius) and *Aphis gossypii* (Glover) are two major sucking pests that thrive under warm and moderately humid conditions. Maximum temperatures are positively correlated with their development and population build-up, whereas excessive rainfall or very high humidity tends to suppress their activity by physically dislodging individuals or hampering reproduction (Marabi *et al*., 2017; Sattar *et al*., 2020). The oviposition and egg viability of whitefly population, in particular are highly sensitive to temperature fluctuations with optimal activity observed between 25-30°C (Sharma *et al*., 2018). The outbreaks of aphids are often favoured by rising temperatures combined with moderate humidity, while heavy rainfall may reduce their populations through wash-off effects. Lepidopteran pests such as *Tuta absoluta* (Meyrick) (***Phthorimaea***

***absoluta*)** and *Helicoverpa armigera* (Hubner) are also significantly affected by weather conditions. These pests generally show a strong positive correlation with increasing maximum and minimum temperature. Warmer temperature accelerates their development, increase the number of generations per season, and intensify damage during the fruiting stage (Fathipour and Sedaratian, 2013). Conversely, higher relative humidity and frequent rainfall can negatively influence larval survival by promoting natural enemies and disease outbreaks.

The interaction between temperature, humidity, and rainfall influences the arrival and extent of pest infestation in tomato ecosystems. Understanding these relationships is critical for developing weather-based pest forecasting models and timely integrated pest management strategies to mitigate economic losses in tomato cultivation; therefore, the present investigation was undertaken.

MATERIALS AND METHODS

The research was carried out at Research Farm of P.G. Department of Agriculture, Khalsa College, Amritsar, Punjab, India during 2023.The experimental site has subtropical semi-arid climate with four distinct seasons: winter (December to March), summer (April to June), monsoon season (July to September) and post-monsoon season (October to November). Temperature in Amritsar varies from 4 to 45°C with annual rainfall of around 726 mm. During the experimental period, the maximum temperature varied from 31.4°C and minimum 16.9°C with average rainfall of 14 mm. The total experimental area of 270 square meters was divided into 3 blocks having 0.5 meter space between them and each block served as a separate replication. Further, each block was divided into six plots with individual plot size of 3m × 5m and kept unsprayed throughout the crop season.

A popular tomato variety, Punjab Varkha Bahar-4 was grown in the field during the month of September as per the Package of Practices of Punjab Agricultural University, Ludhiana **(**Anonymous, 2022). To determine the incidence of insect pests, observations were recorded from the initiation of pest infestation still crop harvest. To record the population of sucking pests, five plants were selected randomly from each untreated plot. The population of nymphs and adults of *A. gossypii* and *B. tabaci* were recorded from per plant whereas, *T. absoluta* and *H. armigera* observations were recorded at weekly intervals right from appearance of the pest till harvesting by direct visual counting of larvae on each plant. The observations from seasonal incidence were correlated with the prevailing weather factors such as maximum and minimum temperature, relative humidity and rainfall. The data on maximum and minimum temperature, relative humidity and rainfall were collected from Agrometeorological Unit, P.G. Department of Agriculture at Khalsa College, Amritsar during 2023. The correlation coefficient of determination was calculated to explore the relation between seasonal incidence of major pests and weather factors using the computer programme OP STAT one factor (Sheoran *et al*., 1998).

RESULTS AND DISCUSSION

The incidence of insects was observed at weekly interval from one month after sowing [41th standard meteorological week (SMW)] till harvesting (52nd SMW).The first appearance of *A. gossypii* was recorded during the 41st SMW, and the last occurrence was observed in the 52nd SMW. The *A. gossypii* population varied from 1.2 to 17.78 per plant with a peak occurrence (17.78 / plant) was observed in the 48th SMW at a maximum temperature of 30.5°C, minimum temperature of 9.5°C, relative humidity of 51.57 per cent and zero rainfall. The lowest aphid population (1.2/ plant) was at 41th SMW when the temperature reached maximum 24.61°C and minimum 18.5°C with a relative humidity of 72.04 per cent and rainfall 2.1 mm (Fig. 1). Correlation analysis indicated that the population of *A. gossypii* had a highly significant positive correlation with maximum temperature, a negative but non-significant correlation with minimum temperature and relative humidity, and a significant negative correlation with rainfall (Table 1).

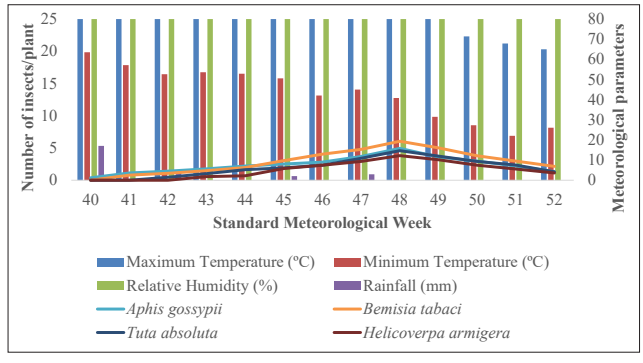

Fig. 1. Seasonal incidence of major insect pests in tomato

Table 1: Relationship between weather parameters and incidence of major insect pests of tomato

Sl. No.	Correlation coefficient (r value)	*Aphis gossypii*	*Bemisia tabaci*	*Tuta absoluta*	*Helicoverpa armigera*
1.	Maximum Temperature (ºC)	0.719**	0.658*	0.622*	0.689*
2.	Minimum Temperature (ºC)	-0.290^{ns}	-0.375^{ns}	-0.396^{ns}	-0.216^{ns}
3.	Relative Humidity (%)	-0.523^{ns}	-0.565^{ns}	-0.580*	-0.411^{ns}
4.	Rainfall (mm)	-0.630*	-0.583*	-0.587*	-0.610*

*values are significant at 5% level of significance, ns – non-significant

The population of *B. tabaci* varied from 0.6 to 21.8 per plant. The first appearance of *B. tabaci* was observed in 41st SMW (0.6/ plant) and remained active up to 52nd SMW (1.1/ plant). The population increased gradually and highest incidence of *B. tabaci* (21.8/ plant) was recorded during 48th SMW when the maximum temperature was 30.5°C and minimum temperature was 9.5°C. Relative humidity recorded was 51.57 per cent whereas rainfall was absent during this week. The activity of whiteflies was declined thereafter and lowest population was recorded during 52nd SMW (1/ plant) when the temperature reached maximum 13.3°C and minimum 8.15°C with relative humidity 61.99 per cent and rainfall 6.2 mm (Fig. 1).The correlation analysis revealed a significant positive association with maximum temperature, a negative but non-significant correlation with minimum temperature and relative humidity, and a significant negative correlation with rainfall (Table 1).

In case of *T. absoluta*, the data revealed that first appearance was during 43rd SMW (0.4 larvae/plant) when temperature maximum temperature 26.6°C minimum during this week was 15.7°C with Relative humidity 67.73 per cent while 4.2 mm rainfall. The population increased thereafter and attained its peak during 48th SMW (5.2 larvae/plant) when the maximum and minimum temperature was 30.5°C and 9.5°C, respectively. Relative humidity was 51.57 per cent while no rainfall was recorded. The population decreased gradually up to 52nd SMW and reached low during 52nd SMW (0 larvae/plant)at maximum temperature of 13.3°C, minimum temperature of 8.15°C, relative humidity of 61.99 per cent and with 6.2 mm rainfall (Fig. 1).The correlation studies revealed that maximum temperature showed significant positive association with the population of *T. absoluta.* On the other hand, negative non-significant correlation with minimum temperature while relative humidity and rainfall exhibited negative significant correlation with the population of *T. absoluta* (Table 1).

The population of *H. armigera* was found during the later stage of growth of crop. Population of *H. armigera* varied from 0.2 to 4.2 larvae. Initiation of this pest was observed during 43rd SMW with a population of 0.2 larvae per plant when the maximum and minimum temperature was 26.6°C and 15.7°C, respectively. Relative humidity was 67.73 per cent with 4.2 mm rainfall. Further, the population increased steadily and acquired its peak during 48th SMW (4.2 larvae/plant) when the maximum temperature was 30.5°C, minimum temperature was 9.5°C, relative humidity was 51.57 per cent with no rainfall. Later, the pest population decreased gradually and minimum population was nil in 52nd SMW when the maximum and minimum temperature was 13.3°C and 8.15°C, respectively. Correlation analysis revealed that maximum temperature showed significant positive association with the *H. armigera* while minimum temperature and relative humidity exhibited negative non-significant. On the other hand, rainfall showed a significant negative correlation with the incidence of *H. armigera* (Table 1).

The multiple linear regression equations presented in Table 2 describe the relationship between pest population (dependent variables) and different weather parameters (independent variables), viz., maximum temperature (X_1), minimum temperature (X_2), relative humidity (X_3) and rainfall (X_4). The coefficient of determination (R^2) indicates the proportion of variation in pest population explained by the combined effect of these weather parameters. For *A. gossypii* (Y1), the regression equation $Y_1 = 2.61 + 0.85\ (T_{max}) - 0.51\ (T_{min}) - 0.16$ (Relative humidity) − 0.16 (Rainfall), with

R^2 = 0.87, indicates that 87 per cent of the variation on aphid population is explained by the selected weather variables. Maximum temperature showed a strong positive influence on population build-up, while minimum temperature, relative humidity and rainfall exerted a negative effect. For *B. tabaci* (Y_2), the equation $Y_2 = -3.03 + 1.22 (T_{max}) - 1.06 (T_{min}) - 0.09$ (Relative humidity) − 0.08 (Rainfall), with $R^2 = 0.86$ suggests that maximum temperature had a substantial positive association with whitefly population, whereas minimum temperature, relative humidity and rainfall reduced their population levels. The relatively high R^2 value (86%) indicates an excellent fit of the model. For *T. absoluta* (Y3), the regression equation Y3 = 6.19 + 0.71 (T_{max}) − 0.73 (T_{min}) − 0.14 (Relative humidity) − 0.52 (Rainfall), with $R^2 = 0.82$, reveals that 82 per cent of the variation in pest population is accounted for by the weather variables. Maximum temperature exhibited a positive relationship with population increase, while minimum temperature, relative humidity and rainfall showed negative effects. Notably, rainfall had the strongest negative coefficient (−0.52), indicating that higher rainfall markedly reduced *T. absoluta* infestation, possibly due to disruption of larval stages and adult activity. For *H. armigera* (Y_4), the equation $Y_4 = -4.55 + 0.70 (T_{max}) - 0.53 (T_{min}) - 0.04$ (Relative humidity) − 0.22 (Rainfall), with $R^2 = 0.71$, implies that 71 per cent of population fluctuation could be explained by the weather parameters. Although maximum temperature positively influenced pest incidence, other parameters exerted negative effects, with rainfall again showing a comparatively stronger suppressive role. Overall, the regression models indicate that maximum temperature is the most influential factor positively affecting pest populations, while minimum temperature, relative humidity, and rainfall generally suppress pest incidence. The high R^2 values (0.71–0.87) confirm that weather parameters play a significant role in regulating population dynamics of insect pests, with maximum temperature being the key driver.

The present results are in agreement with the findings of Kachave *et al.* (2020) who reported the peak population of *A. gossypii* (7.9 nymph/plant) during 46th SMW when temperature reached maximum 33.5°C and, minimum 11°C, with 81 per cent relative humidity. Singh *et al.* (2023) recorded the first incidence of *A. gossypii* in 46th SMW with maximum population in 10th SMW had a negative non-significant correlation between relative humidity and *A. gossypii* population.

First appearance of *B. tabaci* was noticed during 31st SMW with a peak (10.2 nymph / plant), during 42nd SMW when temperature attained maximum 34.4°C and minimum 18°C with relative humidity 74 per cent (Asiry *et al.,* 2022). A non-significant positive correlation was also noticed between the *B. tabaci* population maximum temperature but a significant negative correlation between minimum temperature and relative humidity. Subba *et al.* (2017) also observed a significant positive correlation between the maximum temperature and minimum temperature, whereas, a non-significant negative between rainfall and *B. tabaci.* Likewise, Patel *et al.* (2021) reported the first incidence of *B. tabaci* during 38th SMW (0.2 nymph/plant) and peak population in 48th SMW (5.40 nymph /plant). These variations in the occurrence of the pest are owing to geographical regions and associated abiotic parameters (Dent and Binks, 2020).

Incidence of *T. absoluta* was observed in 32nd SMW with a peak larval population (3.5 larvae/plant) in 41st SMW (Chavan *et al.,* 2013). The when the weather parameters such as maximum and minimum temperature and relative humidity at 36°C, 17.2°C and 64 per cent,

Table 2: Multiple linear regression equation depicting the influence of different weather parameter on pest population

Regression equation	Coefficient of Determination (R^2)
$Y_1=2.61+0.85X_1-0.51X_2-0.16X_3-0.16X_4$	0.87
$Y_2=-3.03+1.22X_1-1.06X_2-0.09X_3-0.08X_4$	0.86
$Y_3=6.19+0.71X_1-0.73X_2-0.14X_3-0.52X_4$	0.82
$Y_4=-4.55+0.70X_1-0.53X_2-0.04X_3-0.22X_4$	0.71

Where Y_1 = *Aphis gossypii* population, Y_2=*Bemisia tabaci* population, Y_3=*Tuta absoluta* population, Y_4= *Helicoverpa armigera* population; X_1= Maximum Temperature, X_2=Minimum Temperature, X_3= Relative Humidity, X_4=Rainfall

respectively play crucial role of the pest. Correlation analysis revealed that minimum temperature and relative humidity indicating negative significant influence on incidence of *T. absoluta*. However, there was a negative non-significant correlation with the population of *T. absoluta* and weather parameter rainfall.

The results of the present study closely match the findings of Singh *et al.* (2025) and Wade *et al.* (2020). They reported the first appearance of *H. armigera* at a low level (0.5 larvae/ plant) during the 32nd SMW. The pest population reached its highest level (3.7 larvae/ plant) in the 41st SMW, when the maximum and minimum temperature was 36.0°C and 17.2°C, respectively and relative humidity was 64 per cent. Their study also showed that *H. armigera* population had a significant negative relationship with relative humidity and a non-significant negative relationship with rainfall. Likewise, Kumar *et al.* (2017) observed the occurrence and peak population of *H. armigera* during the 43rd and 48th SMW, respectively which supports the findings of the present study. Similar observations were also reported by Singh *et al.* (2021). Understanding the seasonal pattern of insect pests in tomato crops helps explain how pest populations change during the crop growth period. This information is important for planning timely and effective pest control measures while reducing negative effects on the environment.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interests

AUTHOR CONTRIBUTIONS

Conceptualization and designing of the research work (K.B., J.T.); Field experiments and data collection (S.); Data analysis and interpretation (S., K.B.); Preparation of manuscript (S., K.B., J.T., A.S.).

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Diurnal activity and seasonal incidence of mirid bug, *Nesidiocoris tenuis* (Reuter), on bottle gourd and its natural enemies in relation to weather parameters

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ABSTRACT: Bottle gourd, *Lagenaria siceraria* (Molina) Standley, is an important cucurbit crop often affected by insect pests. A field study was conducted during *Kharif,* 2024 at Horticulture Farm, Sri Karan Narendra College of Agriculture, Jobner, Jaipur, to assess the diurnal activity and seasonal incidence of the mirid bug, *Nesidiocoris tenuis* (Reuter), a major emerging pest of bottle gourd, and its natural enemies. The mirid bug, *N. tenuis,* exhibited clear diurnal activity, with the maximum abundance at noon, followed by afternoon and early morning and declining activity towards evening. Infestation on leaves began in the 33rd Standard Meteorological Week (SMW) (0.72 bugs/ five leaves per plant) and peaked in the 39th SMW (23.76 mirid bugs/five leaves per plant). Populations on flowers and fruits appeared during the 36th and 37th SMW and reached peaks in the 40th SMW (11.28 mirid bugs/ five flowers per plant) and in the 41st SMW (19.60 mirid bugs/ five fruits per plant), respectively. Natural enemies, mainly coccinellids and spiders, appeared from the 34th SMW, with peak populations of 3.76 and 5.72 per plant, respectively. Mirid bug incidence showed a significant positive correlation with maximum temperature and sunshine hours ($p<0.05$), while fruit infestation was negatively correlated with rainfall. The regression analysis indicated that abiotic factors explained 88.3- 93.3% of mirid bug population variability, highlighting maximum temperature as the most influential factor. The present study findings provide a basis for forecasting and sustainable management of *N. tenuis* in bottle gourd.

Keywords: Diurnal activity, correlation, mirid bug, natural enemies, regression, weather parameters.

INTRODUCTION

Bottle gourd, *Lagenaria siceraria* (Molina) Standley, is an important cucurbitaceous vegetable crop widely cultivated in tropical and sub-tropical regions of the world (Halder *et al.,* 2021; Behera *et al.,* 2023). The crop is valued for its nutritional and medicinal properties. The fruits are a good source of vitamin C, essential minerals such as iron, phosphorus, potassium and magnesium, and contain high levels of choline, which plays an important role in brain function and metabolism (Rahman, 2003; Milind and Satvir, 2011). In addition, bottle gourd has been reported to possess several pharmacological properties including anti-hyperlipidemic, anti-inflammatory, antioxidant, anti-inflammatory, immuno-modulatory, hepatoprotective, and cardioprotective activities (Milind and Satvir, 2011; Minocha *et al.,* 2015; Mahapatra *et al.,* 2023).

In India, bottle gourd occupies an area of approximately 200 thousand hectares, with an annual production of about 3.369 million metric tonnes (Anonymous, 2022–23a). Major bottle gourd-producing states include Uttar Pradesh, Rajasthan, Haryana, Gujarat, Punjab, Bihar, West Bengal, Madhya Pradesh, Karnataka, Assam and Maharashtra. In Rajasthan, the crop is grown mainly in Jaipur, Alwar, Sawai Madhopur, Sirohi, Tonk, Bikaner, Dausa, Jodhpur and Kota districts, covering about 3.79 thousand hectares with a total production of 25.76 thousand metric tonnes and an average productivity of 6.80 t ha^{-1} (Anonymous, 2022-23b).

The productivity of the bottle gourd is constrained by several biotic and abiotic factors, among which insect pests constitute a major limitation (Haldhar and Maheshwari, 2018; Halder *et al.,* 2021; Yadav *et al.,* 2024). Bottle gourd is infested by a diverse complex of insect pests throughout its growth period, including the red pumpkin beetle (*Aulacophora foveicollis* Lucas), melon fruit fly (*Zeugodacus cucurbitae* Coquillett), hadda beetle (*Henosepilachna vigintioctopunctata* Fabricius), aphid (*Aphis gossypii* Glover), whitefly (*Bemisia tabaci*

Gennadius), leaf miner (*Liriomyza trifolii* Burgess), jassid (*Amrasca biguttula biguttula* Ishida), bottle gourd plume moth (*Sphenarches caffer* (Zeller)), pumpkin caterpillar (*Diaphania indica* (Saunders)), and mirid bugs such as *Nesidiocoris tenuis* (Reuter), *Nesidiocoris cruentatus* (Ballard), and *Metacanthus pulchellus* Dallas (Bhowmik and Saha, 2017; Halder *et al.,* 2017; Haldhar and Maheshwari, 2018; Halder *et al.,* 2021; Patra *et al.,* 2022; Raghavendra *et al.,* 2022; Parkash *et al.,* 2023; Divekar *et al.,* 2024). Among these, mirid bug *N. tenuis* (Reuter) (Hemiptera: Miridae) has recently emerged as an important pest of bottle gourd in several regions of India. Severe infestations were recorded during the *Kharif* season of 2023 in Rajasthan, resulting in significant yield losses and reduction in fruit quality. Previous studies have reported that infestation of *N. tenuis* can cause substantial crop losses, with 70-80 % fruit damage and about 30 % of shoots under severe conditions (Halder *et al.,* 2021). Similarly, Raghavendra *et al.* (2022) reported fruit damage ranging from 61.90 to 73.68 % due to this pest. Both nymphs and adults of *N. tenuis* feed tender plant tissues by piercing and sucking plant sap, resulting in small punctures on leaves surrounded by irregular chlorotic areas. On young fruits, feeding results in brown puncture marks accompanied by sap or resin exudation, which later develops into reddish-brown spots or blister-like lesions. These symptoms lead to blemished fruits with reduced market value, as consumers prefer smooth, light green, and unblemished fruits (Halder *et al.,* 2017; Halder *et al.,* 2021; Raghavendra *et al.,* 2022). However, *N. tenuis* is a zoophytophagous, capable of feeding on both plant tissues and small arthropods, including lepidopteran larvae and soft-bodied pests.

Understanding the population dynamics and diurnal activity patterns of this emerging pest is essential for developing timely and effective management strategies. Weather parameters such as temperature, relative humidity and rainfall are known to influence the seasonal abundance and activity of insect pests. Although some studies have documented the seasonal occurrence of *N. tenuis* on cucurbit crops (Bhatt and Patel, 2018; Halder *et al.,* 2017; Halder *et al.,* 2021; Raghavendra *et al.,* 2022), detailed information on its seasonal incidence and diurnal activity in relation to weather parameters under the semi-arid agro-climatic conditions of Rajasthan is limited. We hypothesized that the seasonal incidence and diurnal activity of *N. tenuis* on bottle gourd are strongly influenced by crop phenology and prevailing weather conditions in semi-arid ecosystems. Therefore, the present study was conducted to investigate the diurnal activity and seasonal incidence of *N. tenuis* on bottle gourd and to analyse its relationship with key weather parameters. The findings are expected to provide baseline information for the development of region-specific and timely pest management strategies.

MATERIALS AND METHODS

Experimental site and crop establishment

A field experiment was conducted *Kharif*, 2024, at the Horticultural farm, Sri Karan Narendra College of Agriculture, Jobner, Jaipur, Rajasthan, India (26˚05' N, 75˚ 28' E) to study the diurnal activity and seasonal incidence of the mirid bug, *N. tenuis*, on bottle gourd, *Lagenaria siceraria*. The bottle gourd variety 'Pusa Naveen' was sown during the second week of July 2024. The experiment consisted of five plots, each measuring 2.0 m x 5.0 m. The crop was planted at a spacing of 2.5 m between rows and 0.5 m between plants. Five plants were randomly selected and tagged in each plot for regular observations. Recommended agronomic practices were followed for crop production, except that no plant protection measures were applied to allow natural infestation of insect pests and associated natural enemies.

Insect identification and sampling procedure

Insect specimens collected from the infested field were identified as *Nesidiocoris tenuis* (Reuter) by the ICAR–National Bureau of Agricultural Insect Resources, Bengaluru, India. The population of mirid bugs (both nymph and adult) was recorded at weekly intervals from leaves, flowers and fruits of the tagged plants. For assessing diurnal activity, observations were recorded from five leaves per plant and five fruits per plot at four intervals: 07:00 h (morning), 12:00 h (noon), 15:00 h (afternoon) and 19:00 h (evening). Seasonal incidence of the mirid bug was monitored using the same sampling procedure, with the addition of five flowers randomly selected per plant. The population of natural enemies, particularly ladybird beetles (Coccinellidae) and spiders (Araneae) was recorded from tagged plants during each observation period.

Statistical analysis

The data on mirid bug population and natural enemies were analyzed to determine their relationship with prevailing weather parameters using correlation and regression analysis. Statistical analyses were performed using Microsoft Excel.

RESULTS AND DISCUSSION

Diurnal activity of mirid bug

The present investigation was conducted to assess the diurnal activity and seasonal incidence of mirid bug, *N. tenuis,* and its natural enemies on bottle gourd, *L. siceraria,* under prevailing climatic conditions during *Kharif* 2024. The results indicated that the mirid bug population persisted throughout both the vegetative and reproductive stages of the crop, indicating its continuous association with bottle gourd during the cropping period. Diurnal variations in mirid bug activity were recorded on both leaves and fruits. Infestation on leaves began during 33rd standard meteorological week (SMW) with a low population, which gradually increased and reached a peak during the 38th SMW. Throughout the observation period, mirid bug activity on leaves was consistently highest at noon, followed by afternoon, early morning and evening. The maximum population (27.40 bugs/ five leaves per plant) was recorded at noon. Similarly, the mean population density was highest during noon hours (13.48 ± 2.79) and lowest during evening hours (6.46 ± 1.64) (Fig. 1). The present findings corroborate earlier reports on the pest status and population dynamics of *N. tenuis* on cucurbitaceous crops. Raghavendra *et al.* (2022) reported that *N. tenuis* is a serious pest of bottle gourd, with the highest population density on tender vine tips, followed by fruits and leaves, and two distinct population peaks during the 21st and 24th SMW. Although the timing of peak activity differed slightly, the progressive increase and subsequent decline in pest population observed in the present study followed a similar seasonal trend.

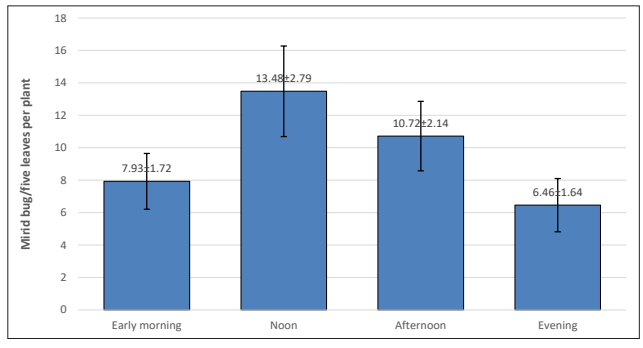

Fig. 1. Diurnal activity of mirid bug, *N. tenuis* on bottle gourd leaves

A similar diurnal pattern was recorded on fruits. Mirid bug infestation commenced during the 36th SMW and continued until the 44th SMW, with peak infestation observed during 41st SMW. The highest population (21.20 bugs/ five fruits per plot) was recorded during noon hours, followed by afternoon, early morning and evening observations. Mean population density on fruits was also highest at noon (10.78 ± 2.38 bugs/ five fruits per plot) and lowest during evening hours (6.80±1.89). These results clearly indicate that mirid bug activity is strongly influenced by the time of day, with peak activity occurring during mid-day hours (Fig. 2).

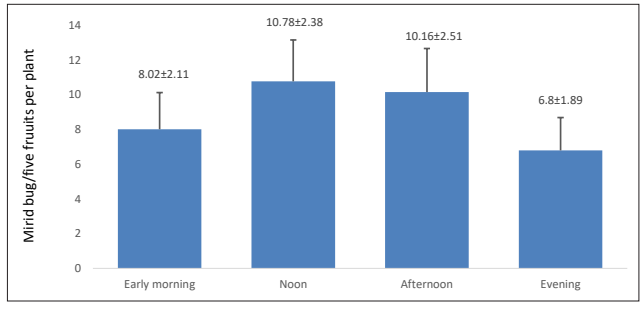

Fig. 2. Diurnal activity of mirid bug, *N. tenuis* on bottle gourd fruits

Table 1: Seasonal incidence of mirid bug, *N. tenuis* and their natural enemies on bottle gourd

SMW	Temperature (°C)		Relative humidity (%)		Rainfall (mm)	Sunshine hours	*N. tenuis* population/ plant		*N. tenuis* population five fruits/ plot	Natural enemies population/ plant	
	Max.	Min.	Mor.	Eve.			Leaves	Flowers	Fruits	Coccinellids	Spiders
33	31.41	24.84	96	83	26.4	1.28	0.72	0.00	0.00	0.00	0.00
34	33.11	22.72	95	79	34.8	2.50	3.36	0.00	0.00	0.12	0.20
35	33.91	24.54	93	79	45.2	5.01	11.40	0.00	0.00	0.36	0.80
36	32.54	24.24	96	82	93.7	4.08	10.84	0.96	0.00	1.04	1.12
37	32.81	24.18	94	80	18.3	4.35	15.92	2.52	4.20	0.92	2.32

38	32.67	23.54	93	71	19.3	3.24	17.64	4.52	8.40	1.60	2.96
39	35.42	24.37	86	63	0	8.42	23.76	9.68	15.20	2.88	5.72
40	36.40	22.52	79	55	0	8.51	22.68	11.28	17.20	3.76	4.24
41	36.94	20.71	62	41	0	8.41	20.72	8.16	19.60	2.72	3.28
42	36.58	17.21	63	33	0	7.91	18.16	5.64	14.40	1.68	2.40
43	35.04	17.45	61	35	0	7.08	7.28	1.88	6.80	0.52	1.12
44	33.24	13.9	65	29	0	7.88	3.92	0.00	1.20	0.08	0.52

Table 2: Correlation between mirid bug and natural enemies population with weather parameters

Weather parameters	Mirid bug population on			Natural enemies population	
	Leaves	Flowers	Fruits	Coccinellids	Spiders
Max. Tem. (°C)	0.682*	0.763**	0.871**	0.728**	0.620*
Min. Tem. (°C)	0.186^{NS}	0.070^{NS}	-0.136^{NS}	0.140^{NS}	0.184^{NS}
Mor. RH (%)	-0.171^{NS}	-0.308^{NS}	-0.540^{NS}	-0.236^{NS}	-0.151^{NS}
Eve. RH (%)	-0.168^{NS}	-0.311^{NS}	-0.515^{NS}	-0.233^{NS}	-0.178^{NS}
Rainfall (mm)	-0.325^{NS}	-0.520^{NS}	-0.636*	-0.376^{NS}	-0.442^{NS}
Sunshine hours	0.595*	0.664*	0.733**	0.630*	0.601*
Coccinellids	0.910**	0.982**	0.903**		
Spiders	0.933**	0.934**	0.841**		

* Correlation coefficient significant at the 0.05 level
** Correlation coefficient significant at the 0.01 level
NS, Non-significant

Population dynamics of mirid bug, *N. tenuis* on leaves, flowers and fruits of bottle gourd

Seasonal incidence of *N. tenuis* on leaves revealed that the pest first appeared during 33th SMW with a population of 0.72 bug per plant. The population increased steadily and reached a peak during the 39th SMW (fourth week of September) with 23.76 bugs per plant. Thereafter, the population declined gradually and reached a minimum level of 3.92 bugs per plant during the 44th SMW (Table 1). Correlation analysis indicated a significant positive association of mirid bug population with maximum temperature (r=0.682, $p<0.05$) and sunshine hours (r=0.595, $p<0.05$). A non-significant positive correlation was observed with minimum temperature, whereas non-significant negative correlations were recorded with morning relative humidity, evening relative humidity and rainfall (Table 2). The multiple regression analysis revealed that abiotic factors explained 82.8% of the variation in the mirid bug population, while stepwise regression indicated that maximum temperature alone contributed 46.5% to the observed variation (Table 3 and 4). The increasing pest importance of *N. tenuis* has also been documented by Halder *et al.* (2021), who reported its continuous occurrence from the 17th to 52nd SMW on bottle gourd in Varanasi, Uttar Pradesh, causing severe crop damage, including 70–80% fruit infestation and nearly 30% shoot damage.

The incidence of mirid bug on flowers began during the first week of September with a population of 0.96 bug per five flowers per plant. The population increased gradually and reached to its peak during the first week of October (40th SMW) with 11.28 bugs per plant. Subsequently, the infestation declined and reached the lowest population level (1.88 bugs per plant) during 43rd SMW (Table 1). Correlation analysis revealed a significant positive relationship between mirid bug population and maximum temperature ($r = 0.763$, $p < 0.01$) as well as sunshine hours ($r = 0.664$, $p < 0.05$). Other

Table 3: Multiple regression analysis between mirid bug and natural enemies with weather parameters

Insect-Pest (s)		Regression equation (Y=a+bX)	R^2 Value
Mirid bug on	Leaves	$Y=-131.29^{a*} + (1.91)T_{Max.} + (2.88)T_{Min.} + (0.79)RH1 + (-0.87)RH2 + (0.02)RF + (0.85)SS$	0.828
	Flowers	$Y=-69.76^{a} + (0.97)T_{Max.} + (1.76)T_{Min.} + (0.44)RH1 + (-0.56)RH2 + (-0.01)RF + (0.05)SS$	0.918
	Fruits	$Y=-109.36^{a} + (2.13)T_{Max.} + (3.12)T_{Min.} + (0.44)\ RH1 + (-0.91)\ RH2 + (-0.02)RF + (-0.82)SS$	0.933
Coccinellids		$Y=-21.84^{a} + (0.29)T_{Max.} + (0.56)T_{Min.} + (0.14)\ RH1 + (-0.18)RH2 + (0.01)RF + (0.05)SS$	0.883
Spiders		$Y=-21.34^{a} + (0.05)T_{Max.} + (0.82)T_{Min.} + (0.21)\ RH1 + (-0.25)\ RH2 + (-0.01)RF + (0.29)SS$	0.917

a, Constant; T_{max}: Temperature maximum; T_{min}: Temperature minimum; RF: Rainfall, RH1: Morning relative humidity; RH2: Evening relative humidity; SS: Sunshine hours

Table 4: Stepwise regression analysis between mirid bug and natural enemies with weather parameters

Insect-Pest (s)		Regression equation (Y=a+bX)	R^2 Value
Mirid bug on	Leaves	$Y=-87.49^{a} + (2.94)T_{Max.}$	0.465
	Flowers	$Y=-54.33^{a} + (1.70)T_{Max.}$	0.582
	Fruits	$Y=-114.57^{a} + (3.57)T_{Max.}$	0.758
Coccinellids		$Y=-15.54^{a} + (0.49)T_{Max.}$	0.728
Spiders		$Y=-18.21^{a} + (0.59)T_{Max.}$	0.384

weather parameters showed non-significant correlations (Table2). Multiple regression analysis indicated that weather factors together explained 90.8% of the variability in the mirid bug population, with maximum temperature alone accounting for 58.2% of the variation (Table 3 and 4). Seasonal incidence patterns observed in the present study are also consistent with those reported by Sharath *et al.* (2021), who recorded mirid bug activity on snake gourd from the 36th to 46th SMW with peak populations around the 40th SMW. Similarly, Mishra *et al.* (2015) reported the onset of mirid bug infestation during the 2nd SMW and a peak population of 0.52 bugs per plant during the 35th SMW, along with a significant positive correlation with temperature, supporting the temperature-dependent population build-up observed in the present investigation.

Infestation of *N. tenuis* on fruits was first observed during the 37th SMW with a population of 4.20 bugs per five fruits per plot (Table 1). The population increased progressively and reached its maximum during the 41st SMW with 19.60 bugs per plot. Thereafter, the population declined gradually and reached its lowest level during the 44th SMW (1.20 bugs per plot). Correlation analysis revealed a significant positive association between mirid bug population and maximum temperature ($r = 0.871$, $p < 0.01$) as well as sunshine hours ($r = 0.733$, $p < 0.01$), whereas rainfall showed a significant negative correlation ($r = -0.636$, $p < 0.05$). Other weather parameters exhibited non-significant correlations (Table 2). Multiple regression analysis indicated that weather variables together accounted for 93.30% of the variation in mirid bug population, with maximum temperature alone contributing 75.80% of the variation (Table 3 and 4). Comparable population dynamics have also been reported on other host crops. Bhagyasree *et al.* (2023) on tomato and Kumar and Sharma (2023) on sesame observed peak *N. tenuis* populations between the 38th and 40th SMW followed by a gradual decline. In agreement with the present findings, Halder *et al.* (2017) reported a significant positive relationship between temperature and mirid

bug population, while relative humidity, wind velocity and rainfall showed negative but non-significant associations. However, Kumar and Sharma (2023) observed a positive association with morning relative humidity and a negative relationship with maximum temperature, suggesting that pest–weather interactions may vary depending on crop species, prey availability and prevailing agro-climatic conditions.

CONCLUSION

Nesidiocoris tenuis has emerged as an important pest of bottle gourd under field conditions. The pest exhibited a distinct seasonal incidence pattern, with peak populations occurring on leaves during the 39th SMW, followed by flowers in the 40th SMW and fruits in the 41st SMW, indicating a progressive shift in infestation across plant parts as the crop advanced in growth. Among the abiotic factors, maximum temperature and sunshine hours significantly influenced the population build-up of *N. tenuis*, whereas the remaining weather parameters showed no significant effect. The positive association of coccinellids and spiders with mirid bug populations suggests their potential role in the natural regulation of the pest. These findings improve our understanding of the seasonal dynamics of *N. tenuis* and provide a basis for developing timely and eco-friendly pest management strategies in bottle gourd cultivation.

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AUTHOR CONTRIBUTION STATEMENT

All authors have contributed significantly to the conception, execution, analysis and preparation of the manuscript.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

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Population dynamics and management of aphid (*Aphis gossypii* Glover) in bitter gourd (*Momordica charantia* L.)

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ABSTRACT: Bitter gourd (*Momordica charantia* L.) is an important cucurbitaceous vegetable cultivated widely in India, valued for its high nutritive and medicinal properties. However, its productivity is severely constrained by insect pests, particularly aphids (*Aphis gossypii*), fruit fly (*Dacus cucurbitae*), red pumpkin beetle (*Aulacophora foveicollis*), epilachna beetle (*Henosepilachna vigintioctopunctata*), and others. Among these, aphids not only cause direct damage through sap feeding also act as vectors of viral diseases, resulting in significant yield reduction. A field survey was conducted at Kadachanenthal and Vadipatti in Madurai district from August to June to study the population dynamics of aphids and their correlation with abiotic factors. Aphid incidence showed significant variation between locations. The maximum population (5.28 aphids/3 leaves) was recorded during the third week of April at Kadachanenthal, while the lowest (0.69 aphids/3 leaves) was observed during the second week of October at Vadipatti. Maximum temperature exhibited a significant positive correlation, whereas rainfall showed a negative correlation with aphid population. Two field experiments were conducted to evaluate the efficacy of newer insecticide molecules and biopesticides against aphids in bitter gourd under randomized block design. Among the newer insecticides, Spinosad 45% SC @ 160 ml/ha proved most effective, recording the lowest aphid population (1.56 aphids/3 leaves) and 93.6 per cent reduction over control. Chlorantraniliprole 18.5 SC @ 150 ml/ha was the next best treatment. Among biopesticides, Neem Seed Kernel Extract (NSKE) 5% and neem oil 3% significantly reduced aphid population, recording 84.80 and 82.81 per cent reduction over control, respectively, and were comparable to the standard check, malathion. The study concludes that spinosad is highly effective among newer insecticides, while NSKE 5% offers an eco-friendly and safer alternative for aphid management in bitter gourd, helping to reduce reliance on synthetic insecticides and conserve pollinators.

Keywords: Bitter gourd, Aphids, Spinosad, NSKE

INTRODUCTION

Bitter gourd (*Momordica charantia* L.; Cucurbitaceae), is one of the important cucurbitaceous vegetables grown in India. In terms of nutritive value, it ranks first among cucurbits, being rich in iron, phosphorus and ascorbic acid (Awasthi and Jaiswal, 1986). Numerous medicinal uses have been documented or claimed particularly, with reference to diabetes treatment (Grover *et al.*, 2002) and prevention of breast cancer (Ray *et al.*, 2010). The presence of secondary metabolites such as alkaloids, saponins, tannins, glycosides and cardiac glycosides in the *M. charantia* may contribute to its medicinal value. Bitter gourd has good export potential and its share in export of green vegetable is to the extent of 20 per cent (Anonymous, 1992).

Insect pests are the major constraints for increasing the production and productivity of this crop. It is attacked by several insect pests during different growth stages, which include melon fruit fly, *Dacus cucurbitae* (Coquillett), Hadda beetle, *Henosepilachna vigintioctopunctata* (Fab.), pumpkin beetle, *Aulacophora foveicollis* (Lucas.), pumpkin caterpillar, *Diaphania indica* (Sounders), snake gourd semilooper, *Plusia peponis* (Fab.)., blister beetle, *Mylabris pustulata* (Thunberg), whitefly, *Bemisia tabaci* (Genn.), stink bugs, *Apspongopus* spp. Thunberg and flea beetle, *Phyllotreta* spp. (Goeze), thrips, *Thrips palmi Karny* and mites *Tetranychus urticae* (Koch).

The fruit fly, *D. cucurbitae* which attacks the ultimate economic part, *i.e.* fruits of the crop, is one

of the most important biotic limiting factors and alone can inflict yield loss in different cucurbitaceous vegetables ranging from 30-100% depending upon the cucurbit species and the season (Dhillon *et al.*, 2005), (Shooker *et al.*, 2006). *Diaphania indica* is an oligophagous pest of Cucurbitaceae (Ayyar, 1940). Though principally a leaf feeder, the pumpkin caterpillar is also known to infest flowers, new tender shoots and young and mature fruits. Attack on fruits reduces their commercial value, leading to huge crop losses during outbreaks (Choi *et al.*, 1990). *Henosepilachna vigintioctopunctata* is one of the major pests of bitter gourd (Mahalya and Jesudasan, 1996). In case of severe infestation, the grub and adults were reported to cause 45-75 per cent defoliation to this crop (Shukla and Upadhyay, 1987). Among different species of pumpkin beetles, incidence of adult stage of red pumpkin beetle (RPB), *A. foveicollis* on different cucurbits have been reported by various workers (Nath, 1964); (Nath and Thakur, 1965); (Bogawat and Pandey, 1967).) Percent damage rating gradually decreases from 70-15% as the leaf canopy increases (Rahaman and Prodhan, 2007). The role of whitefly is more important as a vector of yellow mosaic virus in bitter gourd than its direct damage as a sucking pest. The disease attains significance because the virus is capable of infecting the crop in all the stages of its growth period (Rajinimala et al., 2005).

Number of aphid species that attack cucurbits including melon aphid *Aphis gossypii*, (Glover), cowpea aphid *Aphis craccivora* (Koch), potato aphid *Macrosiphum euphorbiae* (Venkatesh *et al.* 2023) and green peach aphid *Myzus persicae* (Sulzer) (Napier, 2009). Aphids usually feed on the underside of leaves, but can attack the soft growing tips. Large populations in a seedling crop can cause leaves to curl and premature death of the leaf or growing tip. In older crops vine development is retarded and yield can be reduced. The melon aphid is the main vector of the mosaic virus while the other aphid species are minor vectors.

In order to overcome these escalating insect pest problems farmers solely relay on pesticides. Frequent application and large-scale use of insecticides for the control of these pests led to the endangerment of ecosystem including pollinators.

Many horticultural crops are dependent on insect pollination, and better pollination results in higher yields (McGregor, 1976); (Free, 1993); (Klein *et al.*, 2007), bitter gourd always requires pollinating insects for effective pollination and better fruit and seed setting (Ashworth and Galetto, 2002. Honey bees (*Apis mellifera* and *A. cerana indica*) are the major floral visitors of bitter gourd in the Philippines along with some solitary bees (*Trigona* sp. and *Halictus* sp.) (Rodelina and Cervanica, 2009). So, it is necessary to protect pollinators from hazardous chemical insecticides.

MATERIALS AND METHODS

Survey

Periodic field surveys were conducted at weekly intervals from August to June 2017 - 2018 in the bitter gourd-growing areas of Madurai district, namely Kadachanenthal and Vadipatti. During each survey, the populations of key insect pests and pollinators were recorded from ten randomly selected plants in farmers' fields. Plants were examined starting from seven days after germination till crop maturity. Data on weather parameters, maximum and minimum temperatures (^{0}C) relative humidity (%) and rainfall (mm) was recorded during the study period. Abiotic factors were correlated with incidence of key pests and pollinators. The significant correlation between incidence and weather factors was further subjected for regression analysis. Pest populations were assessed at weekly intervals using pest-specific sampling methods. For leaf-eating caterpillars, the population was recorded as the number of larvae per plant. The populations of red pumpkin beetle and epilachna beetle were assessed by counting the total number of adults present on the entire plant and expressed as number per plant. For melon fruit fly, the population was estimated as the mean number of flies captured per trap per day.

Two field experiments were conducted in the farmer's holdings one at Kadachanenthal and another one at Vadipatti, Madurai District to evaluate the efficacy of newer insecticide molecules against the key pests of bitter gourd. All the agronomic practices were adopted uniformly for all the treatments. The details of the field experiments are as below.

The field experiments were conducted using two hybrids, Akash and Asmita, during two seasons. Field Experiment I was conducted with Akash from August to December 2017 at Kadachanenthal, Madurai East, while Field Experiment II was conducted with Asmita from January to May 2018 at Vadipatti, Madurai West. Eight treatments were evaluated in a Randomized Block Design with three replications, using a spacing of 5 × 3 m.

Treatments

Name of the insecticides	Dosage g/ml/ha	Sources
Chlorantraniliprole 18.5% SC	125	Dupont India pvt ltd.,
Chlorantraniliprole 18.5 % SC	150	Dupont India pvt ltd.,
Spinosad 45 % SC	160	Dow agro sciences India Pvt.ltd.
Imidacloprid 17.8 % SL	250	Insecticides (India) limited
Spiromesifen 22.9 % SC	500	Bayer crop science limited
Thiodicarb 75 % WP	750	Bayer crop science limited
Standard check Malathion 50% EC	500	Hindustan insecticides ltd.,
Untreated check		

The above newer insecticide molecules were purchased from pesticide shop in Madurai.

Time and Method of application

The first spray was given after the new flush formation and when damage by key pests reached ETL level (10–15% of plants infested, or 20–25 aphids per leaf) and thereafter another spray was given at 15 days interval with a high volume sprayer using 500 lit of spray fluid per ha. The control plot was maintained without any spraying. The above observations of insect pests and natural enemies were recorded on prior to spraying and 3rd,7th,10th and 14th days after spraying and the percent reduction over control was worked out using the formula

$$\text{Reduction (\%)} = \frac{\text{Population in the control} - \text{Population in the treatment}}{\text{Population in the control}} \text{ X } 100$$

Assessment of pest damage / population

Aphids *Aphis gossypii*

In each plant, three leaves representing top, middle and lower portions were selected. The total number of nymphs and adults on each leaf was counted and it was computed as mean population per three leaves in randomly selected ten plants.

To evaluate the efficacy of biopesticides against Aphids in Bitter gourd

Two field experiments were conducted in the farmer's holdings one at Vadipatti and another one at Malayalathanpatti, Madurai District to evaluate the efficacy of biopesticides against the key pests of bitter gourd. All the agronomic practices were adopted uniformly for all the treatments. The details of the field experiments are as follows.

The field experiments were conducted using the Asmita hybrid during two seasons. Field Experiment I was conducted from August to December at Vadipatti, while Field Experiment II was conducted from January to May 2018 at Malayalathanpatti. Nine treatments were evaluated in a Randomized Block Design (RBD) with three replications, using a spacing of 5 × 3 m

Treatments

Treatment Details	Sources
Neem Seed Kernel Extract (NSKE) @5%	-
Neem oil 3%	Madras fertilizer limited, Chennai.
Notchi (*Vitex negundo*) leaf extract @ 10%	-

Neem soap @ 10 g/litre of water	IIHR, Bangalore
Pungam Soap @ 10 g/litre of water	IIHR, Bangalore
Bt @ 2g/litre of water	Purchased from Pondicherry KVK
Metarhizium anisopliae -1x10^8 CFU/ ml	Agriya agrotech pvt ltd., (Metalin)
Malathion 50 EC@ 500ml/ha Standard check	Hindustan insecticides ltd., (Hilmala)
Untreated check	

Preparation of Neem Seed Kernel Extract (NSKE) 5%

A pulverizer was used to powder the dry neem kernel. Five kilos of pulverized neem seed powder was soaked in 10 liters water at overnight, filtered through double layered khada cloth and the volume was made up to 5 % by adding water. (NSKE solution was applied through high volume sprayer after adding Teepol 0.1 %.). NSKE 5 per cent were sprayed twice at an interval of fifteen days.

Preparation of Notchi (*Vitex negundo*) leaf extract @10 %

Notchi leaf was dried under shade and powdered by using electric grinder and pass through a 20 mesh sieve and kept in a polypropylene bag. 300g of each powdered material was taken into a 2 litre capacity conical flask and 1000 ml distilled water was added and homogenized for 15 min then allowed to settle for 24 h. The extract was separated using fine muslin cloth and then filtered. This filtrate was sprayed twice at an interval of fifteen days.

RESULTS AND DISCUSSION

Population dynamics of Aphids in Bitter gourd in Madurai district

Aphids

A significant difference was observed on the seasonal incidence of aphids in two locations of Madurai district (Table 1). Maximum population (5.28/ 3 leaves) was recorded during third week of April in Kadachanenthal and minimum (1.18) during first week of May. In Vadipatti maximum population was noticed during first week of June (4.86/ 3 leaves) and lowest during second week of October (0.69/ 3 leaves). Correlation analysis revealed that in Kadachanenthal, maximum temperature had a highly significant positive association with aphid population, whereas rainfall was significantly negatively correlated. In contrast, at Vadipatti, only rainfall exhibited a negative correlation with aphid population, while no significant effects were observed for the other weather parameters (Table 1).

Efficacy of newer molecular insecticides against aphids, *Aphis gossypii* in bitter gourd

The aphid population varied significantly in various treatments at all the periods of observation. On 3 DAS, significantly less aphid population was recorded in plots treated with Chlorantraniliprole 18.5 SC @ 150ml/ha (4.20 no./3 leaves) and Spinosad 45 % SC @ 160 ml/ ha (4.40 no./3 leaves) statistically on par with each other. The next treatments in descending order of effectiveness were Chlorantraniliprole 18.5 SC @ 125 ml/ha (6.50 no./3 leaves) and Imidacloprid 17.8 SL @ 250ml/ha (6.85 no./3 leaves). While computing through all periods of observation, Spinosad 45 % SC @ 160 ml/ha was found to be effective in reducing the aphid population (1.71 no. / 3 leaves). The corresponding per cent reduction over control was 93.6. This was followed by Chlorantraniliprole 18.5 SC @ 150ml/ha (1.94 no./ 3 leaves) and Chlorantraniliprole 18.5 SC @ 125 ml/ ha (2.73 no./3 leaves) with the corresponding per cent reduction of 89.88 and 89.79 respectively (Table 2).

The overall results revealed that, the treatment Spinosad 45 % SC @ 160 ml/ha was found consistently effective in reducing the aphid population as it harboured 1.56 aphids / 3 leaves as against 29.32 aphids/ 3 leaves in untreated control respectively. In order of effectiveness, Chlorantraniliprole 18.5 SC @ 150ml/ha (2.83 no./ 3 leaves) and Chlorantraniliprole 18.5 SC @ 125 ml/ha (2.95 no./3 leaves) treatments were proved to be the next alternative in field experiment II (Table 3).

Efficacy of biopesticides against aphids in bitter gourd (Field Experiment I and II)

Aphids

The population of aphids differed significantly due to various treatments in all periods of observation (Table 4).

Table 1: Seasonal incidence of key insect pests of bitter gourd in Madurai district

SMW	Month	Mean No. of aphids / 3 leaves	
		Kadachanenthal	Vadipatti
1	Jan 1 to Jan 7	2.43 (1.56)	3.45 (1.86)
2	Jan 8 to Jan 14	2.61 (1.62)	4.29 (2.07)
3	Jan 15 to Jan 21	4.37 (2.09)	1.78 (1.33)
4	Jan 22 to Jan 28	1.89 (1.37)	4.23 (2.06)
5	Jan 29 to Feb 4	3.76 (1.94)	4.64 (2.15)
6	Feb 5 to Feb 11	3.98 (1.99)	4.42 (2.10)
7	Feb 12 to Feb 18	4.77 (2.18)	4.86 (2.20)
8	Feb 19 to Feb 25	5.21 (2.28)	0.98 (0.99)
9	Feb 26 to Mar 4	4.85 (2.20)	2.8 (1.67)
10	Mar 5 to Mar 11	4.72 (2.17)	2.49 (1.58)
11	Mar 12 to Mar 18	4.94 (2.22)	0.98 (0.99)
12	Mar 19 to Mar 25	4.71 (2.17)	1.65 (1.28)
13	Mar 26 to Apr 1	4.65 (2.16)	1.43 (1.20)
14	Apr 2 to Apr 8	4.72 (2.17)	1.29 (1.14)
15	Apr 9 to Apr 15	2.68 (1.64)	1.18 (1.09)
16	Apr 16 to Apr 22	5.28 (2.30)	4.43 (2.10)
17	Apr 23 to Apr 29	1.29 (1.14)	1.86 (1.36)
18	Apr 30 to May 6	1.18 (1.09)	3.96 (1.99)
19	May 7 to May 13	2.35 (1.53)	3.64 (1.91)
20	May 14 to May 20	4.26 (2.06)	2.51 (1.58)
21	May 21 to May 27	3.85 (1.96)	4.55 (2.13)
22	May 28 to June 4	3.39 (1.84)	4.86 (2.20)
23	June 5 to June 11	4.64 (2.15)	4.53 (2.13)
31	Aug 1 to Aug 7	2.39 (1.55)	2.72 (1.65)
32	Aug 8 to Aug 14	1.62 (1.27)	2.37 (1.54)
33	Aug 15 to Aug 21	3.43 (1.85)	3.15 (1.77)
34	Aug 22 to Aug 28	4.21 (2.05)	2.74 (1.66)
35	Aug 29 to Sep 5	4.26 (2.06)	1.25 (1.12)
36	Sep 4 to Sep 10	2.65 (1.63)	1.23 (1.11)
37	Sep 11 to Sep 17	3.64 (1.91)	2.84 (1.69)
38	Sep 18 to Sep 24	3.58 (1.89)	1.19 (1.09)
39	Sep 25 to Oct 1	3.25 (1.80)	2.97 (1.72)
40	Oct 2 to Oct 8	2.64 (1.62)	0.69 (0.83)

41	Oct 9 to Oct 15	3.82 (1.95)	0.72 (0.85)
42	Oct 16 to Oct 22	3.29 (1.81)	2.54 (1.59)
43	Oct 23 to Oct 29	1.37 (1.17)	2.23 (1.49)
44	Oct 30 to Nov 5	1.25 (1.12)	0.72 (0.85)
45	Nov 6 to Nov 12	2.86 (1.69)	4.29 (2.07)
46	Nov 13 to Nov 19	1.22 (1.10)	1.47 (1.21)
47	Nov 20 to Nov 26	4.35 (2.09)	1.68 (1.30)
48	Nov 27 to Dec 3	2.63 (1.62)	0.85 (0.92)
49	Dec 4 to Dec 10	3.92 (1.98)	0.71 (0.84)
50	Dec 11 to Dec 17	1.42 (1.19)	1.29 (1.14)
51	Dec 18 to Dec 24	1.23 (1.11)	1.64 (1.28)
52	Dec 25 to Dec 31	1.88 (1.37)	1.89 (1.37)
	Mean	**3.28**	**2.49**

Computation of overall mean population throughout the periods in field experiment I revealed that application of NSKE 5% and neem oil 3 % recorded the lowest population of 7.92 and 8.85 aphids/ 3 leaves respectively. The corresponding per cent reduction over control was 82.09 and 80.00 per cent respectively. However, the standard check Malathion 35 EC @ 500 ml/ha registered the lowest population (7.56 / 3 leaves). Similar was the trend observed in second field experiment. The highest percent reduction of aphid population over control was recorded in NSKE 5 % (84.80%) and Neem oil 3% (82.81%) treatments and they were significantly different from each other (Table 5).

Population dynamics of aphids in bitter gourd

The results regarding the population build-up of aphids revealed that the maximum temperature exerts a significant positive correlation while rainfall shows negative correlation. This was in alignment with the findings of Chakraborthy, (2011) who studied the incidence of *A. gossypii* and reported that all weather factors showed significant influence on population. Singh *et al.*, (2013), depicted that the population was negatively correlated with the minimum temperature, rainfall and relative humidity is in accordance with our study.

Efficacy of newer insecticide molecules aphids in bitter gourd

In the present study, Spinosad 45 % SC @ 160 ml/ ha was found consistently effective in reducing the aphid population. The next effective treatment was Chlorantraniliprole 18.5 SC @ 150ml/ha. The present findings were partly collaborated with the findings of Patel *et al.* (2014), reported that spinosad 45 SC @ 125 g a.i/ha emerged as most effective treatment to reduce the aphid population (2.09-3.07 per three leaves/plant).

Efficacy of biopesticides against aphids in bitter gourd

Among the biopesticides evaluated, NSKE found superior to all the other treatments. This was in accordance with the findings of (Jadon, 2008) who reported that NSKE found most effective in reducing the population of aphids and also these were found safer to natural enemies. Jadon tested water and ethanol extracts of botanicals, in comparison to oxydemeton methyl and control. Among the plants extracts neem seed kernel extract found most effective in reducing aphid population. All the tested plant extracts were found safer to natural enemies, *C. Septempunctata* and *D. rapae* in comparison to insecticides. The grain yield and number of siliquae also increased significantly by spray of all the plant extracts.

Ten botanicals tested against aphid, *Lipaphis erysimi* on varuna variety of mustard at Kangda (Anonymous, 2001). The minimum number of aphids per plant was observed in Azadirachtin treated plots. However, the differences among the treatment were not significant and *Mentha spicata*, *M. piperate* and *Vitex negundo* gave comparatively better yield than others.

Table 2: Population of *A. gossypii* as influenced by newer molecular insecticides in Bitter gourd -Field experiment I (Aug – Dec 2017)

Treatment	Dosage	Mean No. of aphids(nymphs and adults) / 3leaves*									Reduction over control (%)
		PTC	I Spray				II spray				
			3 DAS	7 DAS	10 DAS	14 DAS	3 DAS	7 DAS	10 DAS	14 DAS	Mean	
Chlorantraniliprole 18.5% SC	125 ml/ha	21.00	6.50 (2.55)^{b}	1.20 (1.10)^{c}	3.35 (1.83)^{c}	5.40 (2.32)^{c}	1.30 (1.14)^{b}	0.70 (0.84)^{c}	1.35 (1.16)^{b}	2.00 (1.41)^{c}	2.73 (1.65)^{c}	89.79
Chlorantraniliprole 18.5 % SC	150ml/ha	21.60	4.20 (2.05)^{a}	0.95 (0.97)^{b}	2.20 (1.48)^{b}	4.50 (2.12)^{b}	0.90 (0.95)^{a}	0.45 (0.67)^{b}	0.80 (0.89)^{a}	1.55 (1.24)^{b}	1.94 (1.39)^{b}	89.88
Spinosad 45 % SC	160ml/ ha	20.50	4.40 (2.10)^{a}	0.75 (0.87)^{a}	1.95 (1.40)^{a}	3.60 (1.90)^{a}	0.80 (0.89)^{a}	0.20 (0.45)^{a}	0.75 (0.87)^{a}	1.20 (1.10)^{a}	1.71 (1.31)^{a}	93.60
Imidacloprid 17.8 % SL	250ml/ha	21.00	6.85 (2.62)^{b}	1.50 (1.22)^{d}	3.60 (1.90)^{d}	5.80 (2.41)^{d}	1.75 (1.32)^{c}	0.85 (0.92)^{d}	1.50 (1.22)^{bc}	1.80 (1.34)^{d}	2.96 (1.72)^{d}	88.93
Spiromesifen 22.9 % SC	500 ml/ha	21.40	13.25 (3.64)^{e}	4.20 (2.05)^{g}	7.60 (2.76)^{g}	9.80 (3.13)^{f}	3.00 (1.73)^{f}	1.20 (1.10)^{f}	1.95 (1.40)^{d}	2.85 (1.69)^{g}	5.48 (2.34)^{f}	79.52
Thiodicarb 75 % WP	750 g/ha	19.50	11.30 (3.36)^{d}	1.80 (1.34)^{e}	5.20 (2.28)^{e}	9.80 (3.13)^{f}	2.50 (1.58)^{d}	1.00 (1.00)^{e}	1.90 (1.38)^{d}	2.75 (1.66)^{f}	4.53 (2.13)^{e}	83.07
Standard check – Malathion50 % EC	400ml/ha	20.25	8.65 (2.94)^{c}	2.75 (1.66)^{f}	5.95 (2.44)^{f}	8.75 (2.96)^{e}	2.75 (1.66)^{e}	1.00 (1.00)^{e}	1.65 (1.28)^{c}	2.35 (1.53)^{e}	4.23 (2.06)^{e}	84.19
Untreated check	-	20.60	21.00 (4.58)^{f}	23.50 (4.85)^{h}	25.00 (5.00)^{h}	27.20 (5.22)^{g}	27.50 (5.24)^{g}	28.60 (5.35)^{g}	29.00 (5.39)^{e}	32.30 (5.68)^{h}	26.76 (5.17)^{g}	-
S.Ed	-	-	0.336	0.018	0.028	0.027	0.033	0.035	0.033	0.014	0.019	-
CD(0.05)	-	-	0.072	0.039	0.061	0.057	0.072	0.075	0.071	0.030	0.041	-

PTC=Pre Treatment Count, DAS= Day(s) after spraying, NS – Non significant

*Each value is the mean of three replications

Figures in parenthesis are square root transformed values

In a column, means followed by same letter(s) are not significantly different by LSD (p= 0.05)

Table 3: Population of *A. gossypii* as influenced by newer molecular insecticides in Bitter gourd -Field experiment II (Jan - Dec 2017)

Treatment	Dosage	Number of nymphs and adults /3 leaves*									Reduction over control (%)
		PTC	I Spray				II Spray				
			3 DAS	7 DAS	10 DAS	14 DAS	3 DAS	7 DAS	10 DAS	14 DAS	Mean
Chlorantraniliprole 18.5% SC	125 ml/ha	27.20	8.85 (2.97)^{c}	1.50 (1.22)^{b}	3.23 (1.80)^{b}	5.73 (2.39)^{b}	1.00 (1.00)^{b}	0.60 (0.77)^{c}	1.20 (1.10)^{b}	1.50 (1.22)^{c}	2.95 (1.72)^{c}	89.93
T2-Chlorantraniliprole 18.5 % SC	150ml/ha	29.00	7.95 (2.82)^{b}	1.39 (1.18)^{b}	3.25 (1.80)^{b}	4.92 (2.22)^{a}	1.45 (1.20)^{a}	0.50 (0.71)^{b}	1.30 (1.14)^{a}	1.85 (1.36)^{b}	2.83 (1.68)^{b}	90.34
T3-Spinosad 45 % SC	160ml/ ha	26.40	4.25 (2.06)^{a}	0.30 (0.55)^{a}	1.25 (1.12)^{a}	2.00 (1.41)^{a}	1.10 (1.05)^{a}	0.35 (0.59)^{a}	1.40 (1.18)^{a}	1.80 (1.34)^{a}	1.56 (1.25)^{a}	94.67
T4-Imidacloprid 17.8 % SL	250ml/ha	27.20	9.25 (3.04)^{cd}	1.85 (1.36)^{c}	3.32 (1.82)^{b}	6.25 (2.50)^{c}	1.25 (1.12)^{c}	0.85 (0.92)^{d}	1.72 (1.31)^{bc}	1.95 (1.40)^{d}	3.31 (1.82)^{d}	88.71
T5-Spiromesifen 22.9 % SC	500 ml/ha	28.25	12.50 (3.54)^{f}	4.65 (2.16)^{f}	5.40 (2.32)^{d}	6.85 (2.62)^{f}	4.52 (2.13)^{f}	2.35 (1.53)^{f}	3.00 (1.73)^{d}	3.70 (1.92)^{g}	5.37 (2.32)^{f}	81.68
T6-Thiodicarb 75 % WP	750g/ha	28.50	10.45 (3.23)^{e}	3.84 (1.96)^{e}	5.25 (2.29)^{d}	6.59 (2.57)^{e}	3.47 (1.86)^{d}	1.00 (1.00)^{e}	2.35 (1.53)^{d}	2.84 (1.69)^{f}	4.47 (2.12)^{e}	84.75
T7-Standard check – Malathion 50% EC	400ml/ha	24.00	9.64 (3.10)^{d}	3.15 (1.77)^{d}	4.60 (2.14)^{c}	6.38 (2.53)^{d}	2.00 (1.41)^{e}	1.25 (1.12)^{e}	2.15 (1.47)^{c}	2.32 (1.52)^{e}	3.94 (1.98)^{e}	86.56
T8-Untreated check	-	27.50	27.54 (5.25)^{g}	27.59 (5.25)^{g}	28.45 (5.33)^{e}	28.94 (5.38)^{g}	29.65 (5.45)^{g}	30.28 (5.50)^{g}	30.42 (5.52)^{e}	31.68 (5.63)^{h}	29.32 (5.41)^{g}	-
S.Ed	-	-	0.039	0.031	0.024	0.019	0.033	0.035	0.033	0.014	0.019	-
CD(0.05)	-	-	0.083	0.66	0.527	0.040	0.072	0.075	0.071	0.030	0.041	-

PTC=Pre Treatment Count, DAS= Day(s) after spraying, NS – Non significant

*Each value is the mean of three replications

Figures in parenthesis are square root transformed values

In a column, means followed by same letter(s) are not significantly different by LSD (p= 0.05)

Table 4: Population of *A. gossypii as* influenced by Biopesticides in Bitter gourd -Field experiment I (Aug - Dec 2017)

Treatment	Dosage	Number of nymphs and adults / 3 leaves*									
		PTC	I Spray				II Spray				Mean	Reduction over control (%)
			3 DAS	7 DAS	10 DAS	14 DAS	3 DAS	7 DAS	10 DAS	14 DAS		
T1-Neem seed kernel extract	5%	31.54	13.95 (3.73)^{b}	7.82 (2.80)^{a}	9.65 (3.11)^{a}	13.12 (3.62)^{ab}	6.81 (2.61)^{b}	2.43 (1.56)^{a}	3.64 (1.91)^{a}	5.97 (2.44)^{a}	7.92 (2.81)^{a}	82.09
T2-Neem oil	3%	32.93	15.32 (3.91)^{c}	8.61 (2.93)^{c}	10.93 (3.31)^{c}	12.64 (3.56)^{a}	7.27 (2.70)^{b}	3.69 (1.92)^{b}	5.42 (2.33)^{b}	6.88 (2.62)^{b}	8.85 (2.97)^{b}	80.00
T3-Notchi leaf extract	10%	33.52	17.26 (4.15)^{d}	11.54 (3.40)^{f}	14.23 (3.77)^{f}	15.67 (3.96)^{d}	9.21 (3.03)^{c}	6.32 (2.51)^{e}	8.47 (2.91)^{d}	9.89 (3.14)^{c}	11.57 (3.40)^{d}	73.84
T4-Neem soap	10g/l	34.86	16.72 (4.09)^{d}	9.28 (3.05)^{d}	12.06 (3.47)^{d}	14.32 (3.78)^{c}	10.65 (3.26)^{de}	8.42 (2.90)^{f}	6.85 (2.62)^{c}	9.46 (3.08)^{c}	10.97 (3.31)^{c}	75.19
T5-Pungam soap	10g/l	30.65	16.89 (4.11)^{d}	12.43 (3.53)^{g}	15.24 (3.90)^{g}	16.39 (4.05)^{d}	11.74 (3.43)^{f}	4.68 (2.16)^{c}	8.93 (2.99)^{e}	9.95 (3.15)^{c}	12.03 (3.47)^{d}	72.80
T6-*Bacillus thuringiensis*	2g/l	30.25	13.69 (3.94)^{c}	9.81 (3.22)^{e}	12.27 (3.72)^{e}	14.59 (4.03)^{d}	10.53 (3.35)^{ef}	4.26 (2.44)^{d}	5.62 (2.88)^{d}	7.13 (3.26)^{d}	9.74 (3.39)^{d}	77.97
T7-*Metarhizium anisopliae*	$1x10^{8}$ CFU/ml	32.51	15.25 (3.91)^{c}	10.69 (3.27)^{e}	11.84 (3.44)^{e}	13.47 (3.67)^{b}	10.36 (3.22)^{d}	6.28 (2.51)^{de}	8.92 (2.99)^{e}	10.63 (3.26)^{d}	10.93 (3.31)^{c}	75.28
T8-Standard check- Malathion 50 EC	500 ml/ ha	32.23	12.29 (3.51)^{a}	8.23 (2.87)^{b}	10.67 (3.27)^{b}	12.55 (3.54)^{a}	4.57 (2.14)^{a}	2.39 (1.55)^{a}	3.57 (1.89)^{a}	6.21 (2.49)^{a}	7.56 (2.75)^{a}	82.90
T9-Control	-	33.15	35.94 (5.99)^{e}	38.78 (6.23)^{h}	40.15 (6.34)^{h}	42.67 (6.53)^{e}	45.84 (6.77)^{g}	47.68 (6.91)^{g}	50.42 (7.10)^{f}	52.35 (7.24)^{e}	44.23 (6.65)^{e}	-
S.Ed	-	-	0.052	0.028	0.028	0.051	0.047	0.032	0.024	0.045	0.036	-
CD	-	-	0.110	0.060	0.060	0.109	0.100	0.069	0.052	0.095	0.076	-

PTC=Pre Treatment Count, DAS= Day(s) after spraying, NS – Non significant

*Each value is the mean of three replications

Figures in parenthesis are square root transformed values

In a column, means followed by same letter(s) are not significantly different by LSD (p= 0.05)

Table 5: Efficacy of biopesticides on Aphid, *Aphis gossypii* in Bitter gourd- Field experiment II (Jan - May 2018)

Treatment	Dosage	Number of nymphs and adults / 3 leaves*									
		PTC	I Spray				II Spray				Mean	Reduction over control (%)
			3 DAS	7 DAS	10 DAS	14 DAS	3 DAS	7 DAS	10 DAS	14 DAS		
T1-Neem seed kernel extract	5%	33.20	10.50 (3.24)^{b}	4.50 (2.12)^{b}	6.80 (2.61)^{b}	8.20 (2.86)^{b}	2.50 (1.58)^{b}	1.00 (1.00)^{b}	3.40 (1.84)^{b}	6.40 (2.53)^{b}	5.41 (2.33)^{ab}	84.40
T2-Neem oil	3%	32.56	11.25 (3.35)^{c}	5.40 (2.32)^{c}	7.20 (2.68)^{b}	8.50 (2.92)^{b}	3.70 (1.92)^{c}	1.20 (1.10)^{c}	3.60 (1.90)^{bc}	6.80 (2.61)^{bc}	5.96 (2.44)^{ab}	82.81
T3-Notchi leaf extract	10%	34.26	13.20 (3.63)^{de}	6.80 (2.61)^{d}	9.30 (3.05)^{c}	10.60 (3.26)^{c}	5.20 (2.28)^{d}	1.50 (1.22)^{d}	3.80 (1.95)^{c}	7.20 (2.68)^{cd}	7.20 (2.68)^{ab}	79.20
T4-Neem soap	10g/l	33.78	12.80 (3.58)^{d}	6.50 (2.55)^{d}	9.80 (3.13)^{cd}	11.20 (3.35)^{d}	6.30 (2.51)^{e}	2.00 (1.41)^{e}	5.30 (2.30)^{d}	7.60 (2.76)^{de}	7.69 (2.77)^{ab}	77.82
T5-Pungam soap	10g/l	31.64	13.80 (3.71)^{f}	10.60 (3.26)^{f}	12.20 (3.49)^{e}	14.50 (3.81)^{f}	9.20 (3.03)^{g}	5.40 (2.32)^{g}	8.80 (2.97)^{g}	10.20 (3.19)^{g}	10.59 (3.25)^{ab}	69.46
T6-*Bacillus thuringiensis*	2g/l	32.00	13.73 (3.71)^{ef}	8.93 (2.99)^{e}	10.29 (3.21)^{d}	13.68 (3.70)^{e}	7.24 (2.69)^{f}	4.26 (2.06)^{f}	6.13 (2.48)^{e}	7.94 (2.82)^{e}	9.03 (3.00)^{ab}	73.96
T7-*Metarhizium anisopliae*	1x10^{8} CFU/ml	31.90	16.29 (4.04)^{g}	11.25 (3.35)^{g}	13.68 (3.70)^{f}	15.61 (3.95)^{g}	7.28 (2.70)^{f}	5.63 (2.37)^{g}	7.98 (2.82)^{f}	9.53 (3.09)^{f}	10.91 (3.30)^{ab}	68.45
T8-Standard check – Malathion 50 EC	500 ml/ ha	34.20	9.50 (3.08)^{a}	4.20 (2.05)^{a}	6.00 (2.45)^{a}	7.50 (2.74)^{a}	2.20 (1.48)^{a}	0.68 (0.50)^{a}	2.60 (1.61)^{a}	4.20 (2.05)^{a}	4.53 (2.13)^{a}	86.93
T9-Control	-	32.30	32.60 (5.71)^{h}	33.40 (5.78)^{h}	33.80 (5.81)^{g}	34.50 (5.87)^{h}	3 5.20 (5.93)^{h}	35.50 (5.96)^{h}	36.00 (6.00)^{h}	36.40 (6.03)^{h}	34.68 (5.89)^{c}	-
S.Ed	-	-	0.036	0.030	0.044	0.031	0.017	0.035	0.026	0.037	-	-
CD	-	-	0.077	0.064	0.094	0.066	0.037	0.075	0.055	0.078	-	-

PTC=Pre Treatment Count, DAS= Day(s) after spraying, NS – Non significant

*Each value is the mean of three replications

Figures in parenthesis are square root transformed values

In a column, means followed by same letter(s) are not significantly different by LSD (p= 0.05)

Table 6: Correlation coefficients, Regression equations forAphids incidence in Bitter gourd and weather parameters

Locations	Correlation coefficients value #				R^2	Multiple regression equation #
	X_1	X_2	X_3	X_4		
Kadachanenthal	0.497**	0.225 ^{NS}	0.072 ^{NS}	-0.457**	0.36	$Y = -11.874 + 0.269 (X_1)^{NS} + 0.093(X_2)^{NS} + 0.055 (X_3)^{NS} - 0.019 (X_4)^{NS}$
Vadipatti	0.188 ^{NS}	-0.006 ^{NS}	0.055 ^{NS}	-0.525**	0.41	$Y = -9.732 + 0.295 (X_1)^{NS} - 0.068(X_2)^{NS} + 0.054 (X_3)^{NS} - 0.055(X_4)^{NS}$

N = 26 Standard weeks
** Significant at 1 per cent level, * Significant at 5 per cent level, NS - Non Significant
($P < 0.05$ or $P < 0.01$)
X_1 – Maximum temperature (^{0}C), X_2 – Minimum temperature (^{0}C), X_3 – Relative humidity (%), X_4 – Rainfall (mm)

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AUTHOR'S CONTRIBUTION

Adaikkan Yogapriya **(YA) –** carried out data analysis and manuscript preparation

Janani M **(JM) –** carried out the experiment and data analysis

Balakrishnan Usharani **(BU) –** planning and designing of the experiment and revision of the manuscript

Krishnasamy Suresh **(KS) –** planning and designing of the experiment and revision of the manuscript

CONFLICT OF INTEREST STATEMENT

The authors do not have any conflict of interest.

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Diversity and functional profiling of culturable cellulolytic bacteria in wood-feeding termites (Order: Blattodea)

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ABSTRACT: Termites are a large and diverse group of phytophagous insects that feed on cellulose-rich organic materials. During the decomposition of organic matter, they rely on symbiotic microorganisms, particularly bacteria and protozoa present in their digestive tract, to facilitate cellulose degradation. This study aims to identify the cellulolytic bacteria from the gut of the wood feeding termite species based on sequences of 16S ribosomal RNA (rRNA) gene. Berg's agar media supplemented with carboxymethyl cellulose (CMC) was used to culture the cellulose degrading bacteria. Cellulolytic activity was confirmed based on clear zone formation and the cellulolytic index on Berg's agar media using Congo red assay. Total nine isolates of bacteria from the gut of wood feeding termites showed cellulolytic activity. The highest cellulolytic index was recorded in *Bacillus cereus* (CI- 1.31), followed by *Bacillus subtilis* (CI- 1.09). The high cellulolytic index in these isolates is likely owing to their ability to secrete greater amounts of cellulases, which degrade the amorphous regions of cellulose in the CMC substrate.

Keywords: Termite, Gut symbiont, Bacteria, Cellulolytic, *Bacillus*

INTRODUCTION

Termites (Order: Blattodea) are a large and diverse group of soil macrofauna, which are most abundant in tropics and subtropics (Brune, 2014). These phytophagous insects feed on cellulose-rich organic materials such as wood, twigs and leaves, playing a vital role as decomposers in terrestrial ecosystems. However, certain species are also recognised as economically important pests, causing damage to crops in agricultural and horticultural systems and wooden structures (Rana *et al*., 2021). Termites contribute up to 95 per cent of the insect biomass in tropical soils (Breznak and Brune, 1994). Although only a small proportion of the approximately 3000 described species are considered as pests, their impact on plant health and structural materials can be significant under favourable conditions. At the same time, termites contribute to nutrient recycling by breaking down dried plant material, thereby enhancing soil fertility through improvements in its physical and chemical properties (Arif *et al*., 2018; Sugimoto *et al*., 2000).

Termites are considered serious pests in several horticultural crops, particularly in tropical and subtropical regions. They attack roots, stems, cuttings, seedlings and woody tissues of fruit crops, plantation crops, ornamental plants and vegetable crops, leading to wilting, drying and, in severe infestations, plant death. Important horticultural crops such as mango, citrus, coconut, grapevine, pomegranate and several nursery plants are reported to suffer from termite damage (Rana *et al*., 2021). Damage is often more severe under dry soil conditions and in stressed plants, where termites initially feed on dead organic matter and later invade living tissues (Logan *et al*., 1990). Apart from causing direct economic losses through reduction in plant vigour and yield, termite infestation also predisposes plants to secondary infections and structural weakening. Globally, termites are estimated to cause billions of dollars in economic losses annually in agriculture, horticulture, forestry and structural materials (Rust and Su, 2012). Therefore, understanding termite biology and their associated microorganisms is important not only from an ecological perspective but also for developing sustainable termite management strategies in horticultural ecosystems.

In the process of decomposing organic matter, termites utilize microorganisms to degrade cellulose, such as bacteria and protozoa in the digestive tract, especially in the hindgut. In non-Termitidae termites, protozoa predominate over bacteria, whereas in Termitidae termites, bacteria are more dominant than protozoa (Breznak, 2014). These microbial symbionts

play a crucial role in host nutrition, survival, and may also influence termite adaptability and persistence as pests in different ecosystems.

To digest cellulose, termites have to provide cellulolytic enzymes, *i.e.,* cellulase produced by the termite itself and by the termite symbionts (Nakashima *et al*., 2002). Cellulose is a linear polymer of glucose linked through beta-1,4-glycosidic linkages. These linkages are hydrolysed by cellulase, which also plays a role in recycling the polysaccharides. Cellulase consists of various enzymes such as endoglucanase (EC 3.2.1.4), exoglucanase (EC 3.2.1.74) and beta-glucosidase (EC 3.2.1.21) (Morana *et al*., 2011).

Carboxymethyl cellulose (CMC) is widely used as a suitable cellulosic material for detecting endo-acting cellulases, as its modified structure lowers the crystallinity of native cellulose and enhances the availability of amorphous regions for enzymatic action. Endoglucanases (CMCase) act on these regions by randomly cleaving internal β-1,4-glycosidic linkages within the cellulose chain, which leads to a significant decrease in both the degree of polymerization and the viscosity of the substrate (Zhang *et al*., 2006).

Cellulolytic enzymes from microorganisms also have many potential biotechnological and industrial applications. Cellulases are required in large quantities because of their application in many industries, such as textiles, detergent, food, animal feed, bio-fuel, paper and pulp, pharmaceutical and waste management (Mandels, 1985; Bhat, 2000; Park and Park, 2001). Isolating the possible strains is the first stage in creating an industrial method for producing an enzyme (Kasana *et al*., 2008). In addition, understanding cellulolytic gut bacteria of wood feeding termites may provide insights into the microbial mechanisms underlying cellulose degradation, which are important for termite survival and may have implications in developing novel approaches for termite pest management. In this context, the present study focuses on the isolation and screening of cellulolytic gut bacteria from wood feeding termites.

MATERIALS AND METHODS

Collection and identification of termite samples

Wood feeding termites *Odontotermes feae, O. yadevi, O. redemanni* and *Nasutitermes indicola* were collected from Kodagu and Chikkamagaluru districts of Karnataka, and brought to the insect molecular biology laboratory, Department of Entomology, College of Agriculture, GKVK, Bangalore, during the year 2024-25, in sterile plastic boxes. Live termites were collected for microbial isolation and boxes were labeled with the host name, location and collection date. Live worker castes were utilized for bacterial isolation within 24 hours of sampling (Sakolvaree and Deevong, 2016). Soldier caste was used for the termite species identification, utilising the keys provided in Fauna of India and Adjacent Countries Volume I by Roonwal and Chhotani (1989), Volume II by Chhotani (1997) (Santhrupthi *et al*., 2024).

Isolation of bacteria

A selected number of worker termites (3-4 individuals) were taken from the collected samples and surface sterilized with 70 per cent ethanol for one minute, followed by 0.1 per cent sodium hypochlorite, and then rinsed 2-3 times in autoclaved water to remove any contaminants adhered to the surface of the specimens. The entire gut was dissected using sterile forceps, needle and micro scissor under aseptic condition. Gut samples were pooled to ensure a sufficient amount of material for microbial analysis. The dissected guts were homogenized in a micro centrifuge tube using a sterile micro pestle with 1 ml of phosphate buffer saline (PBS) solution (pH 7.4) and then serially diluted till 10^{-7}. An aliquot (100 µl) from each dilution was plated on nutrient agar (NA) medium and spread using a sterile glass spreader. Then, petri plates were wrapped with the para-film and incubated at 32 °C for 24 to 48 h in biological oxygen demand (BOD) incubator (KEMI®).

Morphological characterization and purification of isolated bacteria

After incubation, plates with bacterial growth were observed for morphological characters *viz*., color, shape, margin, opacity, elevation, branching and gram stain. Colonies displaying distinct characteristics not seen on other plates were selected and transferred onto fresh nutrient agar plates for further purification (Kavitha *et al*., 2014). Pure cultures were added to autoclaved nutrient broth in pre-sterilized test tubes with appropriate labels. The tubes were incubated at 37°C for 24 hours in a BOD incubator until the clear broth turned turbid, indicating bacterial growth and multiplication.

Isolation of genomic DNA and amplification of 16S rRNA gene

Genomic DNA was isolated from bacterial cultures grown in nutrient broth following the sucrose

buffer method with minor modifications (Saha *et al*., 1989). The amplification of 16S rRNA was carried out by using universal primers, 16S rRNA forward (5′-AGAGTTTGATCCTGGCTCAG-3′) and 16SrRNA reverse (5′- ACGGCTACCTTGTTACGACTT -3′). Polymerase chain reactions were performed with 25 µl of PCR mixture (ProFlex) with an initial denaturation at 94 °C for 3 min, followed by 35 cycles consisting of denaturation at 94 °C for 1 min, annealing for 45 sec at 59 °C with an extension for 1.5 min at 72 °C followed by final extension for 10 min at 72 °C and kept hold at 4 °C until further processing. The PCR amplified products were subjected to agarose gel electrophoresis on a 1 per cent gel and documented with a gel documentation system (Molecular Imager Gel Doc XR+, BioRad, USA and Software - Version 5.2.1).

16S rRNA Sequence analysis

The amplified PCR products were sent for nucleotide sequencing to Eurofins Genomics India Pvt. Ltd. Bangalore, using the Sanger dideoxy sequencing method. The obtained forward and reverse sequences were aligned, edited, and assembled into a contig sequence using BioEdit software (version 7.2), and the resulting sequences were compared with those in the National Center for Biotechnology Information (NCBI) database using Basic Local Alignment Search Tool (BLAST) for identification. The 16S rRNA gene sequences with maximum similarity were deposited in GenBank database and accession numbers were obtained.

Test for cellulolytic activity

Berg's Agar plates (For 100 ml, 0.2gm $NaNO_3$, 0.05gm $MgSO_4$, 0.005gm K_2HPO_4, 1mg $FeSO_4$, 2 mg $CaCl_2$, 0.2 mg $MnSO_4$, 2gm agar) were prepared with 0.1% carboxymethyl cellulose (CMC) to serve as a substrate for cellulolytic activity. Bacterial isolates were streaked onto these Berg's agar (Berg *et al*., 1972) plates and incubated at 37°C for 48 hours. Following incubation, the plates were flooded with 3 per cent Congo red solution and allowed to stain for 20 min. Excess stain was removed by washing the plates with 1M sodium chloride (NaCl) solution. Cellulolytic activity was indicated by the appearance of clear zones or halo zones, around the colonies against the red background of Congo red. The cellulase enzyme activity of each isolate was quantified using an enzymatic index, calculated by using the equation below (Ferbiyanto *et al*., 2015).

$$\text{Cellulolytic Index (CI)} = \frac{\text{Diameter of zone of clearance - Diameter of bacterial colony}}{\text{Diameter of bacterial colony}}$$

RESULTS AND DISCUSSION

Morphological characterization and Cellulolytic screening

A total of 41 Bacterial species were isolated from four wood feeding termite species. The cellulolytic activity of the isolates was assessed based on the principle of the CMC agar assay, where carboxymethyl cellulose serves as a substrate for cellulase enzymes. Cellulase-producing bacteria hydrolyse CMC, resulting in the formation of clear zones around the colonies upon staining with Congo red, which binds to intact cellulose (Teather and Wood 1982).

When all the obtained bacterial isolates were tested for cellulolytic activity, nine species showed positive result for CMC assay. Three isolates (34C, 29E, 34H) were from *Odontotermes redemanni,* two isolates (25B, 25BF) were from *Nasutitermes indicola*, two isolates (20S, 25S) were from *Odontotermes feae* and one isolate (26D) was from *Odontotermes yadevi*. Among them five were gram positive and four were gram negative. Morphological characterisations of the cellulolytic bacteria are presented in Table 1.

Table 1: morphological characteristics of cellulolytic bacterial isolates

Isolate code	Colour	Opacity	Margin	Shape	Elevation	Branching	Gram staining
34C	Whitish	Opaque	Irregular	Circular	Flat	No	Positive
25B	Off White	Opaque	Irregular	Irregular	Flat	No	Positive
29E	White	Opaque	Irregular	Circular	Flat	No	Positive
34H	White	Opaque	Irregular	Circular	Flat	No	Positive
25BF	Creamy white	Opaque	Smooth	Circular	Raised	No	Positive

26D	Red	Opaque	Smooth	Circular	Raised	No	Negative
20S	Greyish-white	Opaque	Smooth	Circular	Raised	No	Negative
30S	Cream to white	Opaque	Smooth	Circular	Raised	No	Negative
25S	White	Translucent	Smooth	Circular	Raised	No	Negative

Molecular identification of cellulolytic bacteria

Amplification of the 16S rRNA gene from the selected isolates yielded amplicons of approximately 1500 bp, confirming successful PCR amplification. Sequence analysis using BLAST revealed 100 per cent query coverage with closely related sequences in the GenBank database (Table 2), indicating that the entire length of the obtained sequences aligned with reference sequences without gaps, thereby supporting the reliability of sequence-based identification (Camacho *et al.,* 2009).

Based on sequence similarity analysis, isolates 34C and 25B were identified as *Bacillus cereus* and *Bacillus subtilis*, respectively. The corresponding 16S rRNA gene sequences were deposited in the GenBank database, and accession numbers PV809875 and PV819332 were assigned to isolates 34C and 25B, respectively.

Cellulolytic activity and functional hierarchy

The nine cellulolytic isolates exhibited varying degrees of hydrolysis on CMC agar, as reflected in their cellulolytic indices. The CI values ranged from 0.31 to 1.31. *Bacillus cereus* showed the highest cellulolytic index (CI = 1.31), followed by *B. subtilis* (CI = 1.09), indicating strong extracellular cellulase production (Fig. 1). *Bacillus tequilensis* (CI = 0.86) and *Acinetobacter* sp. (CI = 0.76) also displayed relatively high activity, while *Enterobacter cloacae* (CI = 0.69) and *Bacillus paramycoides* (CI = 0.67) showed moderate cellulolytic potential. In contrast, *Serratia marcescens* (CI = 0.31), *Bacillus stercoris* (CI = 0.32) and *Trabulsiella odontotermitis* (CI = 0.32) produced the smallest hydrolysis zones, suggesting low or limited cellulase activity under the tested conditions.

In the present study members of the genus *Bacillus* constituted the dominant cellulolytic bacteria isolated from the gut of wood feeding termites (*Odontotermes feae, O. yadevi, O. redemanni* and *Nasutitermes indicola*) representing five out of nine isolates. This dominance is consistent with the several other culture dependent investigations of termite gut microbiota. Previous studies on subterranean and wood feeding termites such as *Coptotermes* sp., *Odontotermes* sp. have similarly reported *Bacillus* spp. (*e.g., B. cereus, B. subtilis, B. pumilus, B. licheniformis*) as the most frequently obtained cellulolytic isolates, often exhibiting the largest clearing zones on CMC agar and highest CMCase activities among the obtained strains (Christy *et al.*, 2024; Boontanom and Chantarasiri, 2021).

Table 2: Percent similarity based on BLASTn analysis of the 16S rRNA gene sequence

Isolate code	Closest species (Accession number)	Query coverage (%)	*% Similarity
34C	*Bacillus cereus* strain VBE11 (MG027688)	100	98.00
25B	*Bacillus subtilis* strain Maf-Sh832 (OR230097)	100	99.55
29E	*Bacillus paramycoides* strain D1 (OR477310)	100	98.00
34H	*Bacillus stercoris* strain 23865 (OR454011)	100	97.71
25BF	*Bacillus tequilensis* strain HYM41 (KT982221)	100	99.55
26D	*Serratia marcescens* strain SADG7 (PP527159)	100	99.62
20S	*Trabulsiella odontotermitis* strain OLH2 (MH542271)	100	98.00
30S	*Acinetobacter* sp. strain ZJW-6 (MZ206177)	100	96.75
25S	*Enterobacter cloacae* strain ps-5 (KU353685)	100	98.49

*% Similarity indicates the percent identity based on BLASTn analysis of the 16S rRNA gene sequence against the NCBI GenBank database.

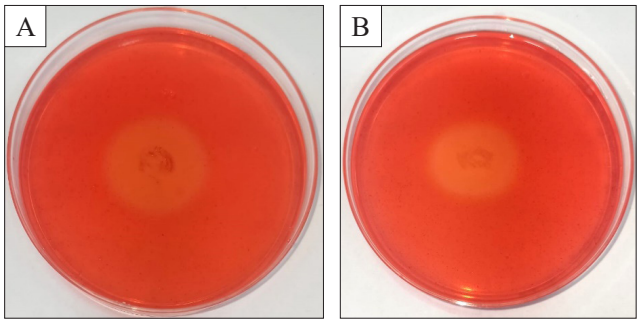

Fig. 1. Cellulolytic activity of isolate A. 34C and B. 25B on CMC agar media

Bacillus spp. produce a diverse array of extracellular glycoside hydrolases (including endoglucanases, exoglucanases and β-glucosidases) that hydrolyse both soluble (CMC) and crystalline cellulose (Lynd *et al*., 2002; Gupta *et al*., 2012). For instance, *B. subtilis* is known for secreting thermostable and alkali-tolerant cellulases suitable for industrial applications, while *B. cereus* isolates have demonstrated high endoglucanase activity and efficient degradation of lignocellulosic biomass under laboratory conditions (Asha and Sakthivel 2014; Wang *et al*., 2024). These enzymatic traits likely provide a competitive advantage to certain strains in cellulose-rich environments such as the guts of wood feeding insects.

In addition to their enzymatic capacity, *Bacillus* spp. may contribute to cellulose degradation in the termite gut through their ecological role as opportunistic and rapidly growing bacteria capable of utilizing partially degraded plant polymers generated during lignocellulose breakdown. By secreting extracellular cellulases, these bacteria are capable of contributing to the hydrolysis of amorphous cellulose and releasing soluble sugars such as cellobiose and glucose, as demonstrated by cellulolytic bacterial isolates from termite guts, including *Bacillus* spp. (Wenzel *et al.*, 2002). Such functional contributions are consistent with observations from termite gut studies that highlight cooperative lignocellulose degradation involving multiple microbial taxa.

The rapid growth of *Bacillus* spp. on standard laboratory media further biases their recovery in culture-dependent approaches compared to more fastidious, strictly anaerobic symbionts (*e.g*., certain *Treponema* or *Fibrobacter* relatives) that dominate culture-independent metagenomic surveys of wood feeding termite guts (Warnecke *et al*., 2007).

CONCLUSION

The high cellulolytic potential observed in the *Bacillus* isolates (e.g., *B. cereus* and *B. subtilis*) indicates their relevance in cellulose degradation within termite gut systems and highlights their potential for industrial applications such as bioethanol production, pulp processing and agricultural waste valorisation. From a pest management perspective, these findings also provide insights into the microbial mechanisms supporting termite nutrition and survival, which may serve as potential targets for developing novel control strategies. However, the reliance on aerobic cultivation may have underestimated the diversity of obligate anaerobic microbes that contribute significantly to in situ cellulose degradation. Future studies integrating metagenomics, meta transcriptomics and targeted anaerobic culturing will enable a more comprehensive understanding of the cellulolytic microbial community and aid in identifying key functional interactions relevant to both biotechnology and termite management.

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AUTHORS CONTRIBUTION

SAB carried out the experimental work, performed data analysis and wrote the manuscript. SB contributed to conceptualization, supervision and critical review of the manuscript. A, AKC and KP contributed to review and editing. All authors read and approved the final manuscript.

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Biology of melon fruit fly, *Zeugodacus cucurbitae* (Coquillett), reared on different fruit-based semi-synthetic diets

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ABSTRACT: Biology of melon fruit fly, *Zeugodacus cucurbitae* (Coquillett) were studied by rearing maggots on four fruit-based semi-synthetic diets prepared from pumpkin (FSD-I), ridge gourd (FSD-II), bitter gourd (FSD-III) and bottle gourd (FSD-IV), along with a standard artificial diet, under laboratory conditions of 25±2°C and 75±5% RH. Larval and pupal development were fastest on FSD-I and FSD-IV (7.25 days larval duration; 8.00–8.50 days pupal period), whereas FSD-III recorded the longest developmental period (9.00 and 9.25 days, respectively). Pupal recovery (77.00%) and pupal weight (1.50 g/100 pupae) were highest on FSD-I, followed by FSD-IV (72.75% and 1.45 g/100 pupae). Adult emergence (83.00%) and flying ability (79.75%) were significantly superior on FSD-I, with a female-biased sex ratio (1:1.16) and the highest fecundity (35.75 eggs/female) and egg hatch (72.50%).

Keywords: biology; fruit-based semi-synthetic diet; *Zeugodacus cucurbitae*

INTRODUCTION

India is one of the leading nations in fruit and vegetable production, with cucurbitaceous vegetables forming an integral part of the horticultural economy owing to their adaptability to diverse agro-climatic conditions and their contribution to farmers' income. In Andhra Pradesh alone, cucurbits are cultivated over 0.028 million hectares with an annual production of 1.328 million metric tonnes (Indiastat, 2025). Cultivation of these crops, however, is severely constrained by the melon fruit fly, *Zeugodacus cucurbitae* (Coquillett) (Diptera: Tephritidae), one of the most economically important tephritid pests attacking more than 81 host plants across 19 families, of which 28 are cucurbits (De Meyer *et al*., 2015). Gravid female flies oviposit inside developing fruits, and the emerging maggots feed internally on the pulp, rendering the fruit unmarketable and often causing complete crop loss under heavy infestation, with yield losses ranging from 30 to 70 per cent depending on season and cultivar (Dhillon *et al*., 2005). Since maggots develop and feed concealed within the fruit, they remain largely inaccessible to contact insecticides (Sohrab *et al*., 2018), and heavy reliance on broad-spectrum insecticides for their management has resulted in resistance development, pesticide residues in produce and leads to disruption of natural enemy populations. An integrated approach is required for fruit fly management, as a first step, a sound understanding of the pest's biology and development on different hosts, since such baseline information underpins the design of rearing systems, sterile insect technique (SIT) programmes and other components of integrated pest management (Radhika *et al*., 2023). Semi-synthetic and artificial diets are indispensable for continuous laboratory rearing of tephritid fruit flies for taxonomic, physiological and applied research, since natural host fruits are difficult to standardize, prone to microbial spoilage and cumbersome to handle at scale (Kirti *et al*., 2018; Cohen, 2015). Although fruit-based semi-synthetic diets incorporating pumpkin have earlier been reported to support satisfactory rearing of *Z. cucurbitae* (Panduranga *et al*., 2018; Kirti *et al*., 2018; Muthulakshmi *et al*., 2021; Abhishek *et al*., 2022), comparative information on the performance of other commonly available cucurbit fruits, *viz*., ridge gourd, bitter gourd and bottle gourd, as diet, alongside the standard artificial diet, remains limited. The present study was therefore undertaken to evaluate and compare the biological performance of *Z. cucurbitae* reared on pumpkin, ridge gourd, bitter gourd and bottle gourd

fruit-based semi-synthetic diets against the standard artificial diet (control), with a view to identifying a suitable, cost-effective diet for laboratory mass rearing of this pest.

MATERIALS AND METHODS

Location and rearing of culture

The study was carried out at the Insectary, Department of Entomology, S.V. Agricultural College, Acharya N.G. Ranga Agricultural University (ANGRAU), Tirupati, Andhra Pradesh, during 2025–26. Melon fruit fly-infested cucurbits collected from farmers' fields and the college Horticulture Garden were used to initiate and maintain the laboratory culture at 25±2°C and 75±5% RH. Third instar maggots emerging from infested fruits pupated in sterilized sand provided in rearing trays, and the harvested pupae were held in adult emergence cages (30 × 30 × 30 cm) provisioned with sugar and yeast hydrolysate (3:1) as adult diet and water-soaked cotton swabs. After a pre-oviposition period of 12 days, males and females of the same age were mated in oviposition cages, and eggs were collected on ovipositional devices placed in the cages for 24 h on alternate days.

Preparation of experimental diets

Four fruit-based semi-synthetic diets (FSD) were prepared using pumpkin (FSD-I), ridge gourd (FSD-II), bitter gourd (FSD-III) and bottle gourd (FSD-IV) by using respective host-fruit. Ripened fruits were sliced and ground into a fine semi-solid pulp, for 1000g of respective fruit pulp 15g yeast extract powder (protein source) and the antimicrobial agents sodium benzoate (1.3g) and methyl paraben (1.8g) were added and thoroughly blended (Panduranga *et al*., 2018; Abhishek *et al*., 2022). The standard artificial diet consisted of brewer's yeast, sugar, citric acid and wheat germ oil in distilled water, along with sodium benzoate and methyl paraben at lower concentrations (0.11 g each). Each diet (250 g) was dispensed in 200 mm petri plates and inoculated with 500 eggs; the standard artificial diet was similarly inoculated at 500 eggs per 250 mL. Each treatment was replicated four times in a completely randomized design (CRD), and inoculated plates were held over 5 cm of sterilized sand for pupation at 25±2°C, 65±5% RH and a photoperiod of 12:12 (L:D) h.

Biological parameters of melon fruit fly

Larval duration, pupal recovery, pupal weight, pupal period, adult emergence, adult flying ability, sex ratio, adult longevity, fecundity and F1 egg hatch were recorded following standard procedures (Abhishek *et al*., 2022). Pupal recovery and adult flying ability were computed as percentages of the eggs inoculated and pupae provided for emergence, respectively; adult flying ability was assessed using a talcum powder-coated PVC pipe (20 cm × 8.5 cm) placed over Petri dish. Fecundity and egg hatch were recorded from twelve-day-old paired adults confined in oviposition cages over a two-week period.

Recording of biological parameters

Larval duration was determined by recording the interval between egg hatching and initiation of pupation and was expressed in days. Pupal recovery was worked out by dividing the total number of pupae obtained by the initial number of larvae inoculated on the diet and expressed as a percentage. Pupal period was recorded as the time interval between pupal formation and adult emergence and expressed in days.

Pupae harvested from different treatments were placed in a glass Petri dish and kept inside an adult emergence cage (30 × 30 × 30 cm) provisioned with sugar and yeast hydrolysate in 3:1 ratio. Observations were recorded daily, and after complete cessation of emergence (up to five days), the number of adults emerged was computed and expressed as a percentage of the initial number of pupae.

Adult flying ability was assessed by randomly collecting fifty pupae from each diet and placing them in a glass Petri dish. A black PVC pipe (20 cm in length and 8.5 cm in diameter), coated on the inside with talcum powder, was placed over the dish within an adult rearing cage. Flying ability was calculated based on the number of flies that flew out through the pipe, expressed as a percentage of the total number of emerged adults.

Sexing of the emerged flies was done based on the presence or absence of the ovipositor, and sex ratio was expressed as the ratio of males to females. Adult longevity was recorded by confining freshly emerged flies to adult rearing cages (30 × 30 × 30 cm) provisioned with sugar and yeast hydrolysate (3:1). Cages were monitored daily for mortality, and the average longevity of adults was expressed in days.

Table 1: Biological parameters of melon fruit fly, *Z. cucurbitae* reared on fruit based semi synthetic diets and standard artificial diet

Parameters	FSD-I	FSD-II	FSD-III	FSD-IV	Standard Artificial Diet	ANOVA
Larval duration (days) **	7.25[a] (2.78±0.02)	8.25 [ab] (2.96±0.02)	9.00[b] (3.08±0.02)	7.25[a] (2.78±0.02)	8.00[ab] (2.92±0.02)	F=8.144; df=4,11; P<0.01
Pupal recovery (%) *	77.00[a] (61.35±0.26)	71.50[b] (57.74±0.26)	63.50[c] (52.69±0.26)	72.75[b] (58.54±0.26)	72.00[b] (58.06±0.26)	F=28.888; df=4,11; P<0.01
Pupal weight (g/100 Pupae) **	1.50[a] (1.42±0.00)	1.40[c] (1.38±0.00)	1.37[c] (1.37±0.00)	1.45 [b] (1.39±0.00)	1.46[ab] (1.40±0.00)	F=23.17; df=4,11; P<0.01
Pupal period (days) **	8.00[a] (2.92±0.01)	8.75 [ab] (3.04±0.01)	9.25 [b] (3.12±0.01)	8.50[ab] (3.00±0.01)	8.50[ab] (3.00±0.01)	F=4.970; df=4,11; P<0.01
Adult emergence (%) *	83.00[a] (65.66±0.18)	73.00[c] (58.70±0.18)	71.00[c] (57.42±0.18)	78.50 [b] (62.39±0.18)	73.75[c] (59.19±0.18)	F=68.811; df=4,11; P<0.01
Sex ratio (♂:♀)	1:1.16	1:1.06	1:1.08	1:1.10	1:1.10	-
Adult fliers (%) *	79.75[a] (63.29±0.25)	66.50[c] (54.64±0.25)	64.00[c] (53.13±0.25)	72.50[b] (58.38±0.25)	70.50[b] (57.11±0.25)	F=53.484; df=4,11; P<0.01
Adult longevity (days) **	45.00[a] (6.75±0.02)	37.00[cd] (6.12±0.02)	35.25[d] (5.98±0.02)	41.00[b] (6.44±0.02)	39.00[bc] (6.28±0.02)	F=31.456; df=4,11; P<0.01
Fecundity (eggs/female) ***	35.75[a] (1.57±0.00)	27.25 [b] (1.45±0.00)	24.00 [c] (1.40±0.00)	32.25[a] (1.52±0.00)	28.50[b] (1.47±0.00)	F=35.135; df=4,11; P<0.01
F1 Egg hatch (%) *	72.50[a] (58.38±0.26)	54.25[c] (47.44±0.26)	53.00[c] (46.72±0.26)	69.75[ab] (56.65±0.26)	67.50[b] (55.25±0.26)	F=91.839; df=4,11; P<0.01

Where; FSD-I: Pumpkin fruit based Semi-synthetic diet; FSD-II: Ridge gourd fruit based Semi-synthetic diet; FSD-III: Bitter gourd fruit based Semi-synthetic diet and FSD-IV: Bottle gourd fruit based Semi-synthetic diet.

Within a row means followed by the same letter are not significantly different (α=0.05), Tukey test, SPSS-20.

Figures in the parenthesis are transformed values ± standard error (m). *Arc sine transformation, **Square root transformation, ***Logarithmic transformation

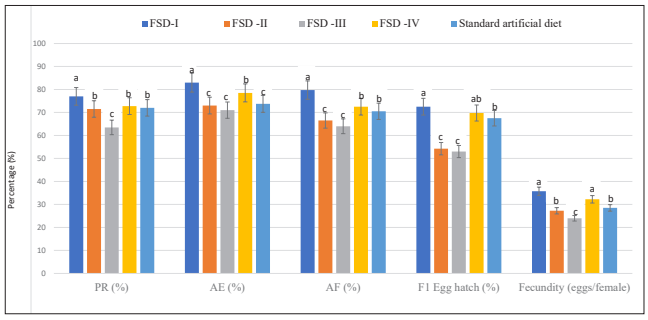

Fig. 1. Biological parameters of melon fruit fly *Z. cucurbitae* reared on fruit based semi synthetic diets and standard artificial diet

Where, PR-pupal recovery, AE-adult emergence, AF-adult fliers, FSD-I: Pumpkin fruit based Semi-synthetic diet, FSD-II: Ridge gourd fruit based Semi-synthetic diet, FSD-III: Bitter gourd fruit based Semi-synthetic diet and FSD-IV: Bottle gourd fruit based Semi-synthetic diet.

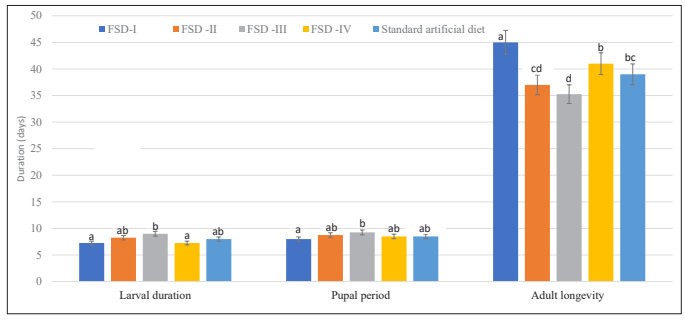

Fig. 2. Biological parameters of melon fruit fly *Z. cucurbitae* reared on fruit based semi synthetic diets and standard artificial diet

Where FSD-I: Pumpkin fruit based Semi-synthetic diet; FSD-II: Ridge gourd fruit based Semi-synthetic diet; FSD-III: Bitter gourd fruit based Semi-synthetic diet and FSD-IV: Bottle gourd fruit based Semi-synthetic diet.

For recording fecundity, equal numbers of 12-day old male and female adult flies were confined to oviposition cages (30 × 30 × 30 cm). Small Petri plates (9 cm diameter) containing the respective fruit-based semi-synthetic diet, covered with parafilm, were provided as ovipositional devices.

Statistical analysis

Data on biological parameters (mean of four replications) were subjected to analysis of variance (ANOVA), and treatment means were compared using Tukey's Honestly Significant Difference (HSD) test at α = 0.05 using SPSS-20.

RESULTS AND DISCUSSION

Biological parameters of *Z. cucurbitae* reared on fruit-based semi-synthetic diets and standard artificial diet

Biological parameters of *Z. cucurbitae* reared on the four fruit-based semi-synthetic diets and the standard artificial diet are presented in Table 1.

Total larval duration ranged from 7.25 to 9.00 days across diets. The shortest duration (7.25 days) was recorded on FSD-I and FSD-IV, and the longest (9.00 days) on FSD-III; FSD-II and the standard artificial diet were intermediate (8.00–8.25 days). All four host fruits used in the semi-synthetic diets belong to the same family Cucurbitaceae, but differ in their carbohydrate, protein and moisture content; diets that provided a more balanced nutrient profile supported faster larval development (Nestel and Nemny-Lavy, 2007). These results agree closely with Muthulakshmi *et al.* (2021), who reported a larval duration of 7.60 days on a pumpkin-based diet, and Abhishek *et al.* (2022), who recorded 8.00 days on the standard artificial diet.

Pupal recovery was significantly higher on FSD-I (77.00%) than on the remaining diets, followed by FSD-IV (72.75%), the standard artificial diet (72.00%) and FSD-II (71.50%); recovery was lowest on FSD-III (63.50%). Pupal weight followed a similar trend, being highest on FSD-I (1.50 g/100 pupae) and lowest on FSD-III (1.37 g/100 pupae), meeting the pre-irradiation pupal-weight benchmark of 1.5–1.68 g/100 pupae recommended for sterile insect technique programmes (FAO/IAEA/USDA, 2019). This indicates that FSD-I supplied adequate digestible protein, carbohydrate and micronutrients for larval growth and successful pupation (Sharp *et al.*, 1983), consistent with the findings of Muthulakshmi *et al.* (2021) and Abhishek *et al.* (2022), who reported 71.12–72.32% pupal recovery on pumpkin-based diets, and Panduranga *et al.* (2018), who obtained 83.20% pupal recovery on a pumpkin-based diet.

Pupal period was shortest on FSD-I (8.00 days) and longest on FSD-III (9.25 days), these findings are in line with Pradhan *et al.* (2020), who reported pupal periods of 8.56 and 8.70 days on pumpkin and bottle gourd, respectively, and shorter than the 6.95 days reported by Chaudhary *et al.* (2025) on cucumber.

Adult emergence and flying ability were highest on FSD-I (83.00% and 79.75%, respectively), followed by FSD-IV (78.50% and 72.50%). The lowest values were recorded on FSD-III (71.00% emergence, 64.00% flying ability), which was statistically on par with FSD-II and the standard artificial diet. These results are consistent with Kirti *et al.* (2018), who reported 80.50% adult emergence and 74.36% flying ability on a pumpkin-based semi synthetic diet. and Abhishek *et al.* (2022), who reported 83.50% adult emergence with a sex ratio of 1:1.11 on a fruit-based semi-synthetic diet.

The sex ratio was skewed in favour of females on all diets, most strongly on FSD-I (1:1.16), followed by FSD-IV and the standard artificial diet, which recorded an identical ratio of 1:1.10; the least skewed ratios were obtained on FSD-II (1:1.06) and FSD-III (1:1.08). Adult longevity followed the same pattern, being highest on FSD-I (45.00 days) and lowest on FSD-III (35.25 days), which is on par with findings of Mir *et al.* (2014), who recorded an adult longevity of 48.56 days on cucumber, and Pradhan *et al.* (2020), who reported 41.00–44.00 days on pumpkin and bottle gourd.

Fecundity and F1 egg hatch were also highest on FSD-I (35.75 eggs/female; 72.50% egg hatch), followed by FSD-IV (32.25 eggs/female; 69.75% egg hatch), and lowest on FSD-III (24.00 eggs/female; 53.00% egg hatch). These values fall within the range reported by Kirti *et al.* (2018) and Panduranga *et al.* (2018) of 28.00–32.00 eggs/female with 68.10–71.80% egg hatch, and are in agreement with Abhishek *et al.* (2022), who reported 77.34% egg hatch on a fruit-based semi-synthetic diet. Adequate protein and fatty-acid content in FSD-I, FSD-IV and the standard artificial diet appears to have supported greater reproductive output relative to the remaining diets

Among all biological parameters studied the pumpkin fruit-based semi-synthetic diet (FSD-I) resulted promising results, bottle gourd-based semi synthetic diet (FSD-IV) as the next best diet; performance on the standard artificial diet was intermediate between FSD-II and FSD-IV and superior to FSD-III. Incorporation of yeast extract as a supplementary protein and fatty acid source into the pumpkin and bottle gourd substrates appears to compensate for any nutritional gaps in the natural fruit matrix, converting it into superior larval growth, pupal quality and adult reproductive fitness. These two fruit substrates therefore offer practical, low-cost alternatives to synthetic bulking agents for laboratory colonization and mass rearing of *Z. cucurbitae*, while avoiding the handling and disposal difficulties associated with unmodified natural host fruits.

CONCLUSION

Pumpkin fruit-based semi-synthetic diet (FSD-I) supported the fastest larval and pupal development, highest pupal recovery and weight, adult emergence, flying ability, fecundity and egg hatch, and produced the largest life stages of *Z. cucurbitae*, followed closely by the bottle gourd-based diet (FSD-IV). Bitter gourd-based diet (FSD-III) was the least suitable substrate across all parameters. The standard artificial diet performed at a level intermediate between the fruit-based diets. Pumpkin and bottle gourd fruit based semi synthetic diets are therefore recommended as suitable, low-cost, and easily manageable alternatives to natural host fruits for laboratory mass rearing of melon fruit fly, including for programmes requiring large numbers of quality insects such as the sterile insect technique.

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AUTHORS CONTRIBUTION

AAB and GSP: conceptualization, designing and implementation of the experiments, data collection and manuscript preparation; RM and KV: planning, supervision, formal analysis and manuscript finalisation.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest with respect to the content of this article.

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An insight into population dynamics of mango fruit borer, *Citripestis eutraphera* (Meyrick), in Gujarat, India

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ABSTRACT: The investigation on population dynamics of mango fruit borer, *Citripestis eutraphera* (Meyrick) based on fecundity per fruit, total number of larvae per fruit and per cent infestation was carried out at Agriculture Experimental Station, Navsari Agricultural University (NAU), Paria, Dist. Valsad (Gujarat) during 2022. Results revealed that the most preferred sites for oviposition by *C. eutraphera* was found to be the upper portion (1/3rd) of the fruit (1.24 eggs) and along the periphery at junction of peduncle and fruit (1.19 eggs). Larval density per fruit varied significantly with fruit developmental stage and infestation pattern. The highest larval densities at the limestone (4.0 larvae fruit^{-1}) and marble (4.7 larvae fruit^{-1}) stages were recorded under single-fruit and adjacent two-fruit infestations, respectively. However, at the mature fruit stage, infestation of multiple adjacent fruits resulted in a significantly greater larval density (7.4 larvae fruit^{-1}). The highest infestation levels were observed during the 16th–18th SMWs in standing fruits, whereas infestations in dropped fruits from individual trees peaked during the 18th–22nd SMWs.

Keywords: Mango fruit borer, *C. eutraphera*, Population dynamics

INTRODUCTION

Mango, *Mangifera indica* L. (Family: Anacardiaceae), is a tropical and subtropical fruit known as "King of Fruits". The states of Andhra Pradesh, Uttar Pradesh, Karnataka, Bihar, Gujarat and Maharashtra are major mango producers of the country. In Gujarat, Valsad, Navsari, Gir Somnath, Kutch and Surat are the major mango producing districts. In mango, about 492 species of insects, 17 species of mites and 26 species of nematodes have been reported from all over the world (Tandon and Verghese, 1985). Of these, 188 species have been reported from India (Butani, 1978; Tandon and Verghese, 1985) but only few are major importance which include hoppers, thrips, mealy bugs, stem borer, fruit flies and stone weevil. Climate change is considered a major driver in the transformation of several minor pests into economically important pests, including scales, thrips, mites, leaf webbers, stem borers, and fruit borers (Anderson and Tran-Nguyen, 2012; Jayanthi *et al*., 2014). The mango fruit borer, *Citripestis eutraphera* (Meyrick) (Lepidoptera: Pyralidae), exemplifies this trend, having expanded its distribution from the Andaman Islands to mainland India in recent years. Mango fruit borer, *C. eutraphera* which was originally described from Java, is a significant borer of mango fruits in South and South-East Asia and some parts of Australia (Anderson and Tran-Nguyen, 2012).

One of the most recent examples of intra-national invasion of an insect pest from the Andaman and Nicobar Islands to mainland India is the mango fruit borer, *C. eutraphera* (Meyrick). The pest was believed to have remained confined to the Islands for nearly two decades until its occurrence was reported in South India by Jayanthi *et al.* (2014). It was recorded from Karnataka and Tamil Nadu, where it caused extensive damage to immature mango fruits. Later, in Gujarat, during 2018, the infestation of *C. eutraphera* was reported for the first time, where it caused significant damage (Bana *et al*., 2018). This species recently invaded and spread to mainland India and infested mango crop in Karnataka, Tamil Nadu, Kerala, Gujarat, parts of Maharashtra and Odisha (Krull, 2004; Krull and Basedow, 2006; Jayanthi *et al.,* 2014; Singh and Kaur, 2014; Hiremath *et al*., 2017; Sunitha *et al*., 2020) and recently in Punjab (Singh *et al*., 2021). Chaudhary and Chavan (2025) documented a fruit borer complex consisting of *C. eutraphera* and *Conogethes punctiferalis* in South Gujarat. *Citripestis eutraphera* was the dominant species, representing 95.66% and 94.82% of the fruit borer population at the respective locations, while *C. punctiferalis* accounted for only 4.34% and 5.18%. It

also infested seedlings and grafts of cashew, *Anacardium occidentale* in Kerala (Jacob *et al*., 2004; Hiremath *et al*., 2017; Kori Nagaraj *et al*., 2020; 2022). Mango-growing pockets in the South-Western parts of Gujarat, as well as parts of Kerala and Tamil Nadu will remain moderately to highly suitable for *C. eutraphera* distribution in 2050 and 2070 (Choudhary *et al*.,2019).

Insect population dynamics has played a prominent role in the development of basic ecology and in the understanding and management of serious pests over the landscape. The monitoring of the pest population and identification of the prevailing insects will need timely application, best methods and application rates relative to the economic threshold of each insect pest. A considerable research work has been carried out on bionomics, pest incidence, prediction level but its population dynamics based on ovipositional studies on different portions of fruits, larval population at different fruit development stages and crop phenology-based infestation have not been studied extensively. By considering this, the present studies on population dynamics of *C. eutraphera* based on fecundity per fruit, total number of larvae per fruit and per cent infestation were carried out at Valsad (Gujarat), India. The study thus helps mango grower to achieve with efficient, sustainable and environmentally sound management practices.

MATERIALS AND METHODS

The present investigation was conducted during 2022 at Agriculture Experimental Station, Navsari Agricultural University (NAU), Gujarat, India in mango orchard (4000 m^2) on *cv*. Kesar grown at 8m x 8m, spacing. All the recommended agronomical practices of NAU, Navsari were followed. The experimental area was kept free from insecticidal spray throughout the study period**.**

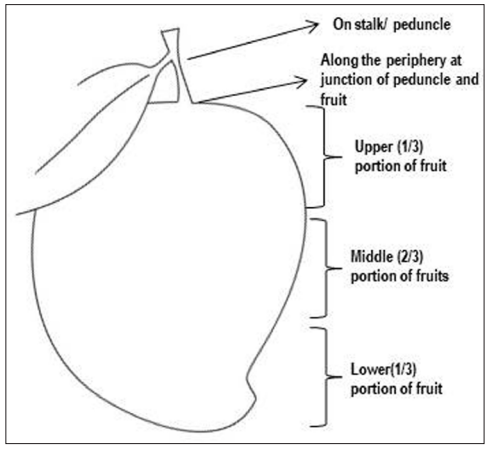

Fig. 1. Different portion of the fruit for ovipositional study

Population dynamics study based on fecundity per fruit by *C. eutraphera* was laid out in Randomized Block Design (RBD), to study the number of eggs laid on different portions of the fruit during each fruit development stage i.e. pea stage, marble stage, lime stone stage (stage when fruit attain hen's egg size) and full mature stage (Fig. 1). Five treatments *viz*., T_1 - Fecundity (eggs laid) on stalk/peduncle, T_2 - along the periphery at the junction of peduncle and fruit, T_3 - upper one third portions of the fruit, T_4 - middle two third portions of fruit and T_5 -lower one third portions of fruit (Fig. 1) were used with five replications (five fruits per replications). On each fruits fecundity on different portion of the fruit were counted with the help of 10X lens. Both, freshly laid eggs and hatched eggs were considered for recording fecundity. Un-hatched fresh eggs were red in colour whereas hatched eggs were characterized by white coloured marking after observed at the oviposition site on the fruit. White markings were also considered for counting the eggs laid by female of *C. eutraphera.*

Population dynamics study based on total number of larvae of *C. eutraphera* per fruit was laid out in RBD design in three different cases of infestation *viz*., single fruit infestation, adjacent couple of fruits infestation and adjacent cluster of fruits (> two fruits) infestation. Four treatments *viz*., T_1 - infestation at pea stage, T_2 - marble stage, T_3 – lime stone stage and T_4 - full mature stage were used with five replications (five infested fruits per replication). Each couple and each cluster of infestation were considered as single infestation. Infested fruits were observed on standing tree which were clearly visible from the ground and brought to the laboratory for dissection. In case of multiple fruit infestation (couple and cluster of fruits infestation) separate polythene bags were used to place all the infested couple or cluster of fruits separately. Total number of larvae per infestation (single fruit or couple of fruits or cluster of fruits) was also noted.

To study the population dynamics study based on infestation**,** paired t-test was used with ten replications (each replication with five trees). Two treatments were selected *viz*., T_1- infestation on standing tree and T_2 - infestation under tree in terms of dropped fruits due to damage by *C. eutraphera*. Observations were recorded at weekly interval as per Standard Meteorological Week (SMW) from pea stage to the harvest. For recording observations on standing tree, 25 fruits per tree clearly visible from the ground were observed and fruit borer

damaged fruits were noted. Based on which per cent infestation was worked out. For recording observation under tree in terms of dropped fruits due to damage by *C. eutraphera*, total number of dropped fruits under each tree were collected and counted. The total numbers of fruit borer infested fruits were separated. Based on this, per cent infestation was worked out. After taking observations, all the dropped fruits were destroyed. The data obtained (egg and larval population, per cent fruit infestation) from the present study were statistically analysed. Statistical analyses were performed using OPISTAT statistical software.

RESULTS AND DISCUSSION

The data presented in Fig. 2A–D on the population dynamics of *C. eutraphera*, based on oviposition preference at different fruit portions and developmental stages, revealed distinct egg-laying patterns. During the pea stage, the highest fecundity was recorded along the periphery at the junction of the peduncle and fruit (0.84 eggs fruit^{-1}), which was statistically at par with the upper one-third portion of the fruit. This was followed by the middle portion (0.32), fruit stalk (0.12), and lower one-third portion (0.04) (Fig. 2A). The number of eggs ranged from 0-0.4 on the fruit stalk, 0.6-1.2 at the peduncle–fruit junction, 0.4-1.2 on the upper portion, 0-0.6 on the middle portion, and 0–0.2 on the lower portion.

At the marble stage, significantly higher fecundity was observed on the upper portion of the fruit (1.32 eggs fruit^{-1}), which was statistically comparable with that at the peduncle–fruit junction (1.20 eggs fruit^{-1}), followed by the middle portion (0.44), fruit stalk (0.12), and lower portion (0.08) (Fig. 2B). Egg numbers ranged from 0-0.4, 0.6-1.8, 0.6-2.2, 0-0.8, and 0-0.4 on the fruit stalk, peduncle–fruit junction, upper, middle, and lower portions, respectively.

A similar trend was observed during the egg stage, wherein the upper portion of the fruit recorded the highest fecundity and remained statistically at par with the peduncle-fruit junction (1.48 eggs fruit^{-1}), followed by the middle portion (0.28), lower portion (0.12), and fruit stalk (0.08) (Fig. 2C). Egg numbers ranged from 0-0.2 on the fruit stalk, 0.8-2.0 at the peduncle–fruit junction, 1.2-2.0 on the upper portion, 0-0.6 on the middle portion, and 0-0.4 on the lower portion.

Likewise, at the mature fruit stage, significantly higher fecundity was recorded on the upper portion of the fruit (1.32 eggs fruit^{-1}), which was statistically comparable with that observed at the peduncle–fruit junction (1.24 eggs fruit^{-1}), indicating a consistent preference of *C. eutraphera* females for oviposition on the upper fruit surface and near the peduncle across fruit developmental stages (Fig. 2D).

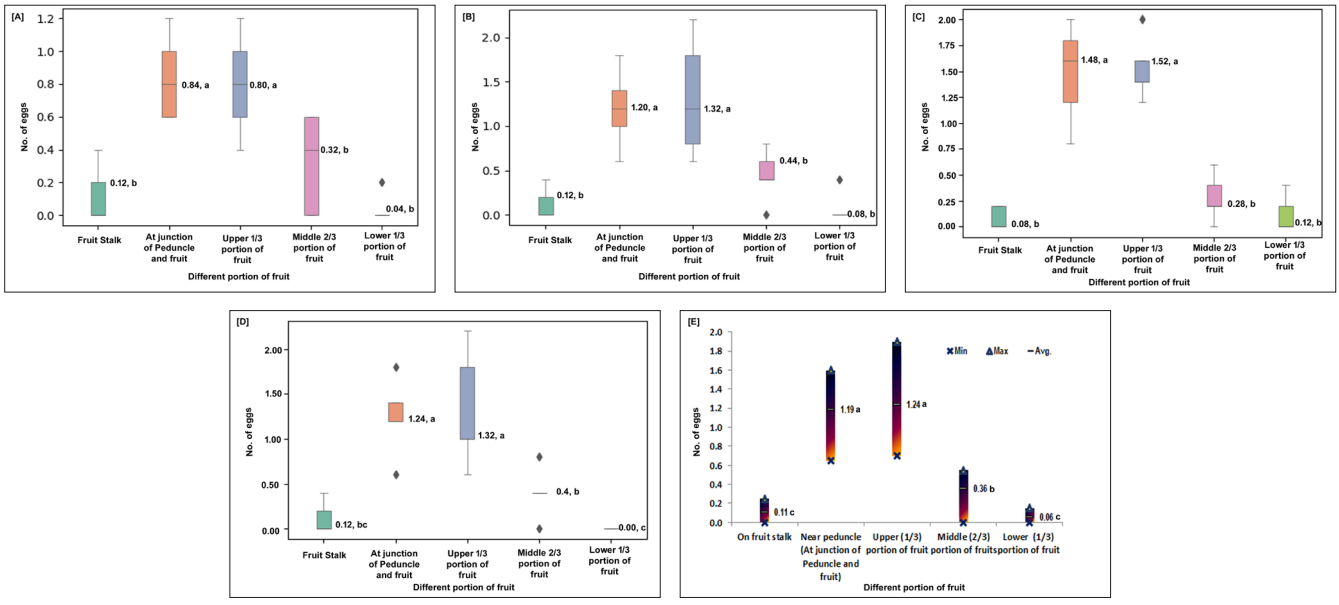

Fig. 2. Population dynamics of *C. eutraphera* based on mean number of eggs laid on different parts of fruit **[A]-** at pea stage, **[B]-** at marble stage, **[C]-** at lime stone stage, **[D]-** at mature stage, [**E**] Pooled of all stages. Values are mean of replicates +S.E. Bars followed by same letters are not significantly different at P= 0.01 Duncan's Multiple Range test. Stage (S) x Treatment (T) is non-significant.

Pooled results of all the stages depicted in Fig.3E showed that significantly highest fecundity was on upper portion (1.24) which statistically at par with eggs laid at junction of peduncle and fruit (1.19) followed by middle portion (0.36), on fruit stalk (0.11) and lower (1/3) portion of fruit (0.06). By considering the overall egg laying behaviour of female adults of *C. eutraphera*, it is evident that upper (1/3) portion of fruit and junction of peduncle and fruit are the most preferred sites for oviposition. The least preferred sites were lower (1/3) portion of the fruit and on the stalk or peduncle. Additionally, it was also observed that, concave portion of dried sepals which remain attached with fruit stalk is the most preferred site (Fig. 5d) by female adult of *C. eutraphera* (Fig. 5r) for egg laying on upper portion of fruit.

Several studies have focused on infestation level, damaging potential of *C. eutraphera*, but most of them have focussed on population dynamics in terms of ovipositional studies, so present results on this aspect were discussed based on other fruit borer species in different crops. According to Murugan and Thirumurugan (2001) and Karuppuchamy *et al*. (1998), some of chemical cues present in young fruits might have induce the lepidopterans to fecundity more. Patil (2022) revealed that leaves and flowers were rarely preferred site for oviposition by pomegranate fruit borer, *Deudorix isocrates* Fab. and mostly the fruits of varying stages were preferred to oviposit. These findings are in accordance with the present results. But, the calyx end of fruit is the highly preferred site of egg laying than other parts like lower half, stalk base, upper half and middle region of the fruit. The similar ovipositional behaviour of female *D. isocrates* has been reported earlier in pomegranate (Shevale and Khaire, 1999), however are not in line with the present results. This might be due to different fruit structure of pomegranate and mango fruits. Sajad Mohi-ud-din *et al.* (2018) studied the ovipositonal preference of females of Anar butterflies (*D. epijarbas*) under laboratory condition and revealed that adult female laid eggs on flowers, fruits and also on stalk and leaves within the vicinity of fruiting parts. Other plant parts *viz*., flower buds, fully opened flowers, leaves, stalk and fruit let stage were least preferred by *D. epijarbas* adults for oviposition. Recently, Chaudhary and Chavan (2025) studied biology and morphometrics of *C. eutraphera* and revealed that adult females laid an average of 41.15 ± 7.22 white coloured eggs on upper 1/3 portion of fruit *viz*., junction of peduncle and fruit which turned red after 1-2 days.

Population dynamics studies based on the number of larvae per fruit revealed that, during the pea stage, infestation ranged from one to three larvae per fruit, with an average of 1.7 larvae per fruit (Fig.3A). Thereafter, mean larval population were increased up to the lime stone size and further declined at mature stage. This may be due to hardening of mango seed kernel at mature stage as soft seed kernel is the preferred by the larvae. At marble stage 1 to 7 larvae per fruit were observed with an average of 3.2 larvae per fruit. Likewise, at lime stone stage 1 to 8 larvae (avg. 4.0) and at mature stage 1 o 7 larvae (avg. 2.8) were observed. Results also illustrated that significantly highest larvae per fruit (4.0) were observed at lime stone stage followed by marble stage (3.2) and mature stage (2.8) when single fruit was infested by *C. eutraphera* (Fig.3A).

The similar trend was noted when adjacent paired fruits were infested. The results depicted in Fig.3B revealed that at pea stage, 1 to 4 larvae per fruit (avg. 2.6) were observed. Thereafter, mean larval population was found to increase up to the mature stage. At marble stage, 1 to 6 larvae per fruit (avg. 3.6) was observed. Likewise, at lime stone and mature stage maximum 9 (avg. 4.7) and 6 (avg. 3.4) larvae per fruit were observed, respectively. Moreover, results also showed that significantly highest larvae per fruit (4.7) was observed at lime stone stage followed by marble stage (3.6) and mature stage (3.4) when adjacent paired fruits were infested by *C. eutraphera* (Fig.3B).

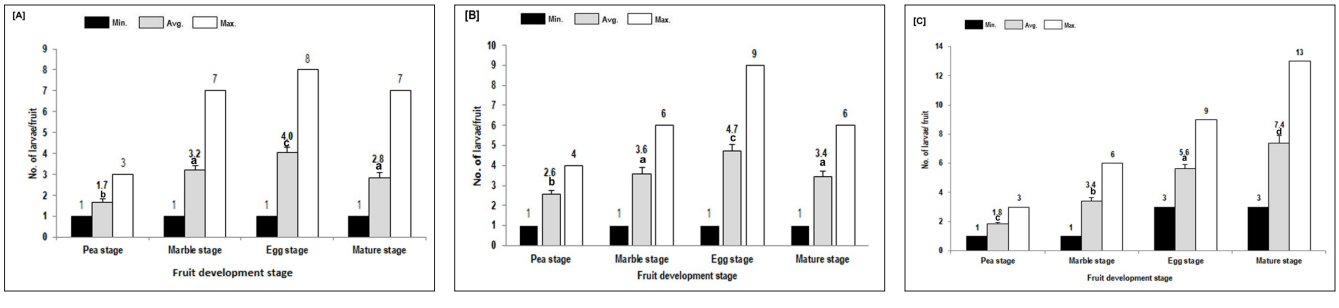

Fig. 3. Population dynamics of *C. eutraphera* based on **[A]** mean number of larvae per fruit when single fruit was infested **[B]** mean number of larva per fruit when adjacent couples of fruits were infested (each couple consider as single infestation) **[C]** mean number of larva per fruit when adjacent multiple fruits (more than two fruits wherein each cluster of multiple fruits considered as single infestation) were infested at different fruit development stages. Values are mean of replicates +S.E. Bars followed by same letters are not significantly different at P= 0.01 Duncan's Multiple Range test

At pea stage maximum 3 larvae per fruit (avg. 1.8) were observed when adjacent multiple (more than two) fruits were infested (Fig.3C). Thereafter, mean larval population was found increasing up to the mature stage. At marble stage, maximum 6 larvae per fruit (avg, 3.4) was observed. Likewise, at lime stone and mature stage maximum 9 (avg, 5.6) and 13 (avg. 7.4) larvae per fruit were observed, respectively. Significantly maximum larvae per fruit (7.4) were observed at mature stage followed by lime stone stage (5.6) and marble stage (3.4) when adjacent multiple fruits were infested by *C. eutraphera* (Fig. 3 C).

The present studies on population dynamics of *C. eutraphera* based on number of larvae per fruit is a new report. Thorough scanning of published literature revealed no published report on the population dynamics study of indigenous restricted fruit borer, *C. eutraphera* based on number of larvae per fruit at different fruit developmental stages.

Population dynamics of *C. eutraphera* based on per cent infestation:

The population dynamics of *C. eutraphera* based on per cent infested fruits on standing tree and dropped fruits under tree revealed that mango fruit borer infestation was found at all the growth and development stages of mango fruit during summer 2022 (Table 1). The infestation commenced from pea stage (11th SMW) and continued up to the harvesting (22nd SMW). In case of infestation on standing tree, the peak activity of *C. eutraphera* was observed during 16th to 18th SMW coincided with marble to lime stone stage, wherein damage percentage ranged between 10.72 and 12.16 per cent. Whereas, in case of infested dropped fruits under tree, maximum fruit drop due to infestation by *C. eutraphera* was observed during 18th to 22nd SMW which coincided with lime stone to mature stage and damage percentage ranged between 34.70 and 53.80 per cent. Significantly maximum fruit damage was observed in case of dropped fruits under tree as compared to damage on standing tree (Table 1) during all the observational period. The maximum fruit infestation of 12.16 per cent and 53.8 per cent was recorded during 17th and 19th SMW on standing tree and dropped fruits under tree, respectively.

The mango fruit borer, *C. eutraphera* has been recorded to cause infestation ranging from 2.46 to 64

Table 1: Population dynamics of *C. eutraphera* based on per cent infested fruits on standing tree and dropped fruits under tree

SMW	Development stage	Damaged fruits by *C. eutraphera* (%)		T - Statistic
		On standing tree	Dropped fruits under tree	
11	Pea	2.08	5.54	-4.537**
12	Pea	4.16	9.90	-4.537*
13	Pea	4.80	13.60	-5.788**
14	Marble	6.72	14.30	-10.488**
15	Marble	7.68	21.70	-8.839**
16	Marble	10.88	29.40	-4.129*
17	Lime stone	12.16	31.40	-4.253*
18	Lime stone	10.72	35.80	-7.211**
19	Lime stone	9.76	53.80	-7.506**
20	Mature	7.84	52.20	-4.938**
21	Mature	6.24	48.70	-17.41**
22	Mature	4.48	34.70	-8.022**
	Average	7.29	29.25	-4.991**

* Significant at 5 % level ** Significant at 1 % level, For individual week, 2.776 (T 0.05) and 4.604 (T 0.01), For average of 12 week, 2.201 (T 0.05), 3.106 (T 0.01)

per cent in Karnataka and Tamil Nadu (Jayanthi *et al.,* 2014; Soumya *et al.,* 2017). Bana *et al.* (2018) observed that *C. eutraphera* caused extensive damage of 5.00 to 45.00 per cent at farmer's field in South Gujarat during 16th to 25th SMW when fruits were at marble to maturity stages. The maximum infestation was observed in 18th SMW (19.04 & 14.42%) followed by 19th (18.46 & 12.88%) and 20th SMW (16.92 & 8.65%) during 2015 and 2016, respectively. The infestation range of 23.33 to 46.67 per cent caused by *C. eutraphera* was reported by Khan *et al.* (2020) in Bangladesh. Soumya *et al*. (2016) noted that there was no infestation of *C. eutraphera* at pea size fruits. The first infestation with low incidence commenced at marble size of fruit. At lime stage, infestation was increased. Thereafter at maturity stage, infestation decreased. Moreover, at full-grown stage and in harvested fruit, there was no infestation. Average 6.83 and 8.58 per cent infestation was observed during 2014 and 2015, respectively. Soumya *et al*. (2017) also reported incidence of *C. eutraphera* during flowering, wherein the infestation was mostly seen during April and May, when the fruits were at marble and lime size. Recently, Singh *et al*. (2021) reported that *C. eutraphera* is the emerging insect pest of mango in Punjab causing infestation level ranging from 2.50 to 10.80 per cent, starting from marble to maturity stage. They also showed the level of adaptation of this borer to varying climatic conditions. Hiremath *et al*. (2017) reported widespread infestation on mango fruits in the third week of September in Kerala. Though, the results of the present study are in agreement with most of the previous studies, while it is also not in agreement with few earlier reports, perhaps because of different fruiting season and climatic condition at various locations.

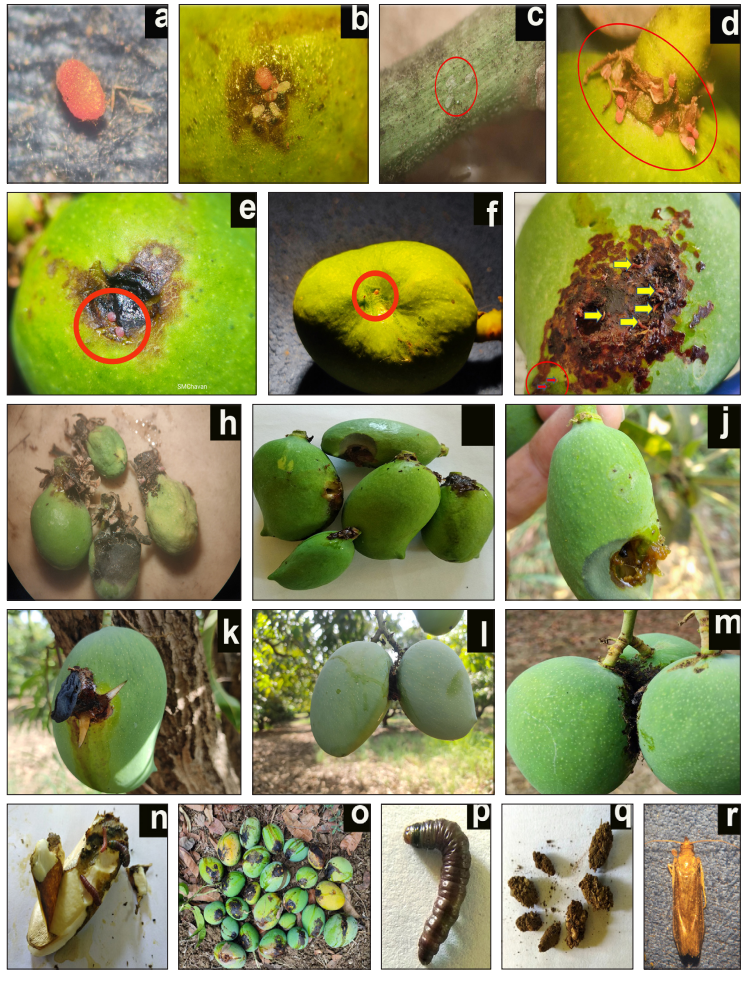

Fig. 4. Different life stages of *C. eutraphera* with Ovipositional and damage pattern a. Freshly laid egg (microscopic view), **b**. Eggs laid in groups on upper portion of fruits showing fresh (red) and hatched eggs (white), **c.** Eggs laid on stalk (hatched eggs-microscopic view), **d**. Eggs laid on upper portion of fruits (within dried sepals), **e.** Eggs laid on rough surfaces generated by larval damage on fruit skin, **f.** Eggs laid on middle portion of fruit, **g.** Eggs laid on lower surface of fruit, **h.** Damage at pea stage, **i.** Damage at marble stage, **j.** Damage at lime stone stage, **k.** Damage at mature stage with fruit cracking, **l.** Infestation at couple of fruit, **m.** Infestation at multiple (more than two) fruits, **n**. Damage on seed kernel, **o**. Damaged fruits dropped under tree, **p.** Mature larva, **q**. Earthen pupa, **r**. Adult in resting stage

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AUTHORS CONTRIBUTION

ANC- Designing and implementation of the experiments and MS preparation implementation of the experiments; SMC- planning, supervising and formal analysis and MS finalisation.

CONFLICT OF INTEREST

The authors do not have any conflict of interest with respect to the content of the article.

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Seasonal incidence of insect pests on Amaranthus and Palak in Malnad region of Karnataka

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ABSTRACT: An investigation was conducted during 2019–20 at the Zonal Agricultural and Horticultural Research Station, Shivamogga, to assess the seasonal incidence of major insect pests of amaranthus and palak and their association with weather parameters. Distinct seasonal trends were observed in pest population dynamics. Tobacco cutworm (*Spodoptera litura*) reached peak incidence during the second week of August in *Kharif* and showed positive correlation with rainfall and evening relative humidity, and negative correlation with sunshine hours and minimum temperature. Leaf miner (*Liriomyza* sp.) incidence was highest during the first week of October in *Kharif* and the fourth week of January in *Rabi*, with positive association with temperature and sunshine hours, and negative association with relative humidity and rainfall. Aphid (*Aphis craccivora*) population peaked during *Rabi* and was positively correlated with maximum temperature and sunshine hours but negatively correlated with rainfall and relative humidity. The findings highlight the strong influence of seasonal weather factors on pest-buildup and provide a basis for weather-based pest monitoring and timely management strategies.

Keywords: Amaranthus, Palak, insect pests, seasonal incidence

INTRODUCTION

Green leafy vegetables are cultivated as a minor crop throughout the year in many parts of the world due to their high nutritional value and short crop duration. In India, leafy vegetables are cultivated both in the plain and hilly regions of Himachal Pradesh, Gujarat, Punjab, Maharashtra, West Bengal, Haryana, Madhya Pradesh, Bihar, Delhi, Uttar Pradesh and Karnataka (Anand *et al*., 2020). The essential leafy vegetables are amaranthus and palak. Amaranthus is very popular due to its early maturity, high nutritional value and palatability. It is also an excellent source of starch, fibre, minerals and vitamins (Coelho *et al.,* 2018). Palak is also one of the important leafy vegetables of the tropical and subtropical regions. It is a rich and cheap source of vitamin A and other essential nutrients. Due to their high nutritional importance and frequent consumption, maintaining their productivity and quality is essential. Leafy vegetables are highly susceptible to several insect and non-insect pests *viz*., leaf webbers, tobacco cutworm, leaf miner, amaranthus bug, aphid, flea beetle, stem weevil, stink bug, grasshopper, thrips, mites, mealy bug and whitefly. These pests directly damage the edible foliage, reducing quality and market value. Since the leaf itself is consumed, even minor infestations can cause significant economic losses. Although pest problems in leafy vegetables have been reported in different regions, there is a lack of systematic and region-specific studies on the incidence, population dynamics and severity of major pests of amaranthus and palak in Karnataka. Pest occurrence and intensity are strongly influenced by local climatic conditions, cropping patterns and agro-ecological factors. Therefore, findings from other regions cannot be directly applied to Karnataka. This highlights the clear research gap: the absence of localised, scientifically documented information on the seasonal incidence and severity of major pests of amaranthus and palak under local conditions. Hence, there is a need to undertake local studies to generate region-specific data, identify peak pest periods and develop effective pest management strategies suitable for supporting sustainable production and minimizing unnecessary pesticide use.

MATERIALS AND METHODS

The studies were conducted during *Kharif* and *Rabi* seasons of 2019-20 at Zonal Agricultural and Horticultural Research Station (ZAHRS), Navile, Shivamogga, to determine the seasonal incidence of major insect and mite pests of amaranthus and palak *viz*., tobacco cutworm (*Spodoptera litura* Fabricius), leaf miner (*Liriomyza* sp.) and aphids (*Aphis craccivora* Walker). The experiment was carried out in an open field using a bulk plot measuring 5 m × 2 m. Seeds were broadcasted uniformly without spacing. For recording

pest incidence, ten plants were selected randomly and permanently tagged to ensure sampling consistency throughout the crop period. Observations were recorded at weekly intervals from the fourth week of July to the first week of October during *Kharif* and from the second week of November to the fourth week of January during *Rabi*. Aphid population was assessed by counting the number of aphids present on 5 cm apical shoot length, including young leaves, from each selected plant and the mean number of aphids per 5 cm shoot length was calculated. In the case of tobacco cutworm, the number of larvae present per plant was counted and expressed as mean larvae per plant. For leaf miner, the total number of leaves infested per plant was recorded and expressed as mean number of infested leaves per plant.

The obtained data were subjected to statistical analysis. Correlation analysis was performed to determine the relationship between pest population and weather parameters at p = 0.01 and p = 0.05 level of significance. The Multiple regression analysis was performed to assess the extent of influence of weather parameters. The weather parameters considered included total rainfall, maximum temperature, minimum temperature, morning relative humidity, evening relative humidity, sunshine hours and wind velocity. Meteorological data were obtained from the meteorological observatory of the College of Agriculture, Navile, Shivamogga. To avoid confounding effects, the experimental plot was selected in a uniform field with similar soil and cropping history. All recommended agronomic practices were uniformly followed except plant protection measures. No insecticides were applied during the crop period to allow natural pest infestation. Regular manual weeding was carried out to prevent weed-mediated pest influence. The experimental area was isolated from pesticide-treated fields to prevent spray drift.

RESULTS AND DISCUSSION

The incidence of insect pests in amaranthus and palak was significantly influenced by various weather parameters. The seasonal incidence of tobacco cutworm (*Spodoptera litura* Fabricius) differed between *Kharif* and *Rabi* seasons in both amaranthus and palak. During *Kharif*, larval population was first recorded in the fourth week of July (1.80 and 1.90 larvae/plant in amaranthus and palak, respectively) and reached a peak during the second week of August (3.20 and 3.10 larvae/plant), followed by a gradual decline toward the first week of October (1.20 and 1.20 larvae/plant). The mean population during *Kharif* was 2.15 ± 0.62 and 2.16 ± 0.55 larvae/plant in amaranthus and palak, respectively. In *Rabi*, infestation commenced during the second week of November (1.00 and 1.10 larvae/plant) and declined steadily to nil population by the third and fourth weeks of January, with seasonal means of 0.418 ± 0.334 and 0.45 ± 0.39 larvae/plant in amaranthus and palak, respectively (Table 1). The present findings are in line with Patel (2010) who reported that the incidence of *Spodoptera litura* on groundnut from 3rd week of July (0.50 larvae/plant) and attained its peak during the 3rd week of August (1.80 larvae/plant). The present findings are also in line with Shakya *et al*. (2015) who reported that the incidence of *S. litura* started from 5th January 2014 on tomato and reached its peak on 26th February.

Table 1: Population dynamics of insect pests in amaranthus and palak during *Kharif* and *Rabi* 2019-20

Season	Period of observation	Standard week	*No. cutworm larvae/ plant		*No. leaf miner larvae/ plant		*No. aphids/5 Cm shoot length
			Amaranthus	Palak	Amaranthus	Palak	Amaranthus
Kharif	July 4th week	30	1.80	1.90	0.10	0.00	3.26
	August 1st week	31	2.70	2.70	0.30	0.20	2.84
	August 2nd week	32	3.20	3.10	0.50	0.40	2.63
	August 3 rd week	33	2.80	2.60	0.90	0.90	3.86
	August 4th week	34	2.50	2.40	1.20	1.30	5.14
	August 5th week	35	2.40	2.40	1.80	1.70	4.86
	September 1st week	36	2.20	2.20	2.20	2.20	4.92

Kharif	September 2nd week	37	1.90	2.00	2.40	2.30	5.63
	September 3rd week	38	1.60	1.80	2.70	2.60	5.92
	September 4th week	39	1.40	1.50	2.90	2.80	5.36
	October 1st week	40	1.20	1.20	3.30	3.10	4.52
	Mean ± SD		2.15±0.62	2.16±0.55	1.66±1.12	1.59±1.099	4.44±1.13
Rabi	November 2nd week	45	1.00	1.10	1.20	1.10	18.34
	November 3rd week	46	0.80	0.90	1.60	1.40	22.83
	November 4th week	47	0.70	0.80	1.90	1.90	25.36
	December 1st week	48	0.60	0.70	1.70	1.50	19.24
	December 2nd week	49	0.50	0.70	1.60	1.20	22.86
	December 3rd week	50	0.40	0.40	1.90	1.70	25.63
	December 4th week	51	0.30	0.20	2.10	2.10	23.36
	January 1st week	52	0.20	0.10	2.00	2.00	24.82
	January 2nd week	1	0.10	0.10	2.30	2.20	25.68
	January 3rd week	2	0.00	0.00	2.70	2.50	26.14
	January 4th week	3	0.00	0.00	2.90	2.80	26.83
	Mean ± SD		0.418±0.334	0.45±0.39	1.99±20.49	1.85±0.53	23.73±2.78

*Mean of 10 plants

Correlation analysis during *Kharif* revealed significant positive association of cutworm population in amaranthus with rainfall (r = 0.630*) and evening relative humidity (r = 0.820*), and significant negative association with minimum temperature (r = –0.777**) and sunshine hours (r = –0.603*). Similar trends were observed in palak, where rainfall (r = 0.643*) and evening relative humidity (r = 0.806**) showed positive correlation, while maximum temperature (r = –0.803**) and sunshine hours (r = –0.616*) showed negative correlation (Table 2). These relationships indicate that humid conditions with reduced sunshine favoured larval buildup. The equation obtained when the data was subjected to multiple linear regression analysis with the coefficients of determination (R^2) of 0.710 and 0.713 during *Kharif* and 0.758 and 0.871 during *Rabi* in amaranthus (71% and 71.30%) and palak (75.80% and 87.10%), respectively indicating the extent of influence of weather parameters on population of cutworm (Table 2, Fig. 1). The results are in close agreement with the findings of Patel (2010) who correlated the incidence of *S. litura* with weather parameters and reported that *S. litura* exhibited a significant positive correlation with evening relative humidity and significant negative correlation with maximum temperature and sunshine hours on groundnut. This is also in close agreement with the results of Shakya *et al*. (2015) who reported that the population of *S. litura* was influenced by weather factors and revealed that there was a significant positive effect with maximum and minimum relative humidity and rainfall, whereas maximum temperature had a significant negative effect on tobacco cutworm population.

Leaf miner (*Liriomyza* sp.) incidence was observed from the fourth week of July (0.10 and 0.00 larvae/plant) and increased progressively to a peak during the first week of October (3.30 and 3.10 larvae/plant) in amaranthus and palak, respectively, with seasonal means of 1.66 ± 1.12 and 1.59 ± 1.09 larvae/plant during *Kharif*. During *Rabi*, infestation ranged from 1.20 and 1.10 larvae/plant in the second week of November to 2.90 and 2.80 larvae/plant in the fourth week of January, with seasonal means of 1.99 and 1.85 larvae/plant in amaranthus and palak, respectively (Table 1). The present findings are in line with Lakshminarayana (2016) who reported that the incidence of groundnut leaf miner was high in August sown crop as compared to June month on groundnut. The present findings are

Table 2: Correlation coefficient (r), Regression equation and Coefficient of determination (R^2) between insect pests and weather parameters in amaranthus and palak during *Kharif* and *Rabi* 2019-20

Insect pest	Correlation coefficient (r) (Amaranthus)												Amaranthus		
	Total Rainfall (mm) (X_1)		Temperature (°C)				Relative humidity (%)				Sunshine (hours/day) (X_6)		Season	Coefficient of determination (R^2)	Regression equation
			Maximum (X_2)		Minimum (X_3)		RH I (X_4)		RH II (X_5)						
	Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*			
Cut worm (No./ plant)	0.630*	0.448	0.520	-0.585	-0.777**	0.638*	0.586	-0.338	0.820*	0.491	-0.603*	-0.154	***Kharif***	0.710	$Y= 9.810 + 0.630X_1 + 0.520X_2 - 0.777X_3 + 0.586X_4 + 0.820X_5 - 0.603X_6$
													Rabi	0.758	$Y= -3.018 + 0.448X_1 - 0.585X_2 + 0.683X_3 - 0.338X_4 + 0,491X_5 - 0.154X_6$
Leaf miner (No./ plant)	-0.488	-0.443	0.027	0.694	0.775**	-0.721	-0.485	-0.029	-0.777*	-0.743	0.756**	0.334	***Kharif***	0.538	$Y= -45.022 - 0.488X_1 + 0.027X_2 + 0.775X_3 - 0.485X_4 - 0.777X_5 + 0.756X_6$
													Rabi	0.651	$Y= 7.944 - 0.443X_1 + 0.694X_2 - 0.721X_3 - 0.029X_4 - 0.743X_5 + 0.334X_6$
Aphids (No./ shoot)	-0.721*	-0.819	0.667	0.707	0.071	-0.705	-0456	-0.025	-0.696	-0.668	0.699	0.649	***Kharif***	0.845	$Y= -40.14 - 0.721X_1 + 0.667X_2 + 0.071X_3 - 0.456X_4 - 0.696X_5 + 0.699X_6$
													Rabi	0.721	$Y= 39.81 - 0.819X_1 + 0.707X_2 - 0.705X_3 - 0.025X_4 - 0.668X_5 + 0.649X_6$

Insect pest	Correlation coefficient (r) (Palak)												Palak		
	Total Rainfall (mm) (X_1)		Temperature (°C)				Relative humidity (%)				Sunshine (hours/day) (X_6)		Season	Coefficient of determination (R^2)	Regression equation
			Maximum (X_2)		Minimum (X_3)		RH I (X_4)		RH II (X_5)						
	Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*			
Cut worm (No./ plant)	0.643*	0.447	-0.803**	-0.640*	0.115	0.622*	0.568	-0.383	0.806**	0.490	-0.616*	-0.145	***Kharif***	0.713	$Y= 9.503 + 0.643X_1 - 0.803X_2 + 0.115X_3 + 0.568X_4 + 0.806X_5 - 0.616X_6$
													Rabi	0.871	$Y= -0.509 + 0.447X_1 - 0.640X_2 + 0.622X_3 - 0.383X_4 + 0.490X_5 - 0.145X_6$
Leaf miner (No./ plant)	-0.508	-0.433	0.770**	0.782	0.024	-0.692	-0.473	-0.022	-0.769**	-0.752	0.760**	0.349	***Kharif***	0.579	$Y= -45.93 - 0.508X_1 + 0.770X_2 + 0.024X_3 - 0.473X_4 - 0.769X_5 + 0.760X_6$
													Rabi	0.672	$Y= 8.302 - 0.433X_1 + 0.782X_2 - 0.692X_3 - 0.022X_4 - 0.752X_5 + 0.349X_6$

N=11; **Correlation is significant at the 0.01 level; Table r value at p=0.01 is 0.735, *Correlation is significant at the 0.05 level; Table r value at p=0.05 is 0.602, X_1= Rainfall, X_2= Maximum temperature, X_3=Minimum temperature, X_4= Morning relative humidity, X_5= Evening relative humidity, X_6= Sunshine hours

also in close agreement with Aswathanarayana and Ashok (2005) who conducted studies on the seasonal monitoring of leaf miner on tomato and reported the peak incidence of leaf miner (*Liriomyza trifolii*) during March and April with 4.90 and 4.40 mines per leaf, respectively. Correlation analysis showed that during *Kharif*, leaf miner population in amaranthus had significant positive correlation with minimum temperature (r = 0.775**) and sunshine hours (r = 0.756**), and significant negative correlation with evening relative humidity (r = –0.777*). In palak, maximum temperature (r = 0.770**) and sunshine hours (r = 0.760**) were positively correlated, while evening relative humidity (r = –0.769**) was negatively correlated (Table 2). These results suggest that relatively higher temperatures coupled with increased sunshine hours and comparatively lower relative humidity, favoured leaf miner activity and population buildup. The regression equation obtained showed moderate explanatory power with R^2 values ranging from 0.538 to 0.672, showing about 53.8 to 67.2 per cent of the variation in leaf miner population, with a moderate level of influence (Table 2, Fig. 1). These results are in line with the findings of Lakshminarayana (2016) who reported that the infestation of groundnut leaf miner was positively correlated with maximum temperature, minimum temperature and negatively correlated with morning relative humidity, evening relative humidity and rainfall. The results are also in close line with the findings of Aswathanarayana and Ashok (2005) who reported that the leaf miner population was significantly influenced negatively by rainfall and had a positive correlation with maximum temperature, while morning relative humidity and evening relative humidity showed a negative correlation with leaf miner.

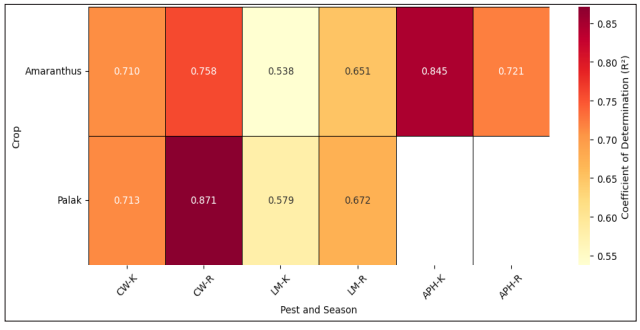

Fig. 1. Heat map of Coefficient of Determination (R^2) between insect pests and weather parameters (2019–20)

CW-K- Cutworm in *Kharif*, CW-R- Cutworm in *Rabi*, LM-K=Leaf miner in *Kharif,* LM-R=Leaf miner in *Rabi*, APH-K=Aphids in *Kharif,* APH-R=Aphids in *Rabi*

Aphid (*Aphis craccivora* Walker) population in amaranthus during *Kharif* ranged from 2.63 to 5.92 aphids per 5 cm shoot length, with peak incidence during the third week of September (5.92 aphids/5 cm shoot) and seasonal mean of 4.44 ± 1.13. During *Rabi*, aphid population increased markedly from 18.34 aphids per 5 cm shoot in the second week of November to a peak of 26.83 aphids per 5 cm shoot in the fourth week of January, with a seasonal mean of 23.73 ± 2.78 (Table 1). These results are in close line with Parul *et al*. (2018) who reported that the population of aphids reached its peak during September (17.2 aphids/5 cm shoot length) in soybean. The findings are also in close agreement with the results of Harshita *et al*. (2019) who reported that the aphid population reached its peak (9.1aphid/leaf) during the first fortnight of February on tomato. Correlation analysis revealed that during *Kharif*, aphid population in amaranthus showed significant negative correlation with rainfall (r = –0.721*) and positive association with maximum temperature (r = 0.667) and sunshine hours (r = 0.699). During *Rabi*, rainfall (r = –0.819) and minimum temperature (r = –0.705) exhibited negative association, while maximum temperature (r = 0.707) and sunshine hours (r = 0.649) showed positive association (Table 2). These findings indicate that reduced rainfall, moderate to higher maximum temperatures and increased sunshine hours, along with comparatively lower minimum temperature and relative humidity, favoured rapid multiplication and population buildup of aphids. The regression model for aphids showed a high coefficient of determination (R^2 = 0.845 during *Kharif* and 0.721 during *Rabi*), indicating strong dependence on weather variables (Table 2, Fig. 1). These results are in close line with Parul *et al*. (2018) who reported that the population of *Aphis gossypii* was influenced negatively by rainfall, morning relative humidity and had a positive correlation with maximum temperature during *Kharif* in soybean. The findings are also in close agreement with the results of Harshita *et al*. (2019) who reported that the aphids showed a positive correlation with maximum temperature and negative correlation with minimum temperature and average relative humidity on tomato.

Overall, the data demonstrate that tobacco cutworm incidence was favoured by higher rainfall and elevated evening relative humidity, whereas leaf miner infestation increased under conditions of higher temperature and greater sunshine hours. In contrast, aphid population buildup was associated with reduced rainfall and moderate temperature conditions. The peak infestation

of tobacco cutworm was recorded during August with a maximum population of 3.20 larvae per plant, while leaf miner incidence reached its maximum during October with 3.30 larvae per plant. Aphid population attained its peak during January with 26.83 aphids per 5 cm shoot length. The identification of these distinct peak periods provides a scientific basis for implementing timely and season-specific pest management strategies for amaranthus and palak under Shivamogga conditions.

CONCLUSION

The present investigation established clear seasonal patterns in the incidence of major insect pests of amaranthus and palak under Shivamogga conditions and demonstrated the significant influence of weather parameters on pest population dynamics. Distinct peak periods were identified for tobacco cutworm during early *Kharif*, leaf miner during later crop stages, and aphids during *Rabi*, confirming that pest occurrence is season-specific and weather-driven. These findings provide a scientific basis for developing weather-based pest forecasting and monitoring systems for leafy vegetables in Karnataka. Identification of peak infestation windows enables targeted field scouting and timely interventions before pest populations reach economic threshold levels. The strong association between pest incidence and specific meteorological factors highlights the scope for incorporating climatic indicators into decision-support tools for management scheduling. Adoption of season-specific and need-based pest management strategies based on these findings can reduce unnecessary pesticide applications, lower production costs, minimize residues on edible foliage and promote sustainable cultivation of amaranthus and palak under similar agro-climatic conditions.

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AUTHORS CONTRIBUTIONS

MBJ - Design of work, data collection, analysis, interpretation of results, and writing the original manuscript; JNH- Conceptualization, design of work, Review, supervision, and editing the draft; RK, GNB and NA - Review, supervision and editing the draft; DR - Assisted in writing and reviewing the manuscript. All authors read and approved the manuscript.

CONFLICT OF INTEREST

Authors have no conflict of interest to express.

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Evaluation of insecticide efficacy, safety and economics for managing chilli thrips, *Scirtothrips dorsalis* (Hood) (Thysanoptera: Thripidae)

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ABSTRACT: The present investigation was conducted during 2021 and 2022 at the Department of Entomology, Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan, to evaluate the bioefficacy of five insecticides against chilli thrips, *Scirtothrips dorsalis*, and their effects on coccinellid populations. The efficacy of the insecticides was assessed based on thrips incidence, abundance of coccinellids (immature and adult stages), and marketable fruit yield in treated and untreated (control) plots. The results revealed that cyantraniliprole 10.26% OD applied at 60 and 120 g a.i./ha provided the highest suppression of thrips, followed by imidacloprid 17.8% SL at 25 and 50 g a.i./ha. Moderate efficacy was recorded with spirotetramat 15.31% OD (60 and 120 g a.i./ha) and fenazaquin 10% EC (125 and 250 g a.i./ha), whereas flubendiamide 20% WG (50 and 100 g a.i./ha) was the least effective against *S. dorsalis*. The highest coccinellid populations were recorded in plots treated with flubendiamide and cyantraniliprole, while the lowest populations occurred in imidacloprid-treated plots, indicating its comparatively greater adverse effect on these beneficial insects. Cyantraniliprole applied at 60 and 120 g a.i./ha also produced the highest marketable yield during both cropping seasons. Overall, cyantraniliprole demonstrated superior efficacy against chilli thrips while exerting relatively lower adverse effects on coccinellids, making it a promising option for sustainable chilli pest management.

Keywords: Bioefficacy, chilli, phytoxicity, pesticides, natural enemies

INTRODUCTION

Chilli (*Capsicum annuum* L.), an important vegetable crop belonging to the family Solanaceae, is widely cultivated in tropical and subtropical regions owing to its wide adaptability (Kim *et al.,* 2020). Chilli fruits are rich in bioactive compounds, particularly capsaicin, which imparts pungency and possesses important pharmaceutical and medicinal properties (Chakrabarty *et al.,* 2017). In India, chilli is cultivated over an area of 471 thousand hectares, with an annual production of 5,754 thousand metric tons. In Himachal Pradesh, it is cultivated over approximately 1.27 thousand hectares, with an annual production of 14.18 thousand metric tons (MoA&FW, 2025). Its cultivation is adversely affected by several insect pests, *viz.,* aphids (*Aphis gossypii* (Glover) (Hemiptera: Aphididae), whitefly (*Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae), and fruit borers (*Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae), mites (*Polyphagotarsonemus latus* (Banks) (Acarina: Tarsonemidae). Among these, chilli thrips, *Scirtothrips dorsalis* (Hood) (Thysanoptera: Thripidae), is recognized as a major and highly destructive pest of chilli in India (Kumar *et al*., 2014; Moanaro and Choudhary, 2018).

Chilli thrips complex has been reported to cause yield losses ranging from 50% to 90% under favorable conditions (Sireesha *et al*., 2021). In addition to direct feeding injury, *S. dorsalis* acts as a vector of several plant viruses, including tomato spotted wilt virus and tobacco streak virus, as well as other plant pathogens, leading to severe crop losses (Rotenberg *et al*., 2015). Consequently, chemical pesticides remain the primary management strategy for controlling *S. dorsalis* and reducing yield losses; however, their indiscriminate and excessive use has led to environmental contamination and health concerns. Continuous and repeated exposure to organophosphate and carbamate insecticides has resulted in the development of resistance in *S. dorsalis* populations, with LC_{50} values significantly higher than those in susceptible populations (Kaur *et al.*, 2023; Kim *et al.,* 2025). This resistance is further intensified by the pest's biological characteristics, including its small size, high reproductive potential, cryptic feeding habit, and continuous availability of host plants throughout the year, all of which contribute to its persistence and management difficulty.

In this context, several insecticides such as Cyantraniliprole 10.26% OD, Spirotetramat 15.31% OD,

and Imidacloprid 17.81% SL have been recommended by the Central Insecticide Board and Registration Committee (CIBRC) for the management of chilli thrips. Their bioefficacy has also been reported under different agro-climatic conditions by various researchers (Layek *et al*., 2024; Poornima *et al*., 2023; Lokare *et al*., 2025). However, in Himachal Pradesh, limited information is available on the comparative bioefficacy of these insecticides against *S. dorsalis* under field conditions, particularly with respect to their impact on beneficial arthropods such as coccinellid predators.

Therefore, there is a need to generate location-specific information on the effectiveness and safety of these insecticides under mid-hill chilli ecosystems to support their inclusion in Integrated Pest Management (IPM) programmes. Accordingly, the present study was undertaken to evaluate the bioefficacy of selected insecticides against chilli thrips and their safety to natural enemies under mid-hill conditions of Himachal Pradesh.

MATERIAL AND METHODS

Bioefficacy of various insecticides against chilli thrips (*S. dorsalis*) during the kharif season of two consecutive years, 2021 and 2022, on the DKC-8 variety was carried out at Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Solan, H.P. The study area was situated at 30°51'23″ N latitude and 77°107″ E longitude at an altitude of 1300 m, with soil ranging from loamy to clay texture and a pH of 6.85 to 7.24, indicating slightly acidic to neutral conditions. The climatic conditions vary between 17.70 to 31.50°C, with an annual rainfall of approximately 1156.19 mm. The study consisted of fifteen treatments, each replicated thrice, pesticide applications administered at a 10-day interval. Control plots were maintained with water spray using a knapsack sprayer equipped with a hollow cone nozzle. The experiment was laid out in a randomized block design (RBD) with three replications. The pesticides and their dosages used in the experiment were as follows: T_0 - Untreated control, T_1 - Cyantraniliprole (10.26% OD) (@ 45 g a.i./ha), T_2 - Cyantraniliprole (10.26% OD) (@ 60 g a.i./ha), T_3 - Cyantraniliprole (10.26% OD) (@ 120 g a.i./ha), T_4 - Imidacloprid (17.8% SL) (@ 19 g a.i./ha), T_5 - Imidacloprid (17.8% SL) (@ 25 g a.i./ha), T_6 - Imidacloprid (17.8% SL) (@ 50 g a.i./ha), T_7 - Spirotetramat (15.31% OD) (@ 45 g a.i./ha), T_8 - Spirotetramat (15.31% OD) (@ 60 g a.i./ha), T_9 - Spirotetramat (15.31% OD) (@ 120 g a.i./ha), T_{10} - Flubendiamide (20% WG) (@ 38 g a.i./ha), T_{11} - Flubendiamide (20% WG) (@ 50 g a.i./ha), T_{12} - Flubendiamide (20% WG) (@ 100 g a.i./ha), T_{13} - Fenazaquin (10% EC) (@ 94 g a.i./ha), T_{14} - Fenazaquin (10% EC) (@ 125 g a.i./ha), T_{15} - Fenazaquin (10% EC) (@ 250 g a.i./ha). Observations were made on five randomly selected chilli plants from each plot. Chilli plants were tapped gently over a white sheet of paper to dislodge thrips, after which the numbers of adults and nymphs were counted. The population of coccinellids (grubs and adults) of *Coccinella septempunctata* (Linnaeus) was recorded from five randomly selected plants in each replication and compared with that in the untreated control plots. Observations on thrips and coccinellid populations were recorded one day before insecticide application and subsequently at 1, 3, 5, 7, and 10 days after spraying. The data were subjected to arc sine and square root transformation, and the transformed data were analysed using analysis of variance (ANOVA) following the procedure of Gomez and Gomez (1984). The per cent reduction in thrips population in insecticide-treated plots over the untreated control was calculated using the Henderson and Tilton formula (Equation 1) (Henderson and Tilton, 1955).

$$\text{Per cent reduction in population} = 100\left(1 - \frac{Ta}{Tb} \times \frac{Cb}{Ca}\right) \quad (1)$$

Where, T_a = Number of insects after treatment

T_b = Number of insects before treatment

C_a = Number of insects in untreated control after treatment

C_b = Number of insects in untreated control before treatment.

Benefit cost ratio

The cost benefit ratio of different treatments was calculated to assess their economic feasibility. The total cost of cultivation included fixed costs (common to all treatments) and variable costs such as insecticide cost and labour charges for spraying. Insecticide cost was calculated based on the dose and prevailing market price. Fruit yield per hectare (q/ha) was computed from plot yield and used to estimate gross income by multiplying with the market price (Rs./q). Net income was obtained by subtracting the total cost of cultivation from the gross income. The benefit cost ratio was calculated for all treatments, including the untreated control, to compare their profitability.

Benefit cost ratio was calculated by using formula (Equation 2):

$$BCR = \frac{\text{Net income}}{\text{Total cost of cultivation}} \quad (2)$$

RESULT AND DISCUSSION

Bioefficiency studies

Pre-treatment observations conducted one day prior to spray application indicated that the population of thrips (*Scirtothrips dorsalis*) ranged from 5.01 to 6.41 individuals per plant. Post-treatment assessments at 1, 3, 5, 7, and 10 days after each spray revealed that all insecticidal treatments significantly reduced thrips population compared to the untreated control.

Among the treatments, Cyantraniliprole at 120 g a.i./ha recorded the highest suppression of thrips population, achieving 81.90% and 84.23% reduction after the first and second sprays, respectively, followed by its lower dose at 60 g a.i./ha (77.15% and 82.12%). Moderate efficacy was observed with Imidacloprid (19, 25, and 50 g a.i./ha), Spirotetramat (45, 60, and 120 g a.i./ha), and Fenazaquin (94, 125, and 250 g a.i./ha), with percent reductions ranging from 52.09% to 75.91% and 53.85% to 78.01% after the first and second sprays, respectively. In contrast, Flubendiamide treatments exhibited the lowest efficacy, with population reduction remaining below 41%. A similar trend was observed during the second season, wherein pre-treatment thrips population ranged from 5.40 to 6.67 individuals per plant. Cyantraniliprole at 120 and 60 g a.i./ha again recorded the highest suppression, with reductions of 83.89% and 81.89% after the first spray, and 86.65% and 83.43% after the second spray, respectively. Intermediate levels of control were recorded with Imidacloprid, Spirotetramat, and Fenazaquin, with reductions ranging from 55.86% to 78.12% and 58.28% to 79.43% following the first and second sprays, respectively. Flubendiamide remained the least effective treatment, with population reduction below 47% (Table 1).

The present findings are in agreement with those reported by Sahani and Mondal (2020) and Layek *et al*. (2024), who demonstrated that application of Cyantraniliprole 10.26% OD at higher doses provided effective control of thrips in chilli. Similar results have been reported in other crops, where Cyantraniliprole exhibited high efficacy against thrips in cotton (Karthik *et al*., 2017; Patel *et al*., 2014). Although Imidacloprid (@ 50 g a.i./ha) has been reported to provide effective control of thrips (Priyadarshini *et al*., 2019), in the present study it was comparatively less effective than Cyantraniliprole, ranking as the second-best treatment. In contrast, Flubendiamide recorded the lowest reduction in thrips population, which is consistent with the findings of Vanisree *et al*. (2017), who reported 42.12% reduction in thrips population 14 days after application of Flubendiamide at 0.012% concentration in chilli.

Effective on natural enemies

The effect of different insecticides on coccinellid population during 2021 is presented in Table 2. Pre-treatment observations (0.80-1.13 beetles per five plants) indicated no significant differences among treatments, suggesting uniform distribution of coccinellids across the experimental plots. Following insecticidal applications, a significant reduction in coccinellid population was observed across all treatments, with a more pronounced decline after the second spray compared to the first spray. The untreated control maintained the highest population (1.20 and 1.31 coccinellids per five plants after first and second spray, respectively), whereas insecticide-treated plots showed varying levels of suppression. Among the treatments, Imidacloprid applied at 19, 25, and 50 g a.i./ha recorded the lowest coccinellid population, with mean values ranging from 0.30 to 0.43 and 0.23 to 0.29 coccinellids per five plants after the first and second sprays, respectively, indicating higher toxicity, followed by Fenazaquin (0.36–0.46 and 0.35–0.39 coccinellids per five plants at 94, 125, and 250 g a.i./ha). Spirotetramat (45, 60, and 120 g a.i./ha) exhibited moderate toxicity, recording values of 0.48–0.67 and 0.49–0.59 coccinellids per five plants after first and second sprays, respectively. In contrast, Cyantraniliprole (45, 60, and 120 g a.i./ha) and Flubendiamide (38, 50, and 100 g a.i./ha) maintained relatively higher populations, with values ranging from 0.53–0.69 and 0.51–0.59 and 0.55–0.80 and 0.57–0.65 after first and second sprays, respectively, indicating their comparatively safer effect on coccinellids. Similar trends were observed during 2022, and the data are presented in Table 2. Pre-treatment population of coccinellids ranged from 0.33 to 0.80 beetles per five plants, with no significant differences among treatments. Post-treatment observations revealed a significant decline in coccinellid population across all treatments. Imidacloprid (19, 25, and 50 g a.i./ha) recorded the lowest population (0.29–0.42 and 0.22–0.31 coccinellids per five plants after first and second sprays, respectively), followed by Fenazaquin (0.35–0.42 and 0.25–0.38). Spirotetramat showed moderate effects, whereas Cyantraniliprole and Flubendamide maintained comparatively higher populations across both sprays, indicating their relative safety to natural enemies.

These findings were in agreement with the studies conducted by Sudhanan *et al.* (2017) who reported that

Table 1: Effect of different pesticides on chilli thrips (*Scirtothrips dorsalis*) during 2021 and 2022

Insecticide	Dosage (a.i. g/ ha)	2021			2022		
		Pre count (Mean No. of thrips/ plant) *	Per cent reduction/control		Pre count (Mean No. of thrips/ plant) *	Per cent reduction/control	
			Mean (1st spray)#	Mean (2nd Spray)#		Mean (1st Spray)#	Mean (2nd Spray)#
Untreated control	-	5.03 (2.45)	-	-	6.30(2.7)	-	-
Cyantraniliprole (10.26 %OD) (x)	45	5.01 (2.45)	63.38 (52.78) f,g	72.57 (58.61) c	6.67 (2.77)	67.69 (55.40) d,e	72.95 (58.76)d
Cyantraniliprole (10.26 %OD) (X)	60	5.19 (2.49)	77.15 (61.53) b	82.12 (65.28) a	5.62 (2.57)	81.89 (65.14) b	83.43 (66.49)b
Cyantraniliprole (10.26 %OD) (2X)	120	5.42 (2.53)	81.90 (64.93) a	84.23(66.95) a	5.93 (2.63)	83.89 (66.61) a	86.65 (69.20)a
Imidacloprid (17.8 % SL) (x)	19	5.22 (2.49)	60.05 (50.81) h	65.02 (53.79) f	6.31 (2.70)	65.01 (53.76) g	68.80 (56.06)e
Imidacloprid (17.8 % SL) (X)	25	6.02 (2.65)	73.14 (58.80)c	74.74 (60.12) c	5.57 (2.56)	76.29 (60.94) c	77.75 (61.94)c
Imidacloprid (17.8 % SL) (2X)	50	6.41 (2.72)	75.91 (60.66) b	78.01 (62.53) b	5.87 (2.62)	78.12 (62.18) c	79.43 (63.25)c
Spirotetramat (15.31 % OD) (x)	45	6.21 (2.68)	54.67 (47.68) i	56.07 (48.49) g	6.30 (2.70)	59.05 (50.23) h	61.64 (51.81)f
Spirotetramat (15.31 % OD) (X)	60	5.68 (2.58)	64.36 (53.37) e	67.64 (55.39) d,e,f	6.67 (2.77)	65.13 (53.90) f,g	69.72 (56.77)e
Spirotetramat (15.31 % OD) (2X)	120	6.25 (2.69)	68.54 (55.94)d	69.93 (56.80) d	6.41 (2.72)	68.25 (55.82) d	7 4.89 (60.04)d
Flubendiamide (20 % WG) (x)	38	5.32 (2.51)	31.94 (34.36)k	34.54 (35.94) j	5.70 (2.59)	34.83 (36.10) k	36.77 (37.24)i
Flubendiamide (20 % WG) (X)	50	5.23 (2.49)	32.35 (34.59) k	37.55 (37.75)i	5.96 (2.64)	36.81 (37.21) k	44.41 (41.75)h
Flubendiamide (20 % WG) (2X)	100	5.20 (2.49)	37.07 (37.44) j	41.49 (40.05) h	5.93 (2.63)	41.94 (40.33) j	47.00 (43.24)h
Fenazaquin (10 % EC) (x)	94	5.93 (2.63)	52.09 (46.18) i	53.85 (47.20) g	5.93 (2.63)	55.86 (48.37) i	58.28 (49.79)g
Fenazaquin (10 % EC) (X)	125	5.61 (2.57)	60.42 (51.07) g, h	65.20 (53.89) e,f	5.40 (2.53)	60.87 (51.34) h	64.42 (53.44)f
Fenazaquin (10 % EC) (2X)	250	5.47 (2.54)	66.11 (54.41)d,e,f	68.12 (55.70) d	6.13 (2.67)	65.78 (54.30) e,f,g	68.60 (56.05)e
$CD_{at\ 5\%}$	-	**NS**	**1.70**	**1.74**	**NS**	**1.33**	**1.68**

#Figure in parentheses is arc sine transformed values; *Figure in parentheses is square root transformed values; x= less than the recommended dose, X= recommended dose, 2X= double the recommended dose

Table 2: Effect of different pesticides on coccinellid population during 2021 and 2022

Insecticide	Dosage (a.i. g/ ha)	2021			2022		
		Pre count (Mean No. of coccinellid/ plant)	No. of coccinellids per plants		Pre count (Mean No. of coccinellid/ plant)	No. of coccinellids per five plants	
			Mean (1st spray)	Mean (2nd Spray)		Mean (1st Spray)	Mean (2nd Spray)
Untreated control	-	1.07 (1.44)	1.20 (1.51)[a]	1.31 (1.52)[a]	0.73 (1.31)	0.85 (1.36)[a]	0.93 (1.39)[a]
Cyantraniliprole (10.26 %OD) (x)	45	1.00 (1.41)	0.69 (1.30)[b]	0.59 (1.26)[b]	0.67 (1.29)	0.57 (1.25)[b]	0.55 (1.24)[b]
Cyantraniliprole (10.26 %OD) (X)	60	0.80 (1.34)	0.60 (1.26)[c]	0.57 (1.25)[b]	0.80 (1.34)	0.48 (1.21)[c]	0.47 (1.21)[b]
Cyantraniliprole (10.26 %OD) (2X)	120	1.13 (1.46)	0.53 (1.24)[c]	0.51 (1.23)[b]	0.60 (1.26)	0.48 (1.22)[c]	0.41 (1.19)[b]
Imidacloprid (17.8 % SL) (x)	19	1.07 (1.44)	0.43 (1.19)[d]	0.29 (1.13)[d]	0.53 (1.24)	0.42 (1.16)[d]	0.31 (1.14)[c]
Imidacloprid (17.8 % SL) (X)	25	0.93 (1.39)	0.36 (1.16)[d]	0.23 (1.11)[d]	0.60 (1.26)	0.31 (1.14)[d]	0.30 (1.13)[c]
Imidacloprid (17.8 % SL) (2X)	50	0.80 (1.34)	0.30 (1.14)[d]	0.23 (1.11)[d]	0.47 (1.21)	0.29 (1.14)[d]	0.22 (1.11)[d]
Spirotetramat (15.31 % OD) (x)	45	1.13 (1.46)	0.67 (1.28)[b]	0.59 (1.26)[b]	0.67 (1.29)	0.57 (1.23)[c]	0.53 (1.24)[b]
Spirotetramat (15.31 % OD) (X)	60	1.07 (1.44)	0.56 (1.24)[c]	0.53 (1.24)[b]	0.53 (1.24)	0.43 (1.21)[c]	0.44 (1.20)[b]
Spirotetramat (15.31 % OD) (2X)	120	1.13 (1.46)	0.48 (1.21)[c]	0.49 (1.22)[c]	0.73 (1.31)	0.43 (1.19)[c]	0.41 (1.19)[b]
Flubendiamide (20 % WG) (x)	38	1.00 (1.41)	0.80 (1.34)[b]	0.65 (1.28)[b]	0.67 (1.29)	0.65 (1.28)[b]	0.57 (1.25)[b]
Flubendiamide (20 % WG) (X)	50	0.93 (1.39)	0.69 (1.30)[b]	0.59 (1.26)[b]	0.73 (1.31)	0.63 (1.27)[b]	0.50 (1.22)[b]
Flubendiamide (20 % WG) (2X)	100	0.80 (1.34)	0.55 (1.24)[c]	0.57 (1.25)[b]	0.47 (1.21)	0.51 (1.23)[c]	0.43 (1.20)[b]
Fenazaquin (10 % EC) (x)	94	1.00 (1.41)	0.46 (1.21)[c]	0.39 (1.18)[c]	0.33 (1.15)	0.42 (1.20)[c]	0.38 (1.17)[c]
Fenazaquin (10 % EC) (X)	125	0.80 (1.34)	0.37 (1.17)[d]	0.37 (1.17)[c]	0.60 (1.26)	0.39 (1.19)[c]	0.32 (1.14)[c]
Fenazaquin (10 % EC) (2X)	250	0.80 (1.34)	0.36 (1.18)[d]	0.35 (1.16)[d]	0.67 (1.29)	0.35 (1.16)[d]	0.25 (1.12)[d]
CD (5%)		**NS**	**0.06**	**0.05**	**NS**	**0.05**	**0.06**

Figure in parentheses is square root transformed values; x= less than the recommended dose, X= recommended dose, 2X= double the recommended dose

Table 3: Economics of insecticidal treatments used against chilli thrips (*Scirtothrips dorsalis*) during 2021 and 2022

Insecticide	Dosage (g a.i./ha)	2021			2022		
		Yield (q/ha)	Net Income (Rs in INR)	B:C	Yield (q/ha)	Net Income (Rs in INR)	B:C
Untreated control		115.60	273654.95	2.09	122.60	298154.95	2.28
Cyantraniliprole (10.26 %OD) (x)	45	144.20	363620.95	2.58	151.00	387420.95	2.75
Cyantraniliprole (10.26 %OD) (X)	60	164.40	430942.95	2.98	169.60	449142.95	3.11
Cyantraniliprole (10.26 %OD) (2X)	120	170.80	439830.95	2.78	175.00	454530.95	2.88
Imidacloprid (17.8 % SL) (x)	19	124.20	303002.95	2.30	131.20	327502.95	2.49
Imidacloprid (17.8 % SL) (X)	25	135.40	341954.95	2.59	139.80	357354.95	2.71
Imidacloprid (17.8 % SL) (2X)	50	139.60	355654.95	2.68	144.20	371754.95	2.80
Spirotetramat (15.31 % OD) (x)	45	126.60	309544.95	2.32	131.40	326344.95	2.44
Spirotetramat (15.31 % OD) (X)	60	137.60	347174.95	2.58	142.40	363974.95	2.71
Spirotetramat (15.31 % OD) (2X)	120	142.60	361194.95	2.62	147.00	376594.95	2.73
Flubendiamide (20 % WG) (x)	38	124.40	301341.67	2.25	129.20	318141.67	2.37
Flubendiamide (20 % WG) (X)	50	135.40	338814.95	2.51	138.20	348614.95	2.58
Flubendiamide (20 % WG) (2X)	100	138.20	344474.95	2.47	152.00	392774.95	2.82
Fenazaquin (10 % EC) (x)	94	143.20	364088.55	2.66	135.40	336788.55	2.46
Fenazaquin (10 % EC) (X)	125	151.00	389354.95	2.80	144.20	365554.95	2.63
Fenazaquin (10 % EC) (2X)	250	158.80	408454.95	2.77	148.60	372754.95	2.53

'x' is the dose less than the recommended dose and 'X' is the standard dose and 2X is the double the standard dose

after the untreated control (5.7/ten plants), the highest population of coccinellids was found in lower dose of Flubendiamide 20 WG (40 g a.i./ha) of 4.3/ten plants in sugarcane. Another study conducted by Narayan *et al.* (2019) also revealed that plots treated with Cyantraniliprole 10 % OD (0.0143 %) (1.34/plant) and Flubendiamide 39.36 % SC (0.0098 %) (1.08 beetles/plant) were less toxic to the coccinellid population. Also the field trials conducted by Kar (2017) showed the maximum reduction of coccinellid population when Imidacloprid 17.8 % SL @ 175 ml/ha (0 and 0.33 beetles/plant) was applied which is somehow in tune with the present study.

Benefit cost ratio

All pesticide treatments resulted in significantly higher marketable yields (124.20–170.80 q/ha and 129.20–175.00 q/ha) than the untreated control (115.60 and 122.60 q/ha) during the first and second seasons, respectively. Based on the yield data, the cost ratio of each treatment was calculated. The highest cost ratio (2.98:1 and 3.11:1) was recorded in plots treated with Cyantraniliprole at 60 g a.i./ha, whereas the untreated control recorded the lowest ratio (2.09:1 and 2.28:1) during 2021 and 2022, respectively (Table 3).

CONCLUSION

Based on two years of field evaluation, cyantraniliprole at 120 g a.i./ha was the most effective treatment for the management of chilli thrips, *S. dorsalis*, outperforming all other insecticides tested. Cyantraniliprole and Imidacloprid provided superior suppression of thrips, whereas Flubendiamide was the least effective. None of the insecticide treatments caused phytotoxic effects on chilli plants at the tested doses, indicating their safety for crop application. Among the insecticides evaluated, Flubendiamide was the safest to coccinellids, particularly at the lower dose, while Imidacloprid and

Fenazaquin had comparatively greater adverse effects on their populations. Although all insecticide treatments significantly increased chilli yield over the untreated control, Cyantraniliprole at 60 g a.i./ha recorded the highest cost:benefit ratio, making it the most economically viable treatment. Overall, Cyantraniliprole emerged as the most promising option for the sustainable management of chilli thrips by providing effective pest suppression, higher yield, economic returns, and relatively lower impact on beneficial coccinellids.

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AUTHOR CONTRIBUTIONS

Formal analysis, investigation, writing- original draft, writing- review & editing (S.B.); Conceptualization, supervision, methodology, review and editing (S.K.; S.S.).

CONFLICT OF INTEREST

Authors don't have conflict of interest to express

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Effect of bee attractants on activity of stingless bee, *Tetragonula* "nr." *pagdeni*, and its significance in pollination of coriander

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ABSTRACT: Coriander (*Coriandrum sativum* L.) is an important seed spice crop that depends largely on insect-mediated pollination for optimum seed production. A field experiment was conducted at Devihosur, Karnataka, to evaluate the efficacy of different bee attractants in enhancing pollination by stingless bees (*Tetragonula* "nr" *pagdeni*) and improving coriander productivity. Seven treatments comprising jaggery (15%), jaggery + lime juice (15%), enriched jaggery (15%), ocimum oil (0.1%), menthol oil (0.1%), ajwain oil (0.1%), and an untreated control were evaluated in a randomized design. Among the treatments, ocimum oil (0.1%) recorded the highest seed yield (14.46 q ha^{-1}), followed by jaggery (15%) (12.91 q ha^{-1}), both of which were significantly superior to the untreated control (9.15 q ha^{-1}). The higher seed yield obtained with ocimum oil was associated with increased stingless bee visitation, resulting in improved pollination efficiency. Enhanced pollination also positively influenced seed quality, with ocimum oil recording the highest seed germination (82.67%), seedling length (12.23 cm), seedling vigour index (1011), and seedling dry weight (0.013 mg) compared with the control. Although ocimum oil produced the maximum yield and superior seed quality, jaggery (15%) resulted in the highest benefit ratio owing to its low input cost. The findings demonstrate that bee attractants can effectively enhance stingless bee activity and coriander productivity, with ocimum oil being the most effective for maximizing yield and seed quality, while jaggery (15%) offers a simple, economical, and farmer-friendly option for profitable coriander seed production.

Keywords: Bee attractants, *Coriandrum sativum*, Enriched jaggery, Ocimum oil, Seed Yield

INTRODUCTION

India is the world's leading producer, consumer, and exporter of seed spices and is widely recognized as the "Home of Spices." Seed spices are economically important, export-oriented crops that contribute substantially to the country's agricultural economy. Among these, coriander (*Coriandrum sativum* L.), an annual herb belonging to the family Apiaceae (Umbelliferae), is one of the most important seed spice crops cultivated in India. It originated in the eastern Mediterranean region and southern Europe and was subsequently introduced into India (Gal *et al.,* 2010). The crop is predominantly cultivated during the rabi season and is valued for its aromatic seeds and fresh leaves, which are widely used in culinary, pharmaceutical, and traditional medicinal applications. Owing to its diverse uses and increasing global demand, coriander has emerged as an important domestic and export commodity (Mane, 2003).

Despite its economic importance, coriander productivity is often constrained by poor seed set resulting from inadequate pollination. Although the flowers are hermaphroditic, coriander is predominantly cross-pollinated because of its protandrous nature, wherein pollen dehiscence generally precedes stigma receptivity (Blade, 2008). Consequently, successful seed production depends largely on insect-mediated pollination, and the absence or low abundance of pollinators during the flowering period is considered one of the major factors limiting yield (Mane, 2003).

A diverse assemblage of insects, including honey bees (*Apis florea* Fabricius, *Apis cerana* Fabricius, and *Tetragonula "nr" pagdeni*), solitary bees, butterflies, and flies, visit coriander flowers for nectar and pollen. Among these, honey bees constitute the dominant pollinator group, accounting for nearly 80.3% of all floral visitors (Ricciardelli *et al.,* 1979). Their high foraging efficiency and abundance make them the principal

pollinators of coriander, contributing significantly to improved pollination, seed set, crop productivity, and overall agricultural sustainability.

The population of managed honey bee colonies in India has declined in recent decades owing to the incidence of pests and diseases, while natural pollinator populations have also been adversely affected by changes in land-use patterns, habitat degradation, and agricultural intensification (Delaplane and Mayer, 2000). The reduced availability of pollinators during the flowering period limits effective pollination and consequently affects seed yield in insect-pollinated crops such as coriander. Therefore, approaches that enhance pollinator visitation to crop flowers are of considerable practical importance.

Honey bees rely predominantly on olfactory cues for locating and selecting floral resources, making bee attractants a promising strategy for improving pollinator activity in crop fields (Doull, 1974; Seeley, 1999). Bee attractants are chemical cues that modify bee foraging behaviour and increase visitation to target crops, thereby enhancing pollination efficiency (Elli and Delaplane, 2009). Previous studies have demonstrated the effectiveness of bee attractants in coriander. Choudhary and Singh (2007) reported that spraying the commercial bee attractant Bee-Q increased pollinator visitation by 20.7%, with an average of 5.2 visitors min^{-1} compared with 4.3 visitors min^{-1} under open pollination. Likewise, Narendra (2014) observed that application of the bee attractant Cacambe (10%) significantly improved yield attributes and seed yield in coriander.

Although commercial bee attractants have shown promising results, their widespread adoption under Indian farming conditions is constrained by their high cost and dependence on synthetic compounds that mimic honey bee pheromones. In contrast, indigenous plant-based attractants are inexpensive, biodegradable, non-toxic, and environmentally friendly, making them well suited for sustainable and organic crop production. However, information on the efficacy of such plant-derived bee attractants for enhancing pollination and seed production in coriander is limited. Therefore, the present study was undertaken to evaluate indigenous plant-based bee attractants for enhancing stingless bee visitation, pollination efficiency, seed yield, and seed quality in coriander.

MATERIAL AND METHODS

The present study was carried out at Horticulture Research and Extension Center (HREC), Devihosur during Rabi season of 2018-19. It is situated in the northern transitional agro-climatic zone (Zone-VIII) of Karnataka with 75° 21' East longitude, 14°47' North latitude and at an altitude of 563 meters above mean sea level (MSL). The experiment was carried out using coriander variety DCC-46 (Devihosur Coriander Cultivar) also known as Varadevi-1. The crop was raised as per package of practice recommended by UHS, Bagalkot. The experiment was carried out in randomized complete block design (RCBD) involving seven treatments each replicated thrice (plot size of 4 m × 4 m area) (Fig.1). Between the treatments one meter distance was maintained as a buffer zone. The treatments included were *viz.*, T_1- jaggery (15%), T_2- jaggery + lime juice (15%), T_3- enriched jaggery (15%), T_4- Ocimum oil (0.1%), T_5- menthol oil (0.1%), T_6- ajwan oil (0.1%) and T_7- control. Three attractants namely jaggery at 15%, jaggery+lime at 15% (Dissolved equal concentrations of jaggery and lime juice (*i.e.* 7.5% + 7.5%) and enriched jaggery at 15% (Two vitamin tablets dissolved in one litre of water) were prepared and three plant based commercial bee attractants *viz.,* concentrated Ocimum oil, menthol oil, and ajwan oil were procured from the online market.

To evaluate the effect of bee attractants on the foraging activity of the stingless bee *Tetragonula* "nr" *pagdeni*, a single colony containing an optimum population of approximately 2,500–3,000 bees was placed at the centre of the experimental field when the crop reached 10% flowering. The colony was maintained in the field until the completion of the flowering period. The colony required for the study was purchased from commercial bee keeper from Brahmavara (Udupi). In each replicated plot (one square meter area), five plants were randomly tagged to record observations (Bee visitation as well as quantitative and qualitative yield parameters). Later, attractants were sprayed two times, first at 10 per cent of flowering and second at 50 per cent of flowering stages. Observations on bee visitation were recorded from five tagged plants per plot on a day before the spray of bee attractants and one, three, five and seven days after each spray at 10:00 to 12:00 h and 15:00 to 17:00 h of the day. Further, the seed quantity parameters like number of umbels per plant, number of seeds per umbel and seed yield were recorded from the tagged plants and mean data was taken for statistical analysis. Similarly, seed quality parameters like Thousand seed weight (Test weight) (g), Per cent seed germination (%), Seedling length (cm), Seedling dry weight (mg), were recorded

after the harvest of umbels. The recorded observations were analyzed using WASP2 software and means were ranked by Duncan's Multiple Range Test (DMRT). Later the bee visitation was correlated with yield attributes of coriander crop and their relationship was determined.

RESULTS AND DISCUSSION

Stingless bee, *T. pagdeni* were found visiting flowers of coriander throughout the study period, but observations were recorded at 10 and 50% flowering. A day before the first spray of attractants, the stingless bee visitation was uniform in all the treatments and varied from 0.73 to 1.00 bee/plant/min and during second spray 0.87 to 1.00 bee/plant/min (Table 1). Following the first spray at 10% flowering, bee attractants significantly influenced the foraging activity of *T. pagdeni*. Among the treatments, ocimum oil (0.1%) recorded the highest overall mean bee visitation (2.49 bees plant^{-1} min^{-1}). This was followed by jaggery (15%), enriched jaggery (15%), and jaggery + lime juice (15%), which attracted 1.85, 1.76, and 1.68 bees plant^{-1} min^{-1}, respectively. Comparatively lower bee visitation was observed with ajwain oil (0.1%) and menthol oil (0.1%), recording 1.45 and 1.40 bees plant^{-1} min^{-1}, respectively. The untreated control recorded the lowest bee visitation (0.83 bee plant^{-1} min^{-1}), indicating that the application of bee attractants substantially enhanced stingless bee activity in coriander.

Following the second spray at 50% flowering, the mean bee visitation recorded over seven days differed significantly among the treatments. Ocimum oil (0.1%) attracted the highest number of stingless bees, recording a mean visitation of 2.44 bees plant^{-1} min^{-1}. The next most effective treatment was jaggery (15%), with a mean visitation of 1.87 bees plant^{-1} min^{-1}, followed by enriched jaggery (15%) and jaggery + lime juice (15%), which recorded 1.77 and 1.70 bees plant^{-1} min^{-1}, respectively. Lastly, untreated control plot recorded least number of bees *i.e.* 0.88 bees/plant/minute (Table 1). The present findings are in line with Abrol *et al*. (2017) who

Table 1: Influence of bee attractants on stingless bee, *Tetragonula "nr" pagdeni* visitation on coriander

Treatment	Number of bees visited / plant / min											
	First spray at 10 per cent flowering						Second spray at 50 per cent flowering					
	1 DBS	1 DAS	3 DAS	5 DAS	7 DAS	MEAN	1 DBS	1 DAS	3 DAS	5 DAS	7 DAS	MEAN
Jaggery 15%	0.87 (0.90)^{a}	2.20 (1.48)^{b}	2.87 (1.69)^{ab}	2.40 (1.54)^{b}	0.93 (0.97)^{a}	1.85 (1.36)^{b}	0.93 (0.97)^{a}	2.20 (1.48)^{b}	2.80 (1.66)^{b}	2.67 (1.62)^{ab}	0.87 (0.93)^{a}	1.87 (1.37)^{b}
Jaggery + lime juice 15 %	0.87 (0.92)^{a}	1.87 (1.33)^{bcd}	2.47 (1.56)^{b}	2.33 (1.52)^{b}	0.87 (0.93)^{a}	1.68 (1.29)^{bc}	1.00 (1.00)^{a}	2.13 (1.45)^{b}	2.40 (1.55)^{b}	2.20 (1.48)^{bc}	0.87 (0.92)^{a}	1.70 (1.31)^{bc}
Enriched jaggery 15%	0.80 (0.89)^{a}	2.07 (1.43)^{bc}	2.73 (1.65)^{ab}	2.40 (1.55)^{b}	0.80 (0.89)^{a}	1.76 (1.32)^{bc}	0.93 (0.96)^{a}	2.07 (1.48)^{b}	2.60 (1.60)^{b}	2.33 (1.53)^{abc}	0.93 (0.96)^{a}	1.77 (1.34)^{b}
Ocimum oil 0.1%	1.00 (0.97)^{a}	3.47 (1.86)^{a}	3.73 (1.93)^{a}	3.20 (1.79)^{a}	1.07 (1.03)^{a}	2.49 (1.58)^{a}	1.00 (0.99)^{a}	3.20 (1.79)^{a}	3.93 (1.98)^{a}	3.00 (1.71)^{a}	1.07 (1.01)^{a}	2.44 (1.55)^{a}
Menthol oil 0.1%	0.87 (0.93)^{a}	1.27 (1.13)^{de}	2.07 (1.43)^{b}	1.87 (1.36)^{b}	0.93 (0.97)^{a}	1.40 (1.19)^{c}	0.87 (0.93)^{a}	1.40 (1.18)^{c}	2.07 (1.43)^{b}	1.87 (1.36)^{c}	0.87 (0.93)^{a}	1.41 (1.19)^{d}
Ajwan oil 0.1%	0.73 (0.84)^{a}	1.40 (1.17)^{cde}	2.33 (1.52)^{b}	1.93 (1.38)^{b}	0.87 (0.93)^{a}	1.45 (1.19)^{c}	0.87 (0.93)^{a}	1.67 (1.28)^{bc}	2.13 (1.45)^{b}	1.93 (1.38)^{c}	0.80 (0.89)^{a}	1.48 (1.21)^{cd}
Control*	0.73 (0.84)^{a}	0.87 (0.93)^{e}	0.93 (0.94)^{c}	0.87 (0.93)^{c}	0.73 (0.85)^{a}	0.83 (0.91)^{d}	0.93 (0.97)^{a}	0.87 (0.93)^{d}	0.93 (0.96)^{c}	0.93 (0.97)^{d}	0.73 (0.85)^{a}	0.88 (0.94)^{e}
S.Em ±	0.08	0.08	0.10	0.07	0.06	0.04	0.07	0.07	0.09	0.08	0.09	0.03
C.D. at 5%	NS	0.26	0.34	0.20	NS	0.14	NS	0.24	0.26	0.24	NS	0.12

DBS- Days Before Spray DAS-Days After Spray

Figures in the parentheses are $\sqrt{x} + 0.5$ transformed values

In a column, means followed by same alphabet do not differ significantly (p= 0.05) by DMRT

*Without any bee attractants spray

investigated and reported that Basil crop when grown around agricultural crops attracted more flower visitors which illustrate the importance of basil as a pollinator reservoir. Another research reported by Pereira *et al.* (2015) revealed that intercropping with Basil, *Ocimum basilicum* increased bee abundance and richness in the area and enhanced bell pepper fruit and seed production (*Capsicum annuum*). Thus, it is confirmed that plant-based products enticed more bees towards the crop. Similar findings are also reported by Gallert *et al.* (1985), who stated that honey bees were attracted to the Lucerne plots sprayed with a crude extract of dried fruit of lavender, *Evodia hupehensis*. The present findings also confirmed the results of Dinesh (2003), who reported that spraying of cacambe 10 per cent and jaggery 10 per cent had significantly attracted a greater number of pollinators on cucumber bloom. Further, Patil *et al*. (2010) reported that Bee-Q at 15g per litre was significantly superior in attracting maximum number of *Tetragonula* sp. in onion as compared to sugar syrup at 5 per cent and molasses at 10 per cent on first day after first spray and their efficacy lasted up to five days.

Application of bee attractants significantly increased the number of seeds per umbel. The highest number of seeds per umbel was recorded with ocimum oil (0.1%) (16.00), followed by jaggery (15%) (15.33). The enhanced seed set observed in these treatments can be attributed to increased stingless bee visitation and improved pollination efficiency. These findings are consistent with those of Kalmath and Sattigi (2005), who reported that a 10% jaggery solution exerted a phagostimulatory effect in onion, attracting a greater number of pollinators following both the first and second sprays. However, both bee visitations were uniform on the seventh day after each spray in all bee attractant sprayed plots. The findings are also in line with Kalmath and Sattigi (2002) who documented that cacambe (10%) had significant influence on number of seeds per umbel (968.96) followed by jaggery solution (10%) in onion. Bee pollination also resulted in increased number of fruits in cucumber (Dinesh, 2003). The highest seed yield was recorded in the crop treated with ocimum oil (0.1%) (14.46 q ha^{-1}), followed by jaggery (15%) (13.75 q ha^{-1}) (Fig. 2; Table 2). These treatments increased

Table 2: Influence of bee attractants on seed quality and quantity parameters of coriander

Treatments	Seed quality parameters						Seed quantity parameters			
	1000 seed weight (g)	Per cent seed germination	Increase over control (%)	Seedling length (cm)	Seedling vigour index	Seedling dry weight (mg)	No. of umbels/ plant	No. of seeds/ umbel	Yield (q/ha)	Increase over control (%)
Jaggery 15%	15.80^{a}	79.67^{ab}	18.32	11.15^{b}	889^{b}	0.013^{a}	26.67^{a}	15.33^{a}	13.75^{ab}	50.29
Jaggery + lime juice 15 %	15.83^{a}	76.33^{bc}	13.37	9.17^{c}	700^{c}	0.012^{ab}	26.73^{a}	13.00^{abc}	12.41^{abc}	35.64
Enriched jaggery 15%	16.03^{a}	77.67^{b}	15.35	10.47^{b}	813^{b}	0.012^{ab}	26.73^{a}	14.67^{ab}	12.91^{abc}	41.11
Ocimum oil 0.1%	16.57^{a}	82.67^{a}	22.77	12.23^{a}	1011^{a}	0.013^{a}	27.00^{a}	16.00^{a}	14.46^{a}	58.05
Menthol oil 0.1%	15.47^{a}	71.33^{de}	5.94	8.98^{c}	641^{c}	0.011^{bc}	26.33^{a}	11.00^{cd}	11.17^{bcd}	22.16
Ajwan oil 0.1%	15.27^{a}	72.67^{cd}	7.92	9.05^{c}	658^{c}	0.011^{bc}	25.73^{a}	11.33^{bcd}	11.32^{cd}	23.72
Control*	15.03^{a}	67.33^{e}		6.97^{d}	470^{d}	0.010^{c}	26.13^{a}	9.67^{d}	9.15^{d}	
S.Em ±	0.13	0.09		0.04	0.56	0.003	0.16	0.15	0.13	
C.D. at 5%	NS	0.29		0.15	1.70	0.01	NS	0.48	0.37	

In a column, means followed by same alphabet do not differ significantly (p= 0.05) by DMRT
*Without any bee attractant spray

seed yield by 58.05% and 50.29%, respectively, over the untreated control, demonstrating the positive effect of bee attractants on coriander productivity. The higher seed yield may be attributed to increased stingless bee visitation, which enhanced pollen transfer during the period of stigma receptivity, resulting in improved cross-pollination, better fertilization, and consequently higher seed set. The increased bee visitation in plots treated with Ocimum oil was mainly due the presence of volatile compounds such as ocimene, thymol and linalool. The attractant capacity of the jaggery could be attributed to the presence of fructose and glucose sugars. Similarly, Kalmath and Sattigi (2002) also recorded higher seed yield from cacambe (10%) and jaggery solution (10%) sprayed plots in onion. In addition Narendra (2014), documented that highest seed yield per hectare (994.51 kg/ha) was recorded in jaggery solution (10%) sprayed plot as against open pollination (602.08 kg/ha) in onion.

The number of umbels per plant did not differ significantly among the bee attractant treatments and the untreated control, ranging from 25.73 to 27.00 umbels per plant. The absence of a treatment effect suggests that umbel production is primarily governed by the genetic potential of the crop and is not influenced by pollinator visitation. Although the 1,000-seed weight ranged from 15.03 g in the untreated control to 16.57 g in the ocimum oil (0.1%) treatment, the differences among treatments were not statistically significant, indicating that bee attractants had no appreciable effect on seed weight. The present findings are in line with findings of Srikanta (2008), who reported that bee pollination had no impact on test weight in sunflower. Contrarily, Viraktamath and Patil (1999), stated that maximum test weight was recorded from crop sprayed with Bee-Q at 15 g per litre in mustard. Per cent germination was highest, when sprayed with Ocimum (82.67%) which accounted for 22.77 per cent increase over control (Table 2 and Fig. 3). The present findings are in line with reports of Kumar *et al.* (2021), who documented that seeds from attractant-treated plots of Egyptian clover (*Trifolium alexandrinum* L.) recorded highest germination percentage (sugar-92.67; jaggery-92.33) when compared with caged (79.33) and hand pollinated (82) plots. Similarly, Kalmath and Sattigi (2005), opined that spray of bee attractant, cacambe enhanced germination percentage of onion.

Significantly highest seedling length, seedling vigour index and dry weight were recorded in Ocimum sprayed plot (12.23 cm, 1011 and 0.013 mg, respectively) followed by jaggery 15% (18.32 cm, 11.15 and 0.013 mg, respectively) Table 2, Fig.4. The present reports confirm the findings of Kalmath and Sattigi (2005), who opined that increased seedling length were obtained from cacambe treated onion plot. Similarly, Chandravathi and Gurumurthy (2016) reported that Bee-Q spray recorded highest seedling vigour index (2627) in pigeon pea.

Table 3: Cost economics of different bee attractants with respect to coriander yield

Treatments	Yield (q/ ha)	Cost of bee attractants (Rs./ha)	Other cost production (Rs./ha)	Total cost of production (Rs./ha)	Gross returns (Rs./ha)	Net returns (Rs./ha)	B:C Ratio
T_1 - Jaggery at 15%	13.75^{ab}	2,850	32,697	35,547	1,64,960	1,29,413	4.64
T_2 - Jaggery + lime juice at 15 %	12.41^{abc}	3,750	32,697	36,447	1,48,880	1,12,433	4.08
T_3 - Enriched jaggery at 15%	12.91^{abc}	4,650	32,697	37,347	1,54,880	1,17,533	4.15
T_4 - Ocimum oil at 0.1%	14.46^{a}	19,950	32,697	52,647	1,73,480	1,20,833	3.30
T_5 - Menthol oil at 0.1%	11.17^{bcd}	7,650	32,697	40,347	1,34,080	93,733	3.32
T_6 - Ajwan oil at 0.1%	11.32^{cd}	10,950	32,697	43,647	1,35,800	92,153	3.11
T_7 – Control*	9.15^{d}	0	31,697	31,697	1,09,760	78,063	3.46
S. Em ±	0.13						
C.D. at 5%	0.37						

Present market price: Rs 120/kg Seed
Net return = Gross return- Total cost
*Without any bee attractant spray
Gross return=Yield × Market price
B: C ratio=Gross return / Total cost
**Spraying cost of Rs. 1000 excluded

However, cost economics of different bee attractant treatment indicated that even though Ocimum oil at 0.1 per cent recorded maximum yield, which has failed to be the best treatment, due to higher cost of production. However, jaggery at 15 per cent registered maximum B:C ratio of 4.64 with net returns, Rs. 1,29,413 per hectare signifying that jaggery at 15 per cent proved as most feasible, ecofriendly and cost-effective treatment from the farmers point of view (Table 3). Therefore, it is confirmed that application of bee attractants enhanced both quantitative and qualitative yield parameters of coriander (Vanitha et al., 2025).

Fig. 1. Stingless bee *Tetragonula* "nr" *pagdeni* foraging on the umbel of coriander flower

CONCLUSION

The present study demonstrated that the application of bee attractants enhanced the foraging activity of the stingless bee *Tetragonula "*nr*" *pagdeni*, resulting in improved pollination and increased seed yield in coriander. Among the treatments evaluated, ocimum oil (0.1%) recorded the highest bee visitation and seed yield, whereas jaggery solution (15%) proved to be the most economical option, with the highest benefit: cost ratio. The increased pollinator activity facilitated more effective pollen transfer and seed set, thereby improving crop productivity. Considering its low cost, ease of availability, and effectiveness in attracting pollinators, jaggery solution (15%) can be recommended as a practical and farmer-friendly bee attractant for enhancing coriander seed production under field conditions.

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AUTHORS CONTRIBUTION

Formal analysis, investigation, writing- original draft, writing- review & editing (V.K., V.M.M., G.J.B.); Conceptualization, supervision, methodology, review and editing (V.B.B.P., M.S.S.).

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Authors don't have conflict of interest to express

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RESEARCH NOTE

Outbreak of looper, *Perixera illepidaria* Guenée, in mango in South Gujarat, India

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ABSTRACT: An outbreak of a looper, *Perixera illepidaria* (Lepidoptera: Geometridae) was observed on mango trees in Gujarat state of India during January to March, 2025. The period of occurrence of looper was severe in February. The larval incidence of looper ranged from 2 to 39 larvae per inflorescence, with peak incidence (27.9 larvae per panicle) recorded during 7th Standard Meteorological Week (SMW) (third week of February). Loopers fed voraciously on flowers, secondary and tertiary branches of inflorescence leaving behind only the panicle axis (rachis). This voracious feeding can cause a dried appearance of the inflorescence, reduced fruit set, and up to 80–100% damage under severe infestations, resulting in substantial yield losses. The larvae exhibited considerable colour variation across the instars, ranging from black to dark brown, often with distinct banding patterns along the body. Moreover, no any natural parasitization either on larvae and pupae were observed. This is the first record of outbreak of *P. illepidaria* on mango crop from Gujarat. Given the economic losses caused by outbreaks, a comprehensive management strategy emphasizing research, monitoring, and preparedness is essential to prevent future losses.

Keywords: Outbreak, Looper, *Perixera illepidaria,* Mango, Gujarat

Mango (*Mangifera indica* L.) is a fruit of major economic and cultural importance and widely cultivated across tropical and subtropical regions of the world. In Gujarat, mango is cultivated over 177,000 ha with a production of 1.115 million ton, and the South Gujarat region contributes significantly, accounting for more than half of the state's mango production (Anon., 2023). Despite its prominence, mango cultivation is seriously hampered by a wide range of insect pests. The intensification of commercial mango production-through the introduction of innovative varieties, changes in crop management, practices, expansion of cultivation areas, and increased chemical inputs-has significantly reshaped the pest community composition. (Reddy *et al*., 2018). Additionally, climate change has led to the emergence of new pests, while the global trade in mangoes has facilitated the dispersal of pests to various regions (Jayanthi *et al*., 2014). Total 260 insect and mite pests have been reported from the Indian subcontinent, of which nearly 30 pests are serious and capable of causing major losses to mango growth and yield (Pena *et al*., 1998; Kapadia, 2003).

Flowering is a critical phase in mango production, during which only a small fraction of flowers develop into fruit. In recent years, mango inflorescences in India have been experiencing severe infestations by multiple species of polyphagous caterpillars belonging to different families. Lepidopteran pests, once considered minor, have now emerged as major threats during the flowering stage. These inflorescence-feeding larvae damage panicles by feeding on floral parts, leading to flower shedding, reduced fruit set, and consequent economic losses. Notably, these caterpillars are now causing greater damage to mango flowers than traditional pests such as hoppers (Jayanthi *et al.,* 2018). The impact of a diverse group of polyphagous caterpillars on panicles remained unrecognized for a long time. In Gujarat, an average avoidable yield loss of 47.33 per cent has been reported (Bana *et al.,* 2023).

There are total fifteen species of lepidopteran pest belonging to various families such as Pyralidae, Tortricidae, Gelechiidae, Noctuidae, Geometridae, Erebidae, Lymantriidae, Crambidae and Pyralidae were reported on mango inflorescence in South Gujarat (Kumari, 2025). Among them fourteen species *viz.*, *Chlumetia euthesticha* Turner Comb, *Platynota* sp., *Dudua aprobola* Meyrick, *Anarsia* sp., *Nanaguna* sp., *Penicillaria jocosatrix* G., *Perixera illepidaria* Guenee, *Euproctis* sp., *Lymantria* sp*., Conogathes punctiferalis* Guenee, *Citripestes eutraphera* (Meyrick), *Thalasodes* sp., *Helicoverpa armigera* Hubner and *Hyposidra* sp. were recorded as external feeder, whereas *Chlumetia*

transversa Walker was reported as sole internal feeder. However, *P. illepidaria* was earlier reported as minor pest, this paper is the first report of its outbreak on mango inflorescence in Gujarat.

Agriculture Experimental Station (AES), Navsari Agriculture University (NAU), Paria, Dist. Valsad (Gujarat) was located at 20^{0}26'58.427"N Lat and 72^{0}57'5.723"E Long. in South Gujarat (Fig. 1). While surveying pests and diseases of mangoes under All India Co-ordinated Research Project on Fruits (AICRP-F) in Gujarat during January to March, 2025, sporadic outbreak of semilooper was recorded at AES, NAU, Paria and also from a few farmers' field.

To identify insect species, live insect samples along with inflorescence were collected in polypropylene bag and immediately brought to the Laboratory. Observe the different instars of insect using a stereo microscope equipped with the Scope Tek DCM130E microscope-camera and capture images. Subsequently insect specimens were molecularly identified as *P. illepidaria* (Lepidoptera: Geometridae) with the assistance of SLS, Research Laboratory, Surat.

Further, field observations were continued to record the period of incidence, nature of damage and also the natural parasitization. We observe the larval population per inflorescence on randomly selected five plants from infested field of mango (*var* Alphonso). The period of occurrence of looper in mango was severe in February. Ten panicles covering all the direction from each tree were selected. The average mean number of insect larvae per

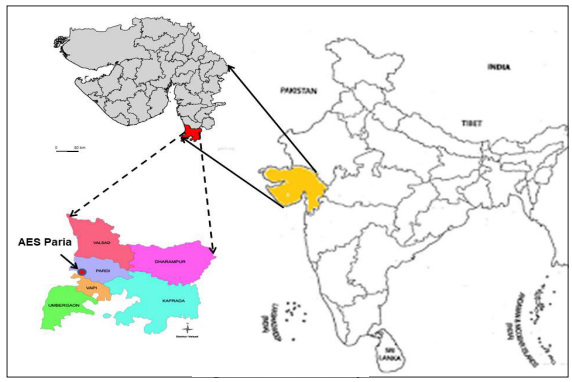

Fig. 1. Location of the study

panicle during 3 SMW (third week of January) was 0.9 larvae per panicle (Table 1). Larval population increases gradually and reached peak 27.9 larvae/ panicle during 7 SMW (third week of February). Thereafter larval population declining and reached 2.7 during 10 SMW (second week of March) (Table 1). Range of larval population was observed to the tune of 2 to 39 per inflorescence. *Larva* causes significant damage to mango inflorescences by feeding on flowers (Fig. 2 A, D), secondary and tertiary branches of inflorescence leaving behind only the panicle axis or rachis (Fig. 3-H). This voracious feeding can lead to a dried appearance of the inflorescence, lower fruit set, and up to 80–100% damage in severe infestations, resulting in major yield losses. The larvae chew on floral parts, which resulted in reduced fruit production. Nature of damage was also confirmed by rearing the larvae in laboratory (Fig. 2 C-7 & Fig. 3-G & H). Larvae observed to be a voracious feeder completely by devouring all the floral parts of panicle (Fig. 2 B & Fig. 3-H).

Table 1: Larval population of *P. illepidaria* on mango inflorescence during 2025

SMW	Period of observation	Number of larvae/panicle/tree					Avg. no. of larvae/ panicle
		1	2	3	4	5	
3	January III	1.4	1.5	0.5	0.3	0.6	0.9
4	January IV	6.0	4.9	3.7	3.7	3.1	4.3
5	February I	12.5	10.6	8.8	8.9	8.4	9.8
6	February II	20.8	18.9	16.5	17.4	15.9	17.9
7	February III	29.0	30.3	26.1	27.6	26.4	27.9
8	February IV	19.0	20.3	16.2	17.4	14.6	17.5
9	Mar I	8.8	9.5	8.7	9.0	7.7	8.7
10	Mar II	3.4	3.1	2.7	2.3	2.1	2.7
	Min.	1.4	1.5	0.5	0.3	0.6	0.9
	Max.	29.0	30.3	26.1	27.6	26.4	27.9
	Avg. ± SD	12.6±9.6	12.4±10.0	10.4±8.7	10.8±9.3	9.9±8.7	11.2±9.2

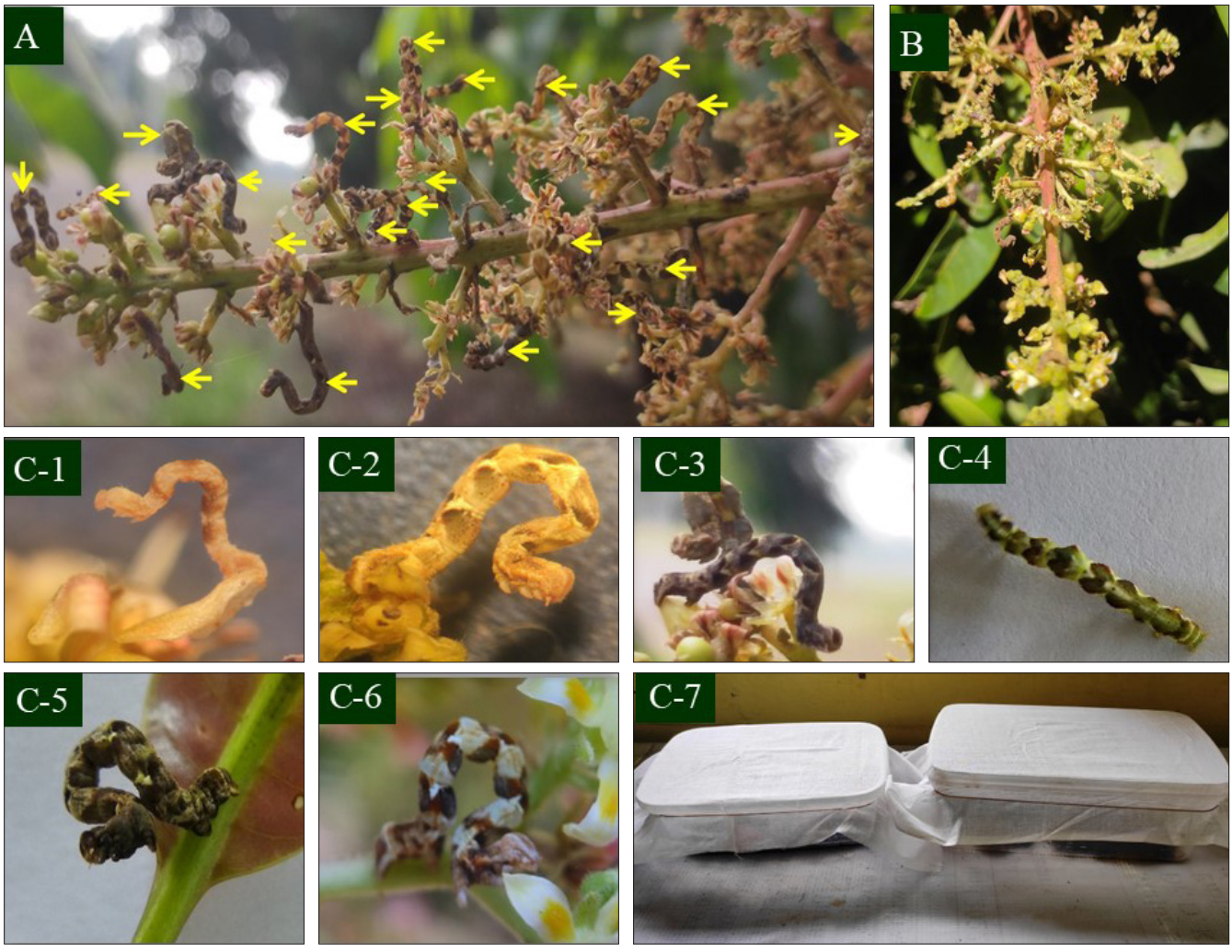

Fig. 2. A- Outbreak of mango looper *Perixera illepidaria* Guenee on mango inflorescence (yellow colored arrow indicate the presence of larva); **B**- Larvae completely devour all the floral parts of the inflorescence; **C-1** to **C-6** larvae exhibited considerable color variation across different instars; **C-7** rearing in laboratory

The larvae exhibited considerable colour variation across different instars, ranging from black to dark brown, often with distinct banding patterns along the body (Fig. 2 C-1 to C-6). These larvae produced silken threads, which they used for mobility and were frequently observed hanging from branches or moving between them. The larva moves in a distinctive looping manner (Fig. 2 C-1 to C-6). Pupation typically occurs on flowers (Fig. 3-C) and also on the underside of leaves close to the inflorescence. Numerous pupae were seen scattered on the upper surfaces of leaves (Fig. 3D). Pupa was triangular, initially green (Fig. 3A), which later changed to brown prior to adult emergence (Fig. 3B). The adult's wings featured two lines of dark brown spots on the upper surface, with the first line located close to the outer edge of each wing (Fig. 3E). Their feeding behaviour involved migrating from one inflorescence to another via these threads, feeding actively on mango flowers and causing substantial damage.

Natural parasitization was also studied by rearing the larvae and pupae in laboratory for observing the emergence of natural enemies, if any (Fig. I). Result revealed that no any parasitization of larvae and pupae were observed. *Perixera illepdidaria* generally oviposits near webs of juvenile spiders as a significant defence against predators (Nafus and Schrecner 1991).

Outbreaks of *P. illepidaria* may be associated with changing climatic conditions. Damage caused by *P. illepidaria* to mango inflorescences directly affects mango production. However losses in terms of fruit yield needs to be studied. Earlier, outbreak of *P. illepidaria* was noticed on litchi trees during 2011 and 2012 in Muzabbarpur (Kumar *et al.,* 2014). Nafus (1997) has reported *P. illepidaria* as

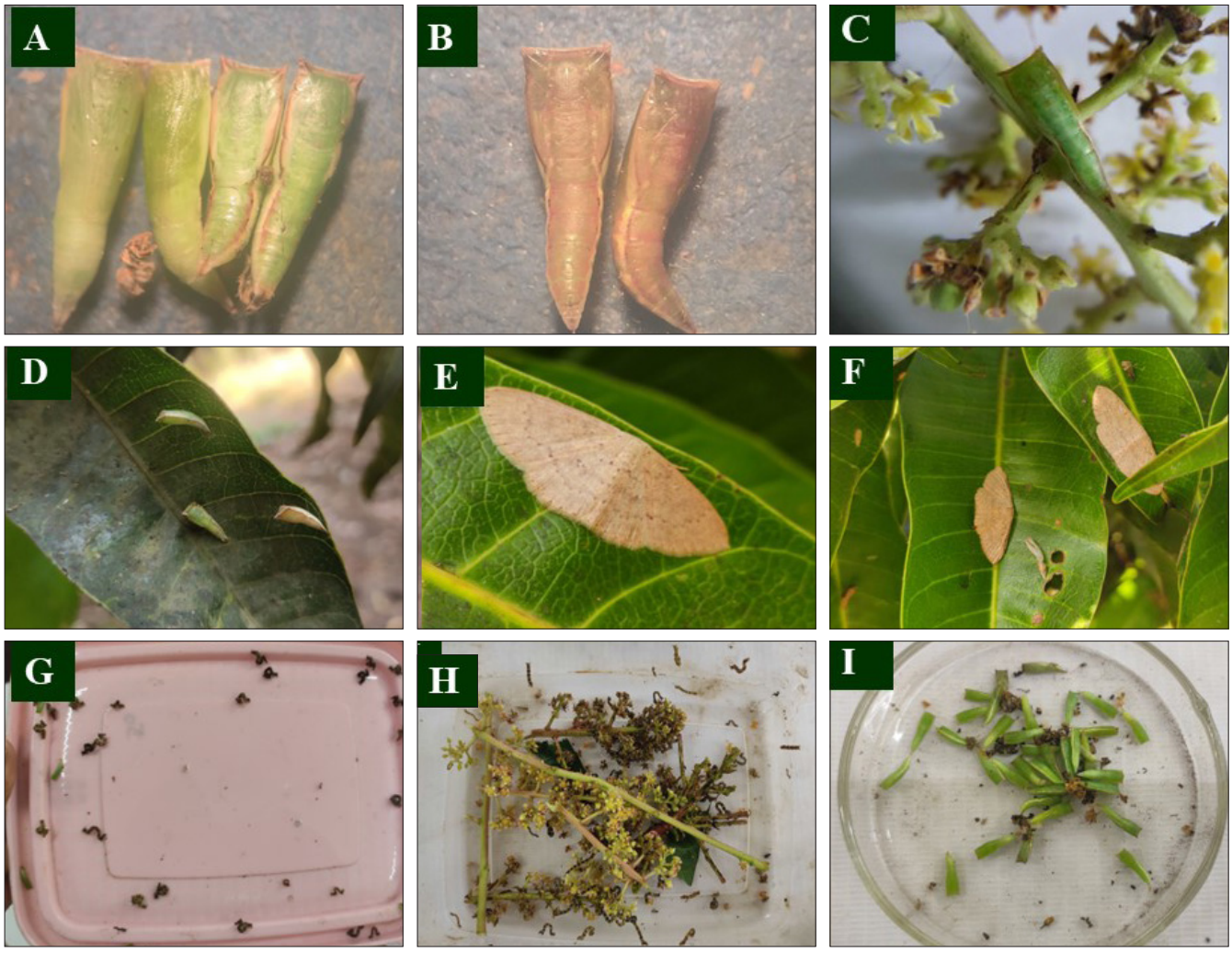

Fig. 3. A-Pupa initially green & triangular in shape; **B**- Mature brown pupa, **C**- Pupation occurs on inflorescence; **D**- Pupation on the leaf near to inflorescence; **E**-Adults; **F**-Outbreak of adults nearby infested area; **G-**Nature of damage was also confirmed by rearing the larvae in laboratory, **H**- Larvae observed as voracious feeder; **I**-Natural parasitization study

pest of mango in the Federal status of Micronesia and in Palau. Likewise, Soumya *et al*. (2021) from Karnataka reported its feeding on mango. Similarly, Nilamudeen *et al*. (2023) recorded serious infestation of *Perixera illepidaria* at Kollengode block of Palakkad district in Kerala. The looper caterpillars were found feeding voraciously on mango flowers. More than twenty larvae were collected from a single inflorescence on slight shaking. The damaged inflorescence presented a dried appearance and flowers became brittle. In addition to mango it also attacks litchi, longan, rambutan and castor (Abrol, 2015)

Considering the recent outbreak and the damage caused by *P. illepidaria* to mango trees, there is a need to keep vigil on the further spread and undertake studies on the eco-biology, behavior and spatial and temporal distribution of *P. illepidaria*.

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AUTHORS CONTRIBUTION

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CONFLICT OF INTEREST

The authors do not have any conflict of interest with respect to the content of the article.

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RESEARCH NOTE

First report of invasive soft scale, *Fistulococcus pokfulamensis* Hodgson & Martin (Hemiptera: Coccidae), in Kerala, India

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ABSTRACT: The soft scale, *Fistulococcus pokfulamensis* Hodgson & Martin (Hemiptera: Coccidae) is an invasive pest recently reported from Karnataka, India. During the field surveys conducted in Kerala, *F. pokfulamensis* was recorded on two host plants, *Jatropha integerrima* Jacq. (Euphorbiaceae) and *Mangifera indica* L. (Anacardiaceae). This new geographical distribution record warrants special attention to prevent further spread and its impact on horticultural crops in the country.

Keywords: Coccinae, Horticultural crops, Invasive pest, Soft scale

The superfamily Coccoidea includes at least 55 families (35 extanct and 20 extinct), among which Coccidae (Soft scale insects) is the third largest, with over 1,200 described species (García Morales, 2016). Soft scales are significant pests of agricultural and horticultural crops as well as ornamental plants. They feed by sucking plant sap and excrete honeydew that allows sooty mould fungus to grow on plant surfaces, and also attracts ants. The sooty mould severely interferes with the plant photosynthesis and vigour. In addition to direct damage to plant, the presence of scale insects is a major phytosanitary issue, as they are often intercepted during international trade. The quarantine authorities are on high alert to prevent the introduction and spread of scale insects to new countries through trade.

Recently, a pest alert was given by ICAR-NBAIR, Bengaluru, with regards to a soft scale species, *Fistulococcus pokfulamensis* Hodgson & Martin (Hemiptera: Coccidae) (Joshi *et al*., 2023). It was first reported in India from Bengaluru district, Karnataka, on two host plants (Joshi *et al*., 2022), which later spread to many economically important host plants within the district as well as in neighbouring districts. In this paper, we report a new distribution of the scale species, *F. pokfulamensis* from Kerala.

During the routine field surveys conducted in November, 2024 to collect soft scales associated with agricultural ecosystems, scale insect specimens were collected on the ornamental plant, *Jatropha integerrima* Jacq. (Euphorbiaceae) from Olavakkode (10.80032°N, 76.64378°E) and on *Mangifera indica* L. (Anacardiaceae) from Muthalamada (12.21055°N, 75.42872°E), in Palakkad district. The infested plant parts were cut with secateurs, kept in polythene cover and secured with rubber band. Ants and natural enemies associated with the soft scales were also collected. The location details viz*.,* latitude and longitude, were noted using GPS Map Camera Lite app. The field photographs were taken using mobile camera. On return to the laboratory, parasitized specimens were kept in a rearing jar covered with wire mesh, until the emergence of adults. The infested plant parts were observed under the stereo-binocular microscope (ZEISS Stemi 305), the soft scale specimens were picked up using a camel hair brush, and preserved in 70 per cent ethyl alcohol for slide mounting. The specimens were also preserved in 90 per cent ethyl alcohol and stored at -20^{o}C in a refrigerator for molecular studies. The specimens were slide mounted by following the method developed by Hodgson and Henderson (2000).

For molecular studies, the DNA was isolated using Qiagen DNeasy blood and tissue kit method, except lysis for about 16-18 h at 65°C. Amplification of the 658 bp region near the 5 terminus of the mitochondrial protein-coding gene, *mt CO* I was carried out by polymerase chain reaction (PCR). The initial denaturation at 94 °C for 3 min. followed by 48 °C for 1 min. for annealing and 72 °C for 5 min for final extension using 20 µl reaction volume containing 10 µl EmeraldAmp® GT PCR Master Mix (Takara), 6 µl of molecular water, 2 µl template DNA, and 1 µl each forward primer and reverse primers. Forward and reverse primers specific to the COI locus (PCOF-10 & LEP-R1), developed by Amouroux *et al.* (2019) were used for the amplification. The amplicons were sequenced by outsourcing at GeneSpec Private Limited, Cochin. The sequence analyses were carried out using *In-silico* tools (BLASTn, MEGA XI) and the sequences were submitted to NCBI GenBank and BoLD.

The morphological and molecular characterisation of the scale insect specimens collected on *J. integerrima* and *M. indica* from two different locations in Palakkad district, Kerala revealed that the species is *F. pokfulamensis*. The species was identified using the taxonomic keys developed by Hodgson and Martin (2005), Joshi *et al.* (2022) and Joshi *et al.* (2023). It was first described by Hodgson and Martin (2005) on *Gnetum luofuense* (Gnetaceae) from Hong Kong and Papua New Guinea. The symptoms, diagnostic characters, and taxonomic characteristics of *F. pokfulamensis* are detailed below.

Field symptoms: The scale insect congregated on the undersurface of the leaves along the midrib and main veins, covered with white waxy material (Plate 1J). Sooty mould growth was noticed on the upper surface of the leaves lying below the infested leaves. The severely affected leaves showed yellowing and premature dropping. The infestation was severe on *J. integerrima* compared to mango.

Diagnostic characters: Body completely flat, with a slight median longitudinal ridge present anterior to the anal plates. Dorsum covered with white waxy dusting, giving the body a frosted appearance in life. White wax filaments or threads arise near the margin. Body becomes transparent yellow, with brownish alimentary canal clearly seen through the derm, on removal of wax.

Taxonomic description: Dorsum: Body broadly oval, membranous, with the anterior end slightly pointed and broadest at posterior, occasionally asymmetrical in shape (Plate 1A); dorsal setae numerous, typically grouped in clusters of 3-6, arranged in crescent shaped pattern between submarginal chambered ducts (Plate 1E); dorsal pores of three distinct types: small microduct associated pores, frequent at submarginal areas, large concave pores, more substantial than those associated with dorsal microducts, located submedially and submarginally (Plate 1F); preopercular pores abundantly arranged in two longitudinal bands originating from the anal plates and extending towards head; submarginal chambered ducts are pipe like and restricted to submargin, each consists of a prominent tubular duct with approximately 8–12 satellites of funnel-shaped pores forming a U-shaped area of sclerotization at the duct opening, typically associated with 3–9 setae (Plate 1E). **Margin:** Marginal setae with blunt apices (Plate 1B); stigmatic clefts highly sclerotized and constricted at the body margin, lacking stigmatic setae (Plate 1C). **Venter:** Antennae 6 segmented but with indistinct segmentation (Plate 1H); legs highly reduced, without clear segmentation between tibia and tarsus (Plate 1I); spiracle without sclerotic plate (Plate 1D); multilocular pores very sparse; anal plate quadrate, each bearing four apical setae (Plate 1G).

Measurements (µm): Body length: 1876. Body width: 1313. Anal plate: anterolateral margin- 472-475; posterolateral margin- 775-780.

Molecular identification: The homology analysis of the *mtCO* I gene sequence of the specimen showed 98.32 per cent similarity with the sequence of *F. pokfulamensis* (Accession OR515185.1) in NCBI database, confirming the species identity. The sequence generated in this study was submitted in the NCBI, GenBank under the accession number - PV765913.1. The assembled sequence submitted to BoLD with process ID: KGBC003-25.

Associated ants and natural enemies: The ant species, *Oecophylla smaragdina* (Fabricius) (Hymenoptera: Formicidae) was found associated with the scale insect. The natural enemies recorded were the parasitoid, *Blepyrus insularis* (Cameron) (Hymenoptera: Encyrtidae) (Plate 1L) and the two predators, an unidentified cecidomyiid (Plate 1K) and *Spalgis epius* (Westwood) (Lepidoptera: Lycaenidae) (Plate 1M). The ant, *O. smaragdina* and the predator, *S. epius* have been reported earlier to be associated with this scale species (Joshi *et al*., 2022; Sampathkumar et al. 2024). *Blepyrus insularis* is known to be associated with Pseudococcidae and Signiphoridae (UCD Community, 2023) and has not been reported from Coccidae. Further studies on the rearing of this parasitoid

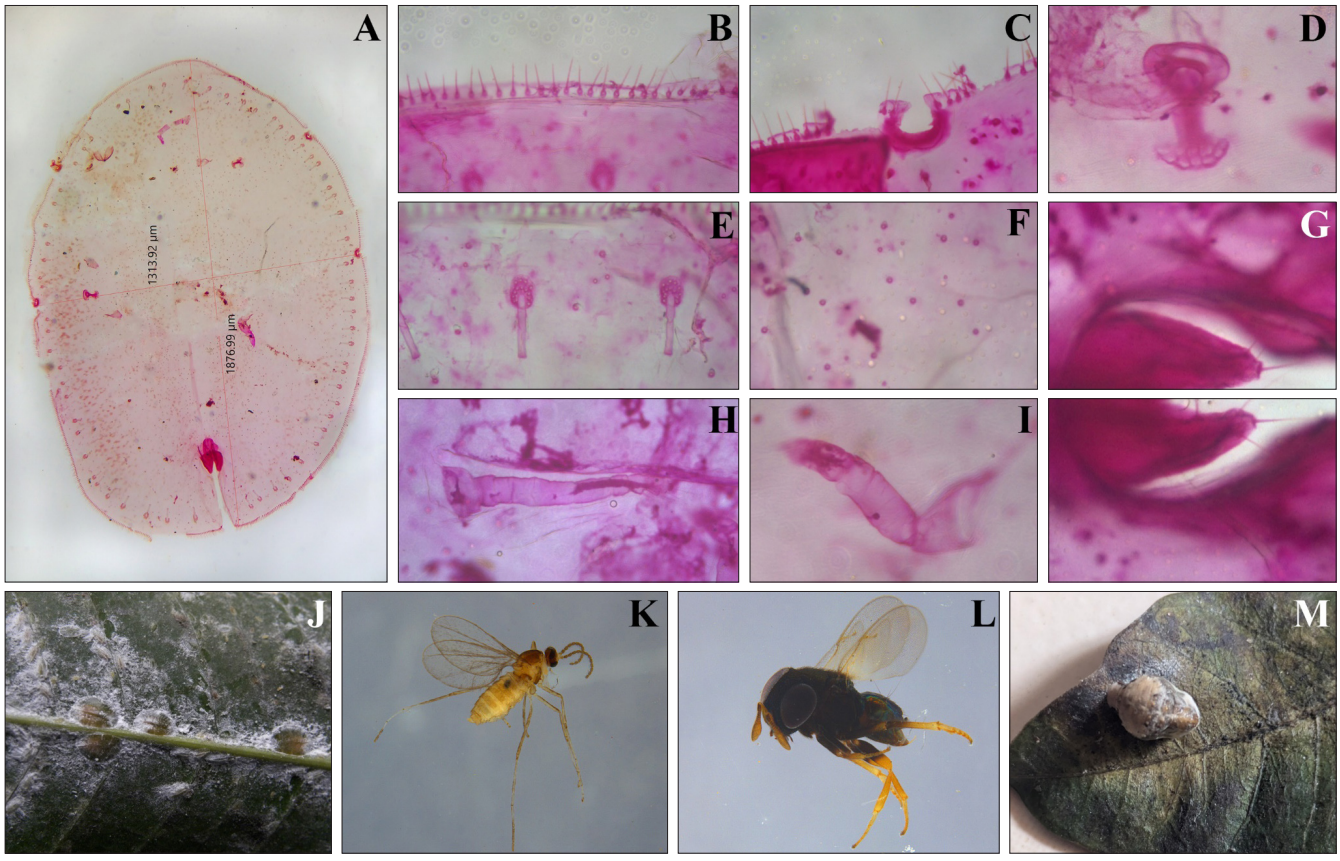

Plate. 1. Diagnostic characters of *Fistulococcus pokfulamensis* and associated natural enemies A. Habitus, B. Marginal setae, C. Sclerotised stigmatic cleft without setae, D. Spiracle, E. Submarginal pipe-like chambered ducts, F. Concave pores, G. Anal plate with four apical setae, H. Antenna, I. Reduced leg, J. Adult female, K. Unidentified cecidomyiid predator, L. Parasitoid, *Blepyrus insularis,* M. Pupa of *Spalgis epius*

on *F. pokfulamensis* as host are necessary to find out if this parasitoid-host association was accidental or if the scale insect was associated with some mealybug during collection, from which the parasitoid might to have emerged. Different species of Cecidomyiid predators have been reported on soft scales from Brazil (Culik and Ventura, 2013; Culik and Ventura, 2013a). Efforts are underway to collect and rear the cecidomyiid predator on *F. pokfulamensis* and to get identified.

This paper reports a new geographical distribution record of *F. pokfulamensis* in Kerala. The soft scale has been reported to spread on several economically important crops in Karnataka, within a short period of its first report in the state, indicating its invasive potential. As Muthalamada (Palakkad district) is the major mango growing belt in Kerala and located adjacent to Tamil Nadu, the scale insect may further spread within and across the state and negatively impact the horticulture crops. Strict vigilance is vital in early detection and containing the pest infestation through periodic surveillance and monitoring in the horticultural/ agricultural ecosystems within the state and bordering areas.

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RESEARCH NOTE

New host plant records of *Apogonia rauca* (Fabricius) (Coleoptera: Scarabaeidae: Melolonthinae) in Kerala, India

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ABSTRACT: *Apogonia rauca* (Fabricius, 1801), a widely distributed scarab beetle, utilizes 16 host plants belonging to 10 families. *Litchi chinensis, Bergera koenigii, Syzygium malaccense,* and *Brownea coccinea* documented as new adult food plants for *A. rauca.*

Keywords: *Bergera koenigii*, *Brownea coccinea,* Host Plant, *Litchi chinensis, Syzygium malaccense*

The genus *Apogonia* Kirby, 1819 (Coleoptera: Scarabaeidae: Melolonthinae: Diplotaxini) comprises more than 530 species distributed across the tropical and subtropical regions of Asia and Africa (Bezdek, 2025). This genus is known for nocturnal adult feeding on the foliage of a wide variety of plants, causing defoliation and economic loss in agricultural and forest plantations, with the grub inhabiting soil and feeding on roots (Kapadia *et al*., 2006).

Apogonia rauca (Fabricius, 1801) is a well-documented, economically important species, known for its wide distribution across Asia (CABI, 2019). Adults resemble *A. ferruginea* (Fabricius) in general morphology but can be readily distinguished by differences in size and coloration. They are relatively large and robust, measuring 7–8 mm in length, and exhibit a shining dark brown coloration. This species is distinctly polyphagous, with a broad adult host range. Among the reported host plants, only *Arachis hypogaea* L. is considered as primary host, with significant yield losses attributed to infestation of roots by grubs (Nath and Singh, 1987; Kapadia *et al*., 2010).

Adults of *A. rauca* is known to feed on 15 host plants belonging to 10 families (Table 1), while the only known larval host plant is *Arachis hypogea*. *Apogonia rauca* adults were observed feeding on curry leaf (*Bergera koenigii* (L.) Spreng., Rutaceae), *Syzygium malaccense* (L.) Merr. & L.M. Perry (Myrtaceae) and *Brownea coccinea* Jacq. (Fabaceae) at Vellayani, Kerala and on litchi (*Litchi chinensis* Sonn., Sapindaceae) at Wayanad, Kerala, India during May – July, 2023. Severe infestation was recorded on *B. coccinea* (Fabaceae), were approximately 70 adults were observed aggregating on a single plant of about 170 cm height during May 2023. The adult population persisted throughout the months of May and June 2023, indicating a prolonged adult activity. The infestation on *B. coccinea* was conspicuous even from a distance during day, suggesting an exceptionally high density of infestation. Adults fed predominantly on tender leaves, with nearly all foliage on the infested plant showing skeletonization (Fig. 1. a & b). Beetles were also collected on litchi (*Litchi chinensis*) in May and on curry leaf (*Bergera koenigii*) in July 2023.On all host species, adults initiated feeding characteristically from the lateral leaf margin, progressively extending towards the midrib (Fig. 1. c & d), a feeding pattern consistent with that of other beetles such as *Melolontha* spp. and the chinese rose beetle (*Adoretus sinicus* Burmeister) (Jayaram, 1997). Voucher specimens of *A. rauca* (Accession no. NIM/NBAIR/COL/SCA-1(1)/072023 to NIM/NBAIR/COL/SCA-1(25)/072023) are deposited in the ICAR – National Bureau of Agriculturally Important Insect Resources, Bengaluru (ICAR–NBAIR).

Sapindaceae and Rutaceae are new host plant families for *A. rauca*. This is also the first report of the species on *L. chinensis*, *B. koenigii*, *S. malaccense* and *B. coccinea* in India.

Table 1: Host plants of *Apogonia rauca* along with new records from Kerala

Family	Scientific name	Common name	Locality	Reference
Euphorbiaceae	*Acalypha sp.*	Acalypha	India (Karnataka)	Jayaram, 1997
Fabaceae	*Acacia* sp.	Acacia sp.	India	Nath and Singh, 1980
			India (Gujarat)	Kapadia *et al*., 2006
			Asia	CABI, 2019
	Arachis hypogaea	Groundnut	India	Nath and Singh, 1980; Kapadia *et al.,* 2010
	Brownea coccinea	Brownea	India (Kerala)	Present study
	Leucaena leucocephala (Lam.) de Wit	Subabul	India	Pawar, 1986
	Tamarindus indica L.	Tamarind	India (Karnataka)	Jayaram, 1997
	Vachellia nilotica (L.) P.J.H. Hurter & Mabb.	Babul	India	Nath and Singh, 1980; Kapadia *et al*., 2010
Lauraceae	*Cinnamomum verum* J. Presl	Cinnamon	India (Karnataka)	Jayaram, 1997
	Persea americana Mill.	Avocado	India (Karnataka)	Jayaram, 1997
Meliaceae	*Azadirachta indica* A.Juss.	Neem	India	Nath and Singh, 1980; Kapadia *et al.,* 2010
			India (Gujarat)	Kapadia *et al*., 2006
Myrtaceae	*Psidium guajava* L.	Guava	India (Karnataka)	Jayaram, 1997
	Syzygium malaccense	Eugenia	India (Kerala)	Present study
Poaceae	*Saccharum officinarum* L.	Sugarcane	India	Nath and Singh, 1980;
Rhamnaceae	*Ziziphus mauritiana* Lam.	Ber	India	Nath and Singh, 1980; Kapadia *et al.,* 2010
			India (Gujarat)	Kapadia *et al.,* 2006
Rosaceae	*Rosa* spp.	Rose	Sri Lanka	Hutson, 1924
			India and Sri Lanka	Veeresh *et al*., 1995
			India	Nath and Singh, 1980; Patil and Veeresh 1984; Kumar *et al*., 2006,
			India (Karnataka)	Jayaram, 1997;
Rubiaceae	*Coffea arabica* L.	Coffee	Indochina	Du pusuvier, 1932;
	Ixora sp.	Ixora	India (Karnataka)	Jayaram, 1997
			India (Kerala)	Present study
Rutaceae	*Bergera koenigii*	Curry leaf	India (Kerala)	Present study
Sapindaceae	*Litchi chinensis*	Litchi	India (Kerala)	Present study
Theaceae	*Camellia sinensis* (L.) Kuntze	Tea	Indochina	Du pusuvier, 1932;

Fig. 1. Adults of *Apogonia rauca* feeding on *Brownea coccinea* (a,b); Damage of *Apogonia rauca* on *Brownea coccinea* (c,d)

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CONFLICT OF INTEREST

Author has no conflict of interest to express

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RESEARCH NOTE

Evaluation of biopesticides and insecticides against *Sciothrips cardamomi* Ramk.

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ABSTRACT: Cardamom thrips, *Sciothrips cardamomi* Ramk., is a major and persistent pest of small cardamom, *Elettaria cardamomum* (L.) Maton, causing significant yield loss in poorly managed plantations. The development of effective and sustainable management strategies is therefore essential. In the present study, four botanicals, namely neem seed kernel extract (NSKE) @ 5%, *Brugmansia suaveolens* (*Br. suaveolens*) leaf extract @ 5%, *Tithonia diversifolia* leaf extract @ 5%, and *Aloe* extract @ 2%; horticultural mineral oil @ 1%; two entomopathogenic fungi*, Lecanicillium lecanii* @ 2% and *Beauveria bassiana* (*B. bassiana*) @ 2%; and four insecticides, Spinetoram 11.7 SC, Thiamethoxam 25 WG, Quinalphos 25 EC, and Spiromesifen 22.9 SC, were evaluated against *S. cardamomi*. The results revealed that Spinetoram 11.7 SC recorded the lowest capsule infestation, followed by Thiamethoxam 25 WG, Quinalphos 25 EC, NSKE 5%, and Spiromesifen 22.9 SC during both dry and monsoon seasons. Significantly reduced capsule infestation was also observed in treatments with horticultural mineral oil, *B. bassiana*, and *Br. suaveolens* leaf extract. These findings indicate that, in addition to the proven efficacy of chemical insecticides and NSKE, horticultural mineral oil, *B. bassiana*, and *Br. suaveolens* possess considerable potential for incorporation into the integrated management programmes for *S. cardamomi*, following further validation and standardization under field conditions.

Keywords: Cardamom thrips, bio-efficacy, evaluation, bio-pesticides, insecticides

INTRODUCTION

Small cardamom, *Elettaria cardamomum* (L.) Maton, belonging to the family Zingiberaceae, is indigenous to the moist evergreen forests of the Western Ghats, southern India (Ravindran, 2002). Globally, India is the largest user and second in production and export of small cardamom (Kuruvila *et al.,* 2022). In India, the cultivation is concentrated in the three southern states viz., Kerala (exceeding 90% of the production), Karnataka, and Tamil Nadu (Ravindran, 2002; Murugan *et al*., 2009; Spices Board, 2024). Insect pests pose serious damage to the cardamom plantations and demand excessive insecticides to tackle them. Out of more than seventy reported insect pests (Gopakumar and Chandrasekar, 2002; Joshi *et al*., 2023; Nafeesa *et al*., 2025a, 2025b), the cardamom thrips, *Sciothrips cardamomi* Ramk. (Thysanoptera: Thripidae), is highly troublesome and enduring pest in cardamom production system (Gopakumar and Chandrasekar, 2002).

The feeding stages of *S. cardamomi*, comprising both nymphs and adults, damage cardamom plants by rasping and sucking sap from tender shoots and various panicle parts, including bracts, perianths, flower buds, peduncle, and immature capsules. Such feeding injury leads to the shedding of flowers and immature capsules, reduced capsule development, and the formation of characteristic scab-like lesions, commonly known as "itch," on mature capsules (Gopakumar and Chandrasekar, 2002; Ranjith and Krishnamoorthy, 2016; Venukumar *et al.,* 2018). *Sciothrips cardamomi* causes considerable economic damage, and the unprotected crop may suffer up to 80 percent damage (45-48% crop loss) (Gopakumar and Chandrasekar, 2002). In the Cardamom Hill Reserves (CHR), Kerala, the estimated pesticide consumption rate for managing this pest is 2.85 kg a.i. ha^{-1} per season (Murugan *et al.,* 2017). Frequency of pesticide application per year in the CHR system is also very high (three times more)

compared to the recommended rate (KAU POP 2016, Kuruvila *et al*., 2022; Nafeesa *et al*., 2024).

Due to the severity of the pest and high value nature of the crop, an array of chemical insecticides were evaluated against *S. cardamomi* by various researchers. Even though some botanicals, biocontrol agents, and chemical pesticides were tested and recommended for the management of cardamom thrips, still unable to provide effective bio or chemical alternatives to manage *S. cardamomi* (Gopakumar and Chandrasekar, 2002; Josephrajkumar *et al.,* 2002; Stanley *et al*., 2014; Jacob *et al.,* 2015; Ranjith and Krishnamoorthy, 2016; Venukumar *et al.,* 2018; Kumar *et al.,* 2015, 2021; Nafeesa *et al.,* 2024). Even though Central Insecticide Board and Registration Committee (CIB & RC) approved only a few pesticides in cardamom system, nearly forty different chemical formulations are widely adopted for pest control in the Cardamom Hill Reserves, Kerala (DPP, QS, 2023; Kuruvila *et al*., 2022). Many ineffective chemicals with high dosages enter the system in place of effective chemicals with right dosages (Nafeesa *et al*., 2024). Hence, deliberate efforts are required to address this issue and to formulate bio and chemical strategies to manage *S. cardamomi.* Under these circumstances, this study was designed and executed to evaluate botanical extracts, horticultural mineral oil, entomopathogenic fungi and chemical pesticides against *S. cardamomi.*

MATERIALS AND METHODS

The study was carried out during 2022–23 at the farm of the Cardamom Research Station (CRS), Pampadumpara, Kerala, India (9.79847° N, 77.16127° E). The experiment comprised twelve treatments, namely neem seed kernel extract (NSKE) @ 5%, *Brugmansia suaveolens* ((*Br. suaveolens*)) leaf extract @ 5%, *Tithonia diversifolia* leaf extract @ 5%, *Aloe* extract @ 2%, horticultural mineral oil (HMO) @ 1%, the entomopathogenic fungi *Lecanicillium lecanii* @ 2% and *Beauveria bassiana* @ 2%, and the insecticides Spiromesifen 22.9 SC @ 7 ml/10 L, Spinetoram 11.7 SC @ 4 ml/10 L, Thiamethoxam 25 WG @ 2 g/10 L, and Quinalphos 25 EC @ 20 ml/10 L, along with an untreated control. Each treatment was replicated three times in a Randomized Block Design (RBD). The study was conducted on seven-year-old cardamom plants of the variety 'Green Gold'. Chemical pesticides were procured from the local pesticide dealers. EPF dust formulations were purchased from the biocontrol laboratory, CRS, Pampadumpara, and botanicals were freshly prepared in the lab. All other crop management practices including fertilizer application and irrigation were done as per the Kerala Agricultural University's POP (2016).

Pesticide sprays were scheduled seven times (four sprays from January to May at monthly intervals and three from August to December during the dry spells of the monsoon period) according to the KAU POP (2016). In each treatment, six plants were maintained, and three plants were marked as observational plants. Year-round field observations were made at monthly intervals. Assessment of the infestation was based on the methodologies given by Joseph Rajkumar *et al*. (2002) and Jacob *et al.* (2015), with slight modifications. Ten panicles were randomly selected from each plant, and the damage symptoms were recorded. The observations, viz., number of infested panicles, total number of capsules in the ten selected panicles, and number of infested capsules (capsules with 'itch'/scab), were noted from the field. Percentage of infested panicles and capsules was calculated using the formula given below.

$$\text{Panicles infested (\%)} = \frac{\text{Number of panicles infested}}{\text{Total number of panicles counted}} \times 100$$

$$\text{Capsules infested (\%)} = \frac{\text{Number of capsules infested}}{\text{Total number of capsules counted}} \times 100$$

Observation from four harvests were taken during the experiment period. The weight of the harvested green capsules and the percentage of infestation on 100 randomly selected capsules were recorded in each treatment in all replications. The data thus obtained were subjected to ANOVA, and all statistical analyses were done using the Statistical Packages WASP (Jangam and Thali, 2004) and grapes Agri1 (Gopinath *et al*., 2021).

RESULTS AND DISCUSSION

The results given in Table 1 show that the treatment means were significantly different among the variables. From the year-round observations, the percentage of panicles that shown visible symptoms of infestation was lowest in cardamom plants treated with Spinetoram 11.7 SC, followed by Thiamethoxam 25 WG, Quinalphos 25 EC, NSKE 5%, Spiromesifen 22.9 SC and HMO. Reduction in panicle infestation was also recorded in plants treated with *B. bassiana* and *Br. suaveolens* over the control (water spray). According to the field count and the observations recorded on harvested capsules, plants treated with Spinetoram 11.7 SC had the lowest percentage infestation on capsules. Thiamethoxam 25 WG, Quinalphos 25 EC, NSKE 5%, and Spiromesifen

Table 1: Infestation percentage of cardamom thrips, *Sciothrips cardamomi* after the application of botanicals, EPF and chemical pesticides in small cardamom

Treatment	Pre count		Field observations after treatment				Wet capsule yield per treatment (kg)	% of capsules infested in harvested capsules
			Rainless period (Jan – May)		Monsoon period (Jun – Dec)			
	% of panicles infested	% of capsules infested	% of panicles infested	% of capsules infested	% of panicles infested	% of capsules infested		
NSKE 5 %	44.44 (41.76)	34.14 (35.73)	41.33^{de} (39.94^{de})	25.41^{cdef} (30.08^{cde})	48.25^{bc} (43.93^{bc})	33.85^{d} (35.49^{d})	2.193	49.92^{c} (44.95^{c})
Br. suaveolens (Leaf extract) 5 %	57.78 (49.57)	39.62 (38.99)	52.22^{bc} (46.28^{bc})	32.57^{bc} (34.79^{bc})	55.56^{ab} (48.23^{ab})	43.45^{bcd} (41.23^{bcd})	2.823	58.42^{bc} (49.85^{bc})
T. diversifolia	61.11 (51.67)	43.55 (41.29)	54.00^{b} (47.31^{b})	35.95^{ab} (36.84^{ab})	60.00^{ab} (51.03^{ab})	44.36^{bc} (41.76^{abcd})	3.767	59.83^{ab} (50.70^{ab})
Aloe extract	63.33 (52.85)	37.30 (37.63)	55.34^{b} (48.08^{b})	36.16^{ab} (36.89^{ab})	62.54^{ab} (52.62^{ab})	45.99^{abc} (42.69^{abc})	4.027	60.08^{ab} (50.90^{ab})
HMO	52.22 (46.28)	36.26 (37.02)	44.22^{cde} (41.56^{cde})	31.19^{bcd} (33.91^{bcd})	56.51^{ab} (48.77^{ab})	40.22^{bcd} (39.33^{bcd})	3.783	55.25^{bc} (48.01^{bc})
L. lecanii	55.56 (48.25)	35.21 (36.35)	56.00^{b} (48.47^{b})	36.05^{ab} (36.90^{ab})	62.06^{ab} (52.49^{ab})	47.95^{ab} (43.77^{ab})	3.140	61.50^{ab} (51.67^{ab})
B. bassiana	52.22 (46.28)	34.51 (35.95)	49.56^{bcd} (44.75^{bcd})	31.76^{bcd} (34.27^{bc})	60.64^{ab} (51.20^{ab})	39.84^{bcd} (39.13^{bcd})	3.320	57.00^{bc} (49.06^{bc})
Spiromesifen 22.9 SC	58.89 (50.89)	37.27 (37.61)	44.67^{cde} (41.92^{cde})	30.32^{bcde} (33.41^{bcd})	55.24^{ab} (48.05^{ab})	35.77^{cd} (36.70^{cd})	3.443	53.75^{bc} (47.15^{bc})
Spinetoram 11.7 SC	61.11 (51.42)	37.25 (37.59)	37.78^{e} (37.91^{e})	16.97^{f} (24.30^{f})	33.81^{e} (35.45^{e})	15.37^{e} (23.07^{e})	4.993	24.42^{e} (29.58^{e})
Thiamethoxam 25 WG	42.22 (40.48)	32.05 (34.24)	38.00^{e} (38.02^{e})	22.07^{ef} (27.82^{ef})	33.97^{e} (35.61^{e})	16.61^{e} (23.93^{e})	3.937	33.92^{d} (35.59^{d})
Quinalphos 25 EC	40.00 (39.09)	30.23 (33.23)	40.22^{e} (39.31^{e})	23.38^{def} (28.72^{def})	46.03^{bc} (42.62^{bc})	22.66^{e} (28.14^{e})	4.960	36.75^{d} (37.09^{d})
Control Water spray	62.22 (52.61)	35.82 (36.72)	70.00^{a} (56.80^{a})	41.97^{a} (40.37^{a})	71.90^{a} (58.26^{a})	55.20^{a} (48.05^{a})	3.993	68.75^{a} (56.06^{a})
CV	21.41 (14.94)	16.42 (9.76)	10.97 (7.07)	16.67 (9.876)	19.61 (13.39)	16.78 (10.26)	29.15	10.45 (7.07)
CD (0.01)	ns	ns	12.28 (7.19)	11.63 (7.54)	24.32 (14.59)	14.21 (8.72)	ns	12.41 (7.46)
CD (0.05)	ns	ns	9.03 (5.29)	8.56 (5.55)	17.89 (10.73)	10.45 (6.42)	ns	9.13 (5.49)
SE(d)	9.48	4.84	4.36	4.13	8.63	5.04	0.88	4.40

In a column, treatment means followed by different letters are significantly different otherwise non-significant.
Values in parentheses are arc sine transformed values.

22.9 SC were next in line. In addition to the above treatments, thrips infestation on capsules was lower on plants treated with HMO, *B. bassiana,* and *Br. suaveolens,* and in most of the variables, these treatments were on par with one another. Variations were recorded on the weight of the harvested capsules under different treatments.

In all of the variables examined, plants treated with Spinetoram 11.7 SC showed the lowest percentage of *S. cardamomi* infestation symptoms. Even though the variations in the average yield of different treatments was not significant, highest average yield was reported from the plants treated with Spinetoram 11.7 SC. Uniform and recommended fertilizer application and irrigation scheduling throughout the experiment period may be one of the reasons for the insignificant variation in yield among the treatments. The efficacy of spinetoram against different thrips species was detailed by various researchers in different annual and perennial agroecosystems (Walter *et al*., 2018; Guruprasad *et al*., 2019; Manideep *et al*., 2023). As per the Pesticides Fact Sheet (2009), spinetoram has been categorized under category IV, having low acute toxicity. This pesticide, which is widely used by cardamom farmers in different states (Manusha *et al.,* 2022; Kuruvila *et al*., 2022), does not have a label claim for cardamom. Of the tested pesticides, Thiamethoxam 25 WG and Quinalphos 25 EC have recorded considerable reduction in thrips infestation, and on par with the Spinetoram 11.7 SC. Previous studies have supported the effectiveness of thiamethoxam against the members of the genus *Sciothrips* and other thrips species (Venukumar *et al*., 2018; Manideep *et al*., 2023).

In this experiment, NSKE @ 5% had a desirable reduction in pest infestation in all of the tested variables, next to the above three chemicals, but numerically, the average yield was the lowest for this treatment. Both positive and negative results were recorded for neem-based formulation against *S. cardamomi* (Josephrajkumar *et al*., 2002; Stanley *et al*., 2014). Other than the chemical pesticides and NSKE, plants treated with HMO, *B. bassiana*, and *Br. suaveolens* showed a significant reduction in *S. cardamomi* infestation in all of the tested variables. The potential of HMO to reduce the population of other thrips species was given by researchers (Xue *et al.,* 2002; Singh *et al*., 2020).

The entomopathogenic fungus *B. bassiana* has been tested on a number of pest species and is widely used in biocontrol strategies worldwide (Boaria *et al.,* 2011). A number of scientific experiments that proved the effectiveness of *B. bassiana* against various thrips species under many agro ecosystems (Boaria *et al.,* 2011; Goa *et al.,* 2012; Zahn *et al.,* 2013; Ain *et al.,* 2021). But it was neither studied in detail nor exploited in the cardamom production system against *S. cardamomi* (Gopakumar and Chandrasekar, 2002; Dhanya *et al.,* 2019; Nafeesa *et al.,* 2024). Kumar *et al.* (2015, 2021), isolated *L. psalliotae* from cardamom thrips and confirmed its infectivity and effectiveness both in the laboratory and field conditions. *Br. suaveolens* is an invasive plant species recorded from the Idukki district of Kerala (Sankaran *et al*., 2013) and is widely distributed in the CHR. The insecticidal property of *B. suaveolens* was discussed by Pundir *et al*. (2022). As per our results, plants treated with 5% leaf extract of *B. suaveolens* secured lesser thrips infestation in panicles and capsules.

CONCLUSION

Based on the results of the present study, Spinetoram 11.7 SC was the most effective treatment against *S. cardamomi*, recording the lowest infestation of panicles and capsules and the highest capsule yield. Among the non-chemical treatments, NSKE @ 5%, horticultural mineral oil (HMO), *B. bassiana*, and *Br. suaveolens* leaf extract showed promising efficacy in reducing pest incidence. Further studies on the standardization of dosage, formulation, and application methods are warranted to enhance their field efficacy and facilitate their wider adoption in cardamom production systems.

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AUTHORS CONTRIBUTIONS

The authors, MN and MM conceived the experiment, performed the field evaluation, analyzed the data and prepared the initial draft of the manuscript; MNI and JSR provided literature and revised the manuscript; D & KK assisted in field evaluation and data analysis. All authors read and approved the manuscript.

CONFLICT OF INTEREST

Declare no conflict of interest among the authors.

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