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Sustainable Management of Insect Pests of Crops and Productive Insects

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Insect pests remain among the most pervasive constraints to agricultural productivity and ecological stability in India, where diverse cropping systems from rice–wheat plains of the Indo-Gangetic belt to pulse, cotton, and horticultural landscapes support the livelihood of millions. In an era of climate variability, warming trends, and altered monsoon patterns, insect pest dynamics have become increasingly unpredictable, with expanded geographic ranges, extended breeding seasons, and frequent outbreak cycles reported across major crops such as rice (e.g., brown planthopper), cotton (e.g., bollworms), pulses (e.g., pod borers), and vegetables (e.g., fruit borers and sap feeders) (Oerke, 2006; Vishal et al., 2025). These pest pressures translate into yield losses that markedly undermine food and nutritional security, equitable growth, and rural resilience (Deutsch et al., 2018).

In India, the ecological and socio-economic implications of insect pest damage are profound. Rice yield losses attributed to stem borers and planthoppers often exceed 10–15 %, cotton losses to bollworm complexes may reach 20–30 % in susceptible cultivars and pod borer infestations have significantly limited pulse productivity, compounding the nation's pulse deficit (Dhaliwal et al., 2010). Moreover, indiscriminate pesticide use has exacerbated secondary pest outbreaks, escalated resistance in target pests and threatened productive insects such as pollinators and silkworms, which are vital components of India's agricultural biodiversity and rural economies (Ndakidemi et al., 2016).

Ensuring food and nutritional security for a rapidly growing population under such conditions demands a fundamental transition from reactive, input-intensive pest control strategies to ecologically informed, sustainable pest management frameworks. Integrated Pest Management (IPM), rooted in ecological principles and systems thinking has emerged as the backbone of sustainable insect pest management in India. Nevertheless, the emergence of invasive pests, rapid development of insecticide resistance, loss of natural enemies and heightened vulnerability of productive insects have exposed the limitations of conventional approaches and highlighted the need for renewed scientific innovation and policy support.

In response to these imperatives, the Indian Ecological Society (IES), Ludhiana initiated this Special Issue of the *Indian Journal of Ecology* on **"Sustainable Management of Insect Pests of Crops and Productive Insects."** The manuscripts compiled in this special issue exemplify the advanced research, practical innovations, interdisciplinary integration and applied relevance required to address the converging ecological, climatic and socio-economic challenges of contemporary insect pest management. Collectively, these contributions reposition insect pest management within a broader ecological and sustainability discourse emphasizing long-term resilience over short-term control.

Reframing Pest Management: From Control to Ecological Regulation

Modern insect pest management must transcend the narrow objective of pest suppression and instead embrace the ecological regulation of pest populations. Agro-ecosystems are complex, dynamic systems in which pests, natural enemies, host plants and environmental drivers interact across spatial and temporal scales. Disruptions to these interactions often caused by indiscriminate pesticide use across rice, wheat, pulses, cotton, sugarcane and horticultural crops have led to pest resurgence, secondary pest outbreaks and the collapse of natural biological control mechanisms (Pimentel and Burgess, 2014).

The research presented in this special issue reinforces the centrality of ecologically based IPM, emphasizing the integration of cultural practices, habitat manipulation, biological control, host plant resistance, and judicious use of chemical inputs. Several studies demonstrate that cropping system diversification, optimized planting schedules, and conservation of non-crop habitats enhance natural enemy abundance and contribute to effective suppression of pest populations. These approaches promote ecological manipulation, farmer participatory learning, and crop- and region-specific IPM modules. Collectively, these findings reaffirm that sustainable pest management is not a standalone intervention but an emergent outcome of well-managed and ecologically balanced agro-ecosystems (Altieri and Nicholls, 2017). Contributions in this issue demonstrate the importance of pest forecasting, phenology-based interventions and climate-responsive IPM modules that anticipate pest pressure rather than merely reacting to damage.

Insect Biosystematics, Bioecology and Emerging Pest Scenarios

Accurate insect biosystematics and sound understanding of pest bioecology form the foundation of effective and sustainable pest management strategies. The manuscripts included under this section underscore the critical role of taxonomy, distributional records, and population ecology in responding to emerging and re-emerging pest threats in Indian agro-ecosystems. Contributions dealing with the taxonomic description and diagnostic differentiation of *Spodoptera frugiperda* and *S. litura*, along with detailed accounts on the predominance, seasonal dynamics, and demographic traits of fall armyworm across diverse agro-climatic regions, provide essential baseline information for surveillance, forecasting, and timely management interventions. Similarly, new pest records and studies on population ecology highlight the dynamic nature of pest assemblages under changing cropping patterns and climate variability.

The insect fauna associated with crop ecosystems further emphasize the importance of regional pest inventories for developing location-specific IPM modules. Inclusion of studies on Indian Odonata and ecosystem engineering broadens the ecological perspective of this section by drawing attention to beneficial insect diversity, trophic regulation, and ecosystem services beyond crop protection alone. These contributions reaffirm that robust pest diagnostics, continuous monitoring, and ecological understanding are indispensable for managing invasive pests, anticipating pest outbreaks, and designing resilient, ecosystem-based pest management strategies in Indian agriculture (Day et al., 2017; Prasanna et al., 2018).

Biological Control and Conservation of Beneficial Insects

Biological control constitutes one of the most ecologically sound and economically viable components of sustainable insect pest management. The manuscripts included under this section of the special issue provide substantial evidence on the role of predators, parasitoids, entomopathogens, and microbial agents, encompassing both classical and conservation biological control approaches. The studies collectively demonstrate that strengthening trophic interactions within agro-ecosystems contributes to stable and long-term suppression of insect pest populations, while simultaneously reducing dependence on chemical insecticides.

Considerable emphasis has been placed on the conservation of productive and beneficial insects, including pollinators such as honey bees and native bees, natural enemies, silkworms, and other economically important insects that play a crucial role in sustaining agricultural productivity and rural livelihoods. Pollinator decline has emerged as a global concern with direct implications for crop yields, ecosystem functioning, and nutritional security (Potts et al., 2016). The manuscripts highlight the adverse effects of pesticide exposure, habitat loss, and monoculture-based production systems on these beneficial organisms and propose ecologically compatible strategies such as habitat diversification, provision of floral resources, reduced-risk pesticide use and ecological engineering for their conservation. The collective findings reinforce the principle that conservation of beneficial insects is an integral component of sustainable pest management rather than a subsidiary objective.

Botanicals, Biopesticides, and Biorational Innovations

The shift towards sustainable pest management necessitates the adoption of safer and environmentally benign alternatives to conventional synthetic insecticides. Manuscripts presented under this section emphasize the growing importance of botanicals, microbial formulations, semi chemicals, and other biorational approaches for the management of key insect pests in major crops such as rice, maize, pulses, cotton and horticultural crops. These interventions are characterized by target specificity, biodegradability, reduced non-target effects, and compatibility with IPM programmes. Several studies document the efficacy of plant-derived compounds, microbial agents such as *Bacillus thuringiensis* and entomopathogenic fungi and pheromone-based techniques for monitoring and management of insect pests across diverse agro-ecological regions. Importantly, the research also addresses the issue of insecticide resistance indicating that diversification of pest management strategies through botanicals and biopesticides can contribute to resistance management and improve the long-term sustainability of pest control programmes (Sparks and Nauen, 2015).

Host Plant Resistance and Emerging Molecular Approaches

Host plant resistance represents one of the most sustainable, cost-effective and farmer-friendly strategies for insect pest management. The contributions included under this section of the special issue address resistance mechanisms across major cropping systems, with studies focusing on resistant rice genotypes against gall midge, groundnut lines exhibiting enhanced tolerance to *Caryedon gonagra*, and cotton germplasm with improved resistance to sucking pests. Such resistance-based approaches play a crucial role in reducing pest pressure and minimizing reliance on external chemical inputs (Smith, 2005). Several manuscripts examine resistance-linked morphological, physico-chemical, and biochemical traits that influence pest preference, survival, and population buildup. Investigations on specific plant traits that contribute to resistance against insect pests, demonstrate the befitting role of host plant resistance in integrated pest management. These findings enhance the understanding of host–pest interactions and provide valuable trait-based information for incorporation into crop improvement programmes (Smith and Clement, 2012).

Advances in genomics, molecular breeding, and marker-assisted selection are also reflected in the contributions, highlighting their potential as transformative tools for the development of insect pest-resistant crop varieties. Modern breeding approaches facilitate precise identification and deployment of resistance genes, thereby accelerating the development of resilient cultivars adapted to diverse agro-ecological conditions (St Clair, 2010). In addition, manuscripts dealing with the molecular characterization of native *Bacillus thuringiensis* strains and the morphological and molecular identification of indigenous entomopathogenic fungi (*Beauveria bassiana* and *Metarhizium rileyi*) complement host plant resistance by strengthening biological components of IPM, enhancing overall system robustness (Lacey et al., 2015). The studies under this section align closely with sustainability goals by improving yield stability under pest pressure, lowering production costs, and minimizing environmental risks. They emphasize the integration of host plant resistance with biological control, cultural practices, and other IPM components for sustainable insect pest management.

Technology, Decision Support and Precision Pest Management

Technological innovation is increasingly reshaping insect pest management by enhancing precision, timeliness and operational scale. The manuscripts included in this special issue highlight the application of unmanned aerial vehicles (UAVs) for pest management, demonstrating their potential in pest management. Such technologies contribute to reduced pesticide use, thereby minimizing unnecessary chemical inputs and associated environmental risks (Huang et al., 2013). However, as emphasized across the contributions, technological tools must function as enablers of ecologically sound pest management rather than as substitutes for ecological understanding. Precision pest management when aligned with IPM principles, emerging technologies such as UAVs and digital surveillance systems can support informed decision-making, reduce selection pressure for resistance, and strengthen the long-term sustainability of pest management strategies (Pedigo and Rice, 2014).

Governance, Policy and Farmer-Centric Approaches

Sustainable pest management is ultimately shaped not only by technological and biological innovations but also by enabling institutional frameworks, coherent policy support and meaningful farmer engagement. The collective evidence presented highlights the critical role of policy frameworks that encourage ecological pest management, rationalize pesticide use, and promote the development and deployment of biopesticides and other safer alternatives. Strengthening linkages among researchers, extension agencies, policymakers and farming communities remains essential for translating IPM principles into field-level impact, thereby ensuring that pest management interventions are productive, profitable and environmentally responsible (Pretty and Bharucha, 2015; van den Berg et al., 2020).

Way Forward

The collective insights from the manuscripts in this special issue demonstrate that sustainable management of insect pests and productive insects is both scientifically feasible and operationally achievable. However, realizing this potential requires a decisive shift from short-term, input-intensive control measures toward integrated, ecology-driven and climate-resilient pest management frameworks. As agriculture confronts escalating pressures from climate change, biodiversity loss and resource constraints, insect pest management must be reimagined as a central component of agro-ecosystem sustainability. The research compiled in this special issue provides robust evidence, practical innovations and conceptual clarity to guide this transition.

The Indian Ecological Society's initiative in curating this special issue reflects a commitment to advancing ecological science in service of sustainable agriculture. It is hoped that the knowledge synthesized herein will inform future research, shape policy discourse and support practitioners in building resilient, productive and environmentally responsible agricultural systems.

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Taxonomic Description for Identification of *Spodoptera frugiperda* (J.E. Smith) and *Spodoptera litura* (Fabricius)

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Abstract: The fall armyworm, a polyphagous pest is of major economic importance worldwide. This study presents a comparative analysis of the taxonomic characters of two species belonging to genus *Spodoptera i.e., S. frugiperda* and *S. litura* (Noctuidae: Lepidoptera). These two species are re-described based on morphological taxonomic characters of adult, larval and pupal stages, as well as the male and female genitalia. *Spodoptera litura* is also a major pest of several economically important crops in Asia, across diverse crop ecosystems in India. Its close resemblance with *S. frugiperda* in larval stages necessitates precise taxonomic identification for effective management. Photographic illustrations and descriptions are provided for both species.

Keywords: Taxonomy, *Spodoptera*, Chaetotaxy, Genitalia, Crochets, Morphology

The word Noctuidae (owlet moths, cutworms or armyworms) is derived from the name of the type genus *Noctua*, which is the Latin name for the little owl, the names "armyworms" and "cutworms" are based on the behaviour of the larvae of this group, which can occur in destructive swarms and cut the stems of plants (Regier et al., 2017). Currently, Noctuidae is the second largest family in Noctuoidea, with about 1,089 genera and 11,772 species worldwide (Zhang 2011). The genus *Spodoptera* was first described by Guenee in 1852.About thirty species are distributed across six continents (Meagher et al., 2008, Nagoshi et al., 2011, Mahmoud et al., 2020). Many species are considered as threat to agriculture around the world. The caterpillars of *Spodoptera* are highly polyphagous, nocturnal insect pest with wide host range over 40 families of dicotyledonous plants and therefore, has huge potential to invade new areas and to adapt to new climatic and ecological situations.

The fall armyworm (FAW), *Spodoptera frugiperda* (J.E.Smith) (Lepidoptera: Noctuidae) is invasive, highly polyphagous insect pest originating from the tropical and sub-tropical regions of the America, where it has more than 350 different host plants under 76 different families including both crop and non-crop species (Montezano et al., 2018). It expanded its habitat to two more continents (Early et al., 2018, Nagoshi et al., 2018, Pogue 2002). The incursion of Fall armyworm as an invasive pest was first reported in India 2018 in the maize fields of College Farm, University of Agricultural and Horticultural Sciences (UAHS), Shivamogga, Karnataka (Sharanabasappa et al., 2018, ICAR-NBAIR Pest alert, 2018, Shylesha et al., 2018). The pest has also been reported on different crops from all states of India (Chormule et al., 2019a, 2019b, Srikanth et al., 2019, Bhavani et al., 2019). The larvae of *S. frugiperda* causing extensive damage to economically important crops *viz.,* maize (77.2%), sorghum (60.1%), rice, sugarcane, cabbage, soybean, tomato etc. (Georgen et al., 2016, Burtet et al., 2017, Capinera, 2017, Sisodiya et al., 2018, Lamsal et al., 2020). As it is a major pest of many crop ecosystems in subtropical India, highlights the need for accurate species identification.

Tobacco cutworm, *S. litura* is a major pest of several economically important crops in Asia, particularly cotton, groundnut, and vegetables. Its close resemblance with *S. frugiperda* in larval stages necessitates precise taxonomic identification for effective management. Therefore, the present investigation aims to know the morphological and taxonomic characters of the genus *Spodoptera*, *i.e., S. frugiperda* and *S. litura* at different stages of its growth along with their genital characters.

MATERIAL AND METHODS

Different life stages (eggs and larva) of *S. litura* and *S. frugiperda* were collected during *Rabi* 2019-20 from the experimental and farmer's fields (longitude 83.94^{0,} latitude 18.38^{0}) and brought to laboratory, Department of Entomology, College of Agriculture, Naira, Srikakulam, Andhra Pradesh. The host plant, castor (*Ricinus communis*) leaves used for rearing larvae and feed is changed every day. The culture was maintained by providing fresh leaves until pre pupal stage under room temperature (27^{0}c and 65-70% RH). At pre-pupal stage larvae transferred to the bed of soil was laid at the bottom of cages to facilitate pupation and covered with muslin cloth, tied with rubber band.

Processing and preservation: The emerged adults were collected and killed using a cotton swab dipped in ethyl acetate and pinned through thorax using nickel coated entomological pins. The adult specimens were dried in hot air oven at 40° C and preserved in insect wooden cabinet boxes (45 cm x 30 cm) for further study. The larvae at each instar were processed and preserved in K.A.A.D mixture, using the ingredients kerosene-1 part, 95 per cent ethyl alcohol- 7 parts, glacial acetic acid- 2 parts and dioxane-1 part and stored in glass jar and labelled. Each specimen was labelled with the details pertaining to date of collection, locality, name of collector and host.

Morphological and genital studies: The procedure advocated by Knight (1965), Rose and Pathania (2003) were followed for mounting, chaetotaxy, abdominal segments, crochets on ventral prolegs of larvae and for genitalia studies, for accurate identification of the adult species, the male and female genitalia were dissected out under the Luxeo 4D Stereo Zoom Binocular Microscope by using minutons following the technique given by Knight (1965).

Illustrations and photography: The photographs of specific characters of larvae, pupae, genitalia and adult wings of both male and female were taken using camera. The photographs of chaetotaxy of thoracic segments, 3rd abdominal segment, arrangement of crochets on the ventral prolegs and genital structures with the help of Olympus Trinocular Research Microscope. The dissected genital structures and illustrations were also made with the help of same microscope using micap 3.6 digital camera attachment using the software under 40 to 100X magnification. All the measurements expressed in cm or mm, using micrometry under Stereo Zoom Binocular Microscope.The drawings were made on tracing paper by using Rotring tikky graphic pen. Identification of adult specimens was done by comparison with photographic plates and various online resources available, using the EPPO bulletin, 2015.

RESULTS AND DISCUSSION

Two species belong to genus *Spodoptera viz*., *S. frugiperda* and *S. litura* were observed for their morphological and genital characters along with larval taxonomic characters of each instar.

***Spodoptera frugiperda* (J.E. Smith 1797)**

Common name: Fall armyworm, Alfalfa worm, corn leafworm, cotton leafworm, grass worm, maize budworm, wheat cutworm.

Morphological Characters

Larva: The 1st instar larva (L_1) very tiny with large black head and the body light greenish colour covered with minute black hairs (Plate 1A). The length of the body is about 0.7 mm. The Second instar (L_2) is measures approximately about 12 to 15 mm length. Head is amber to cream coloured with blackish brown head capsule. Body pale white to yellowish and a brown tinge on the dorsum and also with faint white dorsal and sub-dorsal lines are present. A pinkish line below the spiracle, especially on the posterior abdominal segments (Plate 1B). The 3rd instar (L_3) is in light green to cream coloured with three longitudinally light lines. At this stage body colour changes from pale white to greenish brown. White lines on dorsal and subdorsal areas are plainly visible and the black spots became prominent. The length of body is about 21 to 23 mm. The 4th instar larvae (L_4) body colour varied from olive brown to dark brownish with red pigmentation. The dorsal and sub-dorsal white lines are also become conspicuous. The body length is about 24 to 27 mm. The body of 5th instar larvae (L_5) attained grayish brown to cream colour on the dorsal side and on ventral and sub-ventral sides are greenish. Head with dark brown areas and is in brick red colour. Body length is about 26 to 29 mm.

The 6th larval instar (L_6) is stout and bulged with dark grey head. Body is smooth with clear distinct segmentation. The body is grayish brown to reddish cream on the dorsum and lateral white lines with ventral, sub-ventral sides greenish mottled with reddish brown colour. The mature larva has an inverted '**Y**'- shaped white marking on the head (Plate 1D) and distinct dark spots on the body. On the dorsum of 8th abdominal segment four black spots arranged in square pattern and on remaining segments spots are in trapezoidal shape as shown in Plate 1C. The length of larvae at this stage is 32 to 36 mm.

Chaetotaxy of Thoracic and Abdominal Segments

Thorax: On first thoracic segment SD_1 and SD_2 setae are present on a joint pinaculum at ventral to thoracic shield and at ventral side of the thoracic shield. On prothoracic shield dorsal setae XD_1, XD_2 and dorsal setae D_1, D_2 are present. L_1 and L_2 setae are hair like and situated on ventral margin of spiracular line (Plate 1G). But the L_3 setae is about half the length of L_1 and L_2. On meso and meta thoracic segments spiracles are absent. The crochets on 3rd to 6th abdominal segments are arranged in uniordinal mesoseries heteroideous pattern (Plate 1E, F).

Abdomen: Third abdominal segment with dorsal setae D1, D2 are arranged in trapezoidal pattern. SD_1 is present just above to the spiracle and also with subventral setae SV_1, SV_2, SV_3 and lateral setae L_1, L_2 and L_3 (Plate 1H). The present observations of larval morphological characters, chaetotaxy and crochets arrangement on the ventral prolegs are in parallel with the earlier studies Pogue (2002), EPPO (2015), Shylesha et al. (2018), Venkateshwarlu et al. (2018) Bhavani et al. (2019), Lestari et al. (2020), Kalyan et al. (2020) and Henaish and Elmetwaly (2020).

Pupa: Reddish brown pupa with white tinge. It is measured about 15-18 mm in length, with a cremaster consisting of two spines are about 0.5 mm long. The observations are in conformity with findings of Sharanabasappa et al. (2018) and Manjula et al. (2019).

Adult: In males, front wings are darker than females. The forewings are with discrete markings of light grayish brown shades and with white patch near apical margin. Reniform spot is indistinct at the center of the wing, partially outlined in black with small "V"- shaped marking (Plate 1I). Orbicular spot is in light brown colour, oval and oblique in shape with strongly contrasting crosswise lines and also with a row of small black hour-glass shaped markings near the apical margin of wing. Measurements- body length: 1.5- 2.0 cm; front wing length: 1.4 – 1.6 cm; hind wing length: 1.1- 1.3 cm; wing span: 2.9 – 3.2 cm.

In female, body is robust when compared to males. The female forewing is without reniform spot and contrasting markings near the apical margin. Forewing is imprecise with uniform grayish brown to fine mottling of gray colour (Plate 1J). Orbicular spot is obliquely elongated, narrowly outlined in black with a pale rim in the region of the dark center. The hind wings of male and female are silver -white in colour with partial narrow light brown to pale gray border. Measurements- body length: 1.5 1.7 cm; front wing length: 1.4 – 1.5 cm; hind wing length: 1.2 – 1.4 cm; wing span: 3.2 to 3.4 cm. The described results are in conformity with earlier studies Oliver and Chapin (1981), Pogue (2002), Brambila (2013), Manjula et al. (2019), Bhavani et al. (2019), Sharanabasappa et al. (2018) and Henaish and Elmetwaly (2020).

Genitalia: The male genitalia is characterized by the coremata is with single lobe (Plate 1K) and adeagus well developed. Valve is broad, almost quadrate with tiny clavus. The female genitalia is identified by ostium bursa ventral plate height is greater than width (Plate 1L), ventro lateral ductus bursae are short and completely sclerotized. Appendix bursae are partially sclerotized. The bulbous corpus bursae length is less than the width. The results of genital characters were in conformity with the observations of Oliver and Chapin (1981), Brambila (2013), Ganiger et al. (2018), Bhavani et al. (2019), Sharanabasappa et al. (2018) and Henaish and Elmetwaly (2020).

***Spodoptera litura* (Fabricius 1775)**

Common name: Tobacco cutworm, cotton leaf worm, tropical armyworm, tobacco caterpillar.

Morphological Characters

Larva: The newly emerged 1^{st} instar (L_1) is light green to yellow in colour with black head as shown in Plate 2A; an amber-brown spot is below SD_1 at first abdominal segment, this spot later on develop into a large dark lateral spot. The length of larvae is about 0.7 to 0.9 mm. The 2^{nd} and 3^{rd} instar larvae (L_2, L_3) are recognized by increasing size of dark spot SD1 on first abdominal segment (Plate 2B). As it grows the spot turned into black colour at early 2^{nd} instar and become more prominent during 3^{rd} instar stage. On the 2^{nd} and 3^{rd} thoracic segment and at eighth abdominal segment dark spots develop at D1 position and also small black dorsal spots develop on the other segments. The second instar length is about 8 to 10 mm. Dark spot on 2^{nd} and 3^{rd} thoracic segments turns into yellow to white dot by the end of 3^{rd} stage, except dark spot on eighth abdominal segment. Small yellow to white dots at the base of black patches present on 2^{nd} and 3^{rd} thoracic segments (Plate 2C). The dark lateral spot on first abdominal segment extend laterally (Plate 2D).

The third instar is 9-13 mm in length. The 4^{th} instar larvae (L_4) are in brown or greenish colour with brown to black coloured head. The body is stout and about 25 to 30 mm in length. The dark patches on dorsal side, most prominently on 1^{st} and 8^{th} abdominal segments with yellow or orange mid dorsal line (Plate 2C).

The older instars like 5^{th} and 6^{th} are stout, cylindrical and reddish brown in colour. Two black dorsal patches on meso and meta thoracic segments. Larvae have orange mid dorsal line and sub dorsal line marked by yellow and orange spots. Mid dorsal stripe and dorsolateral stripes are yellow with black segmental spots. Late instar has dark patches on first and eighth abdominal segments (Plate 2D). The full grown larvae are about 39-42 mm length.

Chaetotaxy of Thoracic and Abdominal Segments

Thorax: On prothoracic segment shield highly sclerotised, anterior dorsal setae XD_1, XD_2 and dorsal setae D_1, D_2 are distinct on prothoracic shield. Sub ventral setae SV_1 and SV_2 are distinct (Plate 2F). Lateral setae L_1, L_2 with microscopic setae MV_1, ventral seta V_1 present. Mesothorax with dorsal setae D_1, D_2 and sub dorsal setae SD_1, SD_2 distinct. Lateral setae L_1, L_2 and L_3 present. Sub ventral seta SV_1, ventral seta V_1 and microscopic setae MV_1 and MV_2 present. Black dorsal patches on 2^{nd} and 3^{rd} thoracic segment are smaller than the patches present on the first abdominal segment.

Abdomen: Third abdominal segment is with dorsal setae D_1 and D_2. Sub dorsal seta SD_1 distinct. Lateral setae L_1, L_2 and L_3 present below the spiracle. Sub ventral setae SV_1, SV_2 and SV_3 and ventral seta V_1 are present (Plate 2G). Crochets on prolegs are arranged in uniordinal mesoseries heteroideous pattern as shown in Plate 2E.All the described larval and chaetotaxy characters are in concurrence with the findings of Arunasri (2006) and Giligan and Passoa (2014).

Pupa: The *S. litura* pupa is brown in colour and about 15-22 mm in length. It has a cremaster consisting of two spines of about 0.5 mm long (Plate 2H). The pupal characters are in corroboration with EPPO (2015).

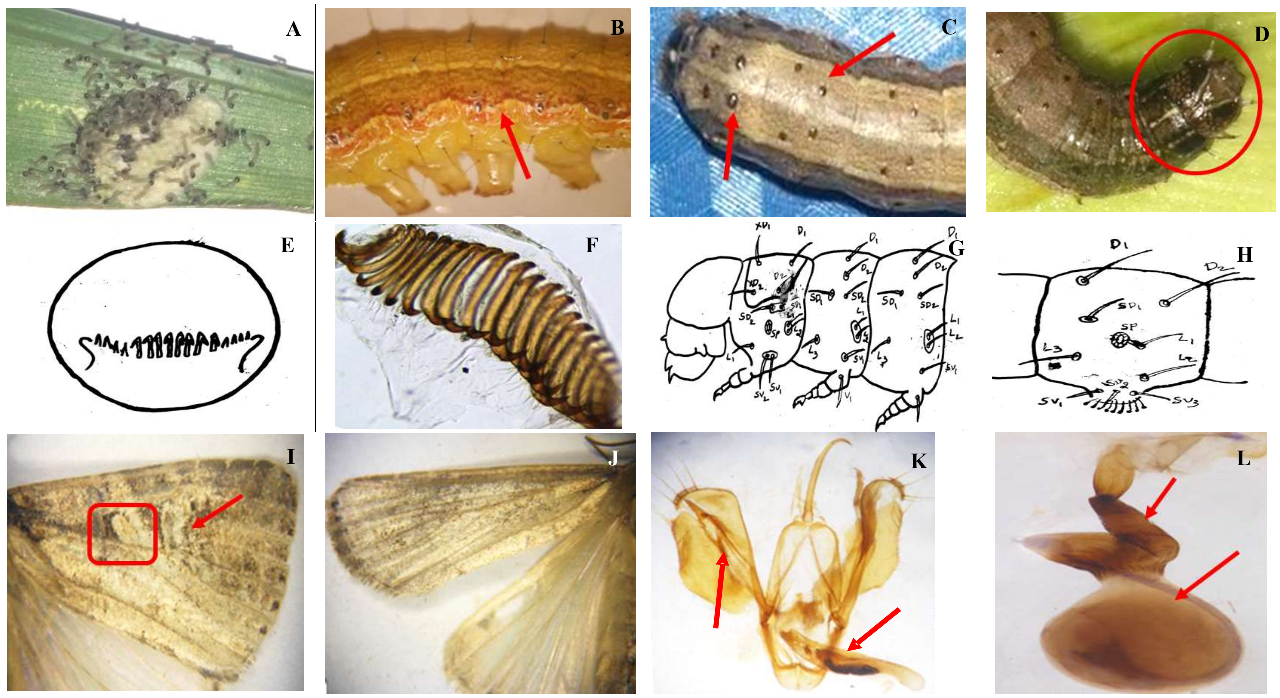

Plate. 1. *Spodoptera frugiperda* (A-L) A. First instar with black head; B. Pinkish line below the spiracle; C. Four black spots on 8th segment in perfect square shape and on remaining segments in trapezoid shape; D. An inverted "Y"- shaped white marking on head; E&F. Uniordinal mesoseries heteroideous type of crochets; G. Chaetotaxy of thoracic segments; H. Chaetotaxy of 3rd abdominal segments; I. Fore wing of male*;* J. Forewing of female with orbicular spot and 'V' shaped reniform spot; K. Male genitalia coremata with single lobe; L. Female genitalia corpus bursae is short and ductus bursae is short and completely sclerotized

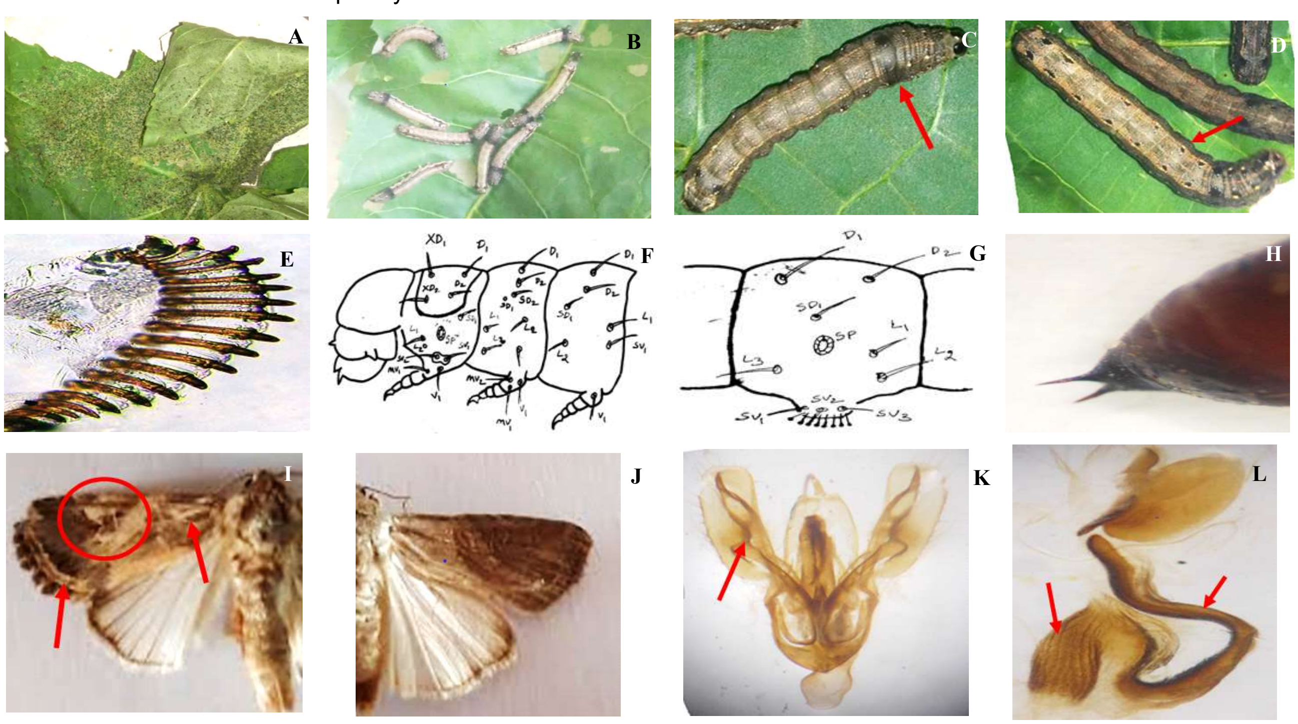

Plate. 2. *Spodoptera litura* (A-L) A. first instars in light green -yellow colour with black head; B. Second instar; C. dark spot on first abdominal segment; D. 2nd, 3rd thoracic segments and all abdominal segments with yellow to white dots; E. crochets in uniordinal mesoseries heteroideous; F. Chaetotaxy of thoracic segments; G. chaetotaxy of 3rd abdominal segment; H. pupa of *S. frugiperda* and *S. litura* with a pair of spines; I. fore wing of male with reniform spot and white fork; J. fore wing of female; K. male genitalia coremata with two lobes; L. female genitalia with long corpus bursae and heavily sclerotized ductus bursae

Adult: The adult male body length is 1.3 cm, fore wing length is 1.4 cm, hind wing length is 1.0 cm and wing span is about 3.2 cm. The adult forewing with a brown reniform spot, with a white margined light brown area at tips, is like a letter "A" as shown in Plate 2I. Orbicular spot is elongate, narrow, oblique trapezoid, light brown and with a light brown center outlined with white border and a row of dark hour-glass shape markings along the outer margin of wing (Plate 2I). Hind wings are opalescent and semi hyaline white with dark brown patch on the margin.

The adult female moth is robust and the body length is 1.4 cm, forewing length 1.6 cm, hind wing length 1.2 cm and wing span 3.3 cm; forewing is without a large yellowish or light brown patch (Plate 2J). These identified characters are in compliance with the observations of Pogue (2002), Brambila (2013), Muddasur and Venkateshalu (2017) and Manjula et al., (2019).

Genitalia: Male genitalia characters are depicted as the coremata with two lobes; one is shorter and another longer and uncus is long and slightly curved (Plate 2K).Valve is elongated, well differentiated with two windows, among them one is triangular and another in rectangular shape separated by a right angle at the center. The female genitalia consist of corpus bursae which is bulbous and its length is two folds more than the width with striate convolutions (Plate 2L). Ductus bursae are heavily sclerotized and its length is three times greater than width and ostium bursae is broad, less sclerotised. The descriptions of the present investigation are in conformity with the findings of Brambila (2009), EPPO (2015) and Ganiger et al. (2018).

CONCLUSIONS

The present study provides a comparative taxonomic description of two species of *Spodoptera viz., S. frugiperda, S. litura* highlighting diagnostic morphological, morphometrics and genital characters of each species across larval, pupal, adult, and genital stages with their key characters. Clear differences such as the inverted "Y" mark on the head and square arrangement of spots on the 8th abdominal segment in *S. frugiperda*, and the prominent lateral abdominal spot and double-lobed coremata in *S. litura*, enable reliable species separation. These diagnostic characters are particularly important for rapid field identification and accurate taxonomic confirmation, which in turn support timely pest monitoring and management strategies. As both species are highly destructive polyphagous pests, precise species identification is essential for implementing effective control measures and preventing economic losses in diverse cropping systems.

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New Record of Leafhopper *Hishimonus viraktamathi* on Blackgram in Coastal Andhra Pradesh

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Abstract: Eighteen species of leafhoppers belonging to the family Cicadellidae were associated with blackgram ecosystems, of which one species *viz*., *Hishimonus viraktamathi* Knight, 1973 is identified first time in Andhra Pradesh during 2022-2024 constituting a new distributional record. This species was identified based on the shape and length of the head, length of the pronotum, serrations and number of micro and macro setae on the subgenital plates of the male genitalia structures. Adequate description of the species was provided along with illustrations for quick identification. In addition, a diagnostic key with illustrations is presented for the identification of the remaining species associated with blackgram.

Keywords: Cicadellidae leafhopper, *Hishimonas viraktamathi* Knight, Subgenital plates, Male genitalia.

Leafhoppers (Hemiptera: Cicadellidae) are an economically important group belonging to suborder Auchenorrhyncha. The family Cicadellidae is one of the largest groups of exopterygote insects, comprising about 2,445 described genera and 22,637 species worldwide and about 340 genera and 1,350 species in India (Viraktamath 2006). They are widely distributed and many are serious pests of many economic crops. Few groups of leafhopper genera act as vectors and transmit phytopathogenic organisms that cause diseases and eventual death of plants, a well know example is the *Hishimonus phycitis* (Distant) transmitting little leaf of brinjal. *Empoasca kerri* is a major sucking pest of blackgram, with populations appearing from the seedling stage and continuing up to pod formation. Peak infestation is typically observed around the 37th standard meteorological week, with an average of 7-8 jassids per leaf. Its incidence is strongly influenced by climatic factors, showing positive correlations with minimum temperature, relative humidity, and vapor pressure, and negative correlations with evapotranspiration, rainfall, and wind speed. Due to its persistent presence and impact on plant health, *E. kerri* is considered a key pest in blackgram cultivation in India.

Literature on the occurrence of leafhoppers in a particular crop ecosystem and their identification "keys" are very meager. Viraktamath (1983) emphasized illustrations of economic species of leafhoppers and preservation of voucher specimens in recognized institutions. Jacob et al. (2000) reported forty species belong to 20 genera associated with oilseed crops from Andhra Pradesh and provided illustrated key for their identification. Jacob et al. (2002) reported 41 species of leafhoppers including twelve new records associated with pulse crop *viz.,* greengram, blackgram, pigeonpea, chickpea, soybean, horse gram, and cowpea ecosystems in Andhra Pradesh. Giridhar et al. (2008) studied leafhopper fauna associated with sugarcane ecosystems of South India and reported 22 leafhopper species. Nagesh et al. (2018) reported fifteen leafhopper species associated with maize and sorghum crop ecosystems of Rayalaseema region of Andhra Pradesh and provided illustrated key for their identification. A detailed identification of 14 leafhopper species under two tribes *viz*., Empoascini and Erythronuerini of the subfamily Typhlocybinae collected from different agricultural and horticultural crop systems was reported by Sangeetha et al. (2020).

In the present investigation, 18 leafhopper species were recorded on blackgram, of which detailed description of the species is available in the literature for 17 species in Andhra Pradesh except for *Hishimonus viraktamathi* Knight, which is reported for the first time in Andhra Pradesh. The objective of the present study is to document the diversity of leafhoppers associated with blackgram in Coastal Andhra Pradesh and to report *H. viraktamathi* as a new record for the state, providing diagnostic features and identification keys for associated species for the use of both economic entomologists and extension field workers. Accurate identification of leafhopper species is crucial for developing appropriate pest management strategies. Various workers in India and abroad have done revisionary works in many genera of leafhoppers (Cicadellidae: Hemiptera) but the literature pertaining to studies and identification techniques of leafhoppers encountered in the specific crop Agro-ecosystems are limited in India. The present investigation was conducted on leafhopper fauna associated with blackgram (*Vigna mungo*) in Coastal districts of Andhra Pradesh *viz*., Srikakulam, Visakhapatnam, Anakapalli, Kakinada, Konaseema, East Godavari, West Godavari, Eluru, Vizianagaram, Krishna, NTR, Guntur, Palnadu, Bapatla, Prakasam and Nellore during 2022-2024.

MATERIAL AND METHODS

Collection, drying and preservation of the specimens: The leafhopper collections were made intensively on blackgram with about 15-20 to and fro insect net sweepings each time. The leafhoppers were aspirated from the net, killed with ethyl acetate swabs and transferred to small glass vials with cork or plastic stoppers, labelled, brought to the laboratory and dried in an hot air oven at 45 - 50^{0}C for about 2-3 hours. Dried specimens were preserved in the homeopathic vials. The vials were properly labelled with collection details, *viz*., name of the collector, collection date, location of collection and host.

Processing of leafhopper for study: For mounting and preparation of genitalia the procedure advocated by Knight (1965) was adopted. The collected leafhoppers were taken to the lab, where they underwent processing, were mounted on thick card triangle mounts and were labelled with the information about the collection, including the host, location, date, and name of the collector.

Preparation of male genitalia: The specimen was carefully placed on a China clay block on its back. Then, using minutons (sharp micro needles) the abdomen was separated from the thorax under a Stereoscopic Zoom Binocular Microscope (CSM2, LABOMED) by applying pressure at the point where the thorax and abdomen met. To aid in the digestion of soft tissues, the abdomen was then placed into a cavity block with a few milliliters of 10% KOH and kept for 10 hours at room temperature. Following 2-3 washes in distilled water, the abdomen was placed on a glass cavity slide with a drop of glycerine for further dissection (separation of the genital organs from the genital capsule) under stereoscopic microscope. The line diagrams of male genitalia were drawn after dissection using Olympus Research Microscope with camera lucida attachment. Whole insect specimens were photographed using Leica S-9 Optical Stereo Zoom Microscope attached with digital analyzer at 10X magnification and micro photographs of genital structures were taken with Olympus Trinocular Research Microscope fitted with photographic attachments and digital analyzer at 40X magnification. Conformation of the species was done by comparing the observed male genitalia parts with keys and literature.

RESULTS AND DISCUSSION

In the present study, 18 species of leafhoppers belonging to 13 genera were collected and identified as; (1) *Aconurella neosolana* (Ramasubbarao and Ramakrishnan); (2) *Austroagallia bifurcata* Sawai Singh and Gill; (3) *Balclutha incisa* (Matsumura); (4) *Balclutha pararubrostriata* Ramasubbarao and Ramakrishnan; (5) *Balclutha saltuella* (Kirschbaum); (6) *Batracomorphus angustatus* (Osborn); (7) *Cicadulina bipunctata* (Melichar); (8) *Empoasca* (*Distantasca*) *terminalis* Distant ; (9) *Empoasca* (*Empoasca*) *kerri* Pruthi; (10) *Empoascanara maculifrons* (Motschulsky); (11) *Exitianus indicus* (Distant); (12) *Hecalus porrectus* (Walker); (13) *Hishimonus phycitis* (Distant); (14) *Hishimonus viraktamathi* Knight; (15) *Maiestas acuminatus*

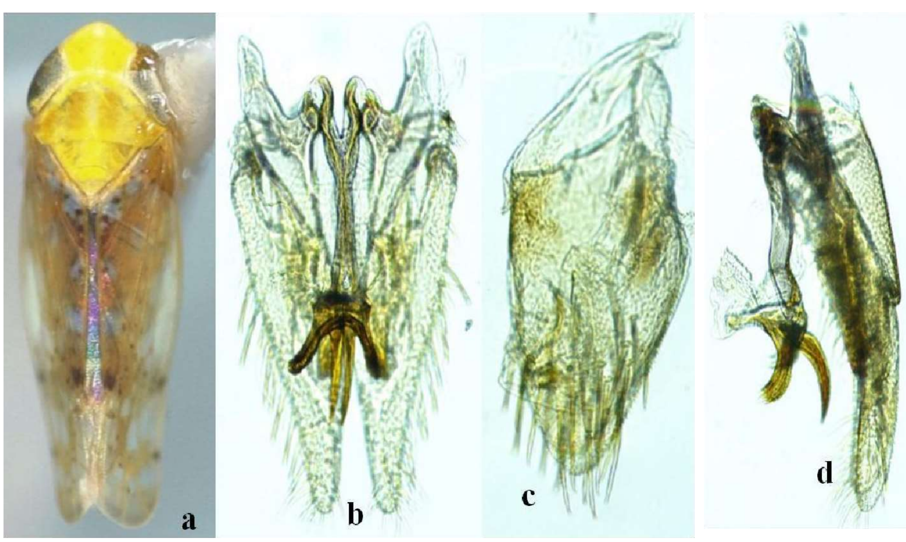


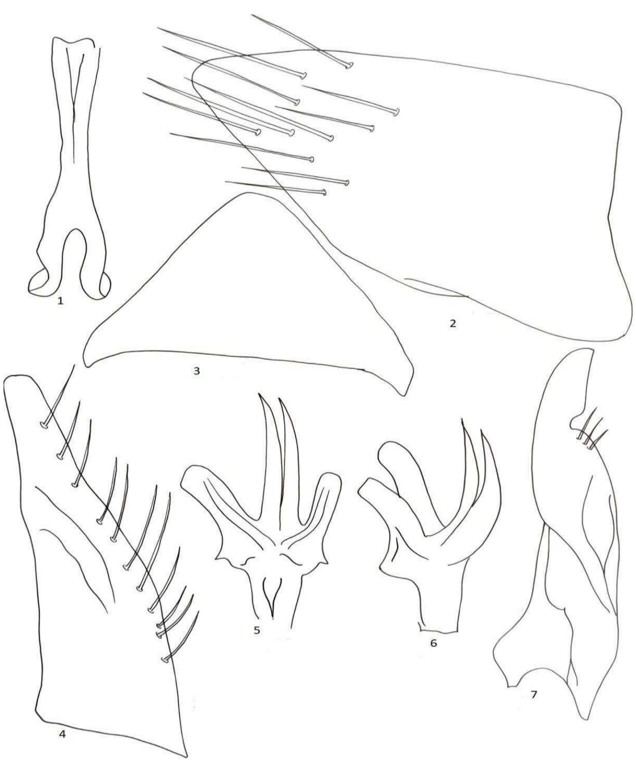
Plate 1. *Hishimonus viraktamathi* Knight a. Adult dorsal view; b. Male genitalia; c. Pygofer lateral view; d. Aedeagus lateral view

(Dash and Viraktamath); (16) *Maiestas dorsalis* (Motschulsky); (17) *Scaphoideus harlani* Kitbamroong and Freytag; and (18) *Yamatotettix sexnotatus* (Izzard).

A perusal of literature indicated that one of the leafhopper species *Hishimonus viraktamathi* Knight was recorded for the first time on blackgram in Andhra Pradesh.

Description of *Hishimonus viraktamathi* Knight : Head is light orange to creamy white; pronotum, scutellum and scutum are yellow. The forewings are hyaline with light and dark brown mottling, the veins are reddish brown, and the ventral side of the thorax is pale and sometimes speckled with dark brown marks. Abdomen is dark brown with golden lateral margins. legs light yellowish, stramineous in appearance. Head equal to or greater than pronotum in width. Subacute vertex, widely rounded at the face. Ocelli situated between the eyes on the anterior edge of vertex. Clypellus elongated with small expansion near the tip. Genal margins bend downward below the eyes. Pronotum is twice as long as the vertex. Tegmina with four apical and three anteapical cells.

The pygofer, in lateral view appears longer than its height, with widely rounded posterior edge and limited macrosetae on posterior half. Valve triangular, posterior angle more widely rounded and is more than 1.5 times longer at the base than it is medially. Subgenital plates are elongate, triangular with marginal and uniseriate setae in addition to short, hair-like setae. Style broad at base, subapical lobe well-developed, apophysis bifid, ventrally oriented. Connective 'Y' shaped, stem is roughly equal to the arms. Aedeagus with short cylindrical shafts that curve slightly dorsal, surface with many tiny denticles; gonopores apical. A pair of long, narrow processes arise between the bases of the shafts, closely opposed, about twice the length of aedeagal shaft. They extend posteriorly and curves slightly dorsally, and it has a row of small teeth along the distal half of the lateral surface.



Hishimonus viraktamathi Knight: 1. Connective, 2. Pygofer lateral view, 3. Valve, 4. Subgenital plate, 5. Aedeagus dorsal view, 6. Aedeagus in lateral view, 7. Style

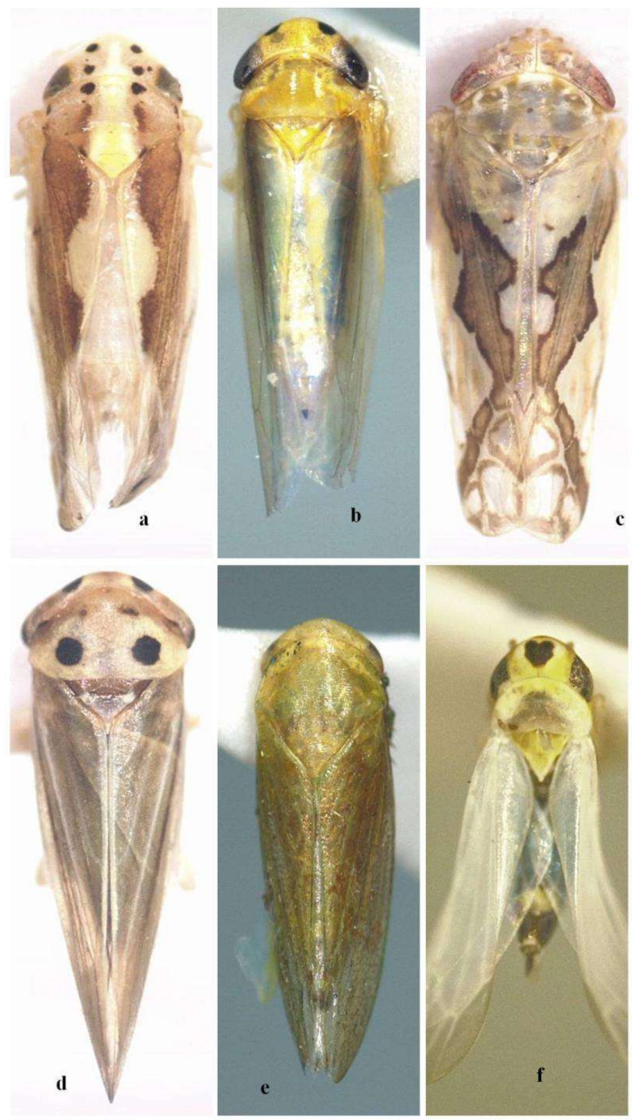


Plate 2. a. *Yamatotettix sexnotatus* (Izzard): Adult dorsal view; b. *Cicadulina bipunctata* (Melichar): Adult dorsal view; c. *Maiestas dorsalis* (Motschulsky): Adult dorsal view, d. *Austroagallia bifurcata* Sawai singh and Gill: Adult dorsal view; e. *Batracomorphus angustatus* (Osborn): Adult dorsal view; f. *Empoascanara maculifrons* (Motschulsky): Adult dorsal view

Measurements

Total length including forewings 1.80 mm, width of the body 0.49 mm. length of the head 0.18 mm, width across the compound eyes 0.31 mm. Length of the pronotum 0.26 mm, length of the scutellum 0.21 mm, length of the wing 1.53 mm and width of the wing 0.286 mm. Length of the male genitalia (including subgenital plates) 0.47 mm and length of the aedeagus 0.13 mm.

Keys for Identification of Leafhopper Fauna Associated with Blackgram Crop Ecosystems

1. Forewings with anteapical cells………………………2

-Forewings without anteapical cells (Fig. 8)...…………..…16

2. Forewings with two anteapical cells (Fig. 10)….………3

-Forewings with three anteapical cells (Fig. 9)…..…8

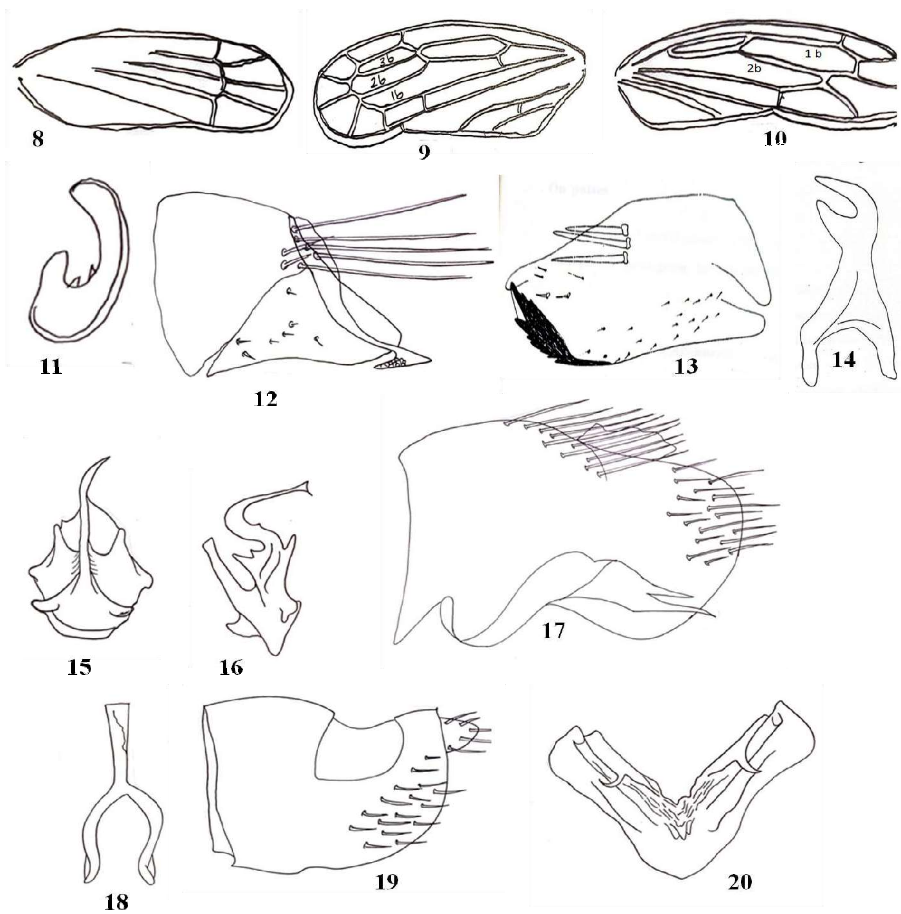
3. Pale brown coloured with a longitudinal pale cream coloured band in the middle from anterior margin of vertex to the apex of tegmina; vertex and pronotum with three pairs of black spots; dorsum of tegmina with a golden stripe running longitudinally that is noticeably wider on the forewing clavus (Plate 2a)……...***Yamatotettix sexnotatus*** **(Izzard)**

-Insects yellowish orange or yellowish green; tegmina with or without distinct colouration, vertex and pronotum without any spots or with a maximum of two spots ……..............…4

4. Yellowish orange coloured insects; dorsal side of the abdomen black in colour. Vertex with a pair of round black spots; pygofer with a curved, bifid process and a robust subapical spine; aedeagus shafts cylindrical, short and 'C' shaped (Figs.11-12 and Plate 2b)…… …………..…***Cicadulina bipunctata*** **(Melichar)**

-Vertex without such round black spots and pygofer process and aedeagus not as above……………....………5

5. Vertex subacute; styles with apophyses claw like; pygofer



Figs. 8. Fore wing without anteapical cells; 9. Fore wing with three anteapical cells; 10. Fore wing with two anteapical cells; 11-12: *Cicadulina bipunctata* (Melichar) Pygofer lateral view and Aedeagus in lateral view; 13-14 *Aconurella neosolana* (Ramasubbarao and Ramakrishnan) Pygofer lateral view and Style; 1516 *Balclutha incisa* (Matsumura) Aedeagus dorsal view and Aedeagus in lateral view; 17. *Balclutha pararubrostriata* Ramasubbarao and Ramakrishnan Pygofer lateral view; 18-19: *Balclutha saltuella* (Kirschbaum) Connective and Pygofer lateral view, 20 *Hishimonus phycitis* (Distant) Aedeagus

with a distinct serrated comb like structure on posteroventral margin; subgenital plates triangular, shorter than pygofer (Figs. 13-14)…………………………… ***Aconurella neosolana*** **Rao and Ramakrishnan**

–Vertex more or less rounded, styles and pygofer not as above…………………….……………..…6

6. Aedeagus with 3 pairs of basal processes or projections (Figs.15-16). …..***Balclutha incisa*** **(Matsumura)**

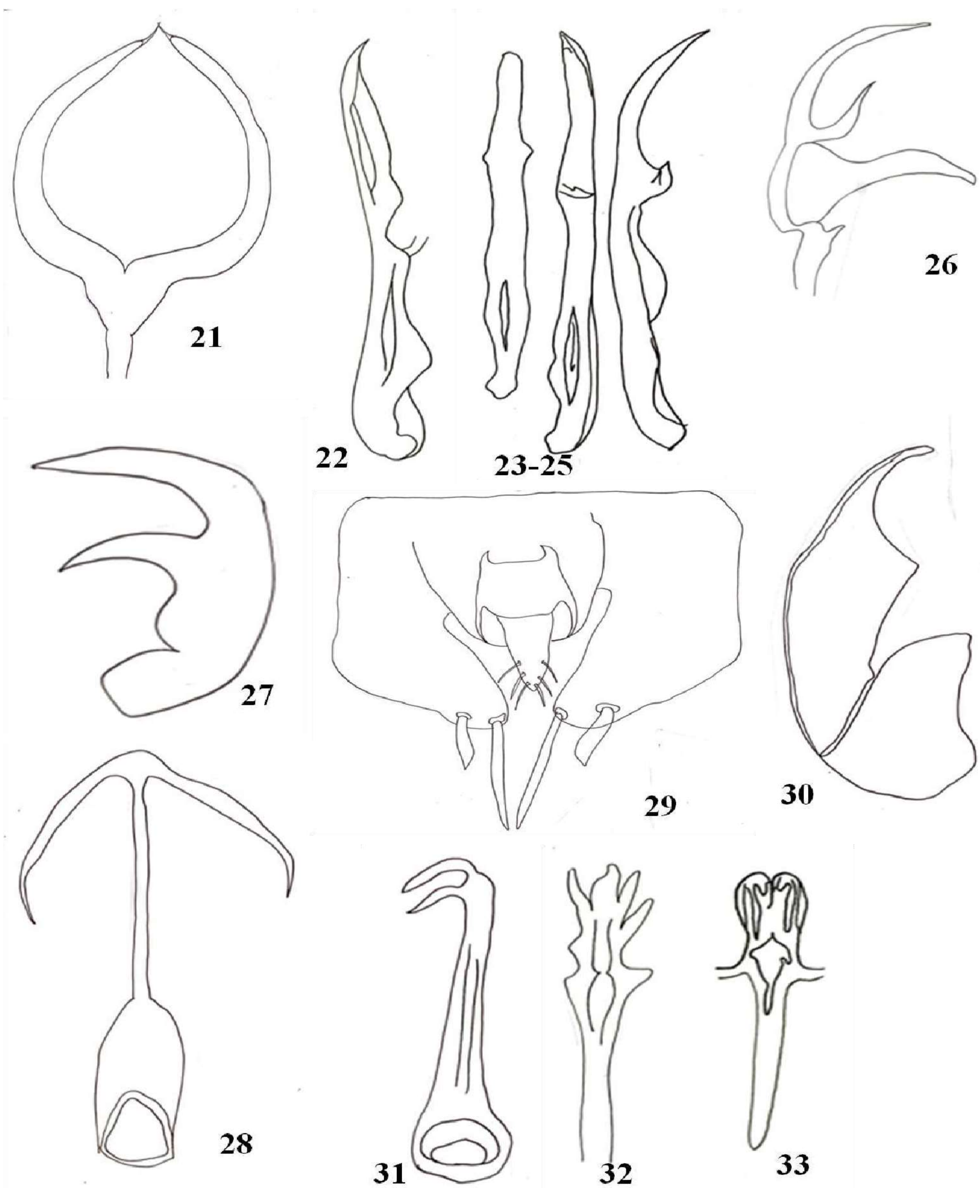
-Aedeagus without such processes………………..…7

7. Pygofer process bifurcated, branches hooked; dorsal branch of the process is smaller, hooked, and directed ventrad while the ventral one longer, recurved, hooked and directed dorsal; connective stem longer than arms; forewings with reddish stripes (Fig. 17)………………...***Balclutha pararubrostriata*** **Rao and Ramakrishnan**

-Pygofer without such processes; Connective stem approximately as long as the arms (Figs. 18-19)…..……….***Balclutha saltuella*** **(Kirschbaum)**

8. Aedeagus with two shafts…......................….……..9

- Aedeagus with single shaft……..............................10



Figs. 21. *Scaphoideus harlani* Kitbamroong and Freytag Aedeagus; 22. *Maiestas dorsalis* (Motschulsky) Aedeagus in lateral view; 23-25. *Maiestas acuminatus* (Dash and Viraktamath) Connective and aedeagus dorsal view, lateral view; 26. *Austroagallia bifurcata* Sawai Singh and Gill Aedeagus lateral view; 27. *Batracomorphus angustatus* (Osborn) Aedeagus in lateral view; 28. *Hecalus porrectus* (Walker) Aedeagus; 29-30: *Exitianus indicus* (Distant) Pygofer dorsal view and Aedeagus; 31. *Empoascanara maculifrons* (Motschulsky) Aedeagus; 32. *Empoasca* (*Distantasca*) *terminalis* Distant Aedeagus; 33. *Empoasca* (*Empoasca*) *kerri* Pruthi Aedeagus

9. Aedeagus shafts broad, apex with lateral mesal margins curved anteriorly, apex acutely rounded in posterior view, with curved processes from lateral margins and turned ventrally (Figs. 20).........................***Hishimonus phycitis*** **(Distant)**

Aedeagus shafts cylindrical, dorsally curved; a pair of long narrow closely opposed processes arise between bases of shafts, approximately twice length of shafts, extending posteriorly and curving slightly dorsally, with row of small, teeth along distal half of lateral surface (Figs. 1-7; Plate 1. a-d)…………………***Hishimonus viraktamathi* Knight**

10. Connective fused or united with parameres of the aedeagus; aedeagus with shaft cone-shaped, convex near the base, base rectangular in ventral view, gonopore subapical (Figs.)…….…***Scaphoideus harlani*** **Kitbamroong and Freytag**

–Connective not fused with parameres, parameres absent ……….11

11.***Aedeagus fused with*** connective (Fig 22)………. 12

-Aedeagus not fused with connective (Fig 20) ……..…13

12. Aedeagus fused with connective; tegmina pale yellowish brown with distinct reddish-brown zigzag markings; aedeagal shaft wider basally, tapering gradually with acute apex and gonopore subapical (Figs 22; Plate 2c)………***Maiestas dorsalis*** **(Motschulsky)**

–Zig zag markings absent on the tegmina; insect orange yellow, vertex with light median fuscous markings; aedeagal shaft strongly curved, wider at base, progressively narrowed to an acutely pointed spine, gonopore dorsoapical (Figs. 23-24)………***Maiestas acuminatus*** **(Dash and Viraktamath)**

13. Vertex very much narrower, its length is shorter by two or two and half times or even more the length of pronotum…..14

–Vertex not much narrower in its length than pronotum…15

14. Vertex round, slender, with two prominent black spots; aedeagus split into two unequal branches, with a well developed aedeagal apodemes; connective broad, extremely short, without clear distinction of stem and arms (Fig.26; Plate 2d)......***Austroagallia bifurcata*** **Sawai Singh and Gill** -Vertex short, transversely rugose with a broadly rounded anterior border in the dorsal aspect; aedeagus is clefted with two finger like extensions at its tip that are widely separated (Fig. 27; Plate 2d) ..…….***Batracomorphus angustatus*** **(Osborn)**

15. Aedeagus long, narrow with a pair of leaf like terminal processes; the apical one third of the forewings brown with white dots in the apical and anteapical cells in the male, these spots are absent in the female (Fig.28)…….***Hecalus porrectus*** **(Walker)**

-Aedeagus without leaf like terminal processes, vertex with a conspicuous black band between compound eyes; pygofer with two prominent dark brown or black spines extending to the apical margin, the upper spine is broader and longer than the lower; aedeagus is simple, curved having an articulation between the base and the shaft (Figs. 29-30)............ ....***Exitianus indicus*** **(Distant)**

16. Aedeagus with one pair of asymmetrical apical processes, but not leaf like, longer one arising from the shaft and the shorter one deriving from the base of the longer one rather than from the shaft; vertex with large black spot on the margin of vertex and face (Fig.31) …….***Empoascanara maculifrons*** **(Motschulsky)**

-Aedeagus without any processes, if present they are short…………….…………………………15

17. Aedeagal shaft narrowed at base, broad at the apex and produced into two pairs of processes near the gonopore; pygofer process elongated, slightly curved and pointed at apex (Fig. 32)…...…..***Empoasca*** **(*Distantasca*)** ***terminalis*** **Distant**

-Aedeagus without any processes, tubular, notched apically, broader apically with middle extensions on both sides and gradually narrowed towards the proximal end; pygofer process elongated, inner surface serrated apically (Fig. 33)……...…..***Empoasca*** **(*Empoasca*)** ***kerri*** **Pruthi**

CONCLUSION

The present study documented 18 species of leafhoppers associated with blackgram ecosystems in Coastal Andhra Pradesh. Among these, *Hishimonus viraktamathi* Knight is reported for the first time from the state, constituting a new distributional record. Detailed description of this species, along with diagnostic features and illustrations, has been provided to facilitate accurate identification. An illustrated key for all recorded species is also presented to support entomologists and field workers in species recognition, which is essential for effective pest surveillance and management in blackgram cultivation.

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Demographic Traits and Population Projection of Solanum Whitefly, *Aleurothrixus trachoides* (Back) on Chilli

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***Abstract*:** Biological traits of solanum whitefly, *Aleurothrixus trachoides* (Back) were determined at 25±3°C, 70±5% relative humidity, and a photoperiod 12:12h (L:D) on Chilli (*Capsicum annuum* L.). The pre-adult development consisted of five stages (egg and four nymphal stages) with the mean duration of 7.52, 6.43, 6.04, 4.65 and 5.03 days, respectively. The mean pre-oviposition period was 2.41 days. Adult longevity averaged 10.84 days in males and 13.63 days in females, with total life span of 40.05 and 43.67 days, respectively. The mean fecundity per female was 104.45 eggs. The intrinsic rate of increase (r) of *A. trachoides* was 0.10 per day. The highest net reproduction rate (R_o) was 53.27 offspring per individual. The mean generation time (T) was 37.91 days. From the life table data, the 60-day projection of population growth revealed the sudden surge in the total population from the 30th day, suggesting that timely control measures are most effective within this specific period to manage this emerging pest.

***Keywords*:** Biology, Life table, Population projection, *Aleurothrixus trachoides*, Solanum whitefly

Whiteflies pose a significant global threat to agriculturists. Over the past 25 years, several exotic whitefly species have invaded numerous countries, resulting in direct losses in agriculture, horticulture and forestry (Sundararaj et al., 2018). Exotic whiteflies are frequently introduced with host plants through international trade, facilitated by their small size, cryptic nature, and tendency to remain attached to hosts during immature stages. These characteristics make them highly transportable and successful invaders in new areas (Simala et al., 2015). In India, 469 whitefly species belonging to 71 genera are reported, including eight invasive species (Sundararaj et al., 2021). Within the last six years alone, nine invasive whitefly species invaded India from Neotropical region *viz.,* solanum whitefly, *Aleurothrixus trachoides* (Back), rugose spiralling whitefly, *Aleurodicus rugioperculatus* Martin, nesting whiteflies, *Paraleyrodes bondari* Peracchi and *P. minei* Iaccarino, legume feeding whitefly, *Tetraleurodes acaciae* (Quaintance), palm infesting whitefly, *Aleurotrachelus atratus* Hempel, woolly whitefly, *A. floccosus* (Maskell), Annona Whitefly, *A. anonae* (Corbett) and Invasive Nesting Whitefly, *P. pseudonaranjae* Martin (Sundararaj et al., 2021, Selvaraj and Sushil, 2024, 2025).

The neotropical solanum whitefly, *A. trachoides*, is now invasive in India and is rapidly spreading across South India. It infests economically important solanaceous crops such as brinjal, chilli, and tomato along with several medicinal, ornamental, and weed species (Dubey and Sundararaj, 2015). This species was recorded on 24 host plants across 11 families, with confirmed distribution in Karnataka, Kerala, Maharashtra, and Tamil Nadu (Sundararaj et al., 2018). This species inflicts direct damage to host by feeding and depleting water and nutrients, thereby reducing growth and causing premature leaf drop. They cause indirect damage by excreting sticky honeydew and producing wax, which create a favourable environment for the growth of black sooty mould on infested plants which reduces the photosynthetic efficiency (Kumar et al., 2018). In addition, *A. trachoides* also act as a vector for transmitting plant viruses such as a begomovirus (Chandrashekar et al., 2020, Kamaliah et al., 2024).

The solanum whitefly will soon achieve invasive pest status as it is establishing on economically important vegetable crops and fruit trees. The main objective of the current research was to record the demographic characteristics of the solanum whitefly on chilli. Understanding the biology of this species is essential to identify vulnerable stages in its life cycle which can guide the development of effective and timely pest management strategies.

MATERIAL AND METHODS

Host plants and *A. trachoides* culture: For this experiment, chilli plants (TNAU hybrid Co.1 variety) were used as host plants. The chilli seeds were sown in 25 cm diameter grow bags filled with pot mixture and placed under shade house conditions with 25±3°C, 70±5% RH, and a photoperiod of 12:12 hours (light:dark). Initially, whitefly pupae were collected from chilli field in Sivapuri, Chidambaram and identified as *Aleurothrixus trachoides* based on the morphological key (*Aleurothrixus* Quaintance and Baker 1914), with diagnostic characters of a crenulated margin (6–8 crenulations per 0.1 mm), marginal teeth each with a basal wax gland, rhachis-form abdominal segments, a subcircular vasiform orifice, and a subcordate operculum. Later, sixty unsexed adults of *A. trachoides* were collected from the same field, using an aspirator and these adults were then released onto chilli plants, enclosed in a fine 400 mesh net cage measuring 30 x 30 x 30 cm. Throughout the study period, the plants were regularly watered and fertilized to ensure their proper growth. The homogeneous population of *A. trachoides* was cultured and utilized for subsequent experiments (Fig. 1A&B) (Mercado et al., 2014, Farooq et al., 2021).

Life table: To assess the developmental duration, forty unsexed adult whiteflies were collected from the culture and released into a clip cage (3 cm diameter and 3.5 cm height) attached to the abaxial surface of leaves of potted plant placed under the same shade house conditions (Liu and Stansly 1998). After 24 hours, the abaxial surface of leaves was examined for eggs using a 10X hand lens, and the adult insects were removed. Leaves were detached and inverted in agar Petri dishes for egg hatching. The total cohort of 100 eggs was used, and any remaining eggs on the leaf were gently removed. Once the crawlers emerged, each one was placed individually on a leaf using 000 fine camel brush with the help of a Leica S4E stereo zoom microscope, and a clip cage was placed over the first instar nymph (Fig. 2A). The settled nymphs were later marked with a marker. After the first instar nymphs established themselves on the leaf, they remained immobile until the adults emerged. The moulting and development of each nymph were observed daily using a 10X hand lens (Fig. 2B). At the pupal stage, the leaves were detached and transferred to a plastic container (9 cm width × 13 cm height) covered with a fine mesh net. After the emergence of the adult whiteflies, daily observations were made on both sexes for oviposition and longevity studies until the death of the individuals.

Population projection: The population growth of *A. trachoides* on chilli was estimated using life table data. The projection was carried out based on the method developed by Chi and Liu (1985) and Chi (1990), using TIMING-MSChart (Chi 2017).

Statistical analysis: The data were analyzed using the TWOSEX-MSChart (Chi 2013). The bootstrap technique with 100,000 replications was applied for the estimation of mean and standard errors for each treatment (Efron and Tibshirani 1993). Origin Pro 2022 was used to draw the figures. The following parameters were calculated according to respective equations. The age-specific survival rate (l_x) and age-specific fecundity (m_x) were calculated as:

$$l_x = \sum_{j=1}^{k} s_{xj}\, m_x = \frac{\sum_{j=1}^{k} s_{xj} f_{xj}}{\sum_{j=1}^{k} s_{xj}}$$

Where *k* exhibits the number of stages.

The net reproductive rate (R_0) was computed as:

$$R_0 = \sum_{x=0}^{\infty} l_x m_x$$

The intrinsic rate of increase (*r*) with age indexed from 0 was corrected by the Euler-Lotka equation (Goodman 1982):

$$\sum_{x=0}^{\infty} e^{-r(x+1)} l_x m_x = 1$$

The following equation was used for the finite rate of increase (λ): $\lambda = e^r$

The mean generation time was demonstrated as

$$T = \frac{\ln R_0}{r}$$

The life expectancy (e_{xj}) was determined as:

$$e_{xj} = \sum_{i=x}^{\infty} \sum_{y=j}^{\beta} s_{iy}$$

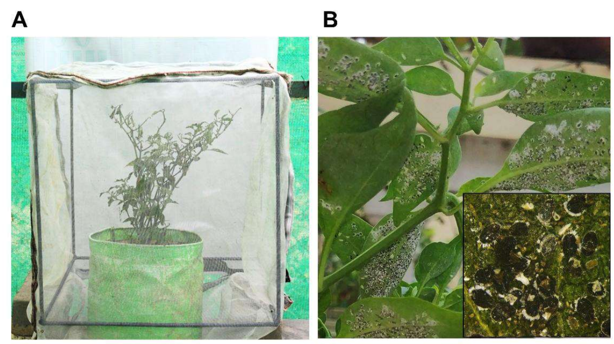

Fig. 1. Host plants and *A. trachoides* culture (A) Chilli plant maintained in mesh cage for adult whitefly collection (B) Symptom showing heavy infestation on abaxial surface of leaves on chilli (*Insert*: microphotograph of crowded nymphal instars)

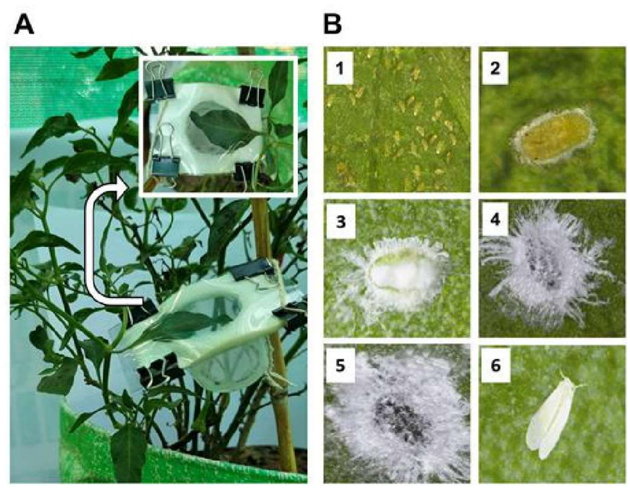

Fig. 2. Developmental stages of *A. trachoides* reared on chilli (A) Clip cage [*insert:* dorsal view of clip cage] and (B) Life stages: (1) Egg; (2) First instar; (3) Second instar; (4) Third instar; (5) Fourth instar / pupae and (6) Adult whitefly

Where S_{iy} shows the probability of survival of each individual of age *x* and stage *j* to age *i* and stage *y* by assuming $S_{xj} = 1$.

The reproductive rate (v_{xj}) was assessed according to (Tuan et al., 2014a, b).

$$v_{xj} = \frac{e^{r(x+1)}}{s_{xj}} \sum_{i=x}^{\infty} e^{-r(i+1)} \sum_{y=j}^{\beta} s_{iy} f_{iy}$$

RESULTS AND DISCUSSION

The total longevity was 43.67 days for females and 40.05 days for males (Table 1). Eggs required an average of 7.52 days for emergence. The duration of first, second ,third and fourth instar nymphs was 6.43 , 6.00, 4.65, and 5.03 days. The total nymphal duration was 22.16 days. The incubation period of eggs was longer than the duration of each post-embryonic stage, a trend also reported in other aleyrodidae species (Liu and Stansly 1998, Hoddle and Soliman 2001). Kumar et al. (2020) reported similar duration of the development stage for *A. trachoides* eggs and four nymphal stages were 8, 7, 6, 4 and 4 days, respectively.

The adult pre-oviposition period (APOP) was 2.41 days and the total pre-oviposition period (TPOP) was 32.45 days. The female adults oviposit for 10.25 days with a mean fecundity as 104.45 eggs. Comparable pre-oviposition periods were reported for *A. floccosus*, which was 2.45 days by Mercado et al. (2014). In other whitefly species, total was 70 days for *Aleurocanthus woglumi* (Pena et al., 2009), 35–37 days for *Bemisia argentifolii* (Liu and Stansly, 1998) and 41 days for *Tetraleurodes perseae* (Hoddle, 2006).

The age-stage specific survival rate (s_{xj}) of *A. trachoides* shows the variability of developmental rate and survival patterns of different life stages over their entire life cycle (Fig. 3A). The variable developmental rates among individuals result in overlapping stage survival curves (s_{xj}). By ignoring stage differentiation, an age-specific survival rate (l_x) provides the probability of an egg surviving until age x (Fig. 3B). The age-stage specific fecundity (f_x) gives the number of eggs produced by adult females of age x, where the age x is counted from the egg stage. The curve of age-specific fecundity (m_x) (Fig. 3B) shows that reproduction of *A. trachoides* began at the age of 21 days on chilli. Based on the two-sex life table, the age-stage specific life expectancy (e_{xj}) gives the expected life span an individual of age x and stage j can live after age x (Fig. 3C). The life expectancy of a newborn was 39.09 days on chilli (Fig. 3C). The reproductive value (v_{xj}) is the contribution of individuals of age x and stage j to the future population (Fig. 3D). The peak value of age-specific fecundity (m_x) was 8.35 at the age of 39 days, which indicates at that particular age, individuals were exhibiting the highest level of reproductive potential (Fig. 3D). The peak value of age-stage reproductive value (v_{xj}) was 62.7 at the age of 33 days, which implies that individuals at age of 33 days have a greater likelihood of contributing to the reproductive success of the population compared to other ages/stages.

The results obtained for demographic parameters of *A. trachoides* revealed that the female adult from all generations have the ability to produce an average of 88.57 individuals per generation. *A. trachoides* exhibited a net reproductive rate (R_0) of 53.27 offspring per female, which indicates a high reproductive potential and the ability of the population to increase substantially under these conditions. The intrinsic rate of increase (r = 0.10 day^{-1}) indicates a moderate population growth potential, while the finite rate of increase (λ = 1.11 ± 0.01) implies the population multiplies by ~11% daily under these conditions. The time needed to complete one generation *i.e.* mean generation time (T) was 37.91 day. These parameters suggest a moderate but steady population growth of *A. trachoides* on chilli. Mercado et al. (2014) recorded the mean generation time of 38.77 days for *A. floccosus*. The population of *A. trachoides* takes approximately 6.61 days to double in size *i.e.* the doubling time (DT) indicating that under optimal conditions, the population can double within a week (Table 2).

Anticipating the growth of a pest population is crucial for formulating the right timing schedule to develop an efficient

Table 1. Developmental duration, longevity and fecundity of *A. trachoides*

Life stages	n (individual)	Mean ± SE (days)
Egg	100	7.52 ± 0.05
N1	98	6.43 ± 0.05
N2	93	6.04 ± 0.06
N3	89	4.65 ± 0.05
N4 (Pupae)	88	5.03 ± 0.07
Adult longevity (day)		
Male	37	10.84 ± 0.34
Female	51	13.63 ± 0.02
Total longevity (day)		
Male	37	40.05 ± 0.19
Female	51	43.67 ± 0.40
APOP (days)		2.41 ± 0.07
TPOP (days)		32.45 ± 0.20
Fecundity (eggs / female)		104.45 ± 3.77
Oviposition days		10.25 ± 0.32

* Where, N1 = 1st nymphal instar, N2 = 2nd nymphal instar, N3 = 3rd nymphal instar, N4 = 4th nymphal instar (pupae); TPOP = Total pre-ovipositional period; APOP = Adult pre-ovipositional period. Standard errors were measured by 100,000 bootstrap resampling

pest management strategy (Huang et al., 2018, Chen et al., 2025). Mistakes in timing not only result in the failure of pest control measures but also lead to the inevitable wastage of money, labour, and time (Pedigo and Rice 2006, Rogers and Brier 2010, Ali et al., 2025). Therefore, the population projection provides valuable insights into changes in stage structure based on life table data (Reddy and Chi 2015). The population projection also aids in determining changes in the feeding potential of the age-stage structure (Peng et al., 2016, Rajabpour and Yarahmadi 2024). The "log(N+1)" transformation ensures that even small changes in population size are visible on the graph (Fig. 4A & B). The population projection of *A. trachoides*, based on life table data encompassing stage size and total population size, indicated an exponential growth of population starts at 30^{th} day when reared on chilli (Fig. 4A&B). *A. trachoides* populations can complete more than one but less than two generations during 60 days period. These findings highlight a critical window for intervention. Timely pest management measures, ideally initiated within 30 days of initial adult emergence, are therefore essential to suppress outbreaks and prevent significant crop losses.

Table 2. Demographic parameters of *A. trachoides*

Parameters	Mean ± SE
GRR (individuals / generation)	88.57 ± 5.70
R_o (offspring / individual)	53.27 ± 5.54
T (d)	37.91 ± 0.22
r (d^{-1})	0.10 ± 0.01
λ (d^{-1})	1.11 ± 0.01
DT	6.61

* Where, GRR = Gross reproductive rate; R_0= Net reproductive rate; T = Mean generation time; r = Intrinsic rate of natural increase; λ = Finite rate of increase; DT = Doubling time. Values are mean ± S.E; Standard errors were measured by 100,000 bootstrap resampling

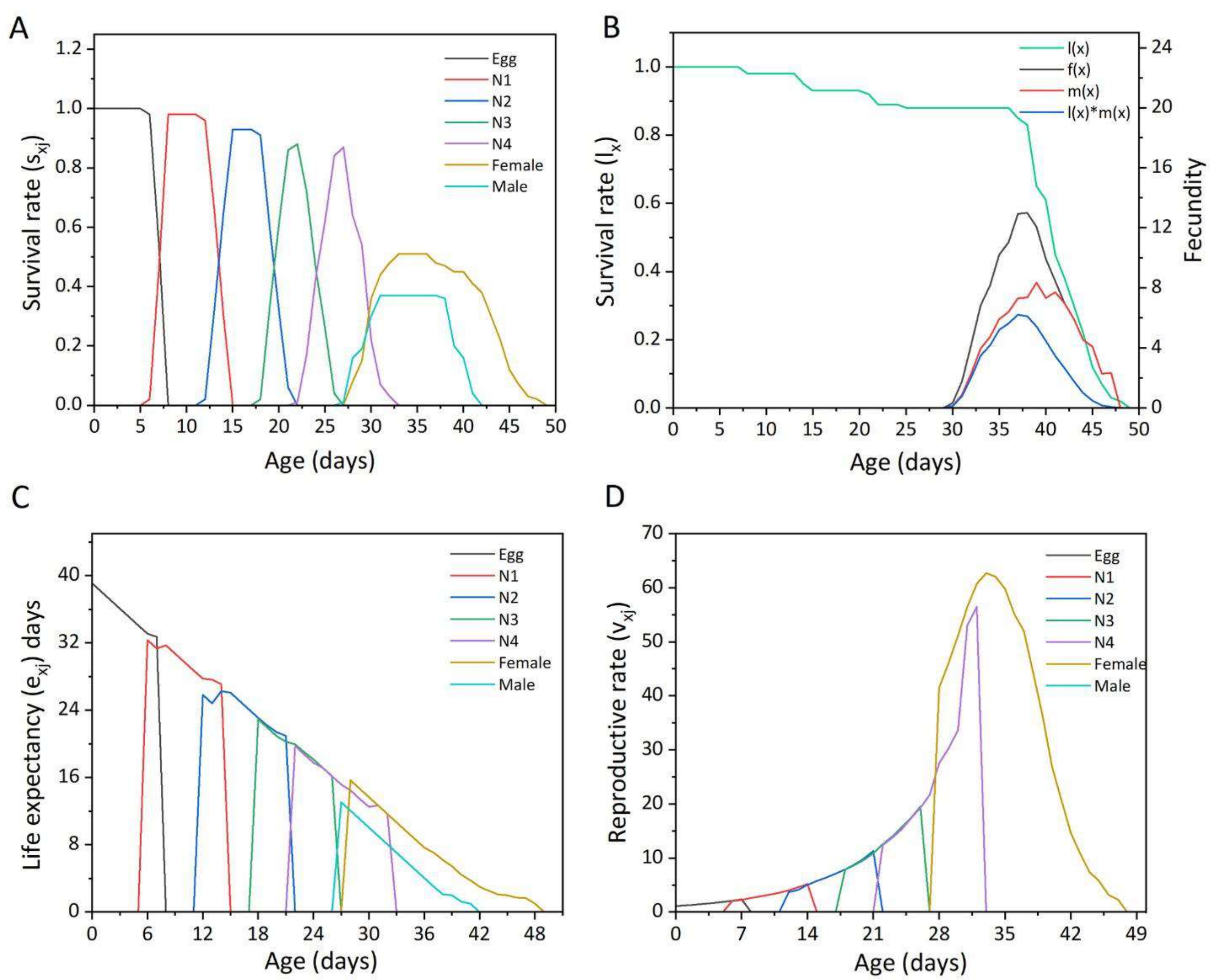

Fig. 3. Age-stage, two-sex life table parameters of *A. trachoides* reared on chilli. (A) Age-stage specific survival rate (s_{xj}); (B) Age-specific survival rate (l_x), Age-stage specific fecundity (f_{xj}), Age-specific fecundity (m_x) and Age-specific maternity ($l_x m_x$); (C) Age-stage specific life expectancy (e_{xj}) and (D) Age-stage specific reproductive rate (v_{xj})

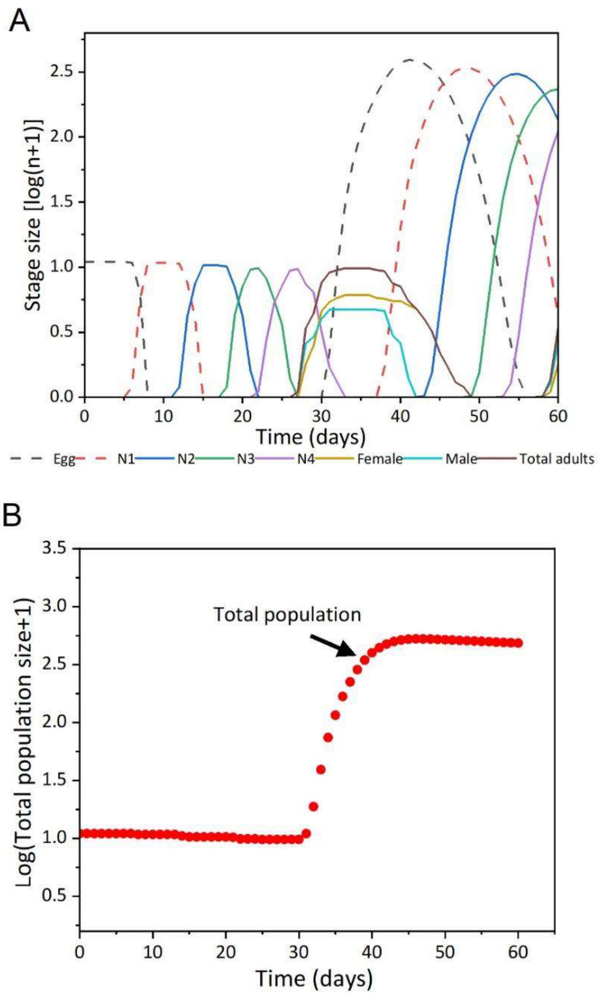

Fig. 4. Population projection of *A. trachoides* reared on chilli, based on (A) stage size and (B) total population

CONCLUSION

The current study provides important insights into the developmental biology and demographic characteristics of solanum whitefly, *A. trachoides* (Back) reared on chili plants. The study confirms that *A. trachoides* is now well-established on chilli crops, posing a potential threat to chilli-growing regions in the near future. The demographic parameters indicate that timely management interventions particularly within the first 30 days of infestation are critical to prevent rapid population build-up. Future research should focus on assessing the influence of climatic factors, host plant variability, and natural enemies on the biology of *A. trachoides* using age-stage and two-sex life table approaches.

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Seasonal Dynamics of *Spodoptera frugiperda* (J.E Smith) on Maize in the *Terai* Region of Uttarakhand

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Abstract: The study on seasonal dynamics of *Spodoptera frugiperda* on maize was carried out at GBPUAT, Pantnagar during *kharif* 2023 and 2024. *Spodoptera frugiperda* population started appearing on maize at 28th and 31st SMW in 2023 and 2024, respectively, and persisted until crop maturity. The larval population reached the peak level of 3.08 larvae/plant in 33rd SMW during 2023 and 2.82 larvae/plant in 36th SMW during 2024 which declined thereafter. The plant damage ranged from 6.67-75.00% in 2023 and 5.00-80.00% in 2024. Pearson correlation revealed a significant and positive association of larval population with minimum temperature (r= 0.614 and r= 0.597) and evening relative humidity (r= 0.357 and r= 0.333) in year 2023 and 2024, respectively, while sunshine hours and rainfall showed negative effects. Principal component analysis confirmed minimum temperature and humidity as the key determinants of pest dynamics. These findings highlighted the significance of weather in *S. frugiperda* outbreaks and provide valuable insights for forecasting and long-term management strategies in maize cultivation.

Keywords: Fall armyworm, Maize, Seasonal incidence, *Spodoptera frugiperda*

Spodoptera frugiperda (J.E Smith) (Lepidoptera: Noctuidae), commonly known as fall armyworm (FAW), has become a major invasive pest, inflicting severe damage on maize (*Zea mays* L.) worldwide. Originally from America, this highly polyphagous insect was first identified in Africa in year 2016 (Georgen et al., 2016) and has since expanded quickly throughout Asia, including diverse agro-climatic zones of India. It was first recorded in India during May 2018 in maize fields at the Agriculture College, Shivamogga, Karnataka (Sharanabasappa et al., 2018). Within just two years, it expanded across almost all maize-growing regions of the country (Suby et al., 2020, Naganna et al., 2020). In Pantnagar, it was detected for the first time in 2019, since then this pest is infesting maize in this region (Maurya et al., 2019).

FAW can infest maize at every stage of development, leading to significant yield reductions. Leaf feeding diminishes photosynthetic capacity, slows plant growth, disrupts reproduction, and ultimately reduces grain output (Chimweta et al., 2020). The early larvae scrape off chlorophyll, leaving a transparent silvery film that develops into elongated white streaks and pinholes. The later larval instars create characteristic "windowpanes" on leaves, leaving frass deposits around the funnel and upper leaves. In addition, the pest bores into stems, tassels, ears, and cobs, lowering grain quality and exposing cobs to secondary infections (Anjorin et al., 2022). This insect presents major challenges to maize production, causing financial harm not solely to farmers but also to broader agricultural sector and regional economy. Tracking pest populations throughout the growing season is essential to determine peak activity periods, allowing farmers to implement timely preventive or control measures. Examining the correlation between pest occurrence and meteorological factors such as temperature, rainfall, and humidity provides critical insights into the triggers of pest outbreaks. Understanding these relationships is key for predicting and managing infestations effectively. Therefore, studying the relation between these climatic variables and FAW incidence is vital for devising effective pest management practices. Hence, this research was done to analyze the impact of key meteorological parameters on FAW infestation and evaluate its damage potential in maize, thereby supporting timely forecasting and sustainable management of this invasive pest.

MATERIAL AND METHODS

This research took place at the Norman E. Borlaug Crop Research Centre, Govind Ballabh Pant University of Agriculture and Technology (GBPUA&T), Pantnagar, Udham Singh Nagar, Uttarakhand, India (29° N latitude, 79° 3′ E longitude, 243.84 meter above mean sea level). The dynamics of *S. frugiperda* was studied on the maize (variety PCM-4) during *Kharif* season of 2023 and 2024. The crop was grown with spacing of 60 cm between rows and 25 cm between plants. Recommended agronomic practices were used to grow the crop. Throughout the experiment, no pesticide applications were made.

Seasonal activity of FAW on maize plants: Observations began two weeks after sowing and continued weekly until harvest. To monitor seasonal incidence of FAW, 60 maize plants (10 plants from each replicate within a plot size of 5 × 5 m²) were randomly selected each week. The larvae of FAW were identified by characteristic 'Y'-shaped mark on the larval head capsule, and four dark spots arranged in a square on the last abdominal segment (Prasanna et al., 2018, Capinera, 2020). As FAW larvae tend to conceal themselves within the midrib of maize leaves due to daytime temperature and light conditions, assessments were conducted in the early morning hours (6:00–9:00 a.m.). The number of larvae on 10 plants was recorded, and expressed as mean larval count per plant ± standard deviation (SD).

Damage assessment: Ten plants were chosen at random from each plot and observations on the number of plants damaged due to FAW were recorded. Plants showing visible signs of FAW damage were categorized as damaged, regardless of whether feeding larvae present or not. These observations were used for estimation of percent plant damage using the formula given by Murua et al. (2006).

Plant damage (%) = {Total number of damaged plants/Total number of plants observed} × 100

Statistical analysis: Weekly weather information was collected from the Department of Agrometeorology, Pantnagar (Fig. 1a & 1b). Regression and correlation analysis were done as per Snedecor and Cochran (1967).

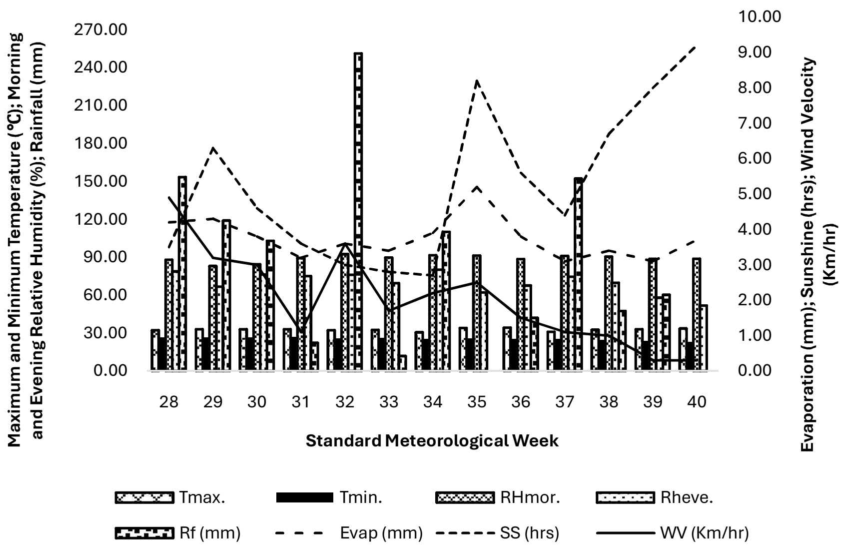

Fig. 1a. Weather data: Temperature (minimum and maximum) (°C), Morning and Evening Relative humidity (%), Rainfall (mm), Sunshine (hours), Wind velocity (km/hr) and Evaporation (mm) during the study duration of 2023

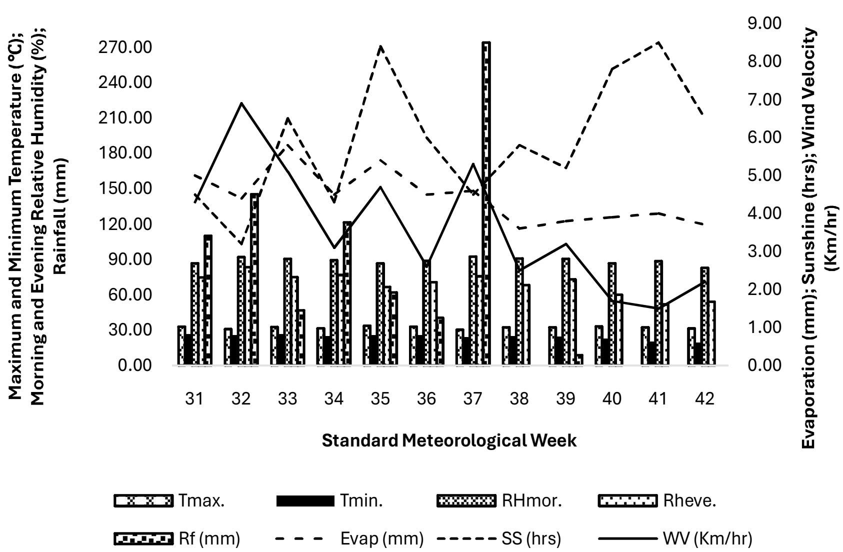

Fig. 1b. Weather data: Temperature (minimum and maximum) (°C), Morning and Evening Relative humidity (%), Rainfall (mm), Sunshine (hours), Wind velocity (km/hr) and Evaporation (mm) during the study duration of 2024

Pearson's correlation coefficient was applied to check the effect of weather parameters on FAW seasonal incidence. Additionally, principal component analysis (PCA) and regression models were employed to predict larval populations, with all analysis done with SPSS software (Version 20, SPSS Inc., Chicago, Illinois, USA).

RESULTS AND DISCUSSION

FAW seasonal incidence, damage percentage and their correlation with abiotic variables: FAW infestation on maize was observed soon after germination, beginning in the 28th and 31st Standard Meteorological Weeks (SMW) during 2023 and 2024, respectively, and persisting until crop maturity (Fig. 2). Kumar et al. (2023) also observed larval activity from the 28th to the 40th SMW (second week of July to first week of October), with population ranging between 0.15 and 4.93 larvae per plant. Similarly, Ganavi and Kulkarni (2024) noted larval activity from the last week of July (31st SMW) until the 41st SMW, with a density of 0.85–2.25 larvae per plant. Suman et al. (2025) similarly observed that population of FAW larvae was first noticed in the 31st SMW and peaked in the 35th SMW in both 2021 and 2022.

The FAW population increased as crop growth progressed. The infestation followed distinct patterns across the two study years. In 2023, two peaks were evident: an initial peak of 2.80 larvae/plant in the 31st SMW, followed by a decline, and then a higher peak of 3.08 larvae/plant in the 33rd SMW (3rd week of August). After that, the population drastically decreased, reaching negligible levels towards the season's end. The research outcomes of Reddy et al. (2020) are partially in line with the current results, which noted that during *Kharif* 2019, the FAW incidence began in the 1st week of August in a 30 days old crop and peaked in the 3rd week of August in a 45 days old crop.

In 2024, the population exhibited a single peak. Populations remained low until the 33rd SMW, then increased steadily to reach 2.82 larvae/plant in the 36th SMW. After this there is a gradual decline in population but still remaining above 1.5 larvae/plant until the 38th SMW. Patil et al. (2024) recorded that larval incidence observed from 31st SMW *i.e.* 5th week of July, to the 43rd SMW *i.e.* 4th week of October with a peak incidence observed (4.05 larvae/ plant) during 39th SMW. While Dhuniya et al. (2025) noticed that the FAW incidence was initiated during 4th week of July (30th SMW), when there were 1.07 larvae/plant. Overall, the graph reveals a clear distinction in the FAW abundance patterns between the two years. Towards the late whorl stage, as the crop growth advances larval numbers declined, with only 1–2 larvae typically confined to the whorl. Rajisha et al. (2022) observed late larval stages were more commonly seen in late whorl stages, but 1st and 2nd larval instars were common in early plant stages, with roughly two to three larvae/plant. This reduction could be attributed to cannibalism, larval dispersal to nearby plants, and decreased preference for mature, tougher leaves by early instars. These observations agree with Deole and Paul (2018) and Pradeep et al. (2022), where FAW larvae preferentially feed on the tender leaves of maize. These findings also proved that phenology of the crop has a significant impact in FAW larval abundance. Durocher et al. (2021) also found that FAW larvae varied depending on the crop's phenological stage. Fall armyworm primarily acts as a defoliator and can cause mortality in young maize plants. Feeding in the whorl reduces the photosynthetic capacity of the crop, while ear feeding lowers grain quality and results in yield losses (Capinera 2020). The most acute damage was seen during the late whorl stage, when whorls predominantly harboured later instar larvae. As voracious feeders, they caused extensive injuries, with nearly 77% of the plant tissue

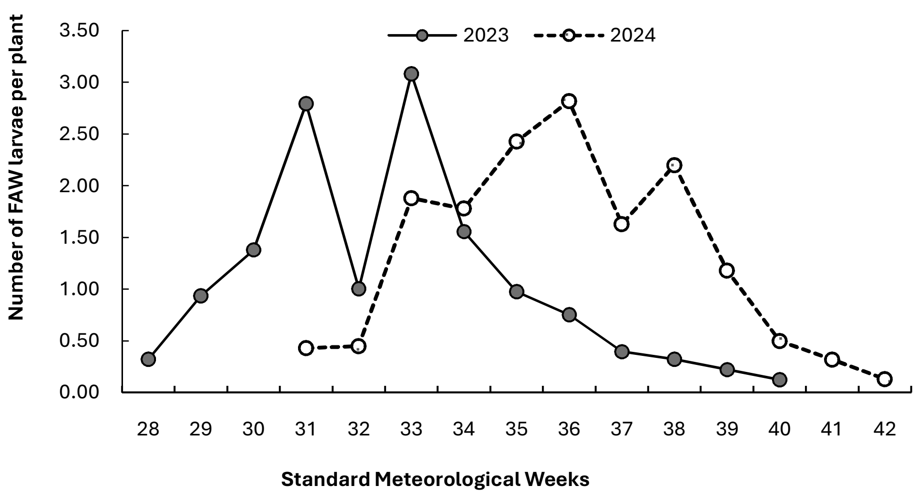

Fig. 2. Seasonal incidence of FAW larvae during 2023 and 2024

consumed during the final instar (Day et al., 2017, Flanders et al., 2017).

The percent of damaged plants closely followed larval population trends (Fig. 3). In 2023, damage began in the second week of July *i.e.* 28th SMW and continued until the first week of October (40th SMW), ranging from 6.67 to 75.0%. In 2024, infestation started slightly later, from the 1st week of August, and extended until the 3rd week of October, with damage varying between 5.0 and 80.0%. Peak infestation occurred in the 33rd SMW of 2023 (75.0%) and the 38th SMW of 2024 (80.0%). Patel et al. (2020) also documented FAW damage ranging from 10% to 81.66% between the 31st and 40th SMWs, and Kumar et al. (2023) recorded infestation levels between 9.3% and 79.1% from 28th to 40th SMW (2nd week of July to 1st week of October). Suman et al. (2025) reported that highest infestation occurred during the 36th SMW (50 days old crop), with an average infestation rate of 65.48 and 69.48% for the two consecutive years (2021 and 2022). Overall, the highest damage coincided with the vegetative growth phase, highlighting FAW's preference for younger maize tissues. As the crop transitioned to the reproductive stage, the percentage of infested plants declined markedly. This preference for tender foliage is consistent with earlier studies (Dhar et al., 2019), which demonstrated that larvae favour younger leaves due to their softer tissues, whereas older leaves, with thicker and tougher cell walls, are less palatable to defoliators (Perez et al., 2014, Bhusal and Bhattarai, 2019). However, damage occurs at all phases of crop growth. It was also reported that FAW is capable of damaging all growth stages of maize, however, damage is more severe in vegetative stage (Georgen et al., 2016, Deole and Paul, 2018, Suby et al., 2020).

The correlation study showed that FAW incidence in maize was significantly influenced by weather conditions during the *kharif* seasons of 2023 and 2024. In 2023, the FAW population showed a substantial and positive association with minimum temperature (r = 0.614*) and a significant and negative association with sunshine hours (r =

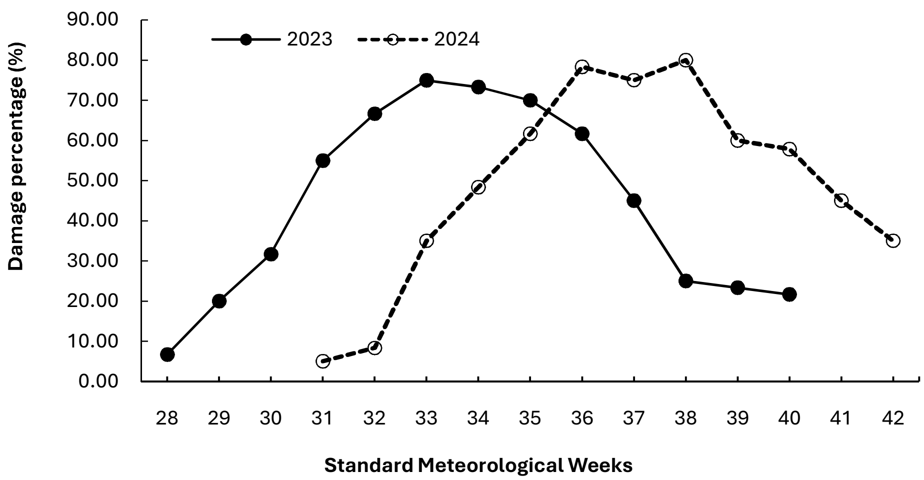

Fig. 3. Damage percentage of FAW larvae during 2023 and 2024

Table 1. Weather-based correlation matrix (Pearson's) for fall armyworm population in maize during *kharif* 2023

Variables	PFAW	T (max.)	T (min.)	RH (mor.)	RH (eve.)	Rf	Evap.	SS
T (max.)	-0.105							
T (min.)	0.614*	-0.170						
RH (mor.)	0.046	-0.330	-0.232					
RH (eve.)	0.357	-0.631*	0.733**	0.114				
Rf	-0.236	-0.557*	0.285	0.059	0.596*			
Evap.	-0.123	0.354	0.231	-0.151	-0.089	-0.089		
SS	-0.589*	0.628*	-0.693**	-0.183	-0.896**	-0.518	0.247	
WV	0.022	-0.151	0.626*	-0.230	0.576*	0.615*	0.549	-0.469

PFAW: FAW population per plant on Maize; T(max.): Temperature maximum (°C); T(min.): Temperature Minimum (°C); RH(mor.): Relative humidity morning (%); RH(eve.): Relative humidity evening (%); Rf: Rainfall (mm); Evap: Evaporation (mm); SS: Sunshine (hours); and WV: Wind velocity (km/h); NS: Non-significant. Correlation data is depicted in the table by bold digits

-0.589*). Maximum temperature, rainfall, and evaporation were adversely associated with larval population, whereas evening and morning relative humidity were positively associated. According to Barrios et al. (2019), the larval population of FAW was positively related with the relative humidity in maize ecosystem. The results suggest that minimum temperature and reduced sunshine hours provides favorable environment for FAW multiplication. These results are in line with previous findings by Patel et al. (2020), who found a negative relationship with rainfall, a non-significant positive association with morning humidity, and a significant and positive relation with minimum temperature. Deole and Paul (2018) also reported that FAW population had a negative non-significant relation with total rainfall.

In 2024, the FAW population had a strong and positive connection with the minimum temperature (r = 0.597*), indicating that higher night temperatures favoured pest incidence. Suman et al. (2025) also noticed that the incidence of FAW was significantly and positively related with the minimum temperature during *kharif* 2021 and 2022. Other abiotic factors *viz*., maximum temperature, morning and evening relative humidity, and evaporation were shown to have no statistical significance with respect to the larval population. Sunshine hours exhibited a weak and non-significant correlation, while rainfall and wind velocity had negligible influence on pest build-up. These findings differed notably from those of Kumar et al. (2020), who observed a negative association with rainfall and a positive but also a significant association with the highest temperature Comparable observations were made by Fonseca-Medrano et al. (2019) and Kumar et al. (2023), also observed that the pest showed a negative association with maximum temperature and sunshine hours while showing a strong positive association with humidity and minimum temperature. Overall, the findings proved that relative humidity and minimum temperature were the key weather parameters favouring the multiplication and persistence of FAW populations in maize, while excess sunshine and rainfall acted in the opposite direction.

PCRA based predictions of FAW population in maize: Eight abiotic variables were employed for Principal component regression analysis (PCRA) in attempt to group these associated parameters to the smallest feasible subgroups, indicating the percentage of variance. The principal component analysis (PCA) of abiotic variables influencing the population of FAW on maize during *kharif* season of 2023 are given in Table 3. The first principal component (PC1) explained 47.22% of the total variance, with strong contributions from minimum temperature, evening and morning relative humidity, rainfall, and wind velocity. This means that these variables collectively had the greatest impact on FAW population dynamics. The second principal component (PC2) accounted for an additional 24.54% of the variance, primarily contributed by maximum temperature, evaporation, and sunshine hours. Together, the first two components explained 71.76% of the total variation. Multiple regression equation was developed between the population of FAW and minimum temperature (Tmin.), relative humidity morning (RHmor.), relative humidity evening (RHeve.), rainfall (Rf), sunshine hours (SS) and wind velocity (WV) from PCA, and the correlation matrix for 2023.

FAW larval population per plant (2023) = 0.529(Tmin.) – 0.014(RHmor.) – 0.090(RHeve.) – 0.002(Rf) – 0.491(SS) – 0.168 (WV) ($P < 0.05$, $R = 0.95$, $R^2 = 0.89$).

The contribution of different weather variables in

Table 3. Principal components (PCs) with Eigen values and variances of *S. frugiperda* on maize during 2023

Variables	Eigen value (%)	Variance	Cumulative variance (%)
$T_{min.}$, $RH_{mor.}$, $RH_{eve.}$, Rf, WV	3.78	47.22	47.22
$T_{max.}$, Evap., SS	1.96	24.54	71.76

Table 2. Weather-based correlation matrix (Pearson's) for Fall armyworm population in maize during *kharif* 2024

Variables	PFAW	T (max.)	T (min.)	RH (mor.)	RH (eve.)	Rf	Evap.	SS
T (max.)	0.261							
T (min.)	0.597*	0.210						
RH (mor.)	0.338	-0.409	0.513					
RH (eve.)	0.333	-0.302	0.845**	0.672*				
Rf	0.090	-0.646*	0.358	0.501	0.638*			
Evap.	0.373	0.240	0.625*	0.118	0.437	0.367		
SS	0.048	0.641*	-0.441	-0.497	-0.808*	-0.625*	0.011	
WV	0.104	-0.367	0.614*	0.504	0.784**	0.699*	0.610*	-0.563

PFAW: FAW population per plant on Maize; T(max.): Temperature maximum (°C); T(min.): Temperature Minimum (°C); RH(mor.): Relative humidity morning (%); RH(eve.): Relative humidity evening (%); Rf: Rainfall (mm); Evap: Evaporation (mm); SS: Sunshine (hours); and WV: Wind velocity (km/h); NS: Non-significant. Correlation data is depicted in the table by bold digits

Table 4. Principal components (PCs) with Eigen values and variances of *S. frugiperda* on maize during 2024

Variables	Eigen value (%)	Variance	Cumulative variance (%)
$T_{min.}$, $RH_{mor.}$, $RH_{eve.}$, Rf, WV	4.48	55.95	55.95
$T_{max.}$, Evap., SS	1.83	22.81	78.76

influencing FAW population during *kharif,* 2024. Indicated that first principal component (PC1) accounted for 55.95% of the total variance, with strongly influenced from minimum temperature, evening and morning relative humidity, rainfall, and wind velocity (Table 4). The second principal component (PC2) explained an additional 22.81% of the variance, primarily contributed by maximum temperature, evaporation, and sunshine hours. Together, PC1 and PC2 explained 78.76% of the total variation in FAW population with respect to weather factors, suggesting that minimum temperature and humidity-related variables were the most critical determinants. Thus, PCA results corroborate the correlation findings, emphasizing that humid conditions along with higher night temperature were optimal for FAW population buildup, while sunshine and evaporation played secondary but notable roles.

FAW larval population per plant (2024) = 1.128(Tmin.) – 0.175(RHmor.) – 0.012(RHeve.) – 0.005(Rf) – 0.935(SS) – 0.421 (WV) ($P < 0.05$, $R = 0.92$, $R^2 = 0.84$).

CONCLUSION

Studies on the seasonal occurrence and abundance of insect pests is essential for the development of successful IPM programs. Seasonal dynamics of *S. frugiperda* across different meteorological weeks indicated that infestation begins shortly after crop emergence, typically 15–20 days after sowing. The number of larvae peaked in the 33rd SMW of 2023 and 2.82 per plant in the 36th SMW of 2024. Correlation analysis of larval populations with weather factors revealed a positive association with minimum temperature in both study years. The results suggest that fluctuations in FAW population is highly influenced by prevailing climatic conditions, as variations in larval abundance and crop damage were observed across both the years. The information obtained on incidence, damage patterns, and the significance of meteorological parameters provides key insights that can guide holistic and successful management measures against this invasive pest.

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Incidence of Rice Gall Midge, *Orseolia oryzae* (Wood-Mason) in Early and Late Sown Crop

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Abstract: Field surveys were conducted to ascertain the incidence of gall midge (*Orseolia oryzae*) in four major rice-growing villages of Bapatla district *viz.*, Karlapalem, Jammulapalem, Appikatla and Kankatapalem. The study focused on five widely cultivated rice varieties *viz.* BPT 5204, BPT 2595, BPT 2270, MTU 1262 and BPT 2782. Gall midge infestation was highest in BPT 5204 (16.27 per cent silver shoots) at Kankatapalem village, followed by BPT 2595 and BPT 2270 at the same village. Relatively high incidence was also observed in BPT 5204 and BPT 2595 at Jammulapalem village. In contrast, least incidence of silver shoots was in BPT 2782 at Karlapalem, BPT 2782 at Appikatla, MTU 1262 at Karlapalem and BPT 2782 at Jammulapalem village. Overall, the results indicate that BPT 5204 and BPT 2595 were more susceptible to gall midge, while BPT 2782 and MTU 1262 exhibited relatively lower levels of infestation, suggesting potential suitability of these for cultivation in gall midge-prone areas.

Keywords: Rice varieties, Survey, Gall midge, Silver shoots, Incidence

The majority of people in India rely on rice as their main source of nutrition. With 27.8% of the world's rice production, India is one of the biggest producers of white rice and has the greatest area under rice cultivation worldwide. India produces 146.7 million tonnes of rice annually on an area of 47.8 million hectares (IRRISTAT 2024). Rice is the staple food crop for most of the world population particularly in Asian countries as 2.9 billion people depend on rice and it is grown in 117 countries. The estimated yield of 787 million metric tonnes were produced every year from 162 million hectares of rice grown worldwide. Asia contributes for 90% of the world's rice production and consumption (FAO 2024)

Rice gall midge, *Orseolia oryzae* (Wood-Mason) is one of the major insect pests, causing extensive damage in several rice growing countries of Asia *viz*., Thailand, China, Sri Lanka, India, Bangladesh, Pakistan, Burma, Kampuchea, Indonesia, Laos, Nepal and Vietnam. Earlier reports have documented prevalence of rice gall midge in African countries such as Sudan, Cameroon, Mali, Upper Volta, Ivory Coast, Senegal, New Guinea, Guinea -Bissau and Nigeria. Gall midge causes an average of US $80 million in crop losses each year in India (Bentur et al*.,* 2003). The pest is endemic in parts of Jharkhand and the damage caused by it typically ranged from 10 to 70%, with an annual production loss of 20 to 70% depending on climatic conditions and varietal susceptibility (Prasad, 2011). This pest is also reported from southern Karnataka districts such as Kodagu, Mysuru, and Hassan and the infestation level in these areas ranged from 10 to 15 per cent (Vijay Kumar et al., 2008). The present study was undertaken to assess the extent of *O. oryzae* infestation among major rice varieties cultivated in key rice-growing villages of Bapatla district, Andhra Pradesh.

MATERIAL AND METHODS

Field survey was conducted in the farmer fields at Bapatla district. The villages selected for this survey were Karlapalem and Appikatla which is situated at an $15^0$94' North latitude, 80^0 50' East longitude in the Krishna Agro Climatic Zone of Andhra Pradesh state of representing early sown crop (August sowings). Kankatapalem and Jammulapalem at which is situated at an $15^0$94' North latitude, 80^0 50' East longitude in the Krishna Agro Climatic Zone of Andhra Pradesh state of India representing late sown situation (September sowings). The study focused on five major rice varieties grown in the district *viz.,* BPT 5204, MTU 1262 BPT 2782, BPT 2270 and BPT 2595. To ensure natural pest build-up, the selected field were not applied with granular insecticides and plant protection sprays either in nursery or in main field. Incidence of gall midge (damaged plants and silver shoots) was recorded at fortnightly intervals on each variety by observing 25 randomly selected hills at 30, 45, and 60 days after transplanting (DAT). The percent silver shoots were calculated.

RESULTS AND DISCUSSION

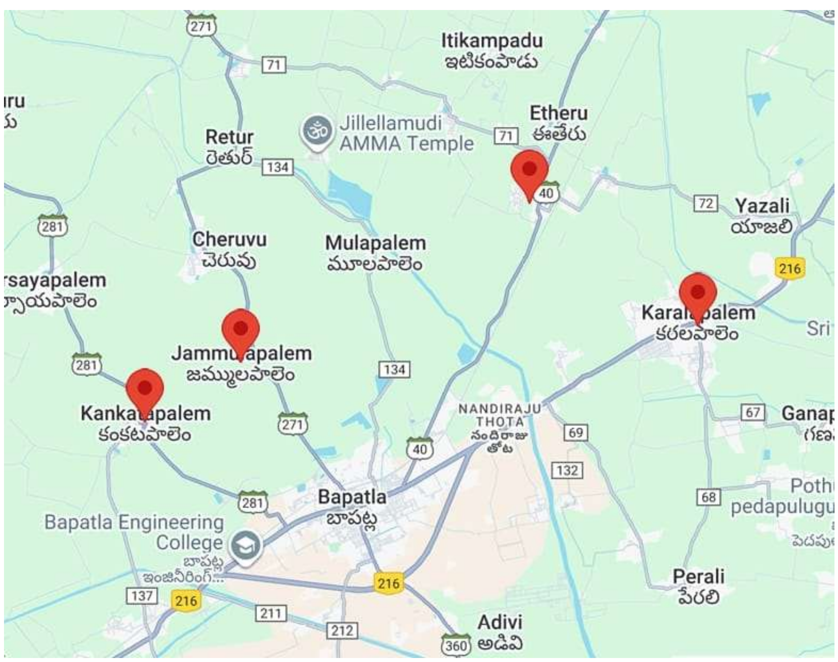
At 30 DAT among the varieties, BPT 5204 recorded the highest silver shoot incidence in all surveyed locations ranging from 10.01 to 15.20 % due to late sown in all villages. The highest incidence was in Kankatapalem followed by Jammulapalem and Appikatla while the lowest silver shoot incidence in Karlapalem village (10.01 %) due to early sown (Table: 1) BPT 2595 recorded slightly lower silver shoots than BPT 5204. Kankatapalem village recorded highest percentage (13.90 %) due to late sown of this variety than BPT 5204. Lowest incidence was in Karlapalem village

(9.27%). BPT 2270 showed moderate infestation (7.04-12.60%), whereas MTU 1262 and BPT 2782 recorded the lowest incidence (2.86-8.00%) because these varieties were early sown in all villages (Table 2).

At 45 DAT the same varietal trend continued. BPT 5204 again recorded the highest levels of silver shoot incidence in all locations (11.13 to 15.30 %) with Jammulapalem showing the peak incidence (15.30) followed by Kankatapalem (15.0%), Appikatla (12.13%) and Karlapalem (11.13 %). BPT 2595 followed closely with highest incidence (14.90 %) at Kankatapalem and lowest was in Appikatla village (12.81 %). BPT 2270 showed intermediate infestation (8.56-13.90%) with highest in Kankatapalem followed by Jammulapalem (12.53%), Appikatla (9.06%), and Karlapalem (8.56 %). The lowest damage (3.53-9.20%) was in MTU1262 and BPT 2782 in all four villages due to early sown and were at par with each other (Table 2).

At 60 DAT, gall midge incidence further increased across all varieties. BPT 5204 registered the maximum infestation (14.92–18.60%), particularly in Kankatapalem followed by Jammulapalem (16.35%) and Appikatla (15.42%). BPT 2595 showed slightly lower infestation levels, ranging from 13.89% (Karlapalem) to 16.10% (Kankatapalem) due to late sown of these two varieties. In BPT 2270, the silver shoot incidence ranged from 9.79% to 14.90 %, with the highest at Kankatapalem (14.90 %) and the lowest at Karlapalem (9.79%). The varieties MTU 1262 and BPT 2782 exhibited the least damage indicating their relative tolerance and were on par with each other. In these two varieties, highest silver shoot incidence was in Kankatapalem (8.30% and 10.40%), followed by Jammulapalem (7.70% and 7.81%), Appikatla (7.63% and 6.54%), while the lowest incidence was recorded in Karlapalem village (6.63 and 5.54%), respectively (Table .2).

Based on mean per cent silver shoot incidence recorded a distinct varietal and location, highest per cent silver shoots in BPT 5204 (16.27) and BPT 2595 (14.97) at Kankatapalem village due to late sown of these varieties, least incidence of



Map shows surveyed villages for gall midge in Bapatla

Table 1. Overall gall midge incidence in different villages around Bapatla

Surveyed villages	Silver shoots (%)				
	BPT 5204	BPT 2595	BPT 2270	MTU 1262	BPT 2782
Karlapalem	12.02	11.99	8.46	5.07	3.98
Appikatla	13.16	12.32	9.63	6.40	4.81
Jammulapalem	14.94	13.29	12.19	8.08	6.16
Kankatapalem	16.27	14.97	13.80	8.50	7.17

Table 2. Rice gall midge incidence in rice growing areas of Bapatla district

Varieties	Silver shoots (%)														
	30 DAT					45 DAT					60 DAT				
	KP	AK	JP	KKP	MEAN	KP	AK	JP	KKP	MEAN	KP	AK	JP	KKP	MEAN
BPT 5204	10.01 (18.4)	11.93 (20.1)	13.19 (22.1)	15.20 (22.9)	12.58	11.13 (19.4)	12.13 (20.3)	15.30 (22.9)	15.00 (22.7)	13.39	14.92 (22.7)	15.42 (20.0)	16.35 (23.7)	18.60 (25.4)	16.32
BPT 2595	9.27 (17.7)	10.77 (18.6)	11.94 (20.1)	13.90 (21.3)	11.47	12.81 (20.5)	11.31 (19.6)	12.22 (20.3)	14.90 (22.2)	12.81	13.89 (21.8)	14.89 (22.2)	15.73 (22.9)	16.10 (23.6)	15.15
BPT 2270	7.04 (15.3)	9.54 (17.9)	10.80 (19.1)	12.60 (20.9)	9.99	8.56 (17.0)	9.06 (17.4)	12.53 (20.1)	13.90 (21.3)	11.00	9.79 (17.7)	10.29 (18.7)	13.24 (21.2)	14.90 (22.2)	12.05
MTU 1262	3.12 (10.1)	5.12 (13.0)	6.64 (14.8)	8.00 (16.2)	5.72	5.46 (13.4)	6.46 (14.7)	7.19 (16.2)	9.20 (17.4)	7.08	6.63 (14.8)	7.63 (16.0)	10.4 (18.8)	8.30 (16.0)	8.24
BPT 2782	2.86 (9.7)	3.86 (11.1)	4.45 (12.1)	6.10 (14.2)	4.31	3.53 (10.7)	4.03 (11.5)	6.23 (14.2)	7.70 (16.0)	5.37	5.54 (13.6)	6.54 (14.8)	7.81 (15.6)	7.70 (16.0)	6.90
C.D.	2.93	2.621	3.356	3.913		4.163	2.912	1.968	4.601		2.665	3.046	2.90	2.871	
C.V.	7.202	5.673	6.654	7.214		8.996	6.097	3.68	8.075		5.147	5.63	4.97	4.835	

Note: Figures in parenthesis are arc sine transformed values
KP: Karlapalem, AK: Appikatla, JP: Jammulapalem, KKP: Kankatapalem
*Mean of incidence recorded at 30, 45 and 60 DAT

silver shoots was recorded in BPT 2782 (3.98-6.16 %) and MTU 1262 (5.07%) across Karlapalem**,** Appikatla and Jammulapalem due to early sown of these varieties (Table 1). These results indicate that BPT 5204 and BPT 2595 were the most susceptible varieties, followed by BPT 2270, whereas MTU 1262 and BPT 2782 showed lower susceptibility to gall midge across all sowing situations.

Mamathad et al*.* (2020), reported higher gall midge incidence in the Cauvery and Kabini command areas of Karnataka, with silver shoot percentages of 9.03 (Mandya) followed by Mysore. Similarly, Krishna et al. (2024) conducted a roving survey in the Chittoor, Nellore, and Y.S.R. districts of the Southern Zone of Andhra Pradesh, Nellore exhibited the highest mean silver shoot damage (15.38%), followed by Y.S.R and Chittoor with BPT 5204 showing maximum susceptibility. The present study corroborates these findings, indicating that BPT 5204 followed by BPT 2595 and BPT 2270 were more susceptible to gall midge across all sowing conditions, whereas MTU 1262 and BPT 2782 showed lower susceptibility. Moreover, higher silver shoot incidence under late-sown conditions (Jammulapalem and Kankatapalem) compared with early-sown fields (Karlapalem and Appikatla) suggests that delayed planting favours pest build-up and enhances gall midge damage.

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CONCLUSION

The current survey confirms that varietal susceptibility and time of sowing play critical roles in determining gall midge incidence. Adoption of tolerant varieties such as MTU 1262 and BPT 2782 coupled with adjustment of sowing time can significantly reduce gall midge-related yield losses in Bapatla district.

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Leafhopper (Cicadellidae: Hemiptera) Fauna Associated with Groundnut Ecosystem in Coastal Andhra Pradesh

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Abstract: Twenty species of leafhoppers (Cicadellidae) were recorded in association with groundnut ecosystem. Among them, *Sophonia linearis* (Distant) is identified and reported for the first time in Andhra Pradesh during 2023-2025 representing a new record for the region. This species is identified based on the shape and length of the head, length of the pronotum. Adequate description of the species was provided supported with illustrations for quick identification. For the remaining species, an identification key with illustrations was developed.

Keywords: Cicadellidae leafhopper, *Sophonia linearis* (Distant), Subgenital plates, Male genitalia

Leafhoppers belong to the family Cicadellidae of superfamily Membracoidea under the Infraorder Cicadomorpha of the suborder Auchenorrhyncha in the order Hemiptera, are considered insects of economic importance. They are distinguished from planthoppers by the absence of the "Y"-shaped cross vein in the forewings which in planthoppers is formed by the fusion of anal veins, 1a and 2a. Around 22,637 recognized species from 2445 genera were described worldwide, of which 1350 species from 340 genera are known to exist in India (Viraktamath 2006) and are arranged in almost 40 subfamilies and 98 tribes. They are small, agile and wedge-shaped insects. Many leafhoppers are important pests of crop plants, particularly because they are vectors of virus, bacteria and phytoplasma diseases (Wilson and Turner 2010).

Groundnut (*Arachis hypogaea* L.) is an important oilseed crop cultivated extensively in Andhra Pradesh. During 2023-2024, was cultivated in 3.11 lakh hectares producing 3.23 lakh tonnes with a productivity of 1038 kg/ha (Department of Agriculture and Farmers Welfare 2025). *Empoasca (Empoasca) kerri* has already attained pest status in groundnut causing losses to the crop. Moreover, under changing climatic conditions, minor and less important pests are emerging as major ones, a trend exacerbated by indiscriminate pesticide use and altered agronomic practices. Although descriptions of numerous leafhopper species and genera are available in scattered literature, reliable identification remains a challenge. Taxonomic keys particularly those accompanied by illustrations and photographs, are vital for accurate species identification and are of great utility for both researchers and field entomologists. Rao (1998) reported 36 species of leafhoppers in rice, sugarcane, cotton and vegetable ecosystems and provided "key" for identification of these economically important species. Jacob et al. (2000) documented forty species belong to 20 genera associated with oilseed crops from Andhra Pradesh and provided illustrated key for their identification. Jacob et al. (2002) reported 41 species of leafhoppers including twelve new records associated with pulse crop ecosystems in Andhra Pradesh. Reddy and Rao (2001) reported 17 leafhopper species on different vegetable crops in Andhra Pradesh. Sangeetha et al. (2020) reported three new records of the Typhlocybinae leafhoppers on redgram ecosystem from the north coastal Andhra Pradesh and provided key for their identification with illustrations. Dhatri et al. (2021) reported nine leafhopper species associated with groundnut in Chittoor district of Andhra Pradesh and provided illustrated key for easy identification. Considering the economic significance of groundnut and the paucity of consolidated information on leafhoppers in its ecosystems, the present study aims to provide a comprehensive account of leafhopper species commonly found in groundnut in coastal Andhra Pradesh. Diagnostic features supported with illustrations are presented to facilitate accurate identification.

MATERIAL AND METHODS

The present investigation was conducted on leafhopper fauna associated with groundnut (*Arachis hypogea*) in coastal districts of Andhra Pradesh *viz*., Srikakulam, Vizianagaram, Visakhapatnam, Anakapalli, Kakinada, East Godavari, West Godavari, Krishna, NTR, Palnadu, Bapatla and SPSR Nellore during 2023-2025 (Table 1).

Collection and preservation of the specimens: The leafhoppers were collected intensively on groundnut with about 15-20 to and fro insect net sweepings per sampling occasion. The leafhoppers were aspirated from the net, killed with ethyl acetate swabs and transferred to small glass vials, labelled, brought to the laboratory and dried in an oven at 45 - 50°C for about 2-3 hours. Dried specimens were preserved in the glass vials. The vials were properly labelled with collection details, *viz*., name of the collector, collection date, location of collection and host. The procedure advocated by Knight (1965) was adopted for mounting and preparation of genitalia. The collected leafhoppers were taken to the lab, they were processed, mounted on thick card triangle mounts and were labelled with the information about the collection, including the host, location, date, and name of the collector.

Preparation of male genitalia: Male genitalia were dissected using a Stereoscopic Zoom Binocular Microscope (CSM2, LABOMED). The abdomen was separated from the thorax with minutons (micro-needles) by applying gentle pressure at the junction of thorax and abdomen. The abdomen was then placed in a cavity block containing 10% KOH solution and left overnight at room temperature to digest soft tissues. After several washes in distilled water, the abdomen was transferred to a glass cavity slide containing a drop of glycerine, where the genital capsule was dissected and the genitalia separated under the stereomicroscope. The line diagrams of male genitalia were drawn after dissection using Olympus Research Microscope with camera lucida attachment. Whole insect specimens were photographed using Leica S-9 Optical Stereo Zoom Microscope attached with digital analyzer at 10X magnification and micro photographs of genital structures were taken with Olympus Trinocular Research Microscope fitted with photographic attachments and digital analyzer at 40X magnification. Confirmation of the species was done by comparing the observed male genitalia parts with available keys and published literature.

RESULTS AND DISCUSSION

Leafhopper diversity in groundnut ecosystem: In the present study, 20 species of leafhoppers belonging to 9 genera were collected and identified (Table 2). A perusal of literature indicated that one of the leafhopper species *Sophonia linearis* (Distant) was recorded for the first time on groundnut in Andhra Pradesh, thereby constituting a new record for the region.

Description of *Sophonia linearis* (Distant): Body is yellow. Vertex with two piceous (=nearly black), apical, elongate, fused spots from which longitudinal, piceous lines traverse posteriorly meeting posterior margin of vertex, lateral margin often with orange-yellow stripe confined to ocelli or extending anteriorly. Pronotum and scutellum with median, longitudinal, piceous line often interrupted before apex of scutellum. Claval margin of forewing piceous with piceous stripe bent obliquely near claval apex and reaching claval suture; spot on second apical cell and two oblique lines from costa in apical half piceous. Head about as wide as pronotum. Vertex nearly twice as long as wide in female, lateral margin raised. Scutellum longer than pronotum. Second apical cell of forewing narrowed apically. Hind margin of seventh sternum straight with median protuberance.

Measurements (mm): Total length including forewings 4.94 mm, width of the body 1.17 mm. length of the head 0.98 mm,

Table 1. Areas surveyed for the collection of leafhoppers on oilseed crops in coastal Andhra Pradesh

District	Place	Latitude	Longitude
Srikakulam	Ragole	18.344974°N	83.889959°E
Vizianagaram	Gajularega	18.12387°N	83.398816°E
Visakhapatnam	Thimmapuram	17.814677°N	83.408232°E
Anakapalli	L.Singavaram	17.800593°N	82.836389°E
Kakinada	Peddapuram	17.087922°N	82.114751°E
East Godavari	Rajamahendravaram	17.004393°N	81.783325°E
West Godavari	Marellamudi	16.913670°N	81.389418°E
Krishna	Gopuvanipalem	16.214436°N	81.191024°E
	Gollamudi	16.77805°N	80.29955°E
	Chopparametla	16.700051°N	80.814717°E
N.T.R	Nandigama	16.783956°N	80.314224°E
Palnadu	Gurazala	16.558004°N	79.637006°E
Bapatla	Bapatla	15.904370°N	80.467500°E
	Cherukupalle	16.049566°N	80.680954°E
	Chinaganjam	15.698071°N	80.237709°E
	Ipurupalem	15.844389°N	80.402395°E
SPSR Nellore	Damavaram	14.697951°N	79.969249°E

width across the compound eyes 0.65 mm. Length of the pronotum 0.39 mm, length of the scutellum 0.52 mm, length of the wing 3.38 mm and width of the wing 0.83 mm.

The detailed description of the other nineteen leafhopper species recorded are available in the literature. However, a key is prepared for all the 20 leafhopper species, for their easy identification.

Identification Key of Leafhopper Fauna Associated with Groundnut Crop Ecosystems

1. Forewings with anteapical cells……..............................2

-Forewings without anteapical cells (Fig. 2)..………….…16

2. Forewings with two anteapical cells…………….……...3

-Forewings with three anteapical cells…………..………6

3. Yellowish orange coloured insects; dorsal side of the abdomen black in colour. Vertex with a pair of round black spots; pygofer with a curved, bifid process and a robust subapical spine; aedeagus shafts cylindrical, short and 'C' shaped (Plate 2a)... ……………………***Cicadulina bipunctata* (Melichar)**

-Vertex without such round black spots and pygofer process and aedeagus not as above……….……………....………4

4.Vertex subacute; styles with apophyses claw like; pygofer with a distinct serrated comb like structure on posteroventral margin; subgenital plates triangular, shorter than Pygofer (Fig. 3)………..…….. ***Aconurella neosolana* Rao and Ramakrishnan**

–Vertex more or less rounded, styles and pygofer not as above………..…………..…5

5. Aedeagus with 3 pairs of basal processes or projections (Fig. 4-5)……….. ………..…***Balclutha incisa* (Matsumura)**

-Aedeagus without such processes. Pygofer without

Table 2. Leafopper species identified in the study

Leafhopper species
Austroagallia bifurcata Sawai Singh and Gill
Aconurella neosolana (Rao and Ramakrishnan)
Chiasmus niger Pruthi
Exitianus indicus (Distant)
Exitianus nanus (Distant)
Nephotettix virescens (Distant)
Cofana unimaculata (Signoret)
Amrasca biguttula (Ishida)
Empoasca (*Empoasca*) *kerri* Pruthi
Empoascanara maculifrons (Motschulsky)
Seriana jaina (Distant)
Balclutha incisa (Matsumura)
Balclutha saltuella (Kirschbaum)
Cicadulina bipunctata (Melichar)
Nirvana pallida Melichar
Sophonia linearis (Distant)
Hishimonus phycitis (Distant)
Doratulina indra (Distant)
Doratulina rubrolineata (Distant)
Doratulina speciosum (Distant)

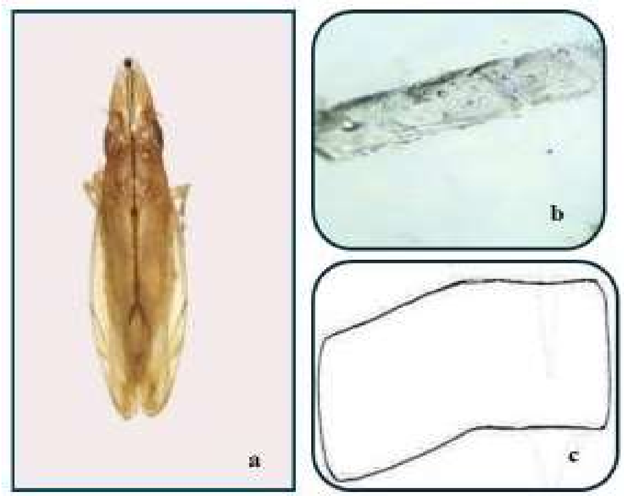

Plate 1. *Sophonia linearis* (Distant) a. Adult dorsal view; b. Female seventh abdominal sternal plate; c. abdominal sternal plate line drawing

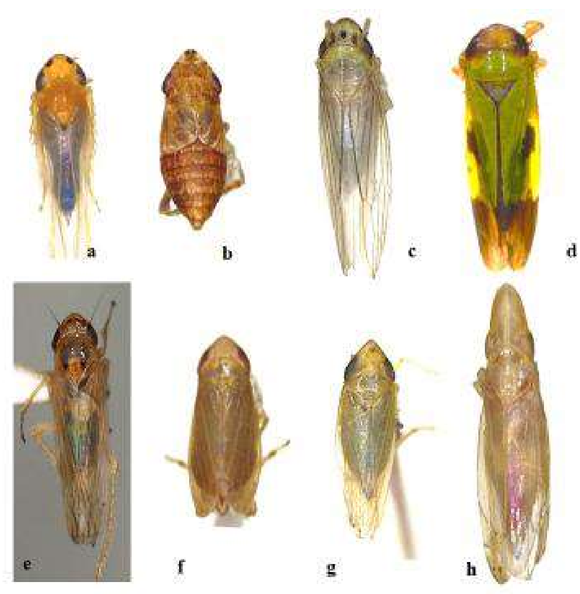

Plate. 2. a. *Cicadulina bipunctata* (Melichar): Adult dorsal view; **b.** *Chiasmus niger* Pruthi: Adult dorsal view; **c.** *Cofana unimaculata* (Signoret): Adult dorsal view; **d.** *Nephotettix virescens* (Distant): Adult dorsal view; **e.** *Exitianus nanus* (Distant): Adult dorsal view; **f.** *Doratulina speciosum* (Distant): Adult dorsal view; **g.** *Doratulina rubrolineata* (Distant): Adult dorsal view; **h.** *Nirvana pallida* Melichar: Adult dorsal view

processes; Connective stem approximately as long as the arms (Fig. 6)……...***Balclutha saltuella* (Kirschbaum)** 6. Tegmina bracypterous, apical margin of forewing and exposed terga of abdomen reddish brown (Fig. 7-8 and Plate 2b)…...............................…***Chiasmus niger* Pruthi**

- Insects variedly coloured; tegmina complete 7

7. Clypeus and clypellus swollen; mostly larger insects, head distinctly green in colour and forewings pale yellowish white, vertex with a black spot at the centre, distinct ocelli on either sides. (Fig. 9-10 and Plate 2c)…..........***Cofana unimaculata* (Signoret)**

- Clypeus and clypellus not swollen; mostly smaller to medium sized insects......…....8

8. Aedeagus with two shafts. Head and pronotum lemon yellow, forewings with pale reddish mottling all over; Aedeagus shafts broad, apex with lateral mesal margins curved anteriorly, apex acutely rounded in posterior view, with curved processes from lateral margins and turned ventrally......................***Hishimonus phycitis* (Distant)**

- Aedeagus with single shaft and is not fused with connective ……...………………9

9. Vertex round, very much narrower, its length is shorter by two or two and half times or even more the length of pronotum with two prominent black spots; aedeagus split into two unequal branches, with a well-developed aedeagal apodemes; connective broad, extremely short, without clear distinction of stem and arms…………***Austroagallia bifurcata* Sawai Singh and Gill**

- Vertex not much narrower in its length than pronotum……...............................10

10. Connective 'Y' shaped; aedeagus simple, not long with slight curvature...…...……11

- Connective 'U' shaped; aedeagal shaft very long, strongly curved dorsocephalad...13

11. Colour opaque green, vertex free of any black marks; in males, the apical third of the wings black, but the black patch does not extend to the claval area; aedeagus with a pair of lateral paraphyses, dorsal surface elongate, sclerotized with five pairs of spines laterally and directed towards apex (Fig. 11 and Plate 2d)…… ……...…***Nephotettix virescens* (Distant)**

- Colour dull brown with various patterns of dark brown or black markings, aedeagus without spines……..................…12

12. Vertex with a conspicuous black band between compound eyes; pygofer with two prominent dark brown or black spines extending to the apical margin, the upper spine is broader and longer than the lower; aedeagus is simple, curved having an articulation between the base and the shaft (Fig. 12-13)...***Exitianus indicus* (Distant)**

- A pair of conspicuous black spots are present at the base of scutellum slightly below the posterior margin of pronotum; pygofer with 3-7 brown or black spines, all are more or less uniform in thickness (Fig. 14-15 and Plate 2e)...…***Exitianus nanus* Distant**

13. Vertex with two prominent black spots between the anterior margins of eyes and two large black spots present on face………………...***Doratulina indra* (Distant)**

- Vertex and face without any black spots……..................17

14. Aedeagus very long, deeply bent dorsocephalad and the shaft with distinct sinuation in the center (Fig. 16)…………………..…***Doratulina speciosum* (Distant)**

- Aedeagus very long, deeply bent dorsocephalad and the shaft without distinct sinuation in the center (Fig. 17 and Plate 2g)……….***Doratulina rubrolineata* (Distant)**

15. Vertex 1.5 to 2.0 times as long as width between eyes...16

-Vertex not long as above……......................................17

16. Vertex with median white stripe and lateral, orange or lemon yellow, submarginal stripe; forewing with a black dot near the apex (Plate 2h).….***Nirvana pallida* Melichar**

- Vertex with two piceous, apical, elongate, fused spots from

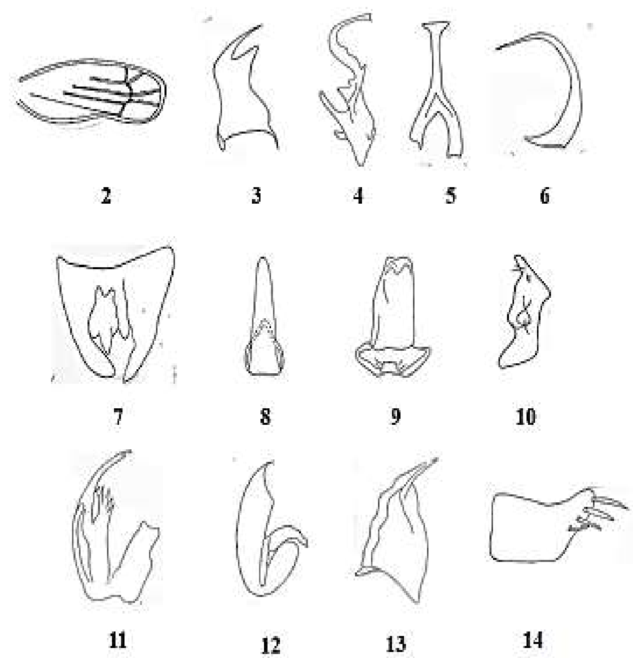

Fig. 2. Fore wing without anteapical cells; 3. *Aconurella neosolana* (Ramasubbarao and Ramakrishnan) Style; 4.-5: *Balclutha incisa* (Matsumura) Aedeagus dorsal view and Connective; 6. *Balclutha saltuella* (Kirschbaum) Aedeagus lateral view; 7-8: *Chiasmus niger* Pruthi Pygofer dorsal view and Aedeagus dorsal view; 9-10: *Cofana unimaculata* (Signoret) Ardeagus dorsal view and Style; 11. *Nephotettix virescens* (Distant) Aedeagus lateral view; 12-13: *Exitianus indicus* (Distant) Aedeagus lateral view and Style; 14. *Exitianus nanus* (Distant) Pygofer

which longitudinal, piceous lines traverse posteriorly meeting posterior margin of vertex. Pronotum and scutellum with median, longitudinal, piceous line often interrupted before apex of scutellum. Claval margin of forewing piceous with piceous stripe bent obliquely near claval apex and reaching claval suture (Fig. 1 and Plate 1a)............. ....***Sophonia linearis*** **(Distant)**

17. Vannal veins fused in the hindwings (Tribe Erythroneurini)……………..................20

- Vannal veins in the hindwings separate apically (Tribe Empoascini)……………..21

18. Aedeagus with two leaf like symmetrical processes, extending to posterior side; a large black spot at the margin of vertex and face; two black spots on scutellum visible through the posterior pronotal region (Fig. 18-19)……...........***Seriana Jaina*** **(Distant)**

- Aedeagus with one pair of asymmetrical apical processes, but not leaf like, longer one arising from the shaft and the shorter one deriving from the base of the longer one rather than from the shaft; vertex with large black spot on the margin of vertex and face (Fig. 22-23)…..................***Empoascanara maculifrons*** **(Motschulsky)**

19. Vertex with two distinct black spots, tegmina also with a large black spot on the apical part; subgenital plates significantly elongated with numerous numbers of macro, micro, and hair like setae; aedeagus short, shaft tube like, slightly curves at apex (Fig. 24-25) ……….....................***Amrasca biguttula biguttula*** **(Ishida)**

- Vertex and forewings without distinct black spots; subgenital plates short, not elongated; aedeagus without any processes, tubular, notched apically, broader apically with middle extensions on both sides and gradually narrowed towards the proximal end; pygofer process elongated, inner surface serrated apically (Fig. 26-27)……. …………..................***Empoasca (Empoasca) kerri*** **Pruthi**

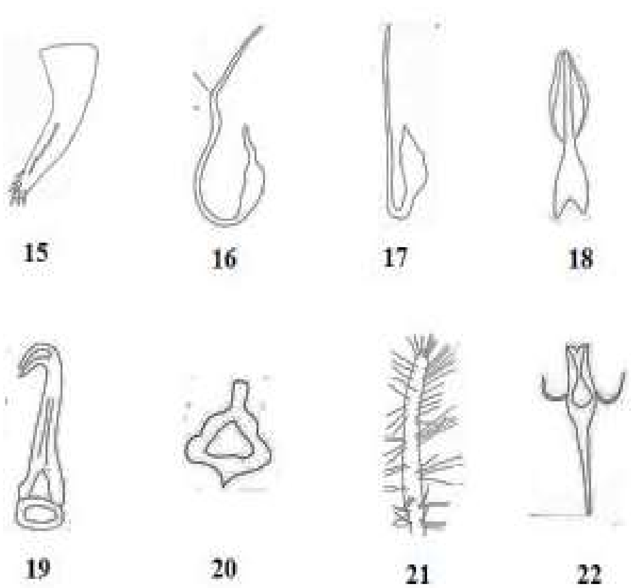

Fig. 15. *Exitianus nanus* (Distant) Subgenital plate; 16. *Doratulina speciosum* (Distant) Aedeagus lateral view; 17. *Doratulina rubrolineata* (Distant) Aedeagus lateral view; 18. *Seriana jaina* (Distant) Aedeagus dorsal view; 19-20: *Empoascanara maculifrons* (Motschulsky) Aedeagus and Connective; 21. *Amrasca biguttula* (Ishida) Subgenital plate; 22. *Empoasca* (*Empoasca*) *kerri* Pruthi Aedeagus dorsal view

Changes in the leafhopper diversity in groundnut crop ecosystem: In the present study 20 leafhopper species were associated with groundnut ecosystem in coastal Andhra Pradesh. Earlier, Jacob et al. (2000) reported 40 species of leafhoppers associated with oilseed crops of which 33 species are recorded on groundnut crop from Andhra Pradesh (undivided state). In the present six species are reported for the first time from groundnut crop ecosystem *viz., Austroagallia bifurcata* Sawai Singh and Gill, *Chiasmus niger* Pruthi, *Doratulina indra* (Distant), *Empoascanara maculifrons* (Motschulsky), *Nirvana pallida* Melichar and *Sophonia linearis* (Distant) apart from the earlier 33 species. Among these species, *Sophonia linearis* (Distant) is being reported for the first time as a new distributional record from Andhra Pradesh whereas other species of leafhoppers are reported on other crops but not from the groundnut crop ecosystem. Dhatri *et al.,* (2021) also reported nine species from groundnut in Chittoor district, but, the earlier mentioned species were not reported. Compared with the earlier studies, the present faunal composition appears richer, possibly due to intensive sampling across multiple coastal districts and extended survey duration (2023-2025). The occurrence of *Sophonia linearis* and other leafhoppers on groundnut for the first time suggests that shifts in species composition may be underway, potentially influenced by changing climatic conditions and cropping patterns.

CONCLUSION

The present study documented 20 species of leafhoppers associated with groundnut ecosystems in Coastal Andhra Pradesh. Among these, *Sophonia linearis* (Distant) is reported for the first time from the state, constituting a new distributional record. A detailed description of this species, along with diagnostic features and illustration of female seventh abdominal sternal plate has been provided to facilitate accurate identification. In addition, an illustrated key for all recorded species is also presented to assist entomologists and extension personnel in species recognition, which is essential for effective pest surveillance and management in groundnut cultivation.

AUTHOR'S CONTRIBUTION

S. Madhurika performed specimen collection, conducted morphological examination, and species identification, curated and analyzed the data, and prepared the original manuscript draft. Dr. P. Sudha Jacob contributed to conceptualization and investigation, validated the taxonomic descriptions, oversaw project administration, and reviewed and edited the manuscript. Dr. S. R. Koteswara Rao provided supervision, participated in validation, and contributed to manuscript review and editing. Dr. V. Prasanna Kumari offered supervision, assisted in validation, and contributed to the writing.

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Taxonomic Documentation of Aphids (Hemiptera: Aphididae) Associated with Oilseed Crops in Andhra Pradesh and Tamil Nadu

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Abstract: Comprehensive survey was undertaken during 2024–25 to document the aphid fauna associated with oilseed crop ecosystems in Tirupati and Chittoor districts of Andhra Pradesh, and Madurai and Virudhunagar districts of Tamil Nadu. The thirteen aphid species, namely *Aphis asclepiadis* (del Guercio), *Aphis craccivora* (Koch), *Aphis fabae* (Scopoli), *Aphis nasturtii* (Kaltenbach), *Acyrthosiphon rubi* (Narzikulov), *Brachycaudus amygdalinus* (Schouteden), *Brachycaudus helichrysi* (Kaltenbach), *Brachycaudus rumexicolens* (Patch), *Brevicoryne brassicae* (Linnaeus), *Lipaphis erysimi* (Kaltenbach), *Myzus dycei* (Carver), *Sitobion leelamaniae* (David) and *Uroleucon carthami* (Hille Ris Lambers) were recorded . Among these, *A. craccivora, A. fabae, A. nasturtii, A. rubi* and *M. dycei* with groundnut crop ecosystem, while *A. nasturtii* in sesame. The aphid species documented from sunflower crop ecosystems include *A. asclepiadis, B. amygdalinus, B. rumexicolens* and *B. helichrysi*, whereas *L. erysimi, B. brassicae* and *M. dycei* were recorded from mustard. *U. carthami* was exclusively associated with safflower. These findings provide baseline information on aphid diversity across major oilseed crop ecosystems of southern India, contributing to future ecological and pest management studies.

Keywords: Aphids, Groundnut, Sesame, Mustard, Sunflower, Safflower

Oilseed crops are cultivated worldwide for their edible oils, high protein content, and diverse industrial applications. They represent the second most important group of crops after cereals, occupying about 14-15% of the gross cropped area in India and contributing significantly to the agricultural GDP. India ranks as the fourth-largest oilseed-producing country, with a production of 39.67 million tonnes during 2023-24 (www.indiastat.com). Aphids (Hemiptera: Aphididae) form one of the most economically significant and taxonomically diverse groups of insect pests infesting oilseed crops. They are characterized by soft bodies, rapid parthenogenetic reproduction, and remarkable polymorphism contributing to their high adaptability and outbreak potential. In addition to causing direct damage by feeding on phloem sap, aphids also transmit viral diseases, compounding their impact on yield and oil quality reduction. More than 4700 aphid species have been described globally and of these over 190 have been reported to transmit more than one plant virus. The majority of the reported aphid vectors belong to the genera *Myzus*, *Aphis*, *Acyrthosiphon* and *Macrosiphum* of the subfamily Aphidinae (Kennedy et al., 1962). In oilseed ecosystems, several species of aphids to cause significant economic losses. *Aphis craccivora* Koch is a major pest of groundnut and sesame, while *Lipaphis erysimi* (Kaltenbach) severely infests mustard and other cruciferous crops. *Aphis gossypii* Glover, *Myzus persicae* (Sulzer), and *Brevicoryne brassicae* (Linnaeus) are also frequently associated with sunflower, safflower, and castor. These species not only reduce yield through direct sap feeding but also act as vectors of important viral diseases like groundnut rosette virus, cucumber mosaic virus, and turnip mosaic virus (Nault 1997, Hull 2002).

In aphid taxonomy, morphological characters such as body size and shape, antennal structure, number and distribution of rhinaria, rostral morphology, cauda and siphunculi structure, and caudal setae play a crucial role in species identification. Detailed examination of these features, supported by taxonomic keys and illustrated diagnostic plates, enables accurate and reliable identification of aphid species. Such precise identification is fundamental not only for understanding biodiversity and systematics but also for developing effective pest management strategies for aphid pests of major oilseeds and legumes crops.

MATERIAL AND METHODS

Surveys were conducted during 2024–2025 in oilseed crop ecosystems of Tirupati and Chittoor districts (Andhra Pradesh) and Madurai and Virudhunagar districts (Tamil Nadu) to collect aphid specimens. Infested plant parts with aphid colonies were placed in plastic containers (12 × 7 cm) or polyethylene bags, and in some cases aphids were also gently removed from plants using a camel hairbrush. Collected specimens were preserved in 70% ethanol in 2.5 ml vials, each labelled with collection details including locality, GPS coordinates, host plant, date, and collector.

Slides mounts were prepared following the procedure of Eastop and van Emden (1972). Preserved aphid specimens were initially boiled in 95% ethanol for 5–10 minutes and subsequently cleared in 10% KOH until the body became transparent. After rinsing with 95% ethanol, the specimens were treated briefly with glacial acetic acid and then transferred to clove oil for complete clearing. Individual specimens were mounted in a drop of thin Canada balsam, oriented dorsally with appendages well spread. The slides were dried horizontally in an oven at 50 °C for 12 hours, with a water bath used during boiling to avoid direct heat damage. Each slide carried two labels: one with details of the host plant, locality, date, and collector, and the other specifying the scientific name and identifier.

RESULTS AND DISCUSSION

Total of thirteen aphid species belonging to eight genera recorded from oilseed crop ecosystems in Andhra Pradesh and Tamil Nadu were *Aphis asclepiadis* (del Guercio), *Aphis craccivora* (Koch), *Aphis fabae* (Scopoli), *Aphis nasturtii* (Kaltenbach), *Acyrthosiphon rubi* (Narzikulov), *Brachycaudus amygdalinus* (Schouteden), *Brachycaudus helichrysi* (Kaltenbach), *Brachycaudus rumexicolens* (Patch), *Brevicoryne brassicae* (Linnaeus), *Lipaphis erysimi* (Kaltenbach), *Myzus dycei* (Carver), *Sitobion leelamaniae* (David) and *Uroleucon carthami* (Hille Ris Lambers). Among these, *B. amygdalinus* was reported for the first time from India. Eight species *viz*., *A. asclepiadis*, *A. nasturtii*, *A. rubi*, *B. amygdalinus*, *B. helichrysi*, *B. rumexicolens*, *M. dycei* and *S. leelamaniae*, were reported for the first time from Andhra Pradesh, while three species *viz*., *A. asclepiadis*, *B. helichrysi* and *S. leelamaniae*, were recorded for the first time from Tamil Nadu. The list of aphid fauna associated with different host plants of oilseed crop ecosystems are presented in the Table 1 and the morphometric data of the recorded aphid species are presented in the Table 2.

***Aphis asclepiadis* (del Guercio):** The body is pale to dark green and measures about 1.4 times the length of the antenna. The antennae are pale with dusky apices. The ultimate rostral segment is narrow and wedge-shaped. The siphunculi are cylindrical, dark, and about 2.2 times longer than the cauda. The cauda is pale or slightly pigmented and tongue-shaped (Plate 1 A).

***Aphis craccivora* (Koch):** The body is approximately 1.6 times longer than the antenna. The abdomen is dorsally black, with pigmentation commonly extending laterally around the sclerites and siphuncular bases, the pigmentation appears fragmented in smaller individuals. Antennae reach about two-thirds of the body length, with segments I, II, and the apex of segment V darkened, while segments III, IV, and the basal part of segment V remain pale. The siphunculi are slightly swollen medially which are cylindrical and appears black in colour and about 1.9 times longer than the cauda. The cauda is pale, tongue-shaped, and bears 4-7 setae (Plate 1 B).

***Aphis fabae* (Scopoli):** Antennal pigmentation is confined to segments I and II, the apical half of segment VI, and the processus terminalis, while segments III, IV, and the basal half of segment V remain pale. The apical two-thirds of the femora are darkened, with similar dusky pigmentation present at the tibial apices and on the tarsi. The siphunculi measures about 1.6 times the length of the cauda, appears dark in colour and cylindrical, slightly swollen medially. The cauda is dark, concolourous with the siphunculi and varies from tongue-shaped to elongate (Plate 1 C).

***Aphis nasturtii* (Kaltenbach):** In apterous viviparous females of *Aphis nasturtii*, the body exhibits a bright pale green to yellowish-green hue and lacks any waxy covering. The body length is approximately 1.8 times longer than the antenna. The dorsal abdomen is translucent and pale, without sclerotized bands or pigmented sclerites. Legs are

Table 1. Aphid fauna associated with oilseed crop ecosystems

Crops	Aphid species recorded in Andhra Pradesh	Aphid species recorded in Tamil Nadu
Groundnut	*Aphis craccivora* (Koch)	*Aphis craccivora* (Koch)
	Aphis fabae (Koch)	*Aphis fabae* (Koch)
	Acyrthosiphon rubi (Kaltenbach)	*Acyrthosiphon rubi* (Kaltenbach)
	Aphis nasturtii (Kaltenbach)	
Sesame	*Aphis nasturtii* (Kaltenbach)	*Aphis nasturtii* (Kaltenbach)
Sunflower	*Aphis asclepiadis* (Fitch)	*Brachycaudus amygdalinus* (Schouteden)
	Brachycaudus amygdalinus (Schouteden)	*Brachycaudus rumexicolens* (Kaltenbach)
	Brachycaudus helichrysi (Patch)	
	Brachycaudus rumexicolens (Kaltenbach)	
Mustard	*Lipaphis erysimi* (Kaltenbach)	*Lipaphis erysimi* (Kaltenbach)
	Brevicoryne brassicae (Linnaeus)	*Myzus dycei* (Carver)
	Myzus dycei (Carver)	
Safflower	*Uroleucon carthami* (Hill Ris Lambers)	-

light to dusky, with the distal portions of the tibiae showing slightly darker pigmentation. The siphunculi are cylindrical, pale, and slightly reticulated at the apex, with faint darkening at the tips and measure about 1.2 times the length of the cauda. The cauda is bluntly conical and bears four to seven setae (Plate 1 D).

***Acyrthosiphon rubi* (Narzikulov):** The dorsal cuticle of the body is colourless and exhibits a wrinkled texture. The frons is distinctly emarginated, showing a faint median prominence, while the lateral prominences remain smooth. Antennae are six-segmented and exceed the body length, measuring approximately 1.3 times that of the body. The siphunculi are long, slender, and finely imbricated, each bearing a distinct flange. They measure about 0.35 times the body length and are approximately 1.6 times longer than the cauda, bearing 1-3 small hairs on one or both siphunculi. The cauda is elongate and subtriangular, and possess 7 to 9 setae. All dorsal, antennal, femoral, and basal tibial hairs are blunt, either spear-shaped or slightly knobbed. The eighth abdominal tergite bears 6-9 hairs (Plate 1 E).

***Brachycaudus amygdalinus* (Schouteden):** The antennae are six-segmented, with the body length measuring about 1.5 times that of the antenna. The ultimate rostral segment (R IV+V) bears four accessory hairs and measures approximately 0.8 times the length of the second hind tarsal segment (HT II). The siphunculi are pale with dusky apices, contrasting with those of *Brachycaudus schwartzi*, which are black and nearly three times longer than the cauda. The cauda is broadly rounded, with its length less than half of its basal width (Plate 1 F). By contrast in *Brachycaudus helichrysi*, the cauda is nearly equal in length and basal width.

***Brachycaudus helichrysi* (Kaltenbach):** The antennae are shorter than the body, which measures approximately 1.8 times the antennal length. The final antennal segment consists of a processus terminalis that is nearly twice as long as its basal portion. The rostrum is relatively short, reaching only up to the mid-coxae, its terminal segment is blunt and furnished with 2–3 accessory setae. The siphunculi are distinctly darker than the cauda, short, tapering, slightly swollen medially, and finely imbricated, with a clear subapical constriction. They are about 1.9 times longer than the cauda. The cauda itself is helmet-shaped, almost equal in length and basal width, and bears between 6 and 9 setae (Plate 1 G).

***Brachycaudus rumexicolens* (Patch):** The antennae are six segmented and measures approximately 0.45 times the length of the body, Body pigmentation is variable, however, the dorsal abdomen consistently shows extensive sclerotization, featuring a distinct dark cross-band on tergite V (occasionally extending across IV–V) and on tergites VI–VIII, often accompanied by smaller sclerites on the anterior tergites. Siphunculi measures 0.13 times the body length and 1.2 times the caudal length and it is very short and conical. They have a slightly constricted base, and a small terminal flange may be present. The cauda is short and broadly rounded, less than half as long as its basal width and generally bears seven setae (Plate 1 H).

***Brevicoryne brassicae* (Linnaeus):** Body length is 1.5 times the length of the antenna. Antennae are 6-segmented, with segment I imbricated, shorter than wide, segment II equal to segment I and the flagellum strongly imbricated. Apterous forms bear ciliated primary rhinaria. Rostrum reaching midcoxae with the ultimate rostral segment shorter

Table 2. Morphometric data of viviparous female aphid

Aphid species	Body length (mm)	Body width (mm)	Antennal length (mm)	Caudal length (mm)	Caudal width (mm)	Siphunculi length (mm)	Siphunculi width (mm)
A. asclepiadis	1.94	1.07	1.35	0.17	0.12	0.38	0.09
A. craccivora	3.45	2.28	2.11	0.39	0.11	0.76	0.08
A. fabae	3.00	1.73	2.68	0.31	0.24	0.52	0.13
A. nasturtii	3.94	2.51	2.11	0.27	0.25	0.33	0.13
A. rubi	2.82	1.54	3.73	0.63	0.29	1.01	0.16
B. amygdalinus	3.96	1.82	2.57	0.16	0.24	0.49	0.16
B. helichrysi	2.35	1.44	1.29	0.18	0.17	0.35	0.09
B. rumexicolens	5.29	2.61	2.43	0.59	0.53	0.68	0.17
B. brassicae	3.62	2.15	2.29	0.27	0.24	0.42	0.12
L. erysimi	5.39	2.59	2.05	0.24	0.35	0.44	0.18
M. dycei	2.40	1.48	1.82	0.48	0.20	1.35	0.23
S. leelamaniae	4.34	1.78	2.30	0.36	0.36	0.34	0.12
U. carthami	3.60	2.07	6.45	2.71	0.57	4.82	0.91

or slightly longer than second hind tarsal segment, bearing four secondary hairs. Siphunculi barrel-shaped, 0.2 times the body length and 1.6 times the length of the cauda. Cauda dark, triangular to elongate and bears 5–7 hairs. Legs smooth, hairs acute to sub-acute, faintly imbricated, tarsi are normally imbricated (Plate 1 I).

***Lipaphis erysimi* (Kaltenbach):** Body broadly oval measuring approximately 2.6 times the length of the antenna. Antennae are 6-segmented, generally dark except segments I, II, and basal half of segment III which are lighter in color. Flagellum imbricated, flagellar hairs minute. Rostrum reaching midcoxae, ultimate rostral segment aculminate, bearing two secondary hairs. Abdominal dorsum is pale. Cauda is medially constricted with a rounded apex rounded, bearing 5–6 hairs. Siphunculi are cylindrical, pale with dark apices, without flanges, and slightly tapering towards the tip and approximately 1.83 times longer than the cauda (Plate 1 J).

***Myzus dycei* (Carver):** Body length is 1.3 times that of the antenna. Cuticle is pale to light brown, sclerotized and corrugated, becoming coarsely spinulose posterior to the siphunculi. Antennae are six-segmented, without secondary rhinaria. Rostrum extends to the hind coxae, ultimate segment is longer than second hind tarsal segment, pale brown with a darker apex and bears 5–7 hairs. Legs are pale to light brown, concolourous with body while tarsi are darker. Siphunculi are stout, slightly expanded basally, gently curved, weakly clavate distally and narrowing apically, their surface shows small, flat imbrications with the apex displaying wo rows of transverse cells. Siphunculi are about 2.8 times longer than cauda. Cauda is triangular, slightly rounded with convex sides and a faint basal constriction, concolourous with body, bearing 5–6 distal hairs (Plate 1 K).

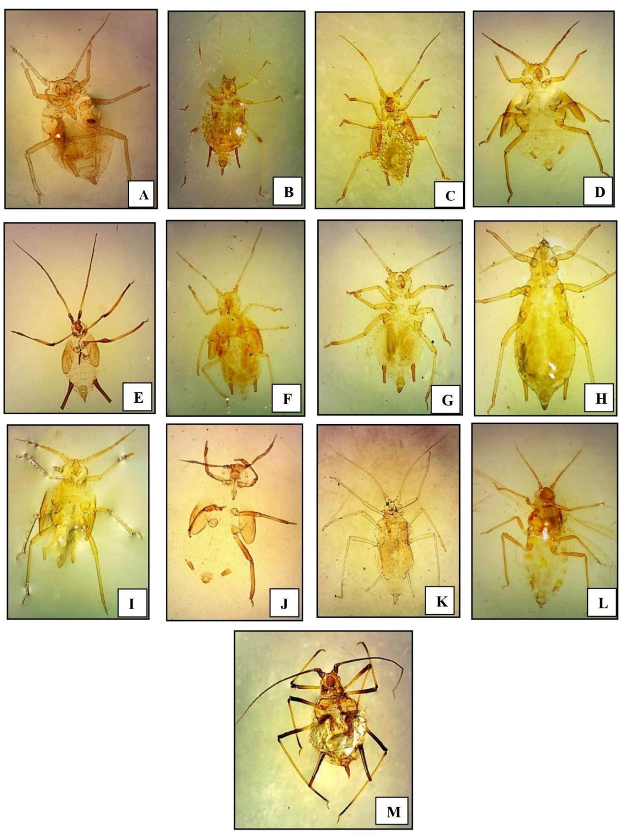

Plate 1. A. *Aphis asclepiadis*; B. *Aphis craccivora*; C.*Aphis fabae*; D. *Aphis nasturtii*; E. *Acyrthosiphon rubi*; F. *Brachycaudus amygdalinus*; G. *Brachycaudus helichrysi;* H. *Brachycaudus rumexicolens*; I. *Brevicoryne brassicae*; J. *Lipaphis erysimi*; K. *Myzus dycei*; L. *Sitobion leelamaniae*; M. *Uroleucon carthami*

***Sitobion leelamaniae* (David):** The body length is approximately 1.9 times that of the antenna. Antennae are six-segmented, with segment III imbricated and bearing few setae. The processus terminalis is 1.8 times the length of the base of the last antennal segment. The ultimate rostral segment is long, narrow, and acuminate, extending beyond the mid-coxae and bearing 2–3 accessory setae. Siphunculi are cylindrical, pale brown, gradually darkening toward the apex, with bases unconstructed. The cauda is tongue-shaped, pale in color, and bears several setae (Plate 1 L).

***Uroleucon carthami* (Hille Ris Lambers):** Adult apterae are spindle-shaped, coloration dark brown to blackish brown. Siphunculi and cauda are black. Antennae are predominantly black except extreme base of segment III and measure about 1.8 times longer than the body. Legs black except basal halves of femora. Rostrum reaches hind coxae with the ultimate rostral segment longer than second hind tarsal segment. Dorsal hairs on body are long, numerous, each anchored by dark sclerotized bases. Marginal tubercles on tergites II–IV very small or absent. Siphunculi are robust, tapering cylindrical structures, about 1.8 times longer than the cauda, with distinct reticulation distally. Cauda is slender, distinctly constricted, bearing 16–22 hairs and measuring approximately 0.75 times the length of the body (Plate 1 M).

Key for the encountered aphid species in the oilseed crop ecosystems during the present study

1. Spiracles of abdominal segments 1 & 2 are placed far apart; abdominal segments 1 & 7 usually possess lateral abdominal tubercles; secondary rhinaria completely absent in apterous forms; Antennal hairs very fine **(Tribe: Aphidini)** ……………………...………… **2**

-Spiracles of abdominal segments 1 & 2 are much closer; abdominal segments 1-7 are devoid of tubercules; secondary rhinaria are mostly present in apterous forms; antennal hairs usually coarse **(Tribe: Macrosiphini)** ………………………………………..…… **5**

2. Soft bodied aphids; body yellowish to greenish colour; Legs pale to dusky, with tibiae exhibiting slightly increased pigmentation towards their distal ends; cylindrical siphunculi with reticulate apex and longer than the cauda; cauda bluntly conical **(Plate 1 D)** …………………………………………. ***Aphis nasturtii***

- Soft bodied aphids; pigmentation varies from dark brown to black with or without shiny appearance…… …………………………………………...**3**

3. Cauda dark tongue shaped, elongate; siphunculi cylindrical dark & swollen; antennae shorter than body but processus terminalis long. Antennal segments I and II, the apical half of segment VI, processus terminalis exhibit dusky to dark pigmentation, whereas segments III, IV, and the basal half of segment V appear white **(Plate 1 C)**……....…..…***Aphis fabae***

- Cauda dark & tongue shaped; siphunculi cylindrical but not swollen……………………**4**

4. Cauda long, pale, tongue shaped with numerous setae; siphunculi cylindrical and dark; antennal segments I, II, and the apex of segment V dark whereas segments III, IV, and the basal portion of segment V remain pale **(Plate 1 B)** ….………………...***Aphis craccivora***

- Cauda tongue shaped with many long setae; siphunculi short and slightly tapering; antennae shorter than body length **(Plate 1 A)**…..………………………***Aphis asclepiadis***

5. Aphid with dark coloured body; prominent diverging lateral tubercules; primary rhinaria ciliated; siphunculi very darkly pigmented, subcylindrical, without flange; cauda very dark, tapering, with numerous setae; rostrum reaching hind coxae **(Plate 1 M)**………………………………………...***Urolecucon carthami***

- Aphid light to dark coloured body; lateral tubercules absent; primary rhinaria present but not ciliated; siphunculi may be pale or dark…………..………………………………..… **6**

6. Siphunculi short or long, cylindrical to sub cylindrical but are always with a prominent apical flange; cauda may be tongue shaped or sub triangular………………………….…**7**

- Siphunculi may be short or long without prominent apical flange……………………… **11**

7. Siphunculi cylindrical, pale brown with apical darkening not basally constricted; cauda, pale, tongue shaped with minimal multiple setae **(Plate 1 L)** ……………………..…***Sitobion leelamaniae***

- With many variably shaped setae on cauda as well as on body……………….………. **8**

8 Siphunculi long, slender, and imbricate, each featuring a distinct flange; Cauda elongate and subtriangular; all hairs on the dorsum, antennae, femora, and basal tibiae are blunt and either spear-shaped or slightly knobbed **(Plate 1 E)**…………………..***Acyrthosiphon rubi***

- Cauda with triangular or helmet shaped………… ………........... **9**

9 Cauda triangular with slightly rounded apex, convex lateral margins, concolorous with the body and with faint basal constriction; siphunculi moderately stout, slightly curved with weak distal clavation, finely imbricated, apically bearing two rows of transverse cells **(Plate 1 K)**………………. …………………………………………….***Myzus dycei***

- Cauda without basal constriction and not triangular …………………….……………**10**

10 Cauda helmet-shaped and approximately equal in length to its basal width; siphunculi short, tapering, with slight median swelling, finely imbricated, and a well-defined constriction below the apex; short rostrum and blunt ultimate rostral segment **(Plate 1 G)** ………………………. …..***Brachycaudus helichrysi***

- Cauda not helmet shaped but broadly rounded or elongate, tongue shaped…………………………………………... **11**

11 Cauda broadly rounded…………………………… ………..… **12**

- Cauda triangular or helmet shaped………………… ……………………………………**13**

12 Cauda broadly rounded with a length less than half its basal width; siphunculi pale with dusky tips and longer than the cauda **(Plate 1 F)**……………***Brachycaudus amygdalinus***

- Cauda broadly rounded and less than half its basal width; siphunculi conical, and longer than the cauda **(Plate 1 H)**……………………...***Brachycaudus rumexicolens***

13. Barrel shaped siphunculi, longer than the cauda; cauda dark, triangular to elongate; antennae 6-segmented; segment I imbricated; segment II equal to segment I **(Plate 1 I)**…………………………………...***Brevicoryne brassicae***

- Siphunculi moderately long, narrow at base, cylindrical or slightly swollen distally, and with a preapical constriction below the flange; cauda broad at base, tongue-shaped to elongate triangular, often with a slight median constriction **(Plate 1 J)**…...…………………………***Lipaphis erysimi***

The diversity and taxonomic characterization of aphids recorded in the present study are in agreement with several earlier reports documenting aphid–host associations across different agroecosystems. Stoetzel and Miller (2001) provided comprehensive information on taxonomic characters, usual hosts, and distribution of aphids within the United States. The observed species were *A. craccivora*, *A. fabae*, *A. gossypi*, *A. Maidiradicis*, *Hysteroneura setariae* (Thomas), *Macrosiphum euphorbiae* (Thomas), *Metopolophium dirhodium* (Walker), *M. persicae*, *R. Maidis*, *Rhopalosiphum padi* (Linnaeus), *Sipha flava* (Forbes), *Schizaphis graminum* (Rondani), and *Sitobion avenae* (Fabricius) and also provided detailed pictorial and dichotomous keys for identification of each aphid species which served as a valuable reference framework for comparative diagnosis in the present study. Trivedi and Singh (2014) also highlighted that *A. craccivora* can be differentiated from other species by its distinct morphological traits. These include the presence of two hairs on the first segment of the hind tarsus; a blackish abdominal dorsum, generally fully sclerotized, with a pale region surrounding the siphunculi and a continuous dark median patch marked with polygonal reticulations; the eighth abdominal tergite bearing only two hairs; siphunculi that are blackish, cylindrical, and strongly imbricated; and a cauda that is elongate, apically pointed, and furnished with 5–7 hairs. These distinguishing features correspond well with the morphological observations made on *A. craccivora* populations associated with groundnut in the current investigation, reaffirming the reliability of these taxonomic traits. The occurrence of *Brevicoryne brassicae* and *Brachycaudus helichrysi* in the present study corroborates the findings of Ali (2014) who recorded five aphid species belonging to Subfamily Aphidinae: *Brevicoryne brassicae* (Linnaeus), *Brachycaudus helichrysi* (kaltenbach), *Lipaphis lepidii* (Nevsky), *Lipaphis pseudobrassicae* (Davis), *M. persicae* infesting cruciferous crops in Iraq.

Singh et al. (2015a) reported extensive aphid diversity on members of the family Asteraceae, identifying 207 plant species infested by 199 aphid species in India. Among the recorded aphid species, *A. gossypii* was recorded feeding on 77 food plants of Asteraceae followed by *B. helichrysi* feeding on 72 species, *A. spiraecola* feeding on 70 species, *M. persicae* feeding on 45 species, *M. ornatus* feeding on 35 species, *A. fabae* feeding on 25 species and *A. craccivora* feeding on 23 species. The present findings of *B. amygdalinus*, *B. helichrysi*, *B. rumexicolens* and *U. carthami* infesting on food plants of Asteraceae are consistent with their observations. Further, Singh et al. (2015b) highlighted *M. persicae* as a widespread pest occurring on 14 plant families, including Brassicaceae, Asteraceae, Fabaceae, and Solanaceae. The current findings of *B. brassicae*, *L. erysimi*, and *M. dycei* on Brassicaceae and *A. asclepiadis* and *B. rumexicolens* on Asteraceae reaffirm the broad host range patterns previously reported. Singh et al. (2016) identified 73 aphid species colonizing legumes in India, with *A. craccivora* being the dominant species, feeding on 83 legume species, followed by *A. gossypii* (39 species) and *Acyrthosiphon pisum* (20 species). In the present study, 13 species were reported from oilseed crop ecosystems, of which four aphid species, *A. craccivora*, *A. fabae*, *A. rubi*, and *A. nasturtii*, were identified as colonizing groundnut (a leguminous crop), is in strong conformity with these results, highlighting the prevalence of *A. craccivora* as a key pest in legume-based systems. Kumar et al (2023) documented 18 aphid species from 55 host plants across the Kumaun region of India. Their report of *A. asclepiadis* on *Helianthus annuus* and *A. nasturtii* on *Sesamum indicum* and *H. annuus* parallels the present findings from Andhra Pradesh and Tamil Nadu. The observation of *A. nasturtii* as a highly polyphagous species capable of colonizing both sesame and groundnut further supports its ecological plasticity and adaptability as noted in their work.

Twenty species of aphids infesting 29 plant species in the Terai region of West Bengal, of which *Brevicoryne brassicae*, *Myzus persicae*, *Lipaphis erysimi* (Kaltenbach), *Aphis gossypii*, and *Sitobion avenae* were identified as the predominant species (Maji et al., 2023). Comparable trends were observed in the current study, where *L. erysimi*, *B. brassicae*, and *M. dycei* were also found to be associated with members of the Brassicaceae, particularly within the mustard crop ecosystem demonstrating a consistent host–aphid relationship across regions. Kumar et al. (2024) reported peak populations of *L. erysimi* during the last week of December in mustard fields across different sowing dates; this seasonal pattern was also evident in the present study, confirming the temporal population dynamics of this species. Among the aphids studied in the present work, *A. nasturtii* was identified as polyphagous species, occurring in both the sesame and groundnut ecosystems. Its ability to colonize multiple hosts across different crop groups highlights its ecological adaptability and potential role as persistent pests. Such polyphagous behavior not only increases its survival potential opportunities but also enhances its significance as vectors of plant viruses, thereby posing greater risks to oilseed and legume production systems in Southern India.

CONCLUSION

The present investigation documented a diverse assemblage of aphid species associated with major oilseed crop systems in Andhra Pradesh and Tamil Nadu, highlighting their host specificity and seasonal abundance patterns. Species such as *Lipaphis erysimi*, *Brevicoryne brassicae*, and *Myzus dycei* exhibited a strong affinity to members of the Brassicaceae, while others like *Aphis gossypii* and *A. craccivora* showed wider host adaptability across different crop groups. The occurrence of polyphagous species such as *A. nasturtii* across sesame and groundnut ecosystems underscores their ecological plasticity and potential epidemiological importance as virus vectors. The findings provide a comprehensive taxonomic baseline for the aphid fauna of oilseed crops in southern India and emphasize the need for continuous monitoring and integrated pest management strategies tailored to the regional agroecosystems.

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Diversity and Abundance of Soil Arthropods in Floriculture, Orchard and Agriculture Crops

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Abstract: Study of soil arthropods is crucial for understanding soil health, which is essential for both ecosystem stability and agricultural productivity. The experiment was conducted to assess soil arthropods diversity and abundance in different crops (Floriculture block, Orchard block, Northern block and Southern block) with varying soil types at the Agricultural College farm, Bapatla during 2021-22. A total of 6248 individual soil arthropods were recorded from all the cropping systems belonging to 4 classes, 7 orders and 15 families. Sampling data was collected and extracted using pitfall traps (macro-arthropods) and Berlese funnels (micro-arthropods) and the data was analysed using Shannon-Weiner diversity index, Simpson's index, Relative abundance, Evenness, Sorenson's similarity index and Kruskal-Wallis test. The results showed that Floriculture block had the highest Shannon-Weiner diversity (2.29), Simpson's index (0.87) and Evenness (0.70) among the blocks. Northern block had the lowest Shannon-Weiner diversity (2.00), Simpson's index (0.78) and Evenness (0.57). Arthropods in the order Coleoptera made up the largest fraction of arthropods in all the blocks. Sorenson's similarity index showed more similarity between Floriculture block and Northern block (74%). The Kruskal-Wallis test revealed significant differences in arthropod distribution among the four blocks, suggesting that soil type and land use influence soil arthropod community structure.

Keywords: Berlese funnel, Biodiversity indices, Kruskal-Wallis test, Pitfall traps, Soil types

The soil is a dynamic, diverse, and highly heterogeneous system that sustains a variety of natural niches, is home to a wide range of living things, and performs essential ecosystem functions (Goncalves and Pereira 2012). It is estimated that about 3,60,000 species accounting for nearly 23 per cent of all documented organisms inhabit the soil with 85 per cent of those species being arthropods (Culliney 2013). Edaphic fauna form an integral component of the agricultural environment and is highly sensitive to disturbances arising from crop and soil management practices. The abundance and dispersal of soil arthropods are influenced by geographic location, climate, soil physical characteristics, litter type and depth, and other abiotic elements like temperature, moisture, and light (Mir 2000).

The soil arthropods are diverse and important for ecosystem functioning. They serve as predators and are crucial in the decomposition of organic matter, nutrient cycling, mobilization of nutrients, regulation of microbial population by predation or dispersion of propagules into environment, disease management, agrochemical degradation, soil structure maintenance, development of soil physio-chemical characteristics and other functions (Toyota et al., 2013, Roy et al., 2011). Owing to these multifaceted roles, they are often referred to as “litter transformers” and “ecosystem engineers”. Biodiversity of soil arthropods is essential for the survival of life on the earth in the long run. It shields the soil from the ecosystem's disruption and stress. Hence, soil arthropod diversity can be used as a sign of soil stability. From this point of view, it is essential to monitor the soil biodiversity in agricultural areas (Rossi et al., 2006). In this context, the present study was undertaken to determine the diversity and abundance of soil arthropods in various blocks of the Agricultural College farm, Bapatla representing varied soil types.

MATERIAL AND METHODS

Study site: The experiment was conducted at the Agricultural College farm, Bapatla during September, 2021 to February, 2022. The College farm consisted of four different blocks representing different cropping systems *viz*., Floriculture block (Perennial flower crops), Orchard block (Banana+ groundnut+ lady's finger), Southern block (Millets + groundnut) and Northern block (Maize) which consisted of different types of soils *viz*., sandy, sandy clay loam, loamy sand and clay soils, respectively. An area of one acre was selected in each block for enumeration of soil micro and macro-arthropods.

Sampling method for soil arthropods: Five soil samples were collected randomly from each block at monthly intervals using a core auger which was placed on the surface of the soil and pressed downwards and turned in clockwise direction to a depth of 10-15 cm in the morning hours between 8:00 am to 10:00 am. A total of 120 samples were collected from all the four blocks during the study period. Soil sample collection was done by slightly modifying the procedure given by Ying-hua et al. (2013). Each soil samples was placed in the polythene bags and brought to the laboratory for extraction of micro-arthropods within 2 hours of sample collection. Micro-arthropods were extracted using Berlese funnel with the beaker filled with 10 ml of 75 per cent ethyl alcohol and funnel with 20 mesh was placed over a glass beaker. The electric bulbs (100 W) were switched-on for 48 hours to generate heat that led the micro-arthropods to move down passing through the sieve of the funnel and get collected in glass beakers. The arthropod samples collected in the glass beakers were labelled and sent for identification.

Macro-arthropods were collected by placing pitfall traps at seven randomly selected areas in each block. Each trap was added with 75 per cent ethyl alcohol as killing agent. Later, the debris was placed over the pitfall trap so that the area around the pitfall trap matched the surrounding soil surface as described by Albajes et al. (2009) and Cheli and Corley (2010).

Identification: Collembolans were sent for identification to Biosystematics division of Entomology at Banaras Hindu University, Varanasi (UP) and mites to All India Network Project on Agricultural Acarology (AINPAA), University of Agricultural Sciences, Gandhi Krishi Vignana Kendra (GKVK), Bangalore. The coleopterans and spiders were identified at ICAR-NBAIR, Bangalore.

Determination of soil parameters: Soil moisture was estimated by the gravimetric method (Reynolds 1970), soil temperature was recorded by using the method given by (Srivastava 2009) and organic carbon content of the soil was determined by rapid titration method given by Walkley and Black (1934).

Statistical analysis: The data recorded during the study period was compiled and analyzed for statistical significance using Alpha diversity indices (Shannon–Wiener, Simpson's, relative abundance and Evenness), Beta diversity (Sorenson's similarity) index, Kruskal- Wallis test and Correlation. Diversity indices were computed using PAST software program (Hammer et al., 2001) and Kruskal-Wallis test and Correlation analyses were performed using SPSS software.

Alpha Diversity Indices

Shannon-Weiner diversity index: The abundance and diversity of insect community was commuted using Shannon's diversity index (H) (Humphries et al., 1996).

$$H = -\sum_{i=1}^{s} p_i \ln(p_i)$$

Where,

H = the Shannon-Weiner diversity index value

p_i = the proportion of individuals found in the i^{th} species

ln = the natural logarithm

s = the no. of species in the community.

Simpson's index:

$D = \sum n_i(n_i-1)/N(N-1)$

Where,

"n_i" is the no. of individuals in "1^{th}" species and

"N" is the total no. of individuals in the sample.

Relative abundance:

$$\text{Relative abundance (\%)} = \frac{\text{Abundance of particular soil arthropod category}}{\text{Total abundance}} \times 100$$

Evenness: (Pielou 1969).

Evenness = H / ln(N)

Where,

H is the Shannon-Weiner diversity index

N is the no. of categories in the community

Beta Diversity Index- Sorensen Similarity Index: It measures similarity in species composition for two sites (Magurran 2004).

$$C_s = \frac{2ab}{a+b}$$

Where a is the no. of species found in site A, b is the no. of species in site B and ab is the no. of species shared by the two sites.

RESULTS AND DISCUSSION

The soil arthropods were collected for a period of six months from September, 2021 to February, 2022 from four blocks of the Agricultural College Farm, Bapatla. A total of 6,248 individuals, representing 4 classes, 7 orders and 15 families, were recorded across all blocks among these 3,333 individuals were recorded from the Floriculture block, representing two classes (Insecta and Arachnida) of arthropods. With 1820 individuals, the Coleoptera order of the class Insecta accounted for the majority of the arthropods in the soil (54.6%) of all the arthropods that were collected. The smallest order of soil arthropods was Hymenoptera (Formicidae) with 187 (5.61%) individuals throughout the sampling period (Fig. 1a).

Throughout the study period, there was flora on the floriculture block and the falling leaves might have provided food for the soil arthropods. The outcomes coincided with those of Roy et al. (2021). However, more species and more evenness were observed in December, the Shannon-Weiner diversity index (H) was highest in December (2.33) and lowest in the February (2.09). Simpson's index (1-D) was at its highest in November and December (0.88) and at its lowest in February (0.83). Evenness (J) was discovered to be highest in January (0.77) and lowest in February (0.68) (Table 1). Continuous vegetation and accumulated litter in the perennial flower crops likely enhanced arthropod diversity in this block.

In orchard block, 1,152 individuals were recorded (Fig. 1b). Coleoptera were the highest population of the soil arthropods with 485 individuals made up 42.10 per cent of the total. The suitable conditions for the presence of higher soil arthropod-diversity in the Orchard block could be attributed to relatively undisturbed nature of soil under banana plantation which occupied more area in the study area. November had the highest Shannon-Weiner diversity index (2.36) coinciding with the post-rainy period, and February had the lowest (1.48). Simpson's index (1-D) peaked in the November (0.89) and at its lowest point in February (0.71). January (0.80) had the highest Evenness (J), while October had the lowest evenness (Table 1). The highest number of soil arthropods in November may be due to the high rainfall that indirectly might have resulted in low soil temperature.

However, 804 individuals were collected from the southern block (Fig. 1c). Coleoptera was the group of organisms that had been collected in the greatest number with 326 individuals (40.54%) of the total number of soil arthropods. The smaller groups were the Chilopoda (1.49%) and Diplopoda (1.74%). Shannon-Weiner diversity index peaked in September (2.33), followed by October (2.28) and reached the lowest in February (1.59). September (0.88) had the highest Simpson's index (1-D), followed by October (0.87) and February had the lowest Simpson's index (0.74). January had the highest evenness (J) (0.87) while December had the lowest (0.64) (Table 1). The peak population of soil arthropods was in September, this might be accounted to the presence of vegetation in the form of *kharif* millets at harvest stage and the soil was in undisturbed condition. Furthermore, the decrease in the population in November can be attributed to ploughing of soil for the preparation of land for *rabi* crops. Although, high rainfall was received in November, the population was less due to the fact of preparatory cultivation in November. The present findings were in accordance with Zayadi et al. (2013) and Ahmed et al. (2016).

From the Northern block, 959 arthropods were collected (Fig 1d). Coleopterans accounting for 58.08 per cent (557) of the total soil arthropods. The other minor category of soil arthropods was Diplopoda (1.25%). September had the highest Shannon-Weiner diversity index (2.09) and February had the lowest (1.47) (Table 1). The results conform to the findings of Mahajan and Singh (1981) who recorded the maximum population during the monsoon months when the soil moisture was high and soil temperature was low. The results were also identical with those of Anjumoni (2016) who reported that highest population of soil arthropod in the monsoon month of August and lowest in April. Simpson's index (1-D) was at its highest point in September (0.79) and its lowest in February (0.72). October (0.55) had the lowest evenness (J), while February had the greatest (0.72).

Comparative analysis revealed that Coleoptera (51.02%)

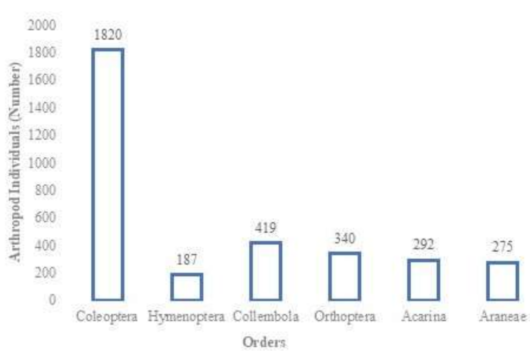

Fig 1a. Different Orders of Soil arthropods in Floriculture block

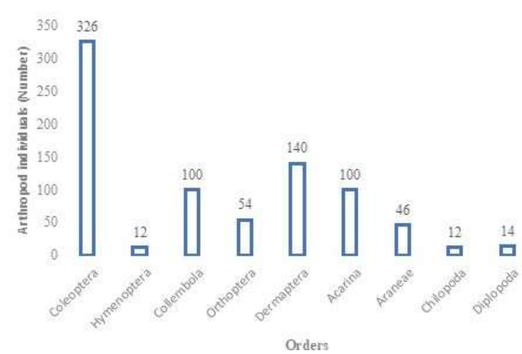

Fig 1c. Different Orders of Soil arthropods in Southern block

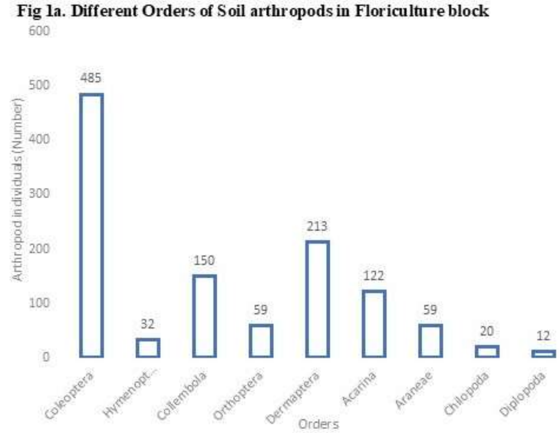

Fig 1b. Different Orders of Soil arthropods in Orchard block

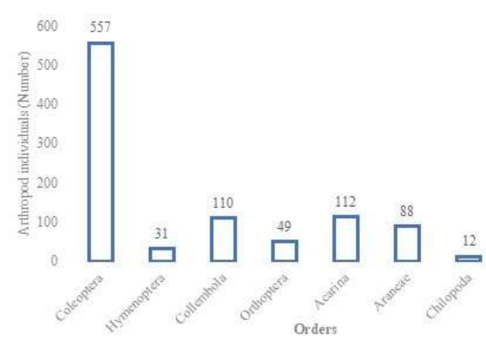

Fig 1d. Different Orders of Soil arthropods in Northern block

was the most dominant order, followed by Collembola (12.46%), Orthoptera (8.06%), Dermaptera (5.65%) and Hymenoptera (4.19%) (Table 2). Two families were identified in the order Collembola *i.e*., Hypogastruridae and Onychiuridae. Among Arachnids, Acari (10.01%) were most abundant and 7.49 per cent of Araneae were recorded. In the Acari, two suborders Mesostigmata and Oribatida were identified. Chilopoda (0.70%) and Diplopoda (0.42%) were the other minor groups recorded during the study period. Among the blocks, Shannon-Weiner diversity index was higher in foriculture block (2.29) followed by Orchard block, Southern block and Northern block. Simpson's index (1-D) was highest in floriculture and orchard blocks (0.87 each), followed by Southern and Northern blocks. The evenness was maximum in Floriculture block (0.70), followed by southern block, orchard block and northern block. The diversity was more in the Floriculture block that may be attributed to the fact that it was an undisturbed land with perennial flower crops for few years which supports stable soil microclimates and organic matter accumulation. Orchard block also had highest diversity as most of the land was undisturbed with fruit trees. Wale and Yesuf (2022) also reported that soil arthropods were more abundant in undisturbed habitats than in the disturbed habitats. Similar findings were reported by Sanalkumar et al. (2012), Holland and Reynolds (2003), Piffner and Luka (2000) and Maribie et al. (2011).

The soil parameters like soil temperature, soil moisture and organic carbon varied from one block to another block. The average soil temperature was more in the southern block (24.6°C) and low in the floriculture block (24.12°C), this could be due to the continuous irrigation given in the floriculture block. This might be the reason for the greater number of soil arthropods in the floriculture block and less number in the southern block. The soil moisture content showed a drastic change among the four blocks and was highest in the northern block (25.32%) and lowest in the floriculture block, Organic carbon content was high in the northern block and orchard block (0.51%) and low in the floriculture block (0.17%). Even though there was less moisture content and less organic carbon in the floriculture block, there were a greater number of soil arthropods. This could be due to the undisturbed nature of the land in the floriculture block and the loose sandy soil which facilitates the easy movement of the soil arthropods. There was also less utilisation of chemical pesticides in the Floriculture block and it was comparatively more in case of other blocks with field crops (Table 3).

Correlation coefficients (Table 4) indicated a negative

Table 1. Diversity indices of soil arthropods in different blocks

Floriculture block	September	October	November	December	January	February
Total no. of individuals	713	694	752	498	378	298
Shannon-Weiner Diversity index	2.27	2.27	2.31	2.33	2.22	2.09
Simpson's index	0.86	0.87	0.88	0.88	0.87	0.83
Evenness	0.69	0.75	0.72	0.73	0.77	0.68
Orchard block						
Total no. of individuals	274	224	346	159	86	63
Shannon-Weiner Diversity index	2.24	2.20	2.36	2.07	1.86	1.48
Simpson's index	0.86	0.86	0.89	0.86	0.82	0.71
Evenness	0.67	0.64	0.75	0.79	0.80	0.73
Southern block						
Total no. of individuals	222	197	150	115	68	52
Shannon-Weiner Diversity index	2.33	2.28	2.10	1.96	1.66	1.59
Simpson's index	0.88	0.87	0.85	0.82	0.79	0.74
Evenness	0.79	0.75	0.68	0.64	0.87	0.70
Northern block						
Total no. of individuals	280	232	153	135	88	71
Shannon-Weiner Diversity index	2.09	1.966	1.98	1.876	1.753	1.47
Simpson's index	0.79	0.77	0.78	0.75	0.76	0.72
Evenness	0.62	0.55	0.60	0.59	0.72	0.72
Mean values of soil arthropods	4.32	3.95	2.84	2.54	1.96	1.24

Table 2. Comparison of the diversity of soil arthropods in different blocks

Class	Order	Family	Floriculture block	Orchard block	Southern block	Northern block	Total	Relative abundance (%)	
Insecta	Coleoptera	Tenebrionidae	327	263	180	65	835	51.02	26.19
		Carabidae	889	0	0	0	889		27.88
		Staphylinidae	371	59	0	52	482		15.11
		Elateridae	196	0	0	0	196		6.14
		Scarabaeidae	0	163	146	413	722		22.64
		Bostrichidae	0	0	0	27	27		0.84
		Unknown	37	0	0	0	37		1.16
		Sub total	1820	485	326	557	3188		100
	Hymenoptera	Formicidae	187	32	12	31	262	4.19	
	Collembola	Hypogastruridae	321	128	74	80	603	12.46	77.40
		Onychiuridae	98	22	26	30	176		22.59
		Sub total	419	150	100	110	779		100
	Orthoptera	Acrididae	285	18	15	10	328	8.06	65.33
		Gryllidae	47	41	39	39	166		33.06
		Gryllotalpidae	8	0	0	0	8		1.59
		Sub total	340	59	54	49	502		100
	Dermaptera	Earwigs	0	213	140	0	353	5.65	
Arachnida	Acarina (Mesostigmata)	Laelapidae	207	82	69	79	437	10.01	69.80
		Dinychidae	3	0	0	0	3		0.04
	Oribatida		82	40	31	33	186		29.71
		Sub total	292	122	100	112	626		100
	Araneae	Araneidae	275	59	46	88	468	7.49	
Chilopoda		Centipedes	0	20	12	12	44	0.70	
Diplopoda		Millipedes	0	12	14	0	26	0.42	
Total no. of individuals			3333	1152	804	959	6248		
Shannon-Weiner Diversity index			2.29	2.26	2.19	2.00			
Simpson's index			0.87	0.87	0.86	0.78			
Evenness			0.70	0.68	0.69	0.57			

Table 3. Rainfall and soil parameters data in different blocks

Month	SMW	Rainfall (mm)/ week	Floriculture block			Orchard block			Southern block			Northern block		
			Soil temperature (°C)	Soil moisture (%)	OC (%)	Soil temperature (°C)	Soil moisture (%)	OC (%)	Soil temperature (°C)	Soil moisture (%)	OC (%)	Soil temperature (°C)	Soil moisture (%)	OC (%)
Sept-2021	39	204.50	23.20	9.43	0.20	23.80	24.40	0.62	23.80	12.24	0.39	24.00	26.87	0.55
Oct-2021	43	178.40	24.20	8.24	0.18	23.80	24.00	0.59	24.00	11.68	0.37	24.20	25.63	0.54
Nov-2021	47	276.00	22.80	9.62	0.18	23.60	24.80	0.54	23.50	13.22	0.37	23.20	27.00	0.54
Dec-2021	52	0.00	25.00	7.23	0.16	24.00	23.80	0.48	24.40	11.60	0.35	24.50	24.97	0.54
Jan-2022	04	60.30	24.50	8.66	0.16	24.60	24.00	0.45	25.40	9.86	0.34	25.00	24.45	0.45
Feb-2022	08	0.00	25.00	5.25	0.16	26.00	22.24	0.42	26.50	8.46	0.26	26.00	23.00	0.45
Mean			24.12	8.07	0.17	24.3	23.87	0.51	24.6	11.18	0.35	24.50	25.32	0.51

Plate 1. Soil micro-arthropods collected in berlese funnel: (a) Acarina- *Androlaelaps sp*., F: Laelapidae, SO: Mesostigmata (b), Acarina -F: Dinychidae, SO: Mesostigmata (c), Acarina -SO: Oribatida (d), Collembola- *Hypogastrura sp*., F: Hypogastruridae (e), Collembola-*Onychiurus sp*., F: Onychiuridae

Plate 2. Soil macro-arthropods collected in the pitfall traps: (a, b, c), Coleoptera-Carabidae, Scarabaeidae; (d), *Onthophagus sp.;* (e), *Sisyphus sp.;* (f), Bostrychidae; (g), Tenebrionidae; (h) , Elateridae; (i), Staphylinidae; (j), Hymenoptera- Formicidae; (k), Dermaptera; (l), Araneae; (m), Acrididae; (n), Gryllidae; (o), Gryllotalpidae; (p), Chilopoda; (q), Diplopoda

Table 4. Correlation of rainfall and soil parameters with soil arthropods in different blocks

Parameters	Floriculture block	Orchard block	Southern block	Northern block
Rainfall	0.858*	0.917**	0.741	0.694
Soil temperature	-0.838*	-0.821*	-0.815*	-0.704
Soil moisture	0.773	0.818*	0.741	0.812*
Organic carbon	0.768	0.787	0.822*	0.830*

*Significant at 5% level; ** Significant at 1% level

relationship between soil temperature and arthropod abundance in all blocks, with significant negative correlations in all except the northern block. Soil moisture and organic carbon showed positive correlation with soil arthropod populations. The increase in the total number of arthropods recovered may be as a result of increase in the soil moisture content due to more rainfall and decrease in temperature. Sorenson's similarity index revealed that the floriculture block which had the highest diversity of soil arthropods showed more similarity with northern block *i.e.,* 0.74 (74%), 0.71 (71%) similarity with Orchard block and 0.66 (66%) similarity with Southern block. Kruskal-Wallis test revealed a significant difference between the mean values of soil arthropods across the four blocks indicating that the distribution of soil arthropods varied significantly with soil type and cropping pattern.

CONCLUSION

The study clearly demonstrates that soil arthropod diversity and abundance are influenced by soil type, moisture, temperature, vegetation cover and management intensity. Undisturbed and perennial systems such as floriculture and orchard blocks supported greater diversity, emphasizing the ecological importance of maintaining habitat stability for soil biodiversity conservation.

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Thrips parvispinus (Karney): An Emerging Invasive Pest to Horticultural Crops

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***Abstract*:** *Thrips parvispinus* (Karney) is an invasive pest first reported from India in 2015 and again in 2018, but no significant damage on major commercial crops was noted until detection on chilli in Andhra Pradesh in 2021. Since then, rapidly spread across different regions of India, infesting a wide range of crops, with a severe outbreak during the 2021–22 season. Morphologically, *T. parvispinus* is distinguished by uniformly dark forewings with a pale base and continuous rows of setae on the first and second veins of forewing. The species exhibits a wide host range, occurring on almost all flowering plants, including weeds. Adults predominantly feed on pollen, with peak populations in chilli coinciding with full bloom. Females insert eggs beneath the leaf epidermis, visible as minute eruptions, and the life cycle comprises egg, two larval instars, prepupa, pupa and adult. Although its damage resembles that of other thrips, *T. parvispinus* shows a stronger preference for flowers and fruits, leading to flower drop and brownish fruit discoloration that reduces market value.

***Keywords*:** Chilli, *Thrips parvispinus*, Life stages, Integrated pest management, Taxonomic characters

Indian chilies are renowned worldwide for their vibrant colour, diverse pungency and rich flavor, which add special taste and appeal to global cuisines. Hence, Indian chilies are most demanded spice in the international spice trade. Moreover, India's diverse climate is well suited for cultivating a wide range of chilli varieties, both in terms of pungency and colour. Major chilli producing countries are India, China, Indonesia, Mexico and Thailand followed by Pakistan, Bangladesh, Ethiopia, Vietnam and United States. In India chilli is cultivated in an area of 0.92 million hectares with the production of 2.69 million metric tonnes. In India major chilli producing states are Andhra Pradesh, Telangana, Madhya Pradesh, Karnataka and West Bengal. In Andhra Pradesh chilli is cultivated in an area of 0.18 million hectares with the production of 10.32 lakh metric tonnes (2024-25) (www.indianspices.com). During 2024-25, India had exported 0.75 million tonnes of chilli with the export value of Rs. 11,404.90 crore (Approximately US $ 1.34 billion). Chilli has great export potential besides huge domestic requirement on other side number of limiting factors contribute for low productivity. Among the sucking pests thrips are causing major loss by infesting the crop continuously from seedling stage to harvesting stage. Thrips is one of the largest genera of the insect's order Thysanoptera in the family Thripidae and consists of numbers of species. Invasive thrips, *Thrips parvispinus* (Karny 1922) (Thysanoptera: Terebrantia: Thripidae)is a member of “Thrips orientalis group” (Mound 2005). It is also called as western thrips/ taiwanese thrips/tobacco thrips. During 2021, *Thrips parvispinus*, invasive thrips species was noticed in all major chilli growing areas of Andhra Pradesh (Sireesha et al., 2021). In the subsequent years the species was dominated over *Scirtothrips dorsalis* which was dominant thrips species earlier to 2021. Severe outbreak of the pest *Thrips parvispinus* was observed during 2021-22 cropping season, resulting in huge economic loss ranging from 50-70%. The systematic studies were conducted on various aspects of pests viz., Taxonomic characters, pest spread, Pest behavior, Alternate hosts, nature of damage, alternate hosts and its management using cultural, mechanical, biological and chemical methods at Horticultural Research Station, Lam, Guntur with a view to provide practical solution to the farmers.

First observation of pest on chilli: *Thrips parvispinus* was first noticed in Chilakaluripeta and Pratipadu mandals of Guntur district (16.09 N 80.16E & 16.16 N 80.22E) during January, 2021 and subsequently its spread was noticed in all chilli growing areas of Andhra Pradesh. Preliminary identification showed that it is complex of *Thrips florum*, *Thrips hawaiiensis*, *Thrips palmi* and *Frankliniella schulzei*. Later it was identified as *Thrips parvispinus* and it was confirmed that the 90-95% of the thrips species collected on chilli were of *Thrips parvispinus*. This was the first record from India on the occurrence of this species in chilli ecosystem (Sireesha et al., 2021). This species is native to Asian tropics and has been reported from Indonesia, India, Thailand, Malaysia, Singapore, Taiwan, China, Philippines, Australia and the Solomon Islands (Mound and Collins 2000, Mound and Masumoto 2005). Though it was reported from India by Tyagi et al. (2015) and Rachana et al. (2018) on other crops it was not reported from chilli ecosystem anywhere in India. It was reported that it is most damaging to papaya in Hawaii and Indonesia, peppers and Solanaceous crops in Indonesia and ornamentals in Europe and Indonesia.

Identification of pest using taxonomic characters: Adult thrips from the chilli flowers were collected in plastic vials containing 70 % alcohol and the taxonomic studies were carried by observing the characters after preparing temporary and permanent slides. The identification of *T. parvispinus* was done by using the key developed by Mound (2005). Samples collected from the chilli fields in Guntur district of Andhra Pradesh consists thrips species *Thrips parvispinus* Karny only. The Characteristic features which differentiate *T. parvispinus* from other known species of the genus Thrips, which falls within *T. orientalis* group are: Adult female body was brown, head and thorax paler than abdomen, legs yellow, Male body was yellow (Fig. 1A). Antennae seven segmented, segments III and IV each with forked sense cone and segment III and bases of IV and V segments are pale (Fig. 1B). Head broader than long, ocellar setae pair III arising at the anterior margin of ocellar triangle, postocular setae III shorter than postocular setae I and IV (Fig. 1C) Pronotum with two pairs of posteroangulars setae and two pairs of poster marginal setae (Fig. 1E). Metanotum with median reticulations, median setae placed well behind the anterior margin, campaniform sensilla absent (Fig. 1D). Forewings uniformly dark or shaded with pale base (Fig. 1I). First and second veins of fore wing with continuous setal row (Fig. IH). Hind wings are present (Fig. 1K). Posterior margin of abdominal tergite VIII without comb a few microtrichia present laterally (Fig. 1G) and abdominal sternites III–VI with discal setae, but absent on II and VII (Fig. 1J).

Pest spread: This species is native to the Asian tropics and has been reported from Indonesia, India, Thailand, Malaysia, Singapore, Taiwan, China, Philippines, Australia and the Solomon Islands (Mound and Collins 2000). However, during the last 20 years the species has been expanding its range and is now found in Greece, France, Spain, The Netherlands, Tanzania, Mauritius, Reunion and Hawaii (The Netherlands Plant Protection Organization Quick scan 2019, Mound et al., 2016).

In India *T. parvispinus*, was first reported on *Carica papaya* L. by Tyagi et al. (2015) from Bengaluru, later it was reported on Dahlia rosea Cav. (Asteraceae) (Rachana et al., 2018) and *Brugmansia sp*. (Solanaceae) (Roselin et al., 2021). In chilli, it was first reported from Andhra Pradesh (Sireesha et al., 2021) followed by Telangana, Karnataka, Chhattisgarh, Gujarat and eastern parts of India. *T. parvispinus* is polyphagous with the preferred hosts varying across its geographic distribution. In regions where the species has been long established, the crops most affected are papaya, peppers, potatoes, eggplants, beans, shallots and strawberries. In Indonesia, field pepper yield losses due to *T. parvispinus* reach 23 percent (Johari et al., 2014).

Host range: During 2021-22, the survey conducted in Guntur district of A.P. to record the incidence and intensity levels of *T. parvispinus* on fruit crops, vegetables, spice crops, flower crops, field crops and weeds were recorded. Incidence of *T. parvispinus* was found on 34 host plants belonging to 15 families which were categorized into Vegetable crops (8 species), Spice Plants (2 species), Fruit crops (2 species), Flower plants (1 species), Field crops (5 species) and Weeds (16 species) (Table 1). Among the different crop families observed, the highest incidence of *Thrips parvispinus* was recorded on crop families viz., Solanaceae, Fabaceae, Cucurbitaceae, Asteraceae,

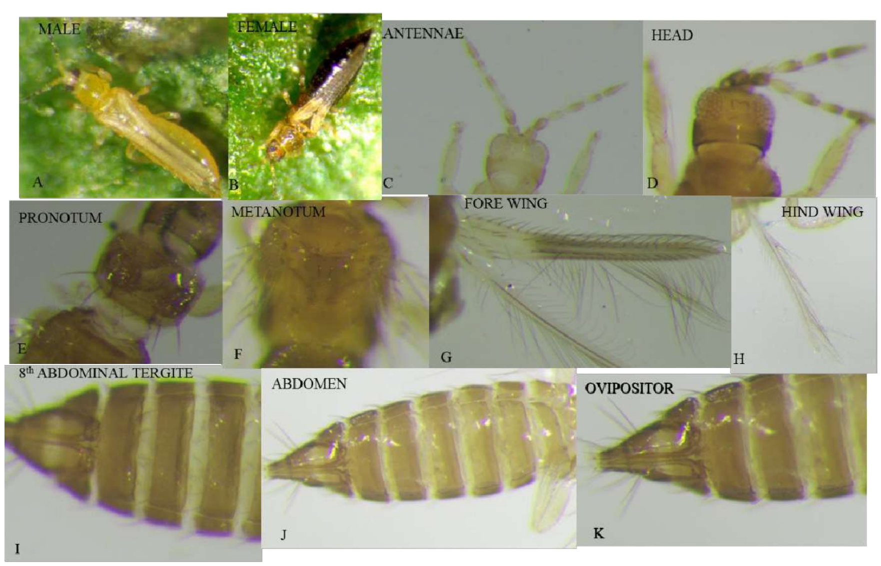

Fig. 1. Identification characters for *Thrips privispinus* Karny

Table 1. Incidence of *Thrips parvispinus* Karny on different host plants

Common name	Scientific name	Order	Family	Incidence and Intensity (Population/ flower)
Vegetable crops				
Beans	*Phaseolous vulgaris*	Fabales	Fabaceae	9.4
Bittergourd	*Momordica charantia*	Cucurbitales	Cucurbitaceae	9.2
Brinjal	*Solanum melongena*	Solanales	Solanaceae	3.6
Coccinia	*Coccinia grandis*	Cucurbitales	Cucurbitaceae	5.4
Cucumber	*Cucumis sativus*	Cucurbitales	Cucurbitaceae	4.2
Gerkhins	*Cucumis anguria*	Cucurbitales	Cucurbitaceae	6.9
Moringa	*Moringa oleifera*	Brassicales	Moringaceae	7.4
Tomato	*Solanum lycopersicum*	Solanales	Solanaceae	7.1
Sorrel/Roselle	*Hibiscus sabdariffa*	Molvales	Malvaceae	5.0
Spice crops				
Ajwain	*Trachyspermum ammi*	Apiales	Apiaceae	5.3
Coriander	*Coriandrum sativum*	Apiales	Apiaceae	5.1
Flower crops				
Marigold	*Tagetes erecta*	Asterales	Asteraceae	8.7
Fruit crops				
Citrus	*Citrussp.*	Sapindales	Rutaceae	3.5
Mango	*Mangifera indica*	Sapindales	Anacardiaceae	8.3
Field crops				
Black gram	*Vigna mungo*	Fabales	Fabaceae	8.2
Green gram	*Vigna radiate*	Fabales	Fabaceae	4.5
Red gram	*Cajanus cajan*	Fabales	Fabaceae	4.7
Sunflower	*Helianthus annus.*	Asterales	Asteraceae	2.8
Tobacco	*Nicotiana tabacum*	Solanales	Solanaceae	5.6
Cotton	*Gossypium hirsutum*	Malvales	Malvaceae	5.2
Weeds				
Goat weed	*Ageratum conyzoides*	Asterales	Asteraceae	2.1
Jews mallow	*Corchorus olitorius*	Malvales	Malvaceae	1.9
Slender amaranth	*Amaranthus viridis*	Caryophyllales	Amaranthaceae	1.8
Hog weed	*Boerhavia diffusa*	Caryophyllales	Nyctaginaceae	2.0
Asian spider flower	*Cleome viscose*	Brassicales	Cleomaceae	2.7
Tooth leaved croton	*Croton bonplandianum*	Malpighiales	Euphorbiaceae	2.4
Native gooseberry	*Physalis minima*	Solanales	Solanaceae	3.7
Black pig weed	*Trianthema sp.*	Caryophyllales	Aizoaceae	1.1
Carrot grass	*Parthenium hysterophorus*	Asterales	Asteraceae	2.6
Tridax	*Tridax procumbens*	Asterales	Asteraceae	4.8
Shrub verbena	*Lantana camera*	Lamiales	Verbenaceae	8.3
Chaff flower	*Achyranthes aspera*	Caryophyllales	Amaranthaceae	3.2
Touch- me- not	*Mimosa pudica*	Fabales	Fabaceae	3.6
Black night shade	*Solanum nigrum*	Solanales	Solanaceae	5.1
Brazilian spinach	*Alternanthra sessilis*	Caryophyllales	Amaranthaceae	2.5
Indian acalypha	*Acalypha indica*	Malpighiales	Euphorbiaceae	2.9

Apiaceae, Euphorbiaceae, Amaranthaceae followed by Malvaceae, Anacardiaceae, Moringaceae, Rutaceae, Aizoaceae, Verbanaceae, Cleomaceae, and Nyctaginaceae. Among the vegetable crops, highest population per flower was recorded in beans (9.4), bittergourd (9.2), moringa (7.4), tomato (7.1) followed by cucurbits and lowest in brinjal (3.6). In spice crops population per umble was recorded in ajowain (5.3) and coriander (5.1). In fruits crops *T. parvispinus* was recorded from mango (8.3) and citrus (3.5). In flower crops it was observed in marigold (8.7). In field crops *T. parvispinus* incidence was recorded from redgram (4.7), green gram (4.5), black gram (8.2), sunflower (2.8) and tobacco (5.6). On weeds, higher number of *T. parvispinus* was recorded on *Lantana camera* (8.3) followed by *Solanum nigrum* (5.1), *Tridax procumbens* (4.8), *Physalis minima* (3.7), *Mimosa pudica* (3.6), *Acalypha indica* (2.9), *Cleome viscose* (2.7), *Parthenium hysterophorus* (2.6), *Alternanthra sessilis* (2.5), *Croton bonplandianum* (2.4), *Ageratum conyzoides* (2.1), *Boerhavia diffusa* (2.0), *Corchorus* (1.9), *Amaranthus viridis* (1.8) and lowest in *Trianthema sp* (1.1). *Thrips parvispinus* was also reported to feed on papaya, peppers, potatoes, eggplants, beans, shallots and strawberries. The damage is inflicted by direct feeding of larvae and adults on leaves and growing buds. In papaya, *Cladosporium* a saprophytic fungus is known to cause a secondary infection on tissue damaged by the thrips (Lim 1989).

Thrips parvispinus has been reported as a serious pest across several Asian countries. In Thailand, it was recorded as a pest of vegetable crops (Bansiddhi and Poonchaisri 1991). Sastrosiswojo (1991) identified it as a major pest on vegetable plants in Indonesia, while Talekar (1991) highlighted its destructive nature on chilli in the same region. Vos (1994) also reported *T. parvispinus* as a significant pest of chilli cultivation in Java. In India, the species was first documented on papaya plantations (Tyagi et al., 2015), followed by reports on ornamental plants such as *Dahlia rosea* Cav. (Rachana et al., 2018) and *Brugmansia* spp. (Roselin et al., 2021), as well as in chilli fields (Sireesha et al., 2021). Present observations across various crops further indicate that *T. parvispinus* is widely distributed and occurs on all flowering plants, including weeds (Table 1).

Pest behavior and life cycle: Adults are mainly pollen feeders and are found in shaded areas of the plant, mainly the underside of leaves and inside flowers. During the initial years of pest infestation, in chilli ecosystem, when the pest was in establishment stage, multiplication of the pest was rampant, and female to male sex ratio was very high (1:20). This indicates pest was multiplied through Thylytoky. Gradually, this difference decreased, and about four years later, the population stabilized with a sex ratio of approximately 1:1, Since then, the pest has become a regular problem in chilli crop. Population of the pest was not observed during summer months.

Male and female insects differ in size and colour. Females are 1 mm long with brown head and prothorax, yellowish brown meso and metathorax and black abdomen, forewings are dark, with light coloured base. Males are 0.6 mm long and evenly yellow. Larvae are bigger in size having different instars and uniform yellow in colour.

Observations on different life stages revealed that the female adult lays eggs beneath the leaf epidermis. The egg-laying sites can be seen as minute eruptions on underside of leaf and are irregular. Total lifecycle has four stages viz., egg, first instar larva, second instar larva, pre pupa and pupa with duration of three to four weeks. Egg period ranges from 5.00 to 6.00 days (5.26±0.60). The eggs are oval, shiny white, with a pair of visible red eyes. First instar larva is shiny white with red eyes and is actively moving and feed on leaf by scraping near midrib and this stage lasts for 2-3 days (2.63±0.52). Early second instar larva is pale yellow gradually turn into dark yellow with increased size and actively moving and feeding on chlorophyll and making the leaf papery. This stage lasts for 3-4 days (3.08±0.51). pupal stage lasts for 4-6 days. Pupa is uniformly yellow, before pupation it searches for the remote place to undergo pupation. It has pre-pupa and pupa, wing buds appear in pre-pupal stage itself. Adults live up to 7-8 days. Total life cycle completed in 21-27 days under normal laboratory conditions.

Nature of damage: On leaves, the infestation begins with deep punctures and scratches on the underside caused by the insects sucking sap (Fig. 2A). Scraping of chlorophyll on the lower surface and continued sap extraction lead to corresponding yellowish patches on the upper surface of the leaf (Fig. 2B). As damage progresses, the underside of the leaf turns reddish brown (Fig. 2C). Distortion of the leaf lamina, along with necrotic areas and yellow streaking, is commonly observed (Fig. 2D). Under severe infestation, especially on newly emerging leaves, the foliage becomes dried or blighted (Fig. 2E), with areas adjacent to veins being particularly preferred.

On flowers, scraping of petal tissues using their mouthparts results in brownish streaks on the petals (Fig. 2F). Thrips also feed on pollen, which can adversely affect pollination. Affected flowers often dry up and wither (Fig. 2G), ultimately reducing fruit set. On fruits, the pest causes brownish streaks on the fruit surface (Fig. 2H), and the fruits become hard and discoloured (Fig. 2I). The pedicel may turn brown, and the overall fruit size is noticeably reduced.

Economic impact: Andhra Pradesh being the largest producer of Chilli contributes 38 per cent to the total

Fig. 2. Nature of damage and symptoms of damage due to *T. parvispinus* on Chilli

production in India. In Andhra Pradesh Guntur alone contributes 15 per cent to total production in Inada. During 2021-22 cropping season, the area under chilli increased from 70,000 ha to 1,06,656 ha due to constant market price for dry chilli and conversion of cotton area to chilli due to incidence of pink boll worm. With rapid spreading ability, thrips species affected chilli crop in approximately 9 lakh acres in Telangana and Andhra Pradesh. As per the survey conducted by Dr. Y.S.R. Horticultural University, Andhra Pradesh, yield loss in Guntur district during 2021-22 (total area surveyed: 106656 ha) is estimated up to 85 to 100% in severely affected areas (60% of the total cropped area), 75 to 85% in moderately affected (18% of the total cropped area), below 50% in less affected (10% of the total cropped area) and 12% of total cropped area is uprooted because of the severe incidence of thrips.

Management: During the initial years of *T. parvispinus* infestation in chilli, farmers misidentified the pest as red spider mite and relied heavily on miticides such as wettable sulphur and abamectin. Excessive use of sulphur during flowering led to severe flower drop. With the intervention of the Horticulture University and the Department of Horticulture, Andhra Pradesh, farmers were trained to correctly identify the pest and to use only recommended pesticides safely. Subsequently, the efficacy of 16 insecticides, along with one biostimulant, water, and kaolin clay, was evaluated against *T. parvispinus*. Among these, Fipronil 80% WG @ 0.2 g/L proved highly effective and performed on par with Fipronil 4% + Acetamiprid 4% SC, Spirotetramat 11.01% + Imidacloprid 11.01% SC, Acetamiprid 20% SP, Diafenthiuron 47% + Bifenthrin 9.4%, Emamectin benzoate 5% SG, and Fipronil 5% SC + Diafenthiuron 50% WP. With the introduction of Isoxazoline-group insecticides viz Broflanilide, Fluxametamide, and Isocycloserum, further trials conducted at the Horticultural Research Station, Lam, confirmed their effectiveness against the pest. Additionally, various botanicals and entomopathogens were evaluated for their bioefficacy. Based on the pest's biology and the performance of chemical and biological options, an Integrated Pest Management (IPM) module was subsequently developed for sustainable management of *T. parvispinus*.

Cultural Methods

- As Gemini virus is the major problem in chilli growing areas use of Resistant varieties against Gemini virus will provide good scope for better management of Thrips parvispinus.
- Application of recommended and balanced use of fertilizers. Recommended fertilizer dose is 120:24:48 NPK/acre. Nitrogen and potash fertilizers need to be applied in five splits during crop growth. Application of Organic fertilizers like FYM@10 tones/ acre, Neemcake @200kg/acre Vermicompost @ 2tonnes/acre Azospirillum and phosphate solubilizing bacteria each @2kg/acre, in order to maintain proper nutrition to the plants.
- Application of neem cake @ 200 kg /acre even on the standing crop helps to break down the life cycle of the pest as it undergoes pupation in soil.
- Application of Vermicompost or well decomposed farmyard manure enriched with the *Metarhizium anisopliae* will have effect on pupae in soil.

- Avoid close spacing (Follow recommended spacing of 75x30 cm).
- Use of 25-30-micron silver mulch helps to disturb the pupation and adults are also get deterred due to reflective light.
- Use of mixed crops, Intercrops, trap crops will help in decreasing the pest load on chilli and encourage the natural enemy population.

Mechanical Methods

- Installation of Blue or white sticky traps near to plant height @ 30 per acre on community basis to reduce the adult population and also for monitoring

Biological Methods

- Encourage development and multiplication of parasitoids and predators through planting boarder crop with maize or Jowar
- Inundative release of predators like lace wing bugs and lady bird beetles as they feed on aphid larvae and adults
- Application of azadirachtin 10,000ppm @1ml/L before flowering either as single application or in combination with recommended chemicals after thorough mixing in order manage the resistance development.

Chemical Control

- Need based application of effective insecticides belong to different categories viz., isoxazolines, phenylpyrazoles, tetramic acid derivatives and spinosyns analog with biologicals/botanicals.
- Effective management of the pest is possible through alternation of the effective molecules with different groups and it is evident with the various experiments conducted at Horticultural Research Station, lam, Guntur.

CONCLUSIONS

Thrips parvispinus (Karny), an invasive species, was first detected in the chilli ecosystem of Andhra Pradesh in 2021 and rapidly spread across regions and cropping systems. A severe outbreak during the 2021–22 season caused extensive damage, significant yield losses, export rejections, and heavy economic distress among farmers. Its wide host range, adaptability, and aggressive reproductive capacity have enabled it to thrive on multiple crops and even displace the previously dominant *Scirtothrips dorsalis* in chilli. The findings underscore the need for a comprehensive Integrated Pest Management (IPM) strategy for sustainable long-term management of this emerging pest.

AUTHOR'S CONTRIBUTION

K. Sireesha designed the experiments, conducted surveys, recorded pest observations, carried out experiments, collected and analyzed data, and contributed to writing and editing the manuscript. Y. Lalitha Priya performed the taxonomic identification, documented photographs, assisted in conducting experiments, and contributed to data collection.

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Assessment of Resistance Linked Morpho-Physical and Biochemical Traits in Mungbean against Sucking Pests

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***Abstract*:** Twenty-nine mungbean (*Vigna radiata* L.) genotypes were evaluated at the Regional Agricultural Research Station, Lam, Guntur, Andhra Pradesh, to identify susceptibility and tolerance to the sucking pest complex. Among them, the genotypes COGG-912, VGG 104 and VGG 17-106 recorded lowest population of whiteflies, aphids, and thrips, respectively. A significant positive correlation was observed between whitefly population and leaf length (r = 0.460 & 0.403), leaf width (r = 0.480 & 0.261), leaf area (r = 0.283 & 0.404), leaf thickness (r = 0.434 & 0.459), and protein content (r = 0.606 & 0.456) at 20 and 50 days after sowing (DAS), respectively. Conversely, a significant negative correlation was recorded between whitefly population and trichome density (r = –0.339 & –0.414), chlorophyll content (r = –0.345 & –0.387) and phenol content (r = –0.428 & –0.338). These findings suggest that higher trichome density and phenol content contribute to enhanced resistance against sucking pests. The identified morpho-physiological and biochemical traits can be effectively utilized in breeding programs aimed at developing pest-resistant mungbean varieties.

Keywords: Biophysical, Biochemical, Chlorophyll content, Mungbean genotypes, Proteins, Phenols, Resistance, Sucking pests, Trichome density

Mungbean (*Vigna radiata* L.) is one of the most important and nutritious pulse crops in India, ranking third in area and production after chickpea and pigeon pea. It contributes to total pulse production with 2.92 million tonnes, cultivated over an area of 5.01 million hectares with an average yield of 582 kg/ha (www.cacp.da.gov.in (Rabi price policy report 2025-26)). However, mungbean is highly susceptible to various sucking pests and the viral diseases they transmit. Among the sucking pests, whiteflies (*Bemisia tabaci* Gennadius), aphids (*Aphis craccivora*) and thrips (*Thrips palmi* Karny) are the major threats not only as direct feeders but also as vectors transmitting viral diseases like Mungbean Yellow Mosaic Virus (MYMV), bud necrosis, and leaf crinkle. Whiteflies, as efficient virus vectors, can cause 30–70% yield loss, while thrips can reduce yield up to 40% in greengram (Sujatha and Bharpoda 2016). The interaction between host plants and insect pests is a dynamic and co-evolutionary process, wherein plants develop defence mechanisms, and insect pests evolve strategies to overcome them. Leaf biophysical traits such as length, width, thickness, and trichome density, as well as physiological traits like chlorophyll content vary among genotypes and significantly influence insect feeding preferences. Trichomes, in particular, can deter insect oviposition and impede movement on the plant surface. Furthermore, biochemical constituents such as leaf protein and total phenol content play key roles in plant defence. These compounds, present in varying quantities and ratios in host plants, are known to profoundly affect the growth, development, survival, and reproduction of insect pests (Painter 1958). Hence, this study was conducted to assess biophysical and biochemical variability among mungbean genotypes and their role in conferring resistance to sucking pests.

MATERIAL AND METHODS

The study was conducted at Regional Agricultural Research Station, Lam, Guntur, Andhra Pradesh, India during 2022 and 2023. Twenty-nine mungbean genotypes, including checks were evaluated under natural field conditions against major sucking insect pests. Observations on thrips, whitefly, and aphid incidence were recorded at weekly intervals from 10 to 50 days after sowing on five randomly selected plants per genotype per replication, using standard procedures. Population of whitefly adults were counted by using the magnifying lens (Salam et al., 2009) during the early hour of the day from fully formed trifoliate leaf of the plant and expressed as mean number per trifoliate leaf in individual genotypes (Men and Sarode 1999). Counted the number of apterous and winged aphids from the 10 cm terminal shoot portion of the plant from five randomly selected plants. Based on the aphid population which expressed as number of aphids per plant and the test genotypes were grouped into six categories based on a 5-point score (Souleymane et al., 2013). A score of 0 indicated very highly resistant (0–1 aphid), 1 denoted highly resistant (1–5 aphids), 2 of moderately resistant (5–20 aphids), 3 of moderately susceptible (20–100 aphids), 4 indicated susceptible (100–500 aphids), and 5 as highly susceptible (>500 aphids). The population of thrips (adults) were recorded early in the morning (6-8 A.M). by tapping the top, middle and bottom leaves on a white paper and expressed as number of thrips/three leaves per plant (Rathore and Tiwari 1999). The insect populations were identified based on taxonomic keys under microscope. Thrips samples were sent to National Bureau of Agricultural Insect Resources (NBAIR) for identification and further confirmation.

Various morpho-physical and biochemical traits were analysed to determine their role in resistance mechanisms against sucking pests. The influence of these traits on pest incidence was assessed through simple correlation and multiple linear regression analyses.

Morpho-Physical parameters: Leaf length and width was measured from tip to base from five leaves in a plant and average was calculated and expressed in cm. Total (infected and healthy) leaves from each plant of each genotype were cleaned properly and placed on the leaf area meter (LI-COR LI-3100C Area Meter) and measured the leaf area and expressed in cm^2. Leaf thickness was measured randomly from three areas of each leaf by using micrometre. Leaf was made into small bits with the help of blade and the small pieces were placed in the micro meter to recorded the readings (Witkowski and Lamont 1991). Number of trichomes per cm^2 of leaf was measured following Hasanuzzaman et al., 2016. Chlorophyll content of leaves was measured at 10 A.M by using a portable chlorophyll detector (Minolta SPAD-502 chlorophyll meter) from the third leaf of plant, like wise in five plants in each genotype and expressed in $\mu g/cm^2$ (Minolta 1989; Monje and Bugbee 1992).

Biochemical parameters: Total protein content was estimated by using Lowry's method (Lowry et al., 1951) and Phenol content in the leaf was estimated (Malik and Singh 1980) using folin's reagent. The data on the sucking pest infestation and morpho physical and bio chemical parameters at 20 and 50 days after sowing were subjected to correlation, regression and Multiple Linear Regression (MLR) analyses, and the computed results are presented.

RESULTS AND DISCUSSION

Sucking pest infestation: Significant variation was observed among the twenty-nine mungbean genotypes against the three major sucking pests under field conditions. Whitefly populations ranged from a low of 0.96 per trifoliate leaf in COGG-912, the least infested genotype, up to 10.70 in MH 18-181, the most susceptible. Other genotypes like Pusa 9072, IGKM 05-18-2, LGG 706, and LGG 686 also exhibited moderate to low whitefly infestations. For thrips, VGG 17-106 had the lowest mean population (2.54), followed by OBGG 59 and IPM 2, while MH 18-181 showed the highest infestation (26.00). COGG-8 and IPM 1603-1 recorded relatively high thrips populations. Aphid infestation was lowest in VGG 104 (0.53 aphids/10 cm shoot), indicating very high resistance, whereas IPM 1603-1 and PUSA M 2241 showed moderate susceptibility with high aphid counts. Genotypes such as OBGG 59, LGG 711, and VGG 17-009 demonstrated high resistance to aphids. Overall, COGG-912, VGG 104, and VGG 17-106 emerged as promising genotypes due to their consistently lower pest loads, whereas IPM 1603-1 and MH 18-181 were identified as susceptible. These results confirm considerable genetic variability among mungbean genotypes for resistance to sucking pests, providing valuable material for breeding programs aimed at developing pest-tolerant cultivars.

Morpho-physical observations and their association with insect pest infestation: The average leaf length across genotypes was 6.45 cm at 20 DAS, with MH 1762 having the longest leaves (7.78 cm) and LGG 711 the shortest (5.14 cm). At 50 DAS, MH 18-181 exhibited the longest leaves, while COGG-912 had the shortest. Leaf width increased from 4.70 cm at 20 DAS to 8.29 cm at 50 DAS; MH 18-181 had the broadest leaves (6.37 cm) at 20 DAS and MHBC 20-8 the widest (9.90 cm) at 50 DAS. Leaf area ranged from 99.03 cm^2 in LGG 574 at 20 DAS to 1042.52 cm^2 in SML 2016 at 50 DAS. Leaf thickness increased from 0.35 mm (20 DAS) to 0.51 mm (50 DAS), with VGG 17-009 and MH 1762 showing the highest values at respective stages. Trichome density averaged about 100/cm^2, peaking in OBGG 59, while chlorophyll content averaged ~41 $\mu g/cm^2$, highest in VGG 17-106 at 20 DAS and COGG-912 at 50 DAS. These morphological and physiological traits varied significantly across genotypes and growth stages, influencing pest resistance dynamics.

Correlation with insect pest infestation: Morpho-physical traits exhibited significant associations with sucking pest incidence in mungbean. Leaf length showed positive correlations with whitefly populations at both 20 and 50 DAS while its association with aphids and thrips was positive but non-significant. Leaf width was positively correlated with whiteflies and thrips at 20 DAS. Similarly, leaf area at 50 DAS exhibited significant positive correlations with whiteflies and aphids (indicating that larger leaf surfaces favor pest colonization. These findings align with earlier reports by Saini et al. (2017), Taggar and Gill (2012), Pal et al. (2021), Mulwa et al. (2023), and Javed et al. (2016). Leaf thickness showed significant positive correlations with whiteflies, aphids, and thrips at 20 DAS, and with whiteflies and) at 50 DAS, corroborating earlier observations (Lakshminarayan et al., 2008, Taggar and Gill 2012). In contrast, trichome density was negatively correlated with whiteflies and thrips at 20 and 50 DAS, suggesting its deterrent role against pest establishment, consistent with reports by Sanchez-Pena et al. (2006), Ramarao et al. (2021), Latha and Hanumanthraya (2018) and Javed et al. (2016). Chlorophyll content (SCMR values) exhibited significant negative correlations with whitefly populations at 20 DAS and 50 DAS, confirming earlier findings that higher chlorophyll indices are associated with reduced whitefly stress (Taggar et al., 2015, Mantesh and Pankaja 2020). The coefficient of determination (R^2) from multiple regression analysis indicated that biophysical traits contributed to sucking pest populations as follows: whiteflies: 29.5% at 20 DAS, and 30.4% at 50 DAS aphids: 31.4% at 20 DAS, and 19.3% at 50 DAS and thrips: 43.0% at 20 DAS and 29.4% at 50 DAS. Overall, leaf size and thickness were positively associated with pest incidence, while trichome density and chlorophyll content contributed to resistance, indicating their potential utility as morphological markers in resistance breeding programs.

Biochemical profiling of mungbean genotypes against sucking pests: Biochemical parameters such as phenol and protein contents were estimated at 20 and 50 DAS) to assess their potential role in imparting resistance to sucking pests in mungbean genotypes. Significant variations were observed

Table 1. Screening of mungbean genotypes to sucking pest incidence during *rabi*, 2022-23

Genotype	*Whitefly (Mean no./trifoliate leaf)	Thrips population (No./three leaves/plant)	*Aphid population (No./10 cm terminal shoot)	Reaction of genotypes to aphid population
COGG-912	0.96 (1.40)	5.00 (2.45)	28.13 (5.40)	MS
IGKM 05-18-2	1.06 (1.44)	8.99 (3.16)^{fg}	24.27 (5.03)^{de}	MS
LGG 706	1.10 (1.45)^{ij}	7.89 (2.98)^{ghi}	21.47 (4.74)^{ef}	MS
LGG 686	1.26 (1.50)	11.10 (3.48)^{d}	8.80 (3.13)^{hij}	MR
COGG-8	1.30 (1.52)	18.50 (4.42)^{b}	19.47 (4.52)^{f}	MR
LGG 574	2.32 (1.82)	5.06 (2.46)^{lm}	5.33 (2.52)^{klm}	MR
MH 18-189	1.48 (1.57)	8.52 (3.09)^{g}	26.40 (5.23)^{cd}	MS
Pusa 9072	1.00 (1.41)^{j}	9.89 (3.30)^{ef}	20.53 (4.64)^{f}	MS
LGG 609	1.30 (1.52)^{hij}	5.06 (2.46)^{lm}	6.13 (2.67)^{jkl}	MR
MH 1762	2.04 (1.74)	8.64 (3.10)^{g}	3.20 (2.05)	HR
LGG 711	1.12 (1.46)^{ij}	4.22 (2.28)^{mn}	2.40 (1.84)	HR
JLPM 707-27	3.02 (2.00)^{e}	8.76 (3.12)^{g}	23.73 (4.97)^{de}	MS
LGG 450 (SC)	4.80 (2.41)^{cd}	6.82 (2.80)^{ijk}	10.13 (3.34)^{hi}	MR
LGG 460 (TC)	1.68 (1.64)^{fghij}	3.42 (2.10)^{nop}	4.53 (2.35)^{lmn}	HR
VGG 16-045	2.38 (1.84)^{efg}	5.42 (2.53)^{l}	8.27 (3.04)^{ijk}	MR
VGG 17-009	1.56 (1.60)^{ghij}	7.16 (2.86)^{hij}	2.93 (1.98)^{mno}	HR
PMS-12	5.68 (2.58)^{bc}	7.97 (2.99)^{gh}	24.67 (5.07)^{d}	MS
OBGG 59	2.32 (1.82)^{efg}	2.78 (1.94)^{op}	1.60 (1.61)^{no}	HR
PM 2	2.64 (1.91)^{ef}	2.72 (1.93)^{op}	5.07 (2.46)^{lm}	MR
VGG 17-106	2.38 (1.84)^{efg}	2.54 (1.88)^{p}	4.53 (2.35)^{lmn}	HR
VGG 104	1.08 (1.44)^{ij}	6.58 (2.75)^{jk}	0.53 (1.24)^{o}	VHR
TMB 146	1.46 (1.57)^{ghij}	3.74 (2.18)^{mn}	3.20 (2.05)^{lmno}	HR
PUSA M 2141	2.16 (1.78)^{efgh}	5.90 (2.63)^{kl}	24.53 (5.05)^{de}	MS
IPM 1103-1	2.46 (1.86)^{efg}	4.04 (2.24)^{mn}	3.20 (2.05)^{lmno}	HR
MHBC 20-8	4.78 (2.40)^{cd}	10.56 (3.40)^{de}	3.73 (2.18)^{lmn}	HR
SML 2016	4.16 (2.27)^{d}	5.46 (2.54)^{l}	14.93 (3.99)^{g}	MR
PUSA M 2241	5.04 (2.46)^{cd}	5.06 (2.46)^{lm}	48.27 (7.02)^{b}	MS
IPM 1603-1	6.42 (2.72)^{b}	15.60 (4.07)^{c}	62.67 (7.98)^{a}	MS
MH 18-181	10.70 (3.42)^{a}	26.00 (5.20)^{a}	11.73 (3.57)^{h}	MR
CV (%)	6.42	3.12	6.71	

***Values in the parenthesis are square root transformed values**
DAS-Days After Sowing; S-Significant ; SC-Susceptible Check; TC-Tolerant Check;
VHR = Very Highly Resistant;, HR = Highly Resistant;, MR = Moderately Resistant and MS = Moderately Susceptible, SC- Susceptible Check TC- Tolerant Check

among the genotypes for both phenol and protein contents at both stages. Among the genotypes, COGG-912 recorded the highest phenol content at 50 DAS (26.89 mg/g FW), followed by LGG 711 (26.70 mg/g), LGG 609 (26.70 mg/g), and VGG 104 (26.42 mg/g), indicating a probable role of elevated phenolic levels in pest resistance. On the contrary, MH 18-181 (13.73 mg/g) and JLPM 707-27 (14.08 mg/g) exhibited lower phenol levels at 50 DAS, suggesting higher susceptibility. Protein content also varied considerably across genotypes. The highest protein content at 20 DAS was recorded in MHBC 20-8 (12.52 mg/g), PMS-12 (11.58 mg/g), and PUSA M 2241 (11.12 mg/g), whereas LGG 460 (TC) showed the lowest value (5.50 mg/g). At 50 DAS, the genotypes LGG 574 (16.83 mg/g) and PUSA M 2241 (16.37 mg/g) had the highest protein levels, which could be linked to improved pest tolerance. In contrast, COGG-912 (8.65 mg/g) and IPM 1103-1 (8.88 mg/g) showed lower protein accumulation at 50 DAS. The data indicate that genotypes with higher levels of phenols and proteins at later growth stages tend to exhibit greater resistance to sucking pests.

Correlation with sucking pest infestation: Biochemical parameters exhibited distinct associations with sucking pest

Table 2. Biophysical characteristics in leaves of mungbean genotypes

Genotype	Leaf length (cm)		Leaf width (cm)		Leaf area (cm^2/plant)		Leaf thickness (mm)		Trichomes (Number/cm^2 leaf area)		SCMR values ($\mu g/cm^2$)	
	20 DAS	50 DAS	20 DAS	50 DAS	20 DAS	50 DAS	20 DAS	50 DAS	20 DAS	50 DAS	20 DAS	50 DAS
COGG-912	5.72	7.47	4.12	5.68	123.75	397.94	0.2745	0.3505	126.70	130.00	54.75	56.53
IGKM 05-18-2	7.47	10.43	5.28	9.30	299.14	944.00	0.4057	0.6318	86.65	90.00	35.23	34.45
LGG 706	7.52	10.03	5.40	9.18	342.76	1014.09	0.4392	0.6038	88.35	98.33	35.88	36.67
LGG 686	5.18	8.37	4.07	8.55	161.90	487.12	0.4245	0.4360	113.00	114.01	46.65	46.37
COGG-8	5.22	7.80	4.33	5.84	160.95	382.63	0.2947	0.4768	88.00	90.00	45.95	48.19
LGG 574	6.32	9.97	3.88	8.78	99.03	256.21	0.2660	0.4237	110.00	108.33	33.22	46.53
MH 18-189	5.84	8.20	3.97	8.97	154.31	455.44	0.3075	0.4107	118.63	119.46	51.77	52.35
Pusa 9072	7.43	10.64	5.47	9.45	311.72	972.68	0.4657	0.6208	83.30	91.67	33.02	31.88
LGG 609	5.37	8.32	4.15	7.14	123.82	451.40	0.2447	0.4307	118.35	113.67	43.62	44.53
MH 1762	7.78	9.12	5.75	9.78	286.50	947.50	0.4640	0.7012	96.27	97.19	35.09	33.93
LGG 711	5.14	7.53	3.67	7.47	165.38	412.58	0.2860	0.3967	110.01	101.67	45.55	49.10
JLPM 707-27	7.35	10.69	5.20	9.80	304.89	978.00	0.4205	0.5997	73.30	90.00	37.77	34.92
LGG 450 (SC)	6.82	9.58	5.18	9.37	238.66	591.17	0.3392	0.3330	100.00	90.00	36.42	39.35
LGG 460 (TC)	6.23	9.20	5.28	8.90	136.78	390.28	0.3135	0.4217	110.00	101.67	49.90	49.77
VGG 16-045	5.68	7.50	3.95	7.72	109.03	324.12	0.2462	0.3459	100.00	100.00	46.58	32.95
VGG 17-009	7.37	10.50	5.65	9.43	406.76	1016.72	0.4880	0.6675	73.40	83.33	39.83	32.85
PMS-12	7.52	10.08	5.42	8.75	270.16	981.94	0.4425	0.6318	80.00	70.00	39.40	35.75
OBGG 59	6.02	9.25	3.88	7.07	231.76	577.50	0.2720	0.3025	130.00	140.00	32.98	36.13
PM 2	5.77	8.95	3.93	7.78	253.86	761.04	0.3332	0.4627	90.00	100.00	37.72	40.75
VGG 17-106	5.74	8.27	3.62	7.95	170.15	310.05	0.2973	0.4605	120.00	120.00	59.38	45.47
VGG 104	5.25	7.65	3.85	5.34	139.66	420.23	0.2650	0.4838	129.54	124.85	56.14	48.78
TMB 146	6.60	8.45	4.48	6.45	117.61	352.73	0.2402	0.3532	80.00	90.00	32.25	53.85
PUSA M 2141	5.98	9.35	4.07	8.92	257.78	644.26	0.1997	0.3037	73.35	70.00	46.35	33.45
IPM 1103-1	5.57	7.77	4.04	5.39	125.23	394.80	0.2653	0.4812	120.00	118.41	46.47	55.88
MHBC 20-8	7.23	10.32	5.47	9.90	342.86	957.62	0.4550	0.6574	90.00	90.00	33.48	32.78
SML 2016	7.26	10.45	5.07	9.55	336.53	1042.52	0.4535	0.6087	93.68	100.00	39.78	35.60
PUSA M 2241	7.38	10.70	6.05	8.79	325.06	1001.95	0.4695	0.6613	91.06	92.16	35.97	34.08
IPM 1603-1	6.97	8.68	4.40	6.90	132.80	735.27	0.4770	0.5835	118.30	110.00	36.75	42.60
MH 18-181	7.57	10.72	6.37	9.19	298.83	969.78	0.4410	0.6522	70.00	73.00	36.48	35.07
CD (p=0.05)	0.08	0.09	0.13	0.07	0.44	0.79	0.03	0.03	0.28	0.33	0.22	0.26

DAS-Days After Sowing; S-Significant, SC-Susceptible Check, TC-Tolerant Check incidence in mungbean. Protein content showed a significant positive correlation with whitefly and 50 DAS, respectively) and thrips populations. This indicates that higher protein content favoured greater pest colonization, corroborating earlier findings of Sameer and Singh (2021), Pal et al. (2021), and Joseph and Peter (2007). Although the correlation with

Table 3. Correlation between biophysical parameters of different mungbean genotypes and sucking pest infestation

Variable	Correlation coefficient	Regression equations	R^2 Value
Whitefly infestation			
Leaf length at 20 DAS (X) Vs Whitefly (Y)	0.460**	-4.5182+1.1247x	0.2115
Leaf length at 50 DAS (X) Vs Whitefly (Y)	0.403*	-4.2441+0.7535x	0.1621
Leaf width at 20 DAS (X) Vs Whitefly (Y)	0.480**	-3.4264+1.3115x	0.2305
Leaf width at 50 DAS (X) Vs Whitefly (Y)	0.261^{NS}	-0.5412+0.3956x	0.0681
Leaf area at 20 DAS (X) Vs Whitefly (Y)	0.283^{NS}	1.2163+0.0067x	0.0802
Leaf area at 50 DAS (X) Vs Whitefly (Y)	0.404*	0.6691+0.0032x	0.1635
Leaf thickness at 20 DAS (X) Vs Whitefly (Y)	0.434**	-0.7852+10.088x	0.1883
Leaf thickness at 50 DAS (X) Vs Whitefly (Y)	0.459**	-1.3574+8.1166x	0.2109
Trichomes at 20 DAS (X) Vs Whitefly (Y)	-0.339*	6.583-0.0384x	0.1149
Trichomes at 50 DAS (X) Vs Whitefly (Y)	-0.414*	7.8752-0.0515x	0.1717
SCMR Values at 20 DAS (X) Vs Whitefly (Y)	-0.345*	6.5426-0.0931x	0.1187
SCMR Values at 50 DAS (X) Vs Whitefly (Y)	-0.387*	6.8008-0.0988x	0.1499
Aphid incidence			
Leaf length at 20 DAS (X) Vs Aphids (Y)	0.311^{NS}	-60.316+15.564x	0.0968
Leaf length at 50 DAS (X) Vs Aphids (Y)	0.139^{NS}	-9.0534+5.3038x	0.0192
Leaf width at 20 DAS (X) Vs Aphids (Y)	0.203^{NS}	-13.194+11.337x	0.0412
Leaf width at 50 DAS (X) Vs Aphids (Y)	0.002^{NS}	39.64+0.0537x	3E-06
Leaf area at 20 DAS (X) Vs Aphids (Y)	0.065^{NS}	32.933+0.0316x	0.0042
Leaf area at 50 DAS (X) Vs Aphids (Y)	0.338*	4.7257+0.0542x	0.1143
Leaf thickness at 20 DAS (X) Vs Aphids (Y)	0.393*	-25.186+186.95x	0.1546
Leaf thickness at 50 DAS (X) Vs Aphids (Y)	0.253^{NS}	-6.0693+91.495x	0.0641
Trichomes at 20 DAS (X) Vs Aphids (Y)	-0.130^{NS}	70.252-0.3008x	0.0169
Trichomes at 50 DAS (X) Vs Aphids (Y)	-0.103^{NS}	66.331-0.2633x	0.0107
SCMR Values at 20 DAS (X) Vs Aphids (Y)	-0.043^{NS}	49.73-0.2361x	0.0018
SCMR Values at 50 DAS (X) Vs Aphids (Y)	-0.102^{NS}	61.93-0.5313x	0.0104
Thrips incidence			
Leaf length at 20 DAS (X) Vs Thrips (Y)	0.282^{NS}	-3.0518+1.6179x	0.0793
Leaf length at 50 DAS (X) Vs Thrips (Y)	0.169^{NS}	0.4894+0.7443x	0.0287
Leaf width at 20 DAS (X) Vs Thrips (Y)	0.412*	-5.0402+2.6439x	0.1698
Leaf width at 50 DAS (X) Vs Thrips (Y)	0.101^{NS}	4.4033+0.3598x	0.0102
Leaf area at 20 DAS (X) Vs Thrips (Y)	0.170^{NS}	5.2367+0.0095x	0.029
Leaf area at 50 DAS (X) Vs Thrips (Y)	0.323^{NS}	3.5039+0.0059x	0.1044
Leaf thickness at 20 DAS (X) Vs Thrips (Y)	0.460**	-1.3765+25.095x	0.2112
Leaf thickness at 50 DAS (X) Vs Thrips (Y)	0.445**	-1.9327+18.471x	0.198
Trichomes at 20 DAS (X) Vs Thrips (Y)	-0.388*	17.716-0.103x	0.1502
Trichomes at 50 DAS (X) Vs Thrips (Y)	-0.359*	17.837-0.1049x	0.1288
SCMR Values at 20 DAS (X) Vs Thrips (Y)	-0.161^{NS}	11.573-0.1025x	0.0261
SCMR Values at 50 DAS (X) Vs Thrips (Y)	-0.209^{NS}	12.534-0.1252x	0.0436

*Correlation is significant at 0.05 level (2 tailed); **Correlation is significant at 0.01 level (2 tailed); NS-non-significant

Table 4. Regression between sucking pest population and biophysical parameters during *rabi*, 2022-23

Variable	Regression equation	R^2 value (%)
Whitefly infestation at 20 DAS	$Y = -0.121+0.140x_1+0.977x_2-0.008x_3+5.542x_4-0.013x_5-0.038x_6$	29.5
Whitefly infestation at 50 DAS	$Y = 3.675+0.598x_1-0.483x_2-0.002x_3+6.546x_4-0.028x_5-0.049x_6$	30.4
Aphid population at 20 DAS	$Y = -131.356+32.501x_1-20.793x_2-0.229x_3+255.264x_4-0.296x_5+1.268x_6$	31.4
Aphid population at 50 DAS	$Y = 58.124-3.362x_1-7.824x_2+0.108x_3-19.422x_4-0.125x_5+0.719x_6$	19.3
Thrips population at 20 DAS	$Y = 16.891-2.993x_1+3.458x_2-0.029x_3+33.523x_4-0.108x_5-0.016x_6$	43.0
Thrips population at 50 DAS	$Y = 18.220-0.664x_1-0.781x_2-0.000x_3+20.728x_4-0.099x_5-0.024x_6$	29.4

DAS-Days after sowing
X_1 = leaf length, X_2 = leaf width, X_3 = leaf area, X_4 = leaf thickness,
X_5 = trichome density and X_6 = SCMR values

Table 5. Biochemical parameters in leaves of mungbean genotypes during *rabi*, 2022-23

Genotype	Phenols (mg/g FW of leaf)		Proteins (mg/g)	
	20 DAS	50 DAS	20 DAS	50 DAS
COGG-912	20.59	26.89	7.83	8.65
IGKM 05-18-2	18.53	22.53	7.39	10.68
LGG 706	13.42	14.77	10.16	14.09
LGG 686	12.52	14.50	7.73	13.45
COGG-8	16.90	22.33	7.75	12.52
LGG 574	18.23	25.08	10.06	16.83
MH 18-189	16.28	20.92	7.32	13.79
Pusa 9072	18.50	21.47	7.82	12.98
LGG 609	19.58	26.70	7.58	11.88
MH 1762	12.74	14.42	10.86	12.11
LGG 711	16.54	26.70	7.39	12.53
JLPM 707-27	12.72	14.08	10.99	14.52
LGG 450 (SC)	18.11	21.33	7.10	12.53
LGG 460 (TC)	20.11	23.55	5.50	11.09
VGG 16-045	15.22	23.95	7.44	11.43
VGG 17-009	12.50	14.75	10.83	12.98
PMS-12	12.15	17.48	11.58	15.61
OBGG 59	17.52	23.27	7.02	11.31
PM 2	13.38	17.38	7.80	12.82
VGG 17-106	16.23	25.93	7.03	10.31
VGG 104	16.67	26.42	7.28	11.87
TMB 146	13.20	16.47	7.76	13.76
PUSA M 2141	12.00	20.90	7.86	10.79
IPM 1103-1	20.19	24.63	7.66	8.88
MHBC 20-8	12.13	17.94	12.52	14.38
SML 2016	12.15	18.02	10.95	12.15
PUSA M 2241	12.19	15.45	11.12	16.37
IPM 1603-1	13.38	25.25	10.90	12.91
MH 18-181	12.05	13.73	11.29	15.75
CD (p=0.05)	0.16	0.18	0.09	0.13
CV (%)	1.99	1.85	1.36	1.66

DAS-Days After Sowing, FW-Fresh Weight, S-Significant, SC-Susceptible Check, TC-Tolerant Check

Table 6. Correlation between biochemical parameters and sucking pest infestation in mungbean genotypes

Variable	Correlation coefficient	Regression equation	R^2 Value
Whitefly infestation			
Phenols at 20 DAS (X) Vs Whitefly (Y)	-0.428*	7.3063-0.2889x	0.1831
Phenols at 50 DAS (X) Vs Whitefly (Y)	-0.338*	6.0813-0.1603x	0.1144
Proteins at 20 DAS (X) Vs Whitefly (Y)	0.606**	-3.2422+0.6803x	0.3667
Proteins at 50 DAS (X) Vs Whitefly (Y)	0.456**	-3.4811+0.4937x	0.2075
Aphid incidence			
Phenols at 20 DAS (X) Vs Aphids (Y)	-0.275^{NS}	100.19-3.7999x	0.0757
Phenols at 50 DAS (X) Vs Aphids (Y)	-0.091^{NS}	58.4-0.8778x	0.0082
Proteins at 20 DAS (X) Vs Aphids (Y)	0.287^{NS}	-17.973+6.6057x	0.0826
Proteins at 50 DAS (X) Vs Aphids (Y)	0.231^{NS}	-24.409+5.1203x	0.0534
Thrips incidence			
Phenols at 20 DAS (X) Vs Thrips (Y)	-0.347*	16.087-0.5501x	0.1204
Phenols at 50 DAS (X) Vs Thrips (Y)	-0.345*	15.395-0.3839x	0.119
Proteins at 20 DAS (X) Vs Thrips (Y)	0.400*	-1.8966+1.056x	0.1602
Proteins at 50 DAS (X) Vs Thrips (Y)	0.379*	-4.772+0.9652x	0.1438

Table 7. Regression between sucking pest population and biochemical parameters during *rabi*, 2022-23

Variable	Regression equation	R^2 value (%)
Whitefly infestation at 20 DAS	$Y = -1.906-0.053x_1+0.624x_2$	37.0
Whitefly infestation at 50 DAS	$Y = -1.415-0.055x_1+0.422x_2$	21.7
Aphid population at 20 DAS	$Y = 36.038-2.160x_1+4.349x_2$	9.7
Aphid population at 50 DAS	$Y = -46.157-0.584x_1+5.880x_2$	5.6
Thrips population at 20 DAS	$Y = 4.369-0.251x_1+0.794x_2$	17.5
Thrips population at 50 DAS	$Y = 3.150-0.213x_1+0.688x_2$	16.8

aphids was positive, it was not statistically significant. In contrast, phenol content displayed a significant negative correlation with whitefly and thrips populations at 20 and 50 DAS, suggesting its role in resistance through deterrent or toxic effects. No significant association was observed with aphids, though the trend remained negative. Similar findings were reported by Sameer and Singh (2021), Ramarao et al. (2021) and Anu et al. (2021) for whiteflies and aphids, and by Chaudhary and Pandya (2019) for thrips in chilli. Multiple linear regression (MLR) revealed that biochemical traits explained 37.0% of the variability in whitefly infestation at 20 DAS, declining to 21.7% at 50 DAS. For aphids, the explanatory power was much lower (9.7 and 5.6% at 20 and 50 DAS).

Between 20 days (DAS) and 50 days (DAS), significant differences were observed in both biophysical and biochemical parameters in mungbean genotypes. The average values for leaf length, leaf width, leaf area, and leaf thickness all showed a marked increase at 50 DAS compared to 20 DAS, signifying active vegetative growth. Trichome number and SCMR values also generally increased from 20 to 50 DAS. However, the magnitude of change in trichome number and SCMR was sometimes smaller or more variable depending on the genotype. Among biochemical traits, both phenol and protein contents increased from 20 to 50 DAS in most genotypes, often quite substantially for proteins. Overall, protein and phenol contents were identified as key determinants of susceptibility and resistance, respectively. While these traits significantly influenced pest dynamics, other physiological and environmental factors also contributed. Hence, protein and phenol levels m may serve as reliable biochemical markers for resistance screening in mungbean breeding programs.

CONCLUSIONS

The mungbean genotypes COGG-912, VGG 104 and VGG 17-106 were identified as resistant to whiteflies, aphids, and thrips. Among the biophysical traits, trichome density, chlorophyll content, and phenol content exhibited a significant negative correlation with pest incidence. On the other hand, leaf area, leaf thickness, and protein content were positively associated with pest populations. Among the biochemical parameters, protein content showed a significant positive correlation with whitefly and thrips populations, whereas phenol content was negatively correlated with all three pests. These morpho-physical and biochemical traits can serve as reliable indicators for screening large germplasm collections for resistance to the sucking pest complex. The resistant genotypes identified in this study may also be effectively utilized as donor parents in breeding programs to develop mungbean varieties with enhanced tolerance to sucking pests and their associated viral diseases.

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Biochemical and Morphological Basis of Resistance in Groundnut to Groundnut Bruchid, *Caryedon gonagra*

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Abstract: Seven groundnut (*Arachis hypogaea* L.) genotypes were evaluated for resistance against the groundnut bruchid, *Caryedon gonagra*, under storage conditions at the Department of Entomology, S.V. Agricultural College, Acharya N.G. Ranga Agricultural University, Tirupati. Key parameters recorded were fecundity, adult emergence, developmental period, pod damage, weight loss and susceptibility index. Based on the susceptibility index, groundnut genotypes were classified as moderately resistant (Kadiri Chitravathi, K-1687), moderately susceptible (K-1677, Dharani, Kadiri Lepakshi), susceptible (K-6), and highly susceptible (K-7 Bold). The moderately resistant genotypes recorded the lowest number of eggs (24.33–34.00 eggs/100 pods), reduced adult emergence (45.67–48.00%), extended developmental period (76.02–76.27 days), and minimal pod damage (20.67–25.33%) with low weight loss (4.14–4.34%). Bruchid resistance was associated with lower protein (18.46–18.81%) and lower total soluble sugars (5.03–5.27%), and higher phenol content (243.07–265.01 mg/100 g). In contrast, the highly susceptible genotype K-7 Bold recorded the highest oviposition (227.67 eggs/100 pods), adult emergence (195.67), pod damage (100%), and weight loss (30.27%). Susceptibility was correlated with higher pod and seed weights, greater intergranular space, and higher protein (23.68%) and sugars (6.76%), coupled with lower phenol content (172.67 mg/100 g).The findings suggest that both morphological and biochemical traits significantly influence resistance in groundnut genotypes to groundnut bruchid, offering valuable insights for breeding programs targeting bruchid resistance.

Keywords: *Arachis hypogaea*, Groundnut bruchid. Biochemical traits, Resistance, *Caryedon gonagra*

Groundnut (*Arachis hypogaea* L.) is one of the most important oilseed crops grown across tropical and subtropical regions. It plays an important role in human nutrition as a rich source of proteins, fats, vitamins and minerals. In India, groundnut is extensively cultivated and holds significant economic and nutritional value, serving as a major source of edible oil and a source of income for millions of farmers. However, storage pests pose a serious threat to groundnut quality and quantity during storage. Among them, the groundnut bruchid, *Caryedon gonagra* is a major pest. The larvae bore into the pods and feed on the seeds, leading to substantial losses, which reduce seed viability, market value, and nutritional quality. Infestations can even result in total pod destruction under prolonged storage conditions. It was estimated that losses of 6-10 % in groundnut have been attributed to storage pests (Ahir et al., 2018). In recent years, increasing attention has been paid to identifying resistant genotypes as a sustainable alternative to chemical based storage protection (Devi and Rao 2005). In this context, the evaluation of biochemical traits such as protein content, total soluble sugars and phenol has emerged as a valuable approach. These biochemical parameters often play a key role in influencing the pest's feeding behavior, development and survival. Studying the traits linked to pest resistance helps in identifying and developing groundnut varieties that can naturally withstand pests during storage. By focusing on genotypes that already show resistance, it is possible to reduce the need for chemical treatments and develop more sustainable pest management strategies.

MATERIAL AND METHODS

The mother culture of groundnut bruchid was collected from groundnut storage godowns of RARS, Tirupati, ANGRAU, Andhra Pradesh. The bruchids were mass multiplied in the laboratory for about 4-5 generations and the freshly emerged adults were used for the study.

Screening of groundnut varieties: Seven groundnut genotypes (Dharani, Kadiri Lepakshi, K6, K-1677, K-1687, K7 Bold and Kadiri Chitravathi) were used in screening studies. The test varieties were subjected to disinfestation by keeping them in the hot air oven at a temperature of 55 °C for 4 hours. About 250 g disinfested groundnut pods of each test variety were placed in plastic jars of 500g capacity separately with three replications. Five pairs of freshly emerged adult bruchids were released into each jar and kept undisturbed for a period of ten days for oviposition. After 10 days, the adult beetles were removed from the jars and the jars with the pods were kept undisturbed for the emergence of F_1 adults. The performance of the test varieties was assessed based on various parameters. After removing the adult beetles from test varieties the number of eggs laid on the surface of the pods were counted with the help of a hand lens and the mean number of eggs laid by the test insect per 100 pods was calculated and expressed as fecundity. The F_1 adults emerged from each treatment were counted and discarded daily to avoid further mating and egg laying. The process was continued till the adults ceased to emerge from all the treatments. The total number of adults emerged was recorded. The mean developmental period of the test insect in each test variety was calculated by using the formula suggested by Howe (1971).

$$D=\frac{\sum(A\times B)}{C}$$

Where, A = Number of adults emerged on n^{th} day

B = 'n' days required for their emergence

C = Total number of adults emerged during the experimental period

D = Mean development period (days)

Susceptibility index was calculated by using the formula suggested by Dobie (1977).

$$I=\frac{\log_e F}{D}\times 100$$

Where, F = Total number of adults emerged

D = Mean developmental period

I = Index of susceptibility

The test varieties were categorized into five groups based on the index of susceptibility (Mensah 1986).

Category	Index of susceptibility
Resistant	0-2.5
Moderately resistant	2.6-5.0
Moderately susceptible	5.1-7.5
Susceptible	7.6-10.0
Highly susceptible	> 10.0

After the cessation of adult emergence from all the treatments, the number of damaged pods in each replication was counted and converted to per cent damaged pods by using the formula.

$$\text{Damaged pods}(\%)=\frac{\text{Number of damaged pods}}{\text{Total number of pods}}\times 100$$

The final weight of the pods was taken and the weight loss due to insect infestation was calculated by using the formula.

$$\text{Weight Loss}(\%)=\frac{\text{Initial weight of sample - Final weight of sample}}{\text{Initial weight of sample}}\times 100$$

Morphological parameters and biochemical parameters of groundnut varieties: The morphological parameters of groundnut varieties *viz*., pod length, width, test weight, shell thickness, pod reticulation and intergranular space of pods was recorded. The biochemical parameters of the groundnut kernels *viz*., proteins, phenols and total soluble sugars were estimated by using standard procedures. Protein content of the groundnut kernels was estimated by using method given by Lowry (1951). The phenol content of groundnut kernels was estimated by using method of Malick and Singh (1980). Total soluble sugars of the groundnut kernels of each treatment were estimated by using method of Hedge and Hofreiter (1962).

RESULTS AND DISCUSSION

Oviposition and adult emergence: Among the seven groundnut genotypes screened, the mean number of eggs laid differed significantly and the fecundity ranged between 24.33 and 227.67 eggs /100 pods (Table 1). The genotype K-7 Bold with larger size, higher test weight and more intergranular space recorded the highest number of adults (195.67 adults / 250 g of groundnut pods), while Dharani with smaller size, lower test weight and low intergranular space recorded comparatively lesser number of adults (51.00 adults / 250 g of groundnut pods) (Table 1). The plausible reason for the lower adult emergence may be due to restricted movement of adults within limited space affecting the mating behaviour of adult bruchids resulting in lower oviposition and reduce in adult emergence.

Mean developmental period: Lowest mean developmental period was in K-7 Bold (51.88 days). The highest mean developmental period was in Kadiri Chitravathi (76.27) and K-1687(76.02) (Table 1) which were on par with each other. Groundnut genotypes like Kadiri Chitravathi with high shell thickness resulted in increased mean developmental period as shell hardness and testa compactness act as barrier for entry of larvae.

Weight loss and pod damage: The pod damage varied significantly among different groundnut genotypes and ranged between 20.67 to 100 per cent (Table 1). The lowest weight loss of 4.15 per cent was in Kadiri Chitravathi which was on par with K-1687 with 4.34 per cent. The variety K-7 Bold recorded the highest weight loss of 30.27 per cent. The genotype Kadiri Chitravathi recorded lowest (20.67 %) pod damage was on par with K-1687 and Dharani. A total of 100 per cent pod damage was recorded in groundnut genotypes K6 and K7 Bold.

Index of susceptibility: Groundnut genotypes were categorized into five groups based on index of susceptibility as suggested by Mensah (1986) (Table 2). The genotypes Kadiri Chitravathi and K-1687 with index of susceptibility of 4.09 and 4.35, respectively, were categorized as moderately resistant. The K-1677, Dharani and Kadiri Lepakshi with index of susceptibility in the range of 5.57 to 7.47 were categorized as moderately susceptible. K-6 with index of susceptibility in the range of 7.72 to 8.69 was categorized as susceptible genotype and K-7 Bold with index of susceptibility greater than 10 was categorized as highly susceptible.

Premkumar et al. (2020) also reported that, groundnut genotypes with significant reticulation recorded a greater number of eggs. Similarly, Prasad et al. (2012) found that the varieties which are highly preferred by the bruchid for oviposition and adult emergence showed the highest per cent weight loss, indicating the differential preference of *C. gonagra* to different groundnut genotypes. Jyothsna (2015) further reported that treatments that favoured the emergence of more number of adults with short developing time recorded a high index of susceptibility, as observed in K-6. Comparable findings were also reported by Mishra (2005) and Sharma and Thakur (2014).

Physical parameters of groundnut genotypes: Various physical parameters of groundnut pods like length (L), width (W), length × width (L × W), shell thickness, seed weight, pod weight, intergranular space and pod reticulation were measured (Table 3).

Biochemical parameters of groundnut genotypes: Biochemical parameters like proteins, total soluble sugars and phenols were estimated for the groundnut genotypes (Table 4). The protein content in kernels of groundnut genotypes ranged from 18.46 to 23.68%. The highest protein content was in K-7 Bold followed by K6 while the lowest protein content was recorded in Kadiri Chitravathi (18.46 %) which was on par with K-1687 . Total soluble sugars ranged from 5.03 to 6.76 per cent and significantly differed among the genotypes. The highest total soluble sugars of 6.76 per cent was in K7 Bold followed by K6 (6.38 %). The lowest total soluble sugars was in Kadiri Chitravathi (5.03 %). Significant differences also observed in phenol content, which ranged between 172.67 and 265.01 mg / 100g. Kadiri Chitravathi recorded the highest phenol content whereas K-7 Bold recorded the lowest.

Correlation between physical parameters of genotypes and biological parameters of groundnut bruchid: Physical parameters of groundnut genotypes such as pod length, width, length × width, shell thickness, pod weight, seed weight and intergranular space were correlated with the biological parameters of groundnut bruchid, *C. gonagra* such as oviposition, adult emergence, mean developmental period, weight loss, pod damage and index of susceptibility (Table 5). Pod length did not exhibit any correlation with biological parameters of bruchid. Pod width showed significant positive correlation with mean developmental period (0.579) and a significant negative correlation with pod damage (-0.401). Pod length × width showed significant positive correlation with mean developmental period (0.474).

Correlation between biochemical parameters of genotypes and biological parameters of groundnut bruchid: The estimated biochemical components of selected groundnut genotypes such as protein content, total soluble sugars and phenols were correlated with the biological parameters of groundnut bruchid, *C. gonagra* such

Table 2. Categorization of groundnut genotypes against *C. gonagra* based on index of susceptibility

Index of susceptibility	Groundnut genotypes	Category
1.0 to 2.5	Nil	Resistant
2.6 to 5.0	Kadiri Chitravathi and K-1687	Moderately resistant
5.1 to 7.5	K-1677, Dharani and Kadiri Lepakshi	Moderately susceptible
7.6 to 10.0	K-6	Susceptible
>10.0	K-7 Bold	Highly susceptible

Mensah (1986): Resistant (0 – 2.5), Moderately Resistant (2.6 – 5.0), Moderately Susceptible (5.1 – 7.5), Susceptible (7.6 – 10.0) and Highly Susceptible (> 10.0)

Table 1. Screening of groundnut genotypes against groundnut bruchid, *Caryedon gonagra*

Groundnut varieties	Eggs laid/ 100 pods*	No. of adults emerged /250 g pods*	Mean developmental period (Days)*	% Weight loss*	% Pod damage**	Index of susceptibility
Dharani	24.33[a]	51.00 (7.17)[a]	63.76 (8.05)[c]	4.58 (2.36)[a]	27.33 (31.34)[a]	6.13
Kadiri Lepakshi	44.67[b]	79.00 (8.88)[b]	64.70 (8.10)[c]	8.16 (2.93)[a]	62.67 (52.41)[b]	6.71
K-6	54.3 (7.43)[c]	142.33 (11.97)[c]	57.03 (7.62)[b]	28.56 (5.42)[b]	100.00 (90.00)[c]	8.69
K-1687	34.00 (5.89)[ab]	48.00 (7.00)[a]	76.02 (8.78)[e]	4.34 (2.30)[a]	25.33 (30.10)[a]	4.35
K-1677	48.00 (6.99)[b]	57.67 (7.66)[ab]	71.49 (8.51)[d]	8.77 (3.12)[a]	53.00 (46.73)[b]	5.67
K-7 Bold	227.67 (15.11)[d]	195.67 (13.99)[d]	51.88 (7.27)[a]	30.27 (5.59)[b]	100.00 (90.00)[c]	10.16
Kadiri Chitravathi	24.33 (4.97)[a]	45.67 (6.83)[a]	76.27 (8.79)[e]	4.15 (2.27)[a]	20.67 (26.95)[a]	4.09

Means followed by same letters are not significantly different by DMRT as oviposition, adult emergence, mean developmental period, weight loss, pod damage and index of susceptibility and discussed hereunder (Table 6).

Proteins and total soluble sugars of groundnut genotypes showed significant positive correlation with oviposition, adult emergence, weight loss, pod damage and index of susceptibility. Proteins and total soluble sugars showed highly significant negative correlation with mean developmental period (-0.949 and -0.964), respectively. Phenols showed significant negative correlation with oviposition, adult emergence, per cent weight loss, per cent pod damage and index of susceptibility. Conversely phenols show significant positive correlation with mean developmental period (0.943) of *C. gonagra*.

Sreedhar et al. (2020) reported that greater pod length × width increases susceptibility to groundnut bruchids. Jyothsna (2015 observed that high shell thickness offered resistance of groundnut genotypes to groundnut bruchid infestation. Pod weight showed significant positive correlation with mean developmental period (0.537). Seed weight showed significant positive correlation with mean developmental period and significant negative correlation with pod damage. Rekha et al. (2017) also mentioned resistance in groundnut genotypes with less pod weight. Intergranular space did not exhibit any significant correlation with biological parameters of bruchid however weak positive correlations were observed, adult emergence and mean developmental period. Similarly, Nadaf (2008) reported that susceptibility is high in groundnut genotypes having more intergranular space. According to present findings all the biochemical parameters *viz.,* proteins, total soluble sugars and phenols had significant effect on development of *C. gonagra.* Venugopal et al. (2000) also reported that the varieties possessing higher amounts of primary metabolites

Table 4. Biochemical parameters of groundnut genotypes

Groundnut genotypes	Protein %	Total soluble sugar %	Phenol (mg/100g)
Dharani	20.28[b]	5.94[d]	224.01[d]
Kadiri Lepakshi	21.23[c]	6.16[e]	213.60[c]
K6	22.31[d]	6.38[f]	201.81[b]
K-1687	18.81[a]	5.27[b]	243.07[f]
K-1677	19.79[b]	5.59[c]	231.61[e]
K7 Bold	23.68[e]	6.76[g]	172.67[a]
Kadiri Chitravathi	18.46[a]	5.03[a]	265.01[g]

Values are average of three replications
Means followed by same letters are not significantly different by DMRT(p=o.95)

Table 3. Physical parameters assessed in the pods of groundnut genotypes

Groundnut genotypes	Length (L) (mm)	Width (W) (mm)	L × W (mm × mm)	Shell thickness (mm)	100 seed weight (g)	100 pod weight (g)	Inter granular space (cc)	Pod reticulation
Dharani	25.28[a]	11.63[a]	294.09[a]	0.57[a]	55.92[a]	85.67[a]	50.67[a]	Smooth
Kadiri Lepakshi	29.29[b]	11.52[a]	337.79[b]	0.86[bc]	56.86[a]	85.00[a]	60.33[bc]	Very prominent
K-6	30.62[bc]	12.09[a]	370.18[b]	0.76[ab]	62.36[b]	97.50[b]	59.33[b]	Very prominent
K-1687	30.97[c]	15.50[b]	480.06[c]	1.15[d]	77.16[c]	145.00[c]	61.33[bc]	Moderate
K-1677	29.84[bc]	15.99[bc]	477.15[c]	1.00[cd]	79.94[cd]	160.00[d]	60.00[b]	Smooth
K-7 Bold	30.63[bc]	16.70[c]	511.57[c]	1.01[cd]	80.46[cd]	192.50[e]	62.33[c]	Moderate
Kadiri Chitravathi	31.09[c]	16.02[bc]	498.67[c]	1.43[e]	82.74[d]	195.00[e]	60.00[b]	Smooth

Means followed by same letters are not significantly different by DMRT(p=0.05)

Table 5. Correlation between physical parameters of selected groundnut genotypes and biological parameters of groundnut bruchid

Biological parameters/ Physical parameters	Oviposition	Adult emergence	Mean developmental period	Weight loss	Pod damage	Index of susceptibility
Length	0.009	0.060	0.081	0.000	-0.089	0.003
Width	0.331	0.081	0.579**	-0.340	-0.401*	-0.314
Length × Width	0.241	0.079	0.474**	-0.263	-0.344	-0.243
Shell thickness	0.685*	-0.435*	0.077	0.282	0.280	-0.317
Pod weight	0.268	0.129	0.537**	-0.278	-0.358	-0.261
Seed weight	0.240	0.071	0.544**	-0.336	-0.381*	-0.282
Intergranular space	0.351	0.238	0.242	-0.024	-0.074	0.014

** Significant at the 0.01% level.
* Significant at the 0.05 % level

Table 6. Correlation between biochemical parameters of selected groundnut genotypes and biological parameters of groundnut bruchid

Biological parameters/ Physical parameters	Oviposition	Adult emergence	Mean developmental period	Weight loss	Pod damage	Index of susceptibility
Proteins	0.759***	0.895***	-0.949***	0.891***	0.840***	0.973***
Total soluble sugars	0.694***	0.844***	-0.964***	0.862***	0.789***	0.960***
Phenols	-0.790***	-0.870***	0.943***	-0.869***	-0.809***	-0.962***

*** Significant at the 0.01% level.

such as proteins and carbohydrates exhibited a significant positive effect whereas total phenols showed significant negative effect on the infestation rate. Jyothsna et al. (2015) reported that proteins and total soluble sugars exerted significant positive influence on infestation and development. Similarly, Singh et al. (2024) observed that the resistant genotypes possessed higher pod phenol content.

CONCLUSION

According to these findings, no single physical component or biochemical constituent of groundnut is solely responsible for imparting tolerance / susceptibility to the bruchid pest. Effect of bruchid tolerance / susceptibility is determined by combined effect of different physical and chemical factors of groundnut genotypes. The physical factors like shell thickness, seed weight, pod reticulation and intergranular space showed some influence on damage caused by *C. gonagra* whereas the biochemical factors like phenols and anti-nutritional factors *viz.,* low sugar and low protein contributed more significantly to the tolerance of groundnut genotypes against bruchid damage and development. The variety Kadiri Chitravathi with high phenol content, low sugars and low proteins recorded low oviposition, lower adult emergence, lesser pod damage and lower weight loss with Index of susceptibility of 4.09 was proved tolerant to groundnut bruchid. The highly susceptible entry K-7 Bold with less phenol content, more sugars and proteins, large size and more intergranular space recorded index of susceptibility of 10.16 which was comparable to susceptible check K-6.

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Influence of Rice Grain Physico-Chemical Traits on Infestation of *Sitotroga cerealella* (Olivier)

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***Abstract*:** Experiment was conducted to observe the influence of grain physical and biochemical parameters against Angoumois grain moth, *Sitotroga cerealella* at Department of Entomology, Agricultural College, Bapatla. A total of 15 pre-released and released rice genotypes were evaluated to analyze their physical and biochemical characteristics. The grain hardness, grain length, grain breadth, husk thickness of rice genotypes ranged from 55.59 to 102.02 N, 7.52 to 9.56 mm, 1.96 to 2.86 mm, 0.09 to 0.23 mm, respectively. The percent protein, total soluble sugars, amylose, ash and silica contents of uninfested rice genotypes ranged from 6.13 to 9.03, 70.44 to 78.67, 20.87 to 35.37, 7.13 to 11.84, 2.91 to 6.18, respectively. Significant positive correlation was observed between grain damage and weight loss due to *S. cerealella* with regard to total soluble sugars, protein and ash content of rice genotypes, whereas, negative correlation was with regard to amylose and silica content of rice genotypes. The infestation of *S. cerealella* on rice genotypes showed significant increase in protein and ash contents after three months of storage.

***Keywords*:** Angoumois grain moth, Genotypes, Grain hardness, Husk thickness, Physiochemical properties

Rice (*Oryza sativa* L.) is a crucial staple for much of the world's population, supplying over one−fifth of daily calories globally. India, with its diverse agro-ecological zones, stands as the second largest producer of rice. Despite advances in cultivation, one of the persistent challenges is post−harvest loss during storage. Storage pests can inflict losses of 20% or more in developing countries, undermining food security and farmers' livelihoods.

Among stored−grain pests, the Angoumois grain moth (*Sitotroga cerealella* (Olivier)) is particularly destructive in rice, as well as in other cereals such as wheat, maize, sorghum, oats and barley. The larvae of *S. cerealella* bore into grains and consume large portions of the endosperm, leading to reductions in germination capacity, development of off−odours and deterioration in appearance and seed quality. Because new rice genotypes are continually released to meet yield, quality, and climate adaptability goals, there is a pressing need to assess how resistant these varieties are to storage pests (Ashamo 2010). Physical traits such as grain hardness, husk or outer layer thickness, grain size, shape, and moisture content may affect the ability of *S. cerealella* to infest, develop and damage grains. Biochemical traits such as protein, starch, fat or lipid content, or other enzymes/metabolites may also play a role in resistance or susceptibility (Demissie et al., 2015). In this study, aim to examine the physico−chemical properties of several rice genotypes and their relationship with infestation, development, and damage by *Sitotroga cerealella*.

MATERIAL AND METHODS

Fifteen rice genotypes were procured from three different Rice Research Stations in Andhra Pradesh. The selected genotypes were disinfested to eliminate any live insect stages present by keeping them in a hot air oven at 60°C for 5 hours and then equilibrated to a moisture content of 12-13%.

Mass rearing of *S. cerealella*: *Sitotroga cerealella* was mass reared on disinfested rice grains of commercial genotype BPT 5204 under controlled laboratory conditions. Stock culture was started by placing 20 adults of *S. cerealella* in culture jar containing 500 g of rice grains. Honey solution (1:10, Honey: water) was provided as adult food for egg laying. The adults of *S. cerealella* were removed after five days and the jars were incubated. Fresh batch of moths started emerging out in about 3-4 weeks after incubation. Newly emerged adults were collected into required number of jars with rice grains. Parent moths were allowed to lay eggs on the grains and jars were kept undisturbed for three weeks. Emerging moths were collected and transferred to the fresh medium and this process was repeated to maintain the culture.

Screening: Fifty grams of disinfested healthy grains of each rice genotype were taken in individual plastic container of 250 ml size and five pairs of one-day-old (0-24h) healthy adults of *S. cerealella* were released and removed once they died. Experiment was conducted under laboratory conditions (28 ± 2^0C and 65±5% RH) with three replications. After twenty days, the jars were examined *daily* for per cent grain *damage*.

Percent grain damage: A sample of 5g was taken from each treatment in which total number of grains and number of damaged grains were counted.

Determination of physical characteristics: The physical properties of genotypes *viz.*, size of the grain, surface texture, grain hardiness and thickness of husk were estimated. Grain size and thickness of husk was measured by using screw gauge. The texture of grains was assessed based on visual observation. The grain hardiness of each genotype was tested by using grain hardness tester (Kiya Seisa Kusho Ltd. Japan).

Biochemical analysis for qualitative/nutritional losses: Total soluble sugars (Yemm and Willis 1954), amylose (McCready et al., 1950), protein (Lowry et al., 1951), ash (AOAC 2000) and silica (Kamath and Proctor, 1998) were determined according to the standard protocols.

Statistical analysis: The influence of physical properties *was* correlated with per cent grain damage of genotypes by *S. cerealella*. The influence of per cent protein, total soluble sugars, amylose, ash and silica contents were correlated with per cent weight loss and grain damage of varieties by *S. cerealella.*

RESULTS AND DISCUSSION

Physical parameters of rice genotypes: The grain hardness of rice genotypes indicated that a minimum of 55.59 Newton force was required to break the grains of MTU 1166 genotype followed by BPT 5204 genotype, *which required 58.86 N*. Highest force of 102.02 Newton was needed to break down the grains of MTU 7029 genotype. *Thus,* MTU 7029 *was* the hardest among all genotypes and MTU 1166 was the most fragile. The grain length and width among rice genotypes ranged between 7.52 and 9.56 mm and 1.96 and 2.86 mm, respectively. Highest grain length was observed in MTU 1290 genotype with 9.56 mm, while the lowest grain length was recorded in NLR 9674 (7.52 mm). Highest grain width was recorded in genotype MTU 3626 (2.94 mm), whereas the lowest grain width was observed in BPT 5204 (1.96 mm). L/B ratio was calculated and it ranged between 2.64 and 4.23. Based on L/B ratio, genotypes were classified as long slender (LS) and medium slender (MS) (Table 1). Husk thickness of rice genotypes ranged between 0.09 and 0.23 mm. More thickness was observed in BPT 1235 (0.23 mm), while the least was observed in MTU 1187 (0.09 mm) (Table 1). The results are in conformity with Aruna and Ratnasudhakar (2009) who evaluated fifteen genotypes of rice against *S. cerealella*. Among the physical parameters grain texture, hardness and husk thickness contributed *resistance* against *S. cerealella*.

Correlation between physical parameters and grain damage: Correlation studies between physical parameters and grain damage are presented in Table 2. Per cent grain damage was significantly negatively correlated with grain hardness (-0.654) and grain length (-0.332), but was negatively and *non-significantly* correlated with grain width. Husk thickness was significantly negatively correlated with per cent damage (-0.0658). Gopala Swamy et al. (2019)

Table 1. Physical parameters of rice genotypes

Genotypes	Grain damage (%)	Length (mm)	Breadth (mm)	Hardness (N)	Husk thickness (mm)	Texture	L/B	Grain type
BPT 5204	10.67	7.78	1.96	58.86	0.11	Super fine grain	3.97	LS
BPT 2846	5.00	8.06	2.06	84.37	0.12	Coarse grain	3.91	LS
BPT 1235	7.33	8.58	2.20	79.79	0.23	Fine grain	3.90	LS
BPT 2295	9.67	8.02	2.02	79.79	0.12	Fine grain	3.97	LS
MTU 7029	5.33	7.56	2.18	102.02	0.10	Coarse grain	3.47	LS
MTU 3626	5.67	8.62	2.94	70.63	0.12	Fine grain	2.93	MS
MTU 1217	6.00	7.56	2.86	96.14	0.21	Fine grain	2.64	MS
MTU 1187	9.33	8.66	2.30	79.79	0.09	Coarse grain	3.77	LS
MTU 1166	12.33	7.56	2.04	55.59	0.11	Coarse grain	3.71	LS
MTU 1290	1.67	9.56	2.26	89.60	0.12	Fine grain	4.23	LS
NLR-9674	7.67	7.52	2.74	87.96	0.10	Fine grain	2.74	MS
NLR 40058	3.33	8.02	2.30	92.87	0.12	Fine grain	3.49	LS
NLR 28523	4.67	7.64	2.68	89.60	0.11	Fine grain	2.85	MS
NLR 34449	5.67	7.82	2.08	74.56	0.12	Fine grain	3.76	LS
NLR 30491	4.33	7.74	2.44	74.56	0.11	Coarse grain	3.17	LS
CD (p=0.05)		0.40	0.15	4.08	NS			

Source of Genotypes: The rice genotypes used in this study were procured from Agricultural Research Station (ARS) Bapatla (BPT 5204, BPT 2486, BPT 1235, BPT 2295) Agricultural Research Station (ARS) Nellore (NLR 9674, NLR 40058, NLR 28523, NLR 34449, NLR 30491) and Regional Agricultural Research Station (RARS) Maruteru (MTU 7029, MTU 3626, MTU 1217, MTU 1187, MTU 1166, MTU 1290)
LS= Long Slender, MS=Medium Slender , Mean of 5 grains

aloes reported that bold varieties with thicker husk were less prone to Angoumois grain moth infestation than the varieties having fine grain with thinner husk.

Biochemical analysis: The uninfested rice genotypes exhibited significant variation in their biochemical composition. Total soluble sugars averaged 74.35%, ranging from 70.44% to 78.67%, with the highest content observed in BPT 5204, followed by MTU 1187, BPT 2846, BPT 1235, and MTU 1166. Protein content varied from 6.13 to 9.03%, with an average of 7.32%; the highest was in MTU 1166, while MTU 1290 showed the lowest. Amylose content ranged from 20.87 to 35.37%, with an average of 26.03%, and the maximum was in NLR 34449. Ash content showed range of 7.13 to 11.84%, with NLR 34449 recording the highest and NLR 40058, the lowest. Silica content varied between 2.91 and 6.18%, averaging 5.11%, with the highest in NLR 40058 and the lowest in MTU 1166.

Protein content of rice genotypes *was* positively correlated with the per cent damage and per cent weight loss due to the infestation ~~of~~ *by S. cerealella* on rice grains (Table 4). This finding is in conformity with Muthukumar (2014) and Rizwana et al. (2011) where positive correlation between protein content of the rice genotypes and per cent weight loss caused by *S. cerealella*. Swamy et al. (2022) alsoo reported a positive correlation between protein content and adult emergence of *S. cerealella*.

The significant positive correlation was observed between total soluble sugars and the percentage of damage caused by *S, cerealella*, indicating that higher sugar content may enhance susceptibility to infestation. Similarly, ash content showed a significant positive correlation with both

Table 2. Correlation studies between physical parameters of rice genotypes and per cent grain damage by *Sitotroga cerealella*

Variable	Correlation Co-efficient	
Grain damage Vs Grain hardness	-0.654**	Significant at 5% level
Grain damage Vs Grain length	-0.332*	Significant at 1% level
Grain damage Vs Grain width	-0.333	Non-significant
Grain damage Vs Husk thickness	-0.0658	Non-significant

*, **Correlation significant at the 0.05 and 0.01 level (2 tailed)

Table 4. Correlation between biochemical parameters of rice grains and damage by *S. cerealella* after three months of storage

Variable	Correlation coefficient	
Biochemical parameters	Per cent weight loss	Per cent damage
Total Soluble Sugars	0.156*	0.004*
Protein	0.9207*	0.066*
Amylose	-0.169	-0.183
Ash	0.812***	0.891***
Silica	-0.745**	-0.752**

***, **, * Correlation is significant at 0.001 , 0.01 and 0.05 level

Table 3. Bio-chemical composition of uninfested rice genotypes during storage

Genotypes	Uninfested grain				
	TSS (%)	Protein (%)	Amylose (%)	Ash (%)	Silica (%)
BPT 5204	78.67	8.14	25.01	10.09	4.70
BPT 2846	78.29	7.39	27.20	8.18	5.58
BPT 1235	77.41	7.57	22.30	9.60	3.54
BPT 2295	72.09	8.02	30.34	9.93	5.16
MTU 7029	73.36	6.80	24.06	8.07	5.54
MTU 3626	75.14	7.40	24.99	8.97	4.62
MTU 1217	74.36	7.50	26.80	9.49	5.60
MTU 1187	78.38	7.99	28.06	10.29	5.04
MTU 1166	76.36	9.03	20.93	11.84	2.91
MTU 1290	70.44	6.13	24.11	7.38	6.09
NLR 9674	71.30	7.53	20.87	8.43	4.61
NLR 40058	72.15	6.34	31.86	7.13	6.18
NLR 28523	73.32	6.67	27.55	7.50	5.74
NLR 34449	73.04	7.08	35.37	9.77	5.91
NLR 30491	71.03	6.24	21.00	8.10	5.43
CD (p=0.05)	1.80	0.37	1.62	0.36	0.33

Table 5. Effect of *S. cerealella* infestation on biochemical characteristics of rice genotypes during storage

Genotypes	Infested grain				
	TSS (%)	Protein (%)	Amylose (%)	Ash (%)	Silica (%)
BPT 5204	73.16	8.32	23.82	10.40	3.85
BPT 2846	74.60	7.41	24.67	8.61	5.29
BPT 1235	71.87	7.60	20.95	10.01	3.11
BPT 2295	67.27	8.14	28.83	10.29	3.80
MTU 7029	68.74	6.90	23.41	8.20	4.88
MTU 3626	70.04	7.49	23.83	9.50	3.97
MTU 1217	69.04	7.53	25.09	9.83	4.02
MTU 1187	73.98	8.03	26.96	10.44	4.69
MTU 1166	67.01	9.28	20.72	12.08	2.01
MTU 1290	68.23	6.15	23.04	7.43	5.88
NLR 9674	67.30	7.59	20.27	8.61	3.59
NLR 40058	70.2	6.38	30.68	7.61	4.84
NLR 28523	70.17	6.70	24.85	7.88	3.81
NLR 34449	66.39	7.13	32.94	9.93	5.56
NLR 30491	69.90	6.29	20.83	8.10	4.36
CD (p=0.05)	1.742	0.167	0.868	0.468	0.308

damage and weight loss, which is consistent with the findings of Rizwana et al. (2011) and Kiran and Kumar (2020). In contrast, silica content exhibited a negative correlation with damage and weight loss, with lower silica levels recorded in highly susceptible genotypes. Higher silica content is believed to enhance grain hardness, thereby creating a physical barrier that delays or prevents larval penetration, thereby conferring resistance. Amylose content was also negatively correlated with damage and weight loss, as lower amylose levels are often associated with higher chalkiness and reduced grain hardness, which may facilitate easier infestation by *S. cerealella*.

Nutritional changes in rice genotypes due to infestation by *S. cerealella* after three months of storage: The protein and ash content increased significantly in rice genotypes following *S. cerealella* infestation, particularly in highly susceptible varieties such as MTU 1166 and BPT 5204 (Table 5). This rise in protein and ash is attributed to the accumulation of insect body fragments, cast skins and metabolic residues within the grain, rather than an actual improvement in nutritional quality (Nisar et al*.,* 2020, Kishore et al*.,* 2024). In contrast, the least susceptible genotype, MTU 1290, showed a smaller increase in protein content, indicating that reduced insect infestation limits these biochemical alterations. Additionally, a significant reduction in total soluble sugars, amylose, and silica contents was observed in infested grains, with more pronounced decreases in susceptible genotypes. This finding aligns with recent research indicating that stored grain pests consume carbohydrates, which serve as their primary energy source, leading to a depletion of total soluble sugars and starch components such as amylose (Zote and Shukla 2025). The decrease in silica content, which is known to strengthen grain husks and act as a natural barrier to pest, further supports the role of physical grain traits in resistance to *S. cerealella* infestation.

CONCLUSION

This study highlights the significant role of grain physical and biochemical parameters influencing rice genotypes susceptibility to *S. cerealella*. Physical parameters such as grain hardness, size and husk thickness were negatively associated with infestation, indicating their importance in pest resistance. Biochemical factors like higher protein, sugars and ash *were associated with* increased infestation, while higher amylose and silica contributed to resistance. The findings suggest that no single trait can predict resistance, but a combination of characteristics *should* be considered. Despite the threat posed by storage pests, breeding efforts have so far focused mainly on field pests. These results provide a valuable foundation for developing resistant rice varieties, offering a sustainable and eco-friendly approach to managing *S. cerealella* in storage.

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AUTHORS CONTRIBUTION

All authors contributed significantly to the development of this work Raja Mallika A conducted the experiment, collected data, performed statistical analysis and interpreted the results. Madhumathi T provided overall guidance, supervision and critical review of the manuscript. Naik R.B.M. contributed to the compilation and interpretation of relevant literature. Swapna M assisted in biochemical analysis and laboratory work. All authors reviewed, edited and approved the final version of the manuscript.

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Relative Susceptibility of Rice Genotypes to Lesser Grain Weevil *Sitophilus oryzae* (L.)

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Abstract: A total of 11 rice genotypes were screened for their relative susceptibility to the lesser grain weevil *Sitophilus oryzae* (L.), under no-choice and free-choice conditions at Post-harvest Technology Centre, Bapatla during 2022-23. Under free-choice conditions on rough rice, the variety *Teja* recorded the highest adult population (61.33) of *S. oryzae,* while the advanced culture BPT 3111 recorded the lowest (18.0) at 60 days after release (DAR). In milled rice, BPT 2841 was the most susceptible genotype, recording the highest weevil populations under both free-choice (110.33) and no-choice (112.67) conditions. In contrast, the genotypes *Bapatla Mahsuri* and BPT 3111 were least preferred, with significantly lower adult weevil populations in milled rice under free-choice (12.33 and 13.33, respectively) and no-choice (49.67 and 47.67, respectively) conditions. The high susceptibility of BPT rice 2841 was further confirmed in the dual choice test, where it supported the maximum progeny emergence (327.50 adults), higher percent grain weight loss (2.40) and a slightly shorter development period (47.17 days) compared with *Bapatla Mahsuri* that recorded fewer progeny (56.67 adults), lower weight loss (0.49 %) and a longer development period (48.37 days). Overall, both rough and milled rice grains of BPT 3111 were consistently less susceptible to rice weevil, indicating its potential as a relatively resistant genotype under storage conditions.

Keywords: Rice genotypes, Rice weevil, Rough rice, Milled rice, Stored grain insects

Rice (*Oryza sativa* L.) is a staple food for more than half of the global population and its safe storage is vital for ensuring food and nutritional security (Kumar et al., 2020). To meet consumer demand, rice is stored in various forms *i.e*., rough rice, milled rice, and parboiled rice at multiple levels including farmers, traders, processors, and public agencies. However, stored grains are highly vulnerable to both biotic and abiotic stresses, among which insect pests are the most serious biotic factor causing significant quantitative and qualitative losses (Rees 2004, Geeta and Yadu 2022). The lesser grain weevil or rice weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae), is one of the most destructive and cosmopolitan primary pests of stored grains (Padin et al., 2002). Unlike secondary pests, it can penetrate intact grains, oviposit within kernels, and complete its larval development internally, making infestations difficult to detect and manage (Hagstrum et al., 2012). Both adults and larvae feed on grain contents, leading to reductions in grain weight, milling recovery, nutritional value, and marketability, while also predisposing grains to moulds and secondary pest infestations (Arannilewa et al., 2002, Singh and Sharma 2024).

The extent of susceptibility of rice genotypes to grain insects varies widely depending on grain form (rough rice/milled rice) and physicochemical characteristics such as husk thickness, kernel hardness, starch composition, and nutrient content (Farzana 2007, Rizwana et al., 2011, Swamy et al., 2022). Resistant cultivars negatively affect insect survival, growth and reproduction thereby offering an eco-friendly and sustainable option for managing stored-product pests (Nawrot et al., 2010, Borzoui and Naseri, 2016, Barzin et al., 2019). Although several studies have examined varietal resistance in rice to stored-grain pests (Ashamo and Khanna, 2006, Rashid et al., 2009, Astuti, 2019, Swamy et al., 2019, Ethan et al., 2023), information on the relative susceptibility of newly released or advanced rice genotypes is scanty, particularly under both rough and milled grain conditions. With increasing interest in specialty rice varieties such as pigmented black and red rice for their nutritional and health benefits, understanding their resistance to storage pests has also become more relevant. In this context, certain rice genotypes were evaluated for their susceptibility to rice weevil. The study aimed to identify promising genotypes with less susceptibility that may serve as safer storage options and contribute to integrated stored-grain pest management strategies.

MATERIAL AND METHODS

A total of 11 genotypes of rice including one advanced culture BPT 3111 (red rice), three pre-released cultures (BPT 2776, BPT 2858 and BPT 3082), and seven released varieties (*Bapatla Mahsuri, Sasya, Teja, Bhavathi*, BPT rice 2841 (black rice), BPT rice 2846 and *Samba Mahsuri*) were screened for their susceptibility to rice weevil under both no-choice and free-choice conditions at Post-harvest Technology Centre, Bapatla during 2022-23. The grains were obtained from the *kharif* crop produced at Agricultural Research Station, Bapatla during 2022. The grain moisture content was ranged from 11 to 12% (wet basis).

Insect bioassays: The initial mother culture of *S. oryzae* was established in the laboratory on rough rice (variety, *Samba Mahsuri*), using a small number of adults obtained from a local warehouse and later they were sub-cultured to ensure continuous supply of adult insects in sufficient numbers required for the experiments. For free-choice test, rough rice grain (50 g) of each genotype was placed in a plastic plate (10 cm diameter and 2 cm height) and arranged in a circular fashion inside a round plastic opaque tray (60 cm diameter and 9 cm height). A total of 50 mixed-age adult population of test insects were released in the center of the tray, giving equal opportunity to secure the host grains of their choice. It was closed with another tray of the same size by keeping in reverse position and secured tightly with binder clips and the setup was left for three days under ambient conditions. Thereafter, the number of adults that moved into each variety of grain was recorded and the respective grains along with insects were transferred individually into plastic jars (250 ml). Since rice weevil is an internal feeder, only adult insects that came out of the grains up on gentle agitation were counted at 40 days after release (DAR) and put them back into respective containers. Final adult counts were recorded again at 60 DAR in the similar manner and for analysis, only total adult population was taken into consideration. A similar free-choice test was conducted with milled rice, wherein 40 g sample of each variety was placed in the plates and 50 adult insects were released at the center. Milled rice was obtained by milling rough rice of above varieties using a lab model dehuller at Post-harvest Technology Centre, Bapatla. For no-choice test, insects (10 adults) were released into each grain sample (40 g), and data on progeny adult emergence were recorded at 40 and 60 DAR as described above. Both no-choice and free-choice experiments were conducted in three replications with completely randomized block design. Insect bioassays were conducted with both rough rice and milled rice in completely randomized block design replicating thrice.

In addition, a dual -choice test was conducted to assess relative growth and development of rice weevil on a resistant variety comparing with a susceptible one. For this 40 g of milled grain of both varieties were taken and 20 adult insects were placed between the two. There were six replications. Data on the number of insects moved into grain, adult emergence at 40 DAR at 60 DAR, egg to adult development period, and percent weight loss were recorded and compared.

Statistical analysis: The data obtained were subjected to one-way analysis of variance (ANOVA) after transforming the values. Differences among the means were tested for significance by the Tukey test at P<0.05 level.

RESULTS AND DISCUSSION

There were significant differences among the test rice genotypes in their susceptibility to *S. oryzae* under storage (Table 1). Under free-choice conditions on rough rice, significantly higher numbers of adult insects moved into grain of *Bhavathi* (5.33) and BPT rice 2846 (5.0) followed by *Bapatla Mahsuri* and BPT 2858 (4.0 each) while the lowest number was recorded in BPT 2776 (0.67). However, the population buildup at 60 DAR was lowest in red rice culture BPT 3111 (18.0 adults) followed by BPT 2776 (23.0 adults) and *Samba Mahsuri* (23.0 adults). In contrast, BPT rice 2846 and *Teja* varieties recorded the maximum adult populations (63.33 and 61.33, respectively). The results corroborate Swamy et al. (2025) who reported that *Teja* (BPT 2595) (in the form of rough rice) was the most susceptible variety to Angoumois grain moth, *Sitotroga cerealella* (Olivier) with maximum adult emergence and grain damage (362 moths and 14%, respectively), while the variety BPT Rice 2841 showed lower susceptibility with minimum values for the same.

On milled rice under free-choice conditions, maximum numbers of adults moved into grain of *Teja* (5.33) followed by *Bhavathi* and BPT rice 2841 (3.67 each), while it was minimum in BPT 2776 and *Bapatla Mahsuri* (1.0 each). Consistent with this, black rice variety BPT rice 2841 significantly recorded the maximum population of adults (110.33) followed by *Teja* (96.33), while *Bapatla Mahsuri* (12.33) and BPT 3111 (13.33) recorded in lower numbers at 60 DAR. Under no-choice conditions on milled rice, the adult population buildup recorded was minimum in BPT 3111 (47.67) and *Bapatla Mahsuri* (49.67), whereas BPT rice 2841 had maximum adult population (112.67) followed by *Bhavathi* (99.0), BPT 2776 (89.0) and *Teja* (85.0) at 60 DAR.

On perusal of data, it was evident that rough rice as well as milled rice grains of BPT 3111 consistently exhibited lower insect preference and adult emergence compared to other genotypes, suggesting that it is relatively less susceptible to *S. oryzae*. In contrast, BPT rice 2846 and *Teja* were highly susceptible to rice weevil, as evidenced by higher insect preference and progeny development with maximum adult populations of 63.33 and 61.33, respectively. The susceptibility of milled grains of different genotypes exhibited a different trend compared to rough rice, as the protective husk acting as a physical barrier was removed. Among the genotypes, *Bapatla Mahsuri* and BPT 3111 consistently recorded the lowest weevil populations in milled rice under both free-choice (12.33 and 13.33 adults, respectively) and no-choice (49.67 and 47.67 adults, respectively) conditions, thereby categorizing them as less susceptible. In contrast, BPT rice 2841 supported the highest weevil populations in milled rice under both free-choice (110.33) and no-choice (112.67) conditions, indicating its high susceptibility.

The pronounced susceptibility of BPT rice 2841 was further validated in dual-choice test which revealed significantly higher progeny adult emergence (327.50) with higher grain weight loss (2.40%) and a slightly shorter development period (47.17 days) compared with *Bapatla Mahsuri* that recorded lower progeny emergence (56.67 adults), minimal weight loss (0.49%) and a slightly longer development period (48.37 days). Irrespective of form of grain *i.e*., rough rice or milled rice of the variety BPT 3111 (red rice variety) consistently demonstrated reduced susceptibility to *S. oryzae*.

The morphological and biochemical composition of the rice grain was the most important factor in determining resistant or preferred rice varieties to *S. oryzae* (Kamal et al., 2024). Sathiyaseelan and Balaji (2025) studied the behavioral responses of *S. oryzae* to volatiles from different grain commodities which can be useful in effective monitoring of the pest in storage environments. The variation in susceptibility among the rice genotypes may be attributed to the thickness of the husk in rough rice (Kamiyo and Adetumbi 2017, Swamy et al., 2019), and to kernel hardness and nutrient composition in milled rice (Swamy et al., 2022). Thus, indicated that hard, thick, and intact hulls serve as physical resistance factors that hinder insect penetration into rice kernels. Among the various physical characteristics, grain hardness was found to have a significant and negative correlation with alive insect, grain weight loss, and preference index (Kamal et al., 2024). Similarly, Zahra et al. (2024) linked grain resistance to rice weevil infestation with physical and biochemical properties and noted that shorter, wider, and harder seeds with lower starch content were less susceptible to stored product insects. True to this, fine grain rice varieties with thinner husks were found more prone to Angoumois grain moth, *Sitotroga cerealella* infestation compared to those with bold grains with thicker husks (Swamy et al., 2019). Mahdi et al. (2021) further suggested that the cultivar Neda was unsuitable for development of *S. oryzae* as it negatively affected the amylolytic and proteolytic enzyme activity of the pest.

Notably, BPT rice 2841 which was found moderately susceptible to *S. oryzae* in the form of rough rice became highly susceptible when offered in the form of milled rice. (Meaning), This indicates that while in the form of rough rice the resistance offered was majorly by the outer hulls. Hasaranga et al. (2018) concluded that rice stored as un-milled paddy provides better protection from *S. oryzae* than milled rice. In addition, unlike *S. cerealella* which deposits its eggs on the grain surface, the female *S. oryzae* oviposits directly into the seeds, on hatching larvae complete their

Table 2. Development of rice weevil on milled rice of *Bapatla Mahsuri* and BPT rice 2841

Parameter	*Bapatla Mahsuri*	BPT rice 2841
Insects moved (No.) into grain	5.33 ± 1.03	13.33 ± 1.21
Adult population (No.) at 40 DAR	28.33 ± 3.72	111.0 ± 16.07
Adult population (No.) at 60 DAR	56.67 ± 6.19	327.50 ± 19.7
Weight loss (%)	0.49 ± 0.12	2.40 ± 0.07
Egg to adult development period (Days) (Range)	48.37 ± 7.12 (37 – 65)	47.17 ± 6.68 (35 – 62)

Table 1. Preference and progeny development of rice weevil on stored rice grain of different genotypes

Genotype	On rough rice under free-choice		On milled rice under free-choice		On milled rice under no-choice
	Insects moved into grain (no.)	Total adult emergence (no.)	Insects moved into grain (no.)	Total adult emergence (no.)	Total adult emergence (no.)
BPT 3111 (Red rice)	3.67^{abc}	18.0^{f}	2.0^{c}	13.33^{g}	47.67^{f}
BPT 2776	0.67^{e}	23.0^{ef}	1.0^{d}	49.33^{e}	89.0^{bc}
BPT 2858	4.0^{abc}	36.0^{c}	3.33^{b}	81.33^{cd}	56.33^{ef}
BPT 3082	1.67^{cde}	25.33^{de}	2.0^{c}	35.67^{f}	52.0^{f}
Bapatla Mahsuri	4.0^{ab}	44.67^{b}	1.0^{d}	12.33^{g}	49.67^{f}
Sasya	2.0^{bcde}	31.0^{cd}	3.33^{b}	93.67^{bc}	69.33^{de}
Teja	3.0^{abcd}	61.33^{a}	5.33^{a}	96.33^{ab}	85.0^{bc}
Bhavathi	5.33^{a}	37.33^{bc}	3.67^{b}	77.33^{d}	99.0^{ab}
BPT rice 2841 (Black rice)	2.33^{bcd}	34.67^{c}	3.67^{b}	110.33^{a}	112.67^{a}
BPT rice 2846	5.0^{a}	63.33^{a}	2.0^{c}	85.0^{bcd}	81.67^{cd}
Samba Mahsuri	1.67^{de}	23.0^{ef}	2.67^{bc}	75.67^{d}	52.33^{f}

In each column, values with the same letters do not vary significantly at P=0.05

development internally (and emerge) before emerging as adults (Neha et al., 2025). By this, the influence of outer hull could be nullified in case of milled rice as there is no need of penetration for the larva.

CONCLUSION

Among the genotypes tested, rough rice of *Teja* and milled rice of BPT 2841 were found as the most susceptible ones, while both rough and milled rice grains of BPT 3111 were less susceptible to rice weevil. Thus, information on the preferences of rice weevil for different rice genotypes and forms, and their level of infestation under storage conditions is useful for formulating effective pest management strategy that enables early detection of insect infestations and facilitates timely implementation of control measures to minimize both quantitative and qualitative losses of stored produce. However, further studies are needed to elucidate the role of specific physico-chemical grain characters in influencing feeding behavior, preference and development of rice weevil.

AUTHORS' CONTRIBUTION

All authors contributed effectively in this research. S V S Gopala Swamy: Conceptualization, methodology, investigation, data curation, formal analysis, supervision, writing of original draft, review and editing, G V Suneel Kumar: Conceptualization, methodology, supervision, review and editing, B Krishna Veni: Procurement of test material, methodology, review and editing. All authors have read and approved the manuscript.

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Molecular Characterization of *Bacillus thuringiensis* Strains from Native Soils in Southern Zone of Andhra Pradesh, India

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Abstract: In search of novel insecticidal *Bacillus thuringiensis* strains effective against *Spodoptera litura,* a total of 44 cultures were isolated from 205 soil samples collected in Nellore district, Andhra Pradesh, India and evaluated against third instar *Spodoptera litura*. The isolates exhibiting more than 50 per cent larval mortality were chosen for molecular characterization with 14 *cry* gene primers specific to Lepidoptera. The bioassay studies indicated that, larval mortality of 86.67 per cent was observed with N30 at 168h after treatment, followed by N3 with 83.33 per cent which were comparable with standard check HD-1 (96.67%). The Other promising isolates, N44, N48 (%), N58 %), N93 %), N115 (%) and N141 which were statistically on par with each other. Molecular characterization of virulent *B.thuringiensis* strains with *cry* gene specific primers indicated that *cry*1I gene was predominant in present *B. thuringiensis* collection and it was reported from seven (N20, N23, N30, N63, N93, N141, N143) strains. The most effective strain, N30 harboured a combination of three *cry* genes *i.e*., *cry*1, *cry*2 and *cry*9. N3 contained only one *cry* gene (*cry*1C). Among the 19 strains characterized, N93 possessed the highest diversity with five *cry* genes (*cry*1Aa, *cry*1C, *cry*1I, *cry*2A(a)1, *cry*9Ca1). The study identified potential *B. thuringiensis* strains with diverse *cry* gene profiles encoding insecticidal crystal proteins. The presence of multiple *cry* genes (*cry*1, *cry*2 and *cry*9) in N30 likely contributed to its superior efficacy against test insect, *S. litura*. This strain shows promise for development into a cost effective *B. thuringiensis* formulation for use as a biopesticide and may also serve as a valuable resource for developing *Bt* transgenic crop plants.

Keywords: *Bacillus thuringiensis*, *Cry* genes, Environmental isolates, *Spodoptera litura*

Bacillus thuringiensis (Berliner) is an agriculturally important microbe having key role in biocontrol of insect pests. The bacterium produces specific crystalline protein inclusions (δ-endotoxin) during sporulation, which are toxic to insect pests belong to the orders Lepidoptera, Coleoptera, Diptera, Hymenoptera, Homoptera, Orthoptera and Mallophaga (Alsaedi et al., 2017). This unique insecticidal property has made *B. thuringiensis* the most widely used microbial biopesticide in the world market. In addition to δ-endotoxins, *B. thuringiensis* also synthesizes insecticidal proteins during its vegetative growth phase, which are subsequently secreted into the culture medium. These proteins are commonly known as vegetative insecticidal proteins (Vips) and exhibit potent insecticidal activity against several lepidopteran, coleopteran and some homopteran pests.

Bacillus thuringiensis is a rod shaped, Gram-positive, filiform, spore forming bacterium, that is ubiquitous in nature. This organism has been isolated worldwide from a great diversified environments including soil, water, dead insects, dust from silos, leaves from deciduous trees, diverse conifers, and insectivorous mammals, and even from human tissues with severe necrosis (Palma et al., 2014). Among the various sources for *B. thuringiensis* isolation, soil is the most suitable media for collecting diverse isolates. There are several *B. thuringiensis* collections across the world, which are being tested against a number of insect pests. Li et al. (2007) reported that, *B. thuringiensis* isolates are distributed worldwide, and more than 60,000 have been collected by various industries in an effort to obtain novel crystal proteins. Each *B. thuringiensis* isolate produces different types of crystal toxins either alone or in combination and exhibits specific activity against one or a few related species of insects. Therefore, large-scale screening programmes have been conducted worldwide, leading to important collections of isolates from different environments and characterized to evaluate their toxic potential against various insect orders (Quesada and Valverde 2004, Ramalakshmi and Udayasuriyan 2010). The studies were conducted at Regional Agricultural Research Station, Tirupati to isolate and characterize the environmental *B. thuringiensis* strains from soil samples collected in Nellore district of Andhra Pradesh, India for their potential to control *Spodoptera litura* (Fabricius).

MATERIAL AND METHODS

Collection, isolation and identification of *B. thuringiensis* from soil samples: During the study, 205 rhizosphere soil samples were collected from various locations in Nellore district of Andhra Pradesh covering crop fields, waste lands, virgin soils and other habitats. Samples were collected aseptically in sterile polythene bags. Sodium acetate selection method was adopted for isolating *B. thuringiensis* with slight modifications (Santana et al., 2008, Devaki et al., 2020). Half a gram of soil sample was added to 10 ml of Luria Bertani (LB) broth in a 100 ml conical flask along with 0.5 M sodium acetate. The mixture was kept on a shaker for 4h at 250 rpm at room temperature and subjected to heat shock at 80°C for 15 min and plated at 10^{-5} dilution on LB agar (LBA) medium. Cream coloured colonies with a characteristic 'fried egg' appearance were picked up after 18h of incubation on LB agar media, followed by Gram's staining. The Gram positive cultures grown on T3 media for 72 h for crystal and endospore production were further characterized for the presence or absence of crystal proteins and endospores using standard protocols (Jisha and Benjamin 2014). The Gram positive culture which were confirmed for crystal and endospore production were further purified by repeated four-way streaking (Merdan et al., 2010) on pre-pasteurized LB agar plates. The cultures which were observed positive in Gram's staining, crystal and endospore staining were further used in bioassay studies.

Bioassay of *B. thuringiensis* against *S. litura:* Fourty four *B. thuringiensis* strains were assayed to ascertain larvicidal activity against third instar larvae of *S. litura*. The standard *B. thuringiensis* (HD1) strain obtained from National Beaureau of Agricultural Insect Resources (NBAIR), Bengaluru was used as a reference strain. Individual *B. thuringiensis* culture was streaked on plain LB agar plates and incubated overnight at 37°C. One loop of the overnight culture was inoculated in LB broth and kept for sporulation under shaking conditions (250 rpm) at 28°C for 72 h. The culture containing spore crystal mixture was pelletized in Eppendorf centrifuge at 10000 rpm for 10 min. The resultant pellet was diluted in sterile water, plated on LBA and colony counts were taken for fixing the doses.

The bioassay was conducted by leaf dip method at a concentration of 5 -10^8 CFU/ml (Devaki et al., 2017). Groundnut compound leaves containing four leaflets were dipped into culture broth containing 0.2 per cent Triton X-100 for 10 minutes and air-dried. After drying, leaf petiole was swabbed with wet cotton to maintain leaf turgidity and dip the leaf in *B. thuringiensis* isolates with different dilutions. One treated groundnut leaf for one replication was placed in a petriplate. Ten third instar larvae were released per replication. HD-1 served as a reference strain. The leaves dipped in distilled water served as control. The larval mortality was assessed after 72 h at regular intervals till pupation and LC_{50} values were determined using probit analysis. Isolates with more than 75 per cent mortality (N3, N30, N44, N48, N58, N93, N115) along with HD1 were tested for determining lethal concentrations following the same leaf dip procedure. Five concentrations viz., 10^3, 10^4, 10^5, 10^6, and 10^7 CFU/ml were used for carrying probit analysis and LC_{50} determination.

DNA extraction and PCR amplification: Genomic DNA was isolated from 18 *B. thuringiensis* strains with ≥ 75% larval mortality of III instar *S. litura* by adopting the protocol of Sambrook and Russell (1998). The resultant DNA was verified for its quality and purity through agarose gel electrophoresis as well as nanodrop spectrophotometer. A total of 14 cry gene-specific primers (*cry*1Aa, *cry*1Ab, *cry*1Ac, *cry*1C, *cry*1Da1, *cry*1Ea1, *cry*1F, *cry*1Fa1, *cry1I*, *cry*2, *cry*2A(a)1, *cry*8, *cry*9Aa1 and *cry*9Ca1) were used in the study. The primers were synthesized with the known sequences available in the literature (Table 1). The conditions like initial denaturation, annealing temperature, elongation and final extension were standardized by using gradient PCR. Composition of the reaction mixture was also standardized and a final proportions of PCR reagents and buffers were as follows; Taq assay buffer (10X) 2.5 µl, dNTP's (2 mM) 1.5 µl, 2.5 µl of each forward and primer, $MgCl_2$ (2.0 mM) 1.5 µl, Taq DNA polymerase (3 U /µl) 0.5 µl, Template DNA (100 ng) 2.5 µl and made to a final volume of 25 µl. Thermal cycling was fixed for each primer in Biorad thermal cycler and resultant PCR product was ran through electrophoresis on 1% agarose gel. The particulars of primer sequencing, annealing temperature, and PCR recipe are listed in the Table 1, 2 and 3.

RESULTS AND DISCUSSION

Isolation and screening of *B. thuringiensis* from soil samples: Out of 205 samples collected from diverse soil environments screened for bacterial cultures, a total of 68 samples were identified as Gram positive organisms. Among these, 48 isolates were capable of producing endospores, of which 44 were confirmed as crystal positive *B. thuringiensis* strains. Based on crystal morphology, 16 produced spherical crystals, 11 irregular, 7 bipyramidal, 6 cuboidal and 4 showed a combination of bipyramidal & cuboidal forms. All these 44 crysal producing strains were used in the laboratory bioassays against third instar larvae of *S. litura*.

Bioassay of *B. thuringiensis* isolates: In the bioassay, larval mortality was recorded from 72 h to 168 h after treatment and the mortality was ranged from 0.0 to 50.0, 0.0 to 36.67, 0.0 to 36.67, 0.0 to 26.67 and 0.0 to 33.33 per cent at 72, 96, 120, 144 and 168 hours after treatment, respectively (Table 4). At 72 hours after treatment, among the 44 isolates, N115 recorded the highest larval mortality of 40 per cent which was statistically on par with standard check HD-1. The next best treatments were N30, N48, (N58 %), N69 , N100 , N118 and N93 and all statistically at par with each other. Whereas, at 96 hours after treatment, isolates N3, N45, N58, N100, N189 each recorded 23.33 per cent mortality and were d significantly superior over the other treatment. At 120 hours after treatment, isolates N173, N141, N93, N3, N115 were effective and on par with each other. Subsequently, N44 (26.67%) and N34 (33.33%) recorded higher larval mortality at 144 and 168 hours after treatment, respectively.

Cumulative mortality data revealed that isolate N30 caused the highest larval mortality (86.67%), followed by N3 which were comparable with standard check HD-1 (96.67%). The other treatments in the order of efficacy was N44, N48, N58, N93, N115, and N141, which were statistically similar in their efficacy. The rest isolates were no way superior to untreated check (Table 3). Probit analysis revealed that the lowest LC_{50} was observed for N30 (1.90-10^5CFU/ml) followed by N3 (2.18- 10^5 CFU/ml), which recorded quicker lethal time to kill 50 per cent population (LT_{50} = 95.70 h). In standard check HD1 recorded the lowest LC_{50} and LC_{90} values with LT_{50} and LT_{90} of 61.99 h and 121.64 h, respectively (Table 4a).

Molecular characterization of *B. thuringiensis* isolates: Molecular characterization of 19 *B. thuringiensis* strains native to Nellore district soil samples, revealed distinct *cry*

Table 2. PCR reaction mixture for amplification of native *B. thuringiensis* strains with specific *cry* primers

Reagents	Volume/reaction
Taq assay buffer (10X)	2.5 µl
dNTP's (2 mM)	1.5 µl
Forward primer (5 pmole)	2.5 µl
Reverse primer (5 pmole)	2.5 µl
$MgCl_2$ (2.0 mM)	1.5 µl
Taq DNA polymerase (3 U /µl)	0.5 µl
Template DNA (100 ng)	2.5 µl
Sterile distilled water	11.5 µl
Total	25.0 µl

Table 1. Details of *cry* primers used in the study

Primer name	Forwardion	Primer sequence	Reference
*cry*1Aa	Forward	ATTATCATATTGATCAAGTTC	Salek et al., 2012
	Reverse	CATAAGGAACCCGTACCTGG	
*cry*1Ab	Forward	GGACCAGGATTTACAGGAGG	-do-
	Reverse	GTTCTCCTACTAATGGTTTCC	
*cry*1Ac	Forward	CTCAATGGGACGCATTTCTT	-do-
	Reverse	CGGTTGTAAGGGCACTGTTC	
*cry*1C	Forward	AAAGATCTGGAACACCTTT	Ceron et al., 1994
	Reverse	CAAACTCTAAATCCTTTCAC	
*cry*1Da	Forward	GTAGCAGACATTTCATTAGG	Pooja et al., 2013
	Reverse	ACATGAATAAGGCTAGTCAG	
*cry*1Ea1	Forward	ATATAGAAGTAGGGGGACAG	-do-
	Reverse	TAGCCCTAGTTGATTTGTAG	
*cry*1Fa1	Forward	GATTTGCTAATACAGACGAC	-do-
	Reverse	CGTGAACTCACTAAGTGTCC	
*cry*1F	Forward	TGTAGAAGAGGAAGTCTATCCA	Ceron et al., 1994
	Reverse	TATCGGTTTCTGGGAGTA	
*cry*1I	Forward	AGCTATGGCCTAAGGGGAAA	Nariman, 2007
	Reverse	TTCCAACCCAACTTTCAA	
*cry*2	Forward	GTTATTCTTAATGCAGATGAATGGG	Ben-Dov et al., 1997
	Reverse	CGGATAAAATAATCTGGGAAATAGT	
*cry*2A(a)	Forward	AAGGAGGAATTTTATATGAA	Ogunjimi et al., 2002
	Reverse	CATTTAGTTCCGTCAATATG	
*cry*8	Forward	ATGAGTCCAAATAATCTAAATG	Bravo et al., 1998
	Reverse	TTTCATTAATGAGTTCTTCCACTCG	
*cry*9Aa1	Forward	ATCGTAGAGAGTGACATTG	Pooja et al., 2013
	Reverse	TGTTGTCCAGAGATTAGTTC	
*cry*9Ca1	Forward	GGATCTAAATGCAAGTGTAG	-do-
	Reverse	ACCATTTACATCGTAGTCAC	

gene profiles. Among these, seven (N20, N23, N30, N63, N93, N141, N143,) *B. thuringiensis* strains harboured *cry*1I genes, six strains (N45, N69, N93, N130, N141, N143) contained *cry*1Aa and four strains (N3, N93, N100, N115) possessed *cry*1C. Three strains were positive for *cry*1Da1 (N44, N69, N96) and *cry*1Fa1 (N141, N143, N158). Only one strain N69 harboured *cry*1Ea1 gene (Tables 5 , 6). Among the *cry*2 group positive isolates, one strain (N20) harboured *cry*2 and five strains (N23, N30, N58, N93, N100) harboured both *cry2* and *cry*2A(a)1 genes. Four strains (N23, N30, N93, N141) possessed *cry*9Ca1 gene. None of the isolates in the present study tested positive for *cry*1Ab, *cry*1Ac*, cry*1F, *cry*9Aa1, *cry*8 genes. There was no definite relationship between the isolate efficacy and number of crystal proteins encoding *cry* genes. However, isolates harbouring multiple *cry* genes tended to exhibit higher larvicidal activity. One representative strain N115 was sequenced using 16S rRNA primer, the gene sequence was deposited in NCBI GenBank with accession Number MF487791. The highest mortality of 86.67 and 83.33 per cent mortality was observed in *B. thuringiensis* isolates, N30 and N3, respectively which were statistically on par with the HD1. The present studies are in line with the earlier studies made by Meihiar et al. (2015) who

Table 3. PCR conditions for each set of *cry* primers used in the analysis

Step		Temperature (°C)	Duration (min)	No. of cycles
Initial denaturation		94.0	10	1
Denaturation		94.0	½	35
Annealing	*cry*1Aa	48.9	1	35
	*cry*1Ab	53.4		
	*cry*1Ac	54.4		
	*cry*1C	52.0		
	*cry*1Da 1	51.3		
	*cry*1Ea1	51.3		
	*cry*1Fa1	50.3		
	*cry*1F	52.0		
	*cry*1I	47.3		
	*cry*2	57.2		
	*cry*2Aa	46.2		
	*cry*8	49.0		
	*cry*9Aa1	51.0		
	*cry*9Ca1	52.3		
	16s rRNA	49.0		
Extension		72.0	2	35
Final extension		72.0	10	1
Hold		4.0	∞	-

reported that, forest, beach and cultivated soils had more *B. thuringiensis* strains than uncultivated and interior arid soils. The frequency of *B. thuringiensis* occurrence was partially dependant on organic matter and pH content of the soil, with about 65 per cent of the isolates found toxic to *Galleria mellonella.* The most toxic isolate of *B. thuringiensis* was obtained from cultivated area and produced bipyramidal, cuboidal and rectangular inclusions.

Similarly, Sharma (2000) reported a mortality of 66.66 to 100 per cent with five *B. thuringiensis* formulations against *S. litura* and *Spilarctia obliqua* under controlled conditions at 26±1°C and 75 per cent relative humidity which were on par with endosulfan. Further, Nariman et al. (2009) reported a higher mortality of 100 per cent and 90 per cent of second instar *S.littoralis* with two *B. thuringiensis* isolates Ts-5 and As-3, respectively collected from seven governorates of Egypt. Lalitha et al. (2012) also reported a mortality of 16.67 to 94.44 per cent with *B. thuringiensis* isolates against second instar larvae of *H. armigera* where *B. thuringiensis* isolates 122 and 22 recorded 83.33 per cent mortality and was statistically on par with HD-1. At the same time Al-Otaibi (2013) reported a higher positive efficiency of *B. thuringiensis* isolates in spore+ crystal mixtures @ 10^9 CFU/ml at 168h after treatment against second instar *S. littoralis* larvae. Ricardo et al. (2000) also reported a mortality of 100 and 80.4 per cent in second instar larvae of *S. frugiperda* with the suspensions of *Bt aizawai* HD 68 and *Bt thuringiensis* 4412, respectively, containing 3- 10^8 cells/ml. Azzouz et al. (2014) also confirmed a higher toxicity of *B. thuringiensis* against *S. littoralis* while Pooja et al. (2013) reported a cumulative mortality of 83.33 per cent with the *B. thuringiensis* isolate DBT153 against *Plutella xylostella* collected from hill ecosystems in Coorg district. Devaki et al. (2017) reported a cumulative mortality of 83.33 per cent with *B. thuringiensis* strains viz., C79, C97, C134 and C212 against third instar larvae of *S. litura* at 5 x 10^5 CFU/ml. As against this, Mohan et al. (2014) reported a low toxicity of *B.thuringiensis* HD-1 strain against *S. litura* and non-toxic effects of HD-73 strain against *S. litura* and *S. oblique*. Liao et al. (2002) also observed that *H. armigera* strain from Australia was poorly susceptible to *cry*9Ca1 toxin produced by *Bt tolworthi*.

The present study also aligns with Nazarian et al. (2009) and Konecka et al. (2012) with high frequency of *cry*1I gene from *B. thuringiensis* isolates. Similarly, Salama et al. (2015) revealed that, the *cry*1 gene (83.33%) was the most abundant in the soil samples of Egypt. Yılmaz (2010) reported that the frequency of *cry*1Ab or *cry*1Ac was highest (47.72%) of all the *cry* genes studied in isolates obtained from Adana region of Turkey. Further, Devaki et al (2020) reported

Table 4. Bioassay of *B. thuringiensis* isolates collected from Nellore district against third instar *S. litura* larvae under laboratory conditions

Isolate	Per cent mortality					
	72h	96h	120h	144h	168h	Cumulative
N2	10.00 (15.00)^{aefg}	10.00 (15.00)^{abcd}	0.00 (0.00)^{a}	3.33 (6.15)^{ab}	0.00 (0.00)^{a}	23.33 (28.78)^{cde}
N3	0.00 (0.00)^{a}	23.33 (28.78)^{de}	23.33 (28.29)^{defgh}	16.67 (23.86)^{de}	20.00 (26.57)^{gh}	83.33 (70.78)^{klm}
N7	0.00 (0.00)^{a}	0.00 (0.00)^{a}	0.00 (0.00)^{a}	0.00 (0.00)^{a}	16.67 (23.86)^{fgh}	16.67 (23.86)^{cd}
N9	30.00 (33.00)$^{h-n}$	6.67 (12.29)^{abc}	6.67 (8.86)^{abc}	6.67 (12.29)^{abcd}	0.00 (0.00)^{ab}	50.00 (45.08)$^{def-j}$
N11	10.00 (18.43^{efgh}	3.33 (6.14)^{ab}	10.00 (15.00)$^{a-e}$	0.00 (0.00)^{a}	10.00 (11.07)$^{a-f}$	33.33 (34.63)^{cdefg}
N15	13.33 (21.14)^{fghi}	6.67 (12.29)^{abc}	20.00 (21.14)$^{b-h}$	3.33 (6.15)^{ab}	6.67 (8.86)$^{a-e}$	50.00 (45.79)$^{ef-j}$
N20	10.00 (15.00)$^{a-g}$	10.00 (15.00)^{abcd}	10.00 (15.00)$^{a-e}$	0.00 (0.00)^{a}	30.00 (33.00)^{h}	60.00 (51.14)$^{f-jk}$
N23	10.00 (15.00)$^{a-g}$	16.67 (23.86)^{cde}	10.00 (15.00)$^{a-e}$	0.00 (0.00)^{a}	30.00 (33.00)^{h}	66.67 (55.37)^{ghijkl}
N30	36.67 (37.14)^{jklmn}	13.33 (21.14)^{bcd}	13.33 (17.71)^{bcdef}	13.33 (21.15)^{cde}	10.00 (15.00)$^{a-g}$	86.67 (72.78)^{lm}
N32	0.00 (0.00)^{a}	10.00 (18.43)^{bcd}	3.33 (6.14)^{ab}	6.67 (12.29)^{abcd}	6.67 (12.29)$^{a-f}$	26.67 (31.00)^{cdef}
N34	3.33 (6.14)$^{a-e}$	0.00 (0.00)^{a}	0.00 (0.00)^{a}	6.67 (8.86)^{abc}	33.33 (35.01)^{h}	43.33 (41.15)^{defghi}
N37	23.33 (28.29)$^{g-m}$	10.00 (18.43)^{bcd}	3.33 (6.14)^{ab}	16.67 (23.86)^{de}	6.67 (12.29)$^{a-f}$	60.00 (50.94)$^{f-jk}$
N44	26.67 (31.00)$^{h-n}$	3.33 (6.14)^{ab}	20.00 (26.57)^{defgh}	26.67 (30.79)^{e}	0.00 (0.00)^{abc}	76.67 (61.22)^{hijkl}
N45	3.33 (6.14)$^{a-e}$	23.33 (28.78)^{de}	20.00 (26.07)^{cdefgh}	6.67 (12.29)^{abcd}	0.00 (0.00)^{abc}	53.33 (46.92)$^{ef-j}$
N48	33.33 (35.22)$^{i-n}$	16.67 (23.86)^{cde}	6.67 (12.29)^{abcd}	0.00 (0.00)^{a}	20.00 (21.93)^{efgh}	76.67 (61.92)^{ijkl}
N58	33.33 (34.93)$^{i-n}$	23.33 (28.78)^{de}	13.33 (21.14)$^{b-h}$	0.00 (0.00)^{a}	6.67 (12.29)$^{a-f}$	76.67 (61.92)^{ijkl}
N61	0.00 (0.00)^{a}	6.67 (12.29)^{abc}	0.00 (0.00)^{a}	10.00 (18.44)^{bcde}	0.00 (0.00)^{abc}	16.67 (23.86)^{cd}
N63	20.00 (22.14)$^{f-j}$	16.67 (19.93)^{bcd}	13.33 (21.14)$^{b-h}$	0.00 (0.00)^{a}	0.00 (0.00)^{abc}	50.00 (44.21)$^{def-j}$
N64	0.00 (0.00)^{a}	10.00 (18.43)^{bcd}	6.67 (12.29)^{abcd}	10.00 (18.44)^{bcde}	0.00 (0.00)^{abc}	26.67 (31.00)^{cdef}
N65	0.00 (0.00)^{a}	10.00 (18.43)^{bcd}	6.67 (12.29)^{abcd}	0.00 (0.00)^{a}	0.00 (0.00)^{abc}	16.67 (23.86)^{cd}
N69	33.33 (35.22)$^{j-n}$	16.67 (23.86)^{cde}	6.67 (12.29)^{abcd}	10.00 (15.00)^{bcd}	0.00 (0.00)^{abc}	66.67 (55.07)^{ghijkl}
N93	23.33 (24.15)$^{f-jk}$	10.00 (18.43)^{bcd}	30.00 (33.00)^{fgh}	3.33 (6.15)^{ab}	10.00 (18.44)^{defg}	76.67 (65.85)^{jklm}
N100	33.33 (35.22)$^{j-n}$	23.33 (28.78)^{de}	0.00 (0.00)^{a}	3.33 (6.15)^{ab}	0.00 (0.00)^{abc}	60.00 (50.85)$^{f-jk}$
N105	0.00 (0.00)^{a}	16.67 (23.86)^{cde}	3.33 (6.14)^{ab}	10.00 (18.44)^{bcde}	3.33 (6.15)^{abcd}	33.33 (35.22)^{cdefg}
N106	10.00 (18.43)^{efgh}	0.00 (0.00)^{a}	0.00 (0.00)^{a}	0.00 (0.00)^{a}	0.00 (0.00)^{abc}	10.00 (18.43)^{ac}
N107	6.67 (12.29)$^{a-f}$	6.67 (12.29)^{abc}	0.00 (0.00)^{a}	13.33 (21.15)^{cde}	6.67 (12.29)$^{a-f}$	33.33 (35.01)^{cdefg}
N108	0.00 (0.00)^{a}	0.00 (0.00)^{a}	0.00 (0.00)^{a}	6.67 (8.86)^{abc}	10.00 (18.44)^{defg}	16.67 (23.36)^{cd}
N115	40.00 (39.15)^{kmn}	10.00 (18.43)^{bcd}	23.33 (28.78)^{defgh}	0.00 (0.00)^{a}	3.33 (6.15)^{abcd}	76.67 (65.85)^{jklm}

Cont..

Table 4. Bioassay of *B. thuringiensis* isolates collected from Nellore district against third instar *S. litura* larvae under laboratory conditions

Isolate	Per cent mortality					
	72h	96h	120h	144h	168h	Cumulative
N117	0.00 (0.00)^{ab}	30.00 (28.08)^{cde}	10.00 (18.43)$^{b-g}$	3.33 (6.15)^{ab}	0.00 (0.00)^{abc}	43.33 (39.99)^{cdefgh}
N118	33.33 (35.22)$^{j-n}$	20.00 (26.07)^{cde}	3.33 (6.14)^{ab}	0.00 (0.00)^{a}	3.33 (6.15)^{abcd}	60.00 (51.14)$^{f-jk}$
N122	0.00 (0.00)^{abc}	10.00 (18.43)^{bcd}	3.33 (6.14)^{ab}	3.33 (6.15)^{ab}	0.00 (0.00)^{abc}	16.67 (23.86)^{cd}
N130	23.33 (28.78)$^{g-m}$	20.00 (26.07)^{cde}	3.33 (6.14)^{ab}	3.33 (6.15)^{ab}	0.00 (0.00)^{abc}	50.00 (45.08)$^{def-j}$
N131	16.67 (23.86)$^{f-j}$	10.00 (18.43)^{bcd}	6.67 (12.29)^{abcd}	0.00 (0.00)^{a}	0.00 (0.00)^{abc}	33.33 (35.22)^{cdefg}
N138	10.00 (18.43)^{efgh}	3.33 (6.14)^{ab}	10.00 (18.43)$^{b-g}$	3.33 (6.15)^{ab}	0.00 (0.00)^{abc}	26.67 (30.79)^{cdef}
N141	20.00 (26.07)$^{f-jklm}$	20.00 (26.07)^{cde}	33.33 (35.22)^{gh}	0.00 (0.00)^{a}	0.00 (0.00)^{abc}	73.33 (59.71)^{hijkl}
N143	16.67 (23.86)$^{f-j}$	10.00 (18.43)^{bcd}	26.67 (31.00)^{efgh}	0.00 (0.00)^{a}	0.00 (0.00)^{abc}	53.33 (46.92)$^{ef-j}$
N148	16.67 (23.86)$^{f-j}$	20.00 (26.07)^{cde}	13.33 (21.14)$^{b-h}$	10.00 (15.00)^{bcd}	0.00 (0.00)^{abc}	60.00 (51.14)$^{f-jk}$
N158	23.33 (24.15)$^{f-l}$	10.00 (18.43)^{bcd}	13.33 (21.14)$^{b-h}$	3.33 (6.15)^{ab}	0.00 (0.00)^{abc}	50.00 (45.00)$^{def-j}$
N173	0.00 (0.00)^{abcd}	0.00 (0.00)^{a}	36.67 (37.14)^{h}	3.33 (6.15)^{ab}	3.33 (6.15)^{abcd}	43.33 (41.07)^{defghi}
N188	0.00 (0.00)^{abcd}	10.00 (15.00)^{abcd}	10.00 (15.00)$^{a-e}$	6.67 (12.29)^{abcd}	0.00 (0.00)^{abc}	26.67 (30.29)^{cdef}
N189	0.00 (0.00)^{abcd}	23.33 (24.15)^{cde}	10.00 (18.43)$^{b-g}$	0.00 (0.00)^{a}	10.00 (15.00)^{abdefg}	43.33 (40.86)^{defghi}
N190	0.00 (0.00)^{abcd}	0.00 (0.00)^{a}	16.67 (23.86)^{cdefgh}	0.00 (0.00)^{a}	0.00 (0.00)^{abc}	16.67 (23.86)^{cd}
N192	0.00 (0.00)^{abcd}	0.00 (0.00)^{a}	0.00 (0.00)^{a}	0.00 (0.00)^{a}	0.00 (0.00)^{abc}	0.00 (0.00)^{a}
N193	0.00 (0.00)^{abcd}	0.00 (0.00)^{a}	0.00 (0.00)^{a}	0.00 (0.00)^{a}	0.00 (0.00)^{abc}	0.00 (0.00)^{a}
HD1	50.00 (45.00)^{n}	36.67 (37.22)^{e}	3.33 (6.14)^{ab}	6.67 (12.29)^{abcd}	0.00 (0.00)^{abc}	96.67 (83.86)^{m}
Control	0.00 (0.00)^{abcd}	0.00 (0.00)^{a}	0.00 (0.00)^{a}	0.00 (0.00)^{a}	0.00 (0.00)^{abc}	0.00 (0.00)^{ab}
SEd	6.27	6.50	7.06	5.95	5.99	8.88
LSD	12.46	12.92	14.03	11.81	11.88	17.65

Figures in parentheses are arcsine transformed values
Alphabets indicating Duncan Multiple Range Test (DMRT)

Table 4a. Lethal dose calculation for effective *B. thuringiensis* strains

Bt isolates	Regression equation	LC_{50} values CFU/ ml	LC_{90} values CFU/ ml	LT_{50} (h)	LT_{90} (h)
N3	Y =-2.267 +0.425X	2.18×10^5	2.27×10^8	129.25	175.33
N30	Y =-2.616+0.496X	1.90×10^5	7.33×10^7	95.70	180.74
N44	Y =-1.891 +0.315X	9.93×10^5	1.15×10^7	116.47	193.62
N48	Y =-2.256 +0.365X	1.50×10^6	4.85×10^9	107.79	233.62
N58	Y =-2.687 +0.453X	8.42×10^5	5.65×10^8	92.78	206.34
N93	Y =-2.398 +0.387X	1.59×10^6	3.27×10^9	115.31	196.39
N115	Y =-2.689+0.434X	1.57×10^6	1.40×10^9	88.68	205.28
HD-1	Y =-2.252+0.452X	9.59×10^4	6.56×10^7	61.99	121.64

Table 5. Origin of native *B. thuringiensis* isolates with > 50 per cent mortality against *S. litura* collected from Nellore district

Isolate	Mortality (%)	Place of collection	Crop/ location
N3	83.33	Mambattu	Groundnut
N9	50.00	Mamillapadu	Cultivated Fallow
N15	50.00	Vaddipalem	Grass
N20	60.00	Chamellapadu	Fodder
N23	66.67	Venambakkam	Cultivated Fallow
N30	86.67	Chembedupalem	Grass
N37	60.00	Sullurpet	Sugarcane
N44	76.67	Venkatagiri	Jack fruit
N45	53.33	Petlur	Fallow
N48	76.67	Petlur	Neem
N58	76.67	Venkatagiri	Cultivated Fallow
N63	50.00	Peddayachasamudram	Grass
N69	66.67	Marlagunta	Teak
N93	76.67	Chaaganam	Hill
N100	60.00	Saidapuram	Mango
N115	76.67	Kasumur	Eucalyptus
N118	60.00	Gurivindapudi	Neem
N130	50.00	Anuppallipadu	Grass
N141	73.33	Narasareddypalli	Sugarcane
N143	53.33	Narasareddypalli	Fodder
N148	60.00	Gudur	Cultivated Fallow
N158	50.00	Naidupet	Brinjal

that the *cry*1I was the predominant gene among *B. thuringiensis* collections from soil samples in undisturbed environments of Andhra Pradesh, India. Some of the strains in present *B. thuringiensis* collections harbored *cry*2 genes. Similar findings were reported by Liang et al. (2011), who studied the diversity of *cry*2 genes in Sichuan basin, western China. Among the 791 *Bt* strains isolated from 2650 soil samples in different ecological regions, it was found that, 322 *B. thuringiensis* strains harboured *cry*2-type genes with four different RFLP patterns. The combination of *cry*2Aa/*cry*2Ab gene was the most frequent (90.4%), followed by *cry*2Aa (6.8%) and *cry*2Ab alone (2.5%).

CONCLUSIONS

The soil samples from Nellore district of Andhra Pradesh, India harboured good number of *B. thuringiensis* isolates. Out of 205 soil samples screened, 44 cultures were identified and evaluated against third instar larvae of *S. litura*. The highest per cent mortality was observed with N30, followed N3 both of which were statistically superior over the other strains and on par with standard strain HD1**.** Molecular characterization of the virulent *B. thuringiensis* strains with *cry* gene specific primers indicated that *cry*1I gene was predominant in seven *B. thuringiensis* strains, which was reported to confer specific toxicity against lepidopteran insects.

Table 6. *Cry* genes in effective native *B. thuringiensis* strains effective against *S. litura* collected from southern zone of Andhra Pradesh

Isolate	Mortality (%)	*cry* gene(s) observed	No. of *cry* genes
N3	83.33	*cry*1C	1
N20	60.00	*cry*1I, *cry*2	2
N23	66.67	*cry*1I, *cry*2A(a)1, *cry*9Ca1	3
N30	86.67	*cry*1I, *cry*2A(a)1, *cry*9Ca1	3
N44	76.67	*cry*1Da1	1
N45	53.33	*cry*1Aa	1
N48	76.67	-	-
N58	76.67	*cry*2A(a)1	1
N63	50.00	*cry*1I	1
N69	66.67	*cry*1Aa, *cry*1Da1, *cry*1Ea1	3
N93	76.67	*cry*1Aa, *cry*1C , *cry*1I, *cry*2A(a)1, *cry*9Ca1	5
N100	60.00	*cry*1C , *cry*2A(a)1	2
N115	76.67	*cry*1C	1
N118	60.00	-	0
N130	50.00	*cry*1Aa	1
N141	73.33	*cry*1Aa, *cry*1Fa1, *cry*1I	3
N143	53.33	*cry*1Aa, *cry*1Fa1, *cry*1I	3
N148	60.00	-	0
N158	50.00	*cry*1Fa1	1

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Varietal Screening of Rice against Pink Stem Borer, *Sesamia inferens* (Walker)

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Abstract: The pink stem borer (PSB), *Sesamia inferens* (Walker) (Lepidoptera: Noctuidae) is a serious pest of rice in Andhra Pradesh causing substantial yield loss. This study evaluated the tolerance of eight rice varieties to PSB under greenhouse conditions at ICAR-IIRR, Hyderabad. Test entries were infested with third instar larvae @ 15 larvae/m^2 and damage was recorded as dead hearts (%) and white ears (%). All the test entries exhibited varying levels of susceptibility (22.53-39.56%) at 35DAR in vegetative phase. Among tested varieties, PB1 recorded highest overall incidence of mean dead hearts (25.55 %) and white ears (26.05 %) indicating greater susceptibility to *S. inferens.* In contrast, MTU 1061 (14.73 &10.75%) and TKM 6 (16.44 & 10.41%) exhibited comparatively lower levels of damage. Significantly lower white ear damage due to continuous feeding by PSB larvae in BPT5204, MTU1121 and W1263 with high tillering ability reflects their tolerance. The study highlights the importance of reaction of entries to PSB damage and underscores the importance of detailed studies on identifying tolerant mechanisms which serve as a key component of sustainable pest management.

Keywords: Screening, Pink stem borer, *Sesamia inferens, Oryza sativa,* PB1

Rice (*Oryza sativa* L.) is a staple food for millions of people across South and Southeast Asia. India occupies the leading position worldwide in terms of rice cultivation area, spanning approximately 51.42 million hectares, and ranks second in global production, contributing around 149.07 million tonnes, which represents 27.82% of the world's total output, with an average productivity of 2899 kg/ha (Department of Agriculture and Farmers Welfare 2024). Among the numerous insect pests infesting rice, stem borers are recognized as the most destructive group, responsible for substantial yield reductions. Field surveys conducted across major rice-growing regions of India have revealed a diverse assemblage of insect fauna associated with the rice ecosystem, however, lepidopteran stem borers consistently dominate at various crop growth stages (Giri and Mohapatra 2024). In fact, more than six species of rice stem borers have been reported to infest rice, with their prevalence and intensity varying across ecological zones. Among these, in India the pink stem borer, *S. inferens* stands out as one of the most damaging species after the yellow stem borer (Katti et al., 2011).

In recent years, the incidence and severity of *S. inferens* have increased remarkably, particularly in coastal areas (Jena et al., 2018), where it has attained the status of a major pest. The prevalence of pink stem borer has increased significantly under rice-based cropping systems in coastal districts of Andhra Pradesh notably in West Godavari during the past two to three years, with damage levels often exceeding the economic threshold level (ETL5-10% DH PSB) (Dutta and Roy 2022, Swarupa et al., 2025). The PSB damage is often hidden and goes unnoticed in the field as the larvae engage in extensive tunnelling within the tillers and filling the bored holes with excreta, which makes early detection of this pest difficult (Swarupa et al., 2024). It has been conclusively demonstrated that the pest can successfully survive and complete its entire life cycle on rice, typically ranging from 41 to 73 days, thereby resulting in serious yield losses (Swarupa et al., 2025). Alarmingly, the most popular and widely cultivated rice varieties, which have dominated Andhra Pradesh for decades, have exhibited high levels of damage.

Host plant resistance (HPR) is a desirable approach for managing *S. inferens* as it is sustainable and environment friendly. Although chemical control using diamide insecticides such as chlorantraniliprole has been widely practiced by rice farmers of Andhra Pradesh, increasing dependence on these insecticides has raised concerns about susceptibility variation and the potential development of resistance in PSB populations. Research efforts focused on identifying resistant varieties against PSB in rice are still in the preliminary stage, highlighting the need for systematic screening of rice accessions to identify resistant sources against *S. inferens*. Understanding the nature and extent of pest damage across selected rice varieties provides valuable insights into varietal preference, crop loss patterns, and vulnerable stages of infestation, thereby contributing to the development of more effective pest management strategies. Hence, the present investigation was undertaken to screen rice varieties for their relative resistance or susceptibility to *S. inferens* and to examine preference mechanisms influencing pest incidence.

MATERIAL AND METHODS

The experiment was conducted under greenhouse conditions at ICAR-IIRR, Hyderabad (17.320921°N, 79.396614°E) at amean temperature of 28 ± 2 °C and relative humidity 60-80%. Eight rice varieties *viz*., BPT 5204, MTU 1121, MTU 1061 (mega varieties), Sasyasree, W1263, TKM 6, Pusa basmati 1 and TN1 were evaluated to assess the damage potential of *S. inferens*. Rice plants were raised in cement pots of 1m diameter with nine plants per pot. The rice plants were maintained in the greenhouse under natural light conditions up to 40 days and were used for artificial screening studies. The experiment was conducted in randomised block design with three replications. The larvae of *S. inferens* were collected from infested rice fields in the West Godavari district and reared on artificial diet under controlled laboratory conditions for one generation and the F_1 insects conditioned on rice plants were used in the present study. The 3rd instar PSB larvae were released once on to the rice plants at vegetative phase. A total of 15 larvae per meter (three larvae/hill) were released onto rice plants with the help of camel hair brush and infested plants were covered with mylar sheet to avoid the movement of larvae (Fig. 1).

Observations on dead hearts during the vegetative phase and white ears during the reproductive phase were recorded at ten-day intervals following the release, i.e., at 5, 15, 25, 35 days after release (DAR) in the vegetative stage and at 55, 65, 75 days after release during the reproductive stage. The per cent damage of dead hearts/ white ears was calculated (Heinrichs et al., 1985) to estimate the PSB damage. Data was subjected to angular transformation using OPSTAT (One factor analysis), version:14.139.232 and observations were subjected to analysis of variance (ANOVA) and Duncan's Multiple Range Test (DMRT) ($P \leq 0.05$) by using SPSS (Statistical Package for Social Sciences) statistics version 20.

RESULTS AND DISCUSSION

The results showed significant variation in PSB damage among the tested rice varieties Among the different rice varieties tested, PB1 recorded maximum infestation of PSB in terms of both percent DH and WE damage indicating high susceptibility to *S. inferens* (Table 1). The mean percentage of dead heart damage ranged from 14.73 (MTU 1061) to 25.55 (PB1) and the WE damage from 10.41 (TKM 6) to 26.05 (PB 1) per cent. The highest per cent of dead hearts were with PB1 (39.60) followed by Sasyasree< TN1< BPT 5204 respectively at 35 days after release where MTU 1061 and TKM6 exhibited relatively lower damage.

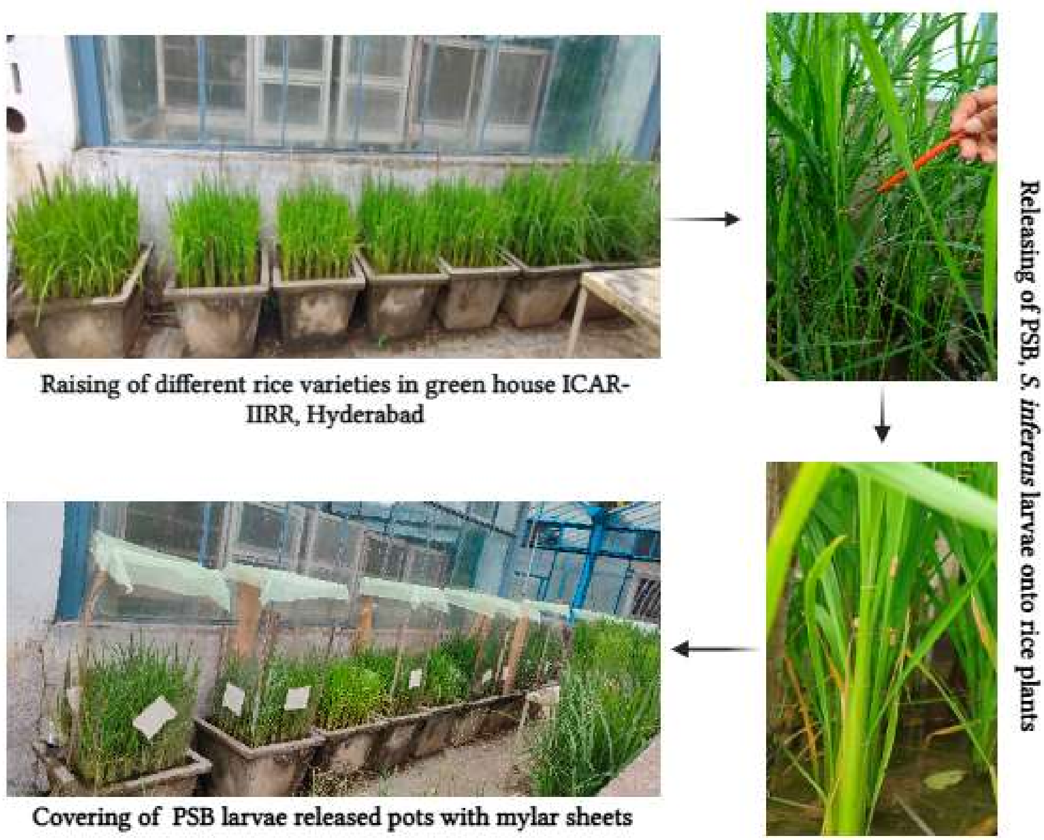

Fig. 1. Screening of rice varieties against pink stem borer, *S. inferens* under greenhouse conditions

The overall mean damage of dead hearts in MTU 1061 was statistically on par with BPT 5204, MTU 1121 and TKM 6 followed by W 1263, Sasyasree and TN 1 which showed intermediate susceptibility and were on par with each other while, PB1 recorded the highest incidence (25.55 %). Duringre productive phase, the overall mean white ear damage was highest in PB1 (26.05 %) followed by Sasyasree > TN1 > BPT 5204 > W1263 > MTU 1121 > MTU 1061 > TKM 6 , respectively. The maximum damage was from PB 1 variety whereas TKM 6 exhibited significantly lowest white ear damage where all the varieties were on par with each other (Fig. 2).

The infestation of rice varieties by PSB larvae continued from vegetative phase to booting stage which showed that insect was able to survive in all the test rice varieties and continue to damage in reproductive phase and resulted in white ear formation. It was also observed that the larvae were able to complete its life cycle and there was no negative effect on the life cycle of the PSB in tested rice varieties. All the varieties tested were susceptible to PSB infestation under artificial screening method in greenhouse but a variation in the level of infestation was observed. Apart from the dead hearts and white ears, the other symptoms of damage by pink stem borer were observed as bored holes and extensive tunnelling of rice stems filled with excreta inside the tunnels. Earlier workers reported that the dead heart damage can be compensated by producing new tillers or overcompensate by redirecting resources to produce larger and more rice grain (Horgan et al., 2016). In the current study, all tested varieties, despite exhibiting low white ear damage, produced panicles with poorly filled grains. Additionally, delay in the maturity of infested rice plants was observed. This study provides one of the first detailed accounts quantifying PSB damage at the critical stages of rice crop under artificial infested conditions demonstrating that none of the tested varieties escaped infestation entirely.

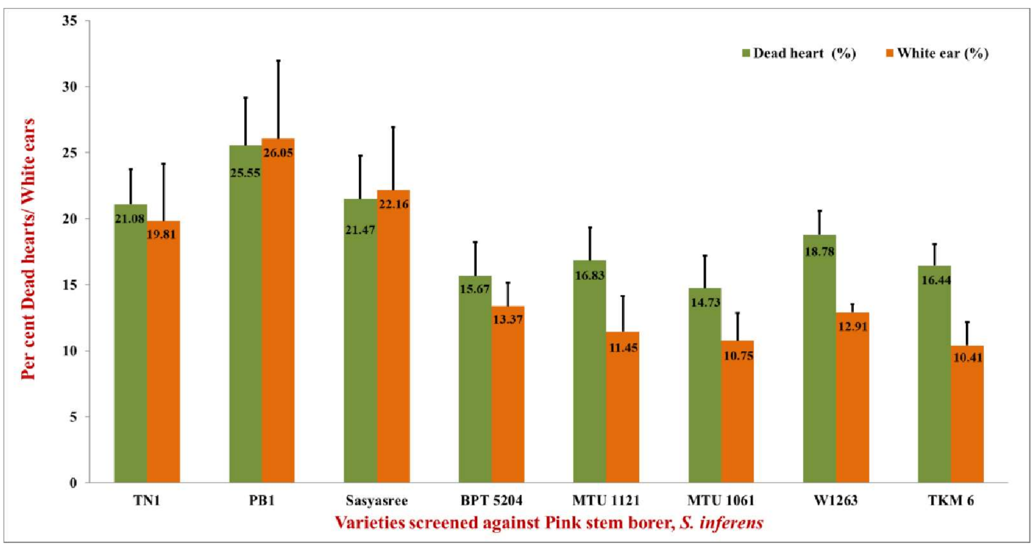

Fig. 2. Overall mean damage caused by *S. inferens* in different rice varieties under artificial infestation

Table 1. Damage by Pink stem borer, *S. inferens*, in selected rice varieties under artificial infestation in greenhouse conditions

Rice varieties	*Per cent dead hearts				*Per cent white ears		
	5 DAR**	15 DAR	25 DAR	35 DAR	55 DAR	65 DAR	75 DAR
Taichung Native 1	10.85^{abc}	17.57^{ab}	25.32^{ab}	29.82^{bc}	11.36^{ab}	22.22^{ab}	25.84^{b}
Pusa Basmati1	13.19^{a}	21.62^{a}	30.08^{a}	39.60^{a}	15.63^{a}	26.53^{a}	36.00^{a}
Sasyasree	9.09^{abc}	18.63^{ab}	24.58^{b}	34.06^{b}	14.71^{a}	20.69^{b}	31.08^{a}
BPT 5204	7.00^{c}	11.36^{c}	17.20^{c}	26.59^{cd}	10.53^{ab}	12.90^{c}	16.67^{c}
MTU 1121	7.21^{bc}	14.18^{bc}	19.87^{bc}	25.54^{cd}	7.32^{b}	10.53^{c}	16.49^{c}
MTU 1061	5.71^{c}	10.95^{c}	18.34^{c}	22.63^{d}	8.00^{b}	9.41^{c}	14.85^{c}
W1263	12.90^{ab}	16.04^{abc}	20.59^{bc}	25.97^{cd}	12.50^{ab}	12.12^{c}	14.10^{c}
TKM 6	10.43^{abc}	14.93^{bc}	18.30^{c}	22.53^{d}	7.14^{b}	10.96^{c}	13.13^{c}

*Mean of damaged tillers from nine hills; **DAR-Days after release; Means followed by same letters are not significantly different by DMRT

Geerthana et al. (2022) also reported TKM 6 as aresistant variety and TN1 as susceptible variety against PSB. Dutta and Roy (2022) reported TKM 6 asa resistant rice cultivar for PSB. Aggarwal and Singh (2003) tested 11 rice varieties against multiple stem borers *viz*., YSB, WSB and PSB damage and observed PR 114 and PB1 as highly susceptible to all stem borers.They further noted that 35.71(PR 114) and 80 (PB1) per cent of white ears in these varieties were caused by PSB alone and concluded that PSB prefers heading to dough stage than the tillering stage of rice which is in confirmation with present studies.

Singh and Tiwari (2019) assessed eight varieties under field conditions in Uttar Pradesh where they stated that YSB, PSB, DHSB, SSB and WB were causing dead hearts with YSB being dominant one. The extent of damage caused by YSB and PSB during the vegetative, reproductive and maturity stages in MTU 7029 (Swarna) was 5.14, 25.76, 15.18 and 3.39, 14.7, 15.81 per cent, respectively (Rahman et al., 2004). The susceptibility was attributed to the loosely wrapped leaf sheaths, which only partially covered the internodes. Variation in resistance was attributed to the accessibility of migrating larvae to the inner part of the leaf sheath before burrowing into the stem. The study observed that 95% of the larvae migrated between the sheath and the stem within 48 hours after hatching finding it easier to establish on varieties with loose leaf sheaths.

Ntanos and Koutroubas (2000) further emphasized that late maturing rice varieties with high tillering capacity and wider stems tend to support greater borer survival. Pusa basmati 1 has been consistently reported as highly susceptible to the yellow stem borer both under field conditions (Padmakumari and Pasalu 2003) and infested conditions (Athulya et al., 2022) which aligns with the present finding of high PSB damage in this variety. Devasena et al. (2018) evaluated 44 varieties in Tamil Nadu against YSB, of which TN 1 and PB 1 were highly susceptible whereas TKM 6 and W 1263 were found to be resistant cultivars to YSB, reflecting parallel trends in PSB infestation patterns. Although Several researchers screened the rice varieties for resistance against the rice yellow stem borer (Mohankumar et al., 2003, Khan et al., 2010, Elanchezhyan and Arumugachamy, 2015), research on the pink stem borer remains limited. The present findings contribute valuable insights into varietal response under standardized artificial infestation, forming a useful basis for future breeding programs aimed at developing PSB-resistant rice varieties.

CONCLUSION

There is a significant varietal differences in susceptibility to the pink stem borer in rice under artificial infestation. Among the tested rice varieties, PB1 exhibited the highest levels of dead heart and white ear damage, indicating high susceptibility, whereas TKM 6 has been found to portray low dead heart and white ear damage under infested conditions. W1263 and the test entries *viz*., BPT5204, MTU1121, MTU1061 which are long duration and high yielding could tolerate the damage throughout the crop growth phase because of high tillering capacity exhibiting notable tolerance to pink stem borer. Further research is needed to understand the mechanism of resistance and develop suitable pest management strategies.

AUTHOR'S CONTRIBUTION

Authors declare that this research is an original piece of work and has not been published or submitted elsewhere. Proper citations and acknowledgements have been provided for all referenced materials. No part of the work has been copied or reproduced without permission.

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Morphological and Biochemical Resistance to *Spodoptera frugiperda* (J.E. Smith) in Maize Inbreds

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***Abstract*:** Twenty maize in breds were evaluated under natural fall armyworm (FAW) infestation at ANGRAU, Lam, Guntur, during the late*Kharif*2024–25 season to identify lines combining high yield with FAW tolerance. Performance of the studied genotypes revealed the presence of varying degrees of FAW damage ratings, indicating the presence of FAW tolerant genotypes. Correlation analysis showed negative association between FAW infestation and secondary metabolite levels. The multi-trait genotype–ideotype distance index (MGIDI) was applied at 25% selection intensity to rank genotypes against an ideo type defined by high yield, low FAW damage, and elevated defense traits. Five in breds (PL 22389, PL 22339, LM14, PL 22373, PL 23150) achieved MGIDI scores closest to the ideotype, with desirable selection differentials in FAW damage score (–27.5%), total soluble sugars (–22.5%), and positive gains in grain yield (23.1%), tannin content (24.0%), trichome density (20.8%), and phenol content (15.9%). These tolerant lines represent valuable genetic resources for sustainable FAW management and could reduce reliance on chemical control.

***Keywords*:** Maize germplasm, Fall armyworm, Tannins, Phenols, Tolerance, MGIDI

Maize (*Zea mays* L.) is one of the most important cereal crops globally with annual production exceeding 1.23 billion metric tons (Food and Agriculture 2024) and serves as a staple food source providing as a staple food for over 900 million people globally and functioning as a critical component in both human nutrition and industrial applications. However, maize production and productivity are consistently challenged by biotic and abiotic constraints that threaten food security and economic stability. Among biotic stresses, the arrival of the invasive fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), represents one of the most significant threats to maize cultivation in recent years (Bankar and Bhamare 2023).

In India, FAW was first reported in May-July 2018 in maize fields at Shivamogga, Karnataka (Sharanabasappa et al., 2018), and subsequently spread to over 20 states including Karnataka, Tamil Nadu, Andhra Pradesh, Telangana, Maharashtra, and Odisha within months of its initial detection (Karuppannasamy et al., 2024). FAW larvae are voracious feeders attacking all above-ground plant parts including stems, leaves, whorls, tassels, and developing cobs at all crop development stages (Chimweta et al., 2020). Young larvae initially create characteristic "window-pane" feeding damage, while later instars (fourth to sixth) consume approximately 77% of total foliage, causing extensive defoliation, interfering with pollination through silk and tassel destruction, and boring into developing cobs thereby reducing grain quality (Mohamed et al., 2023). These substantial crop damages translate into significant economic consequences globally. In India, FAW induced yield losses were estimated to be around 44% (Prakash et al., 2024).

Integrated pest management (IPM) strategies that prioritize host plant resistance (HPR) represent the most sustainable, cost-effective, and environmentally benign approach to (FAW) control. Resistance to FAW in maize manifests through three complementary mechanisms-antibiosis, antixenosis, and tolerance each contributing uniquely to pest suppression and crop resilience. Antibiosis operates through the production of secondary metabolites, notably tannins and phenolics, which deter larval feeding, disrupt protein synthesis, and inhibit digestive enzymes, thereby reducing larval weight gain and adult emergence rates (Grover et al., 2022, Jin-Yan et al., 2025), ultimately leading to lower survival and adult emergence rates. Meanwhile, antixenosis encompasses non-nutritive deterrents and surface traits that discourage oviposition and feeding on resistant genotypes. In this context, trichome density emerges as a critical physical barrier: maize lines bearing dense foliar trichomes exhibit significantly lower FAW feeding damage and enhanced tolerance, with trichomes impeding larval movement and mandible action on the leaf surface(Moya-Raygoza, 2016).The multifaceted nature of tolerance demands integrated selection criteria capable of capturing genetic gains across multiple traits simultaneously. The multi-trait genotype-ideotype distance index (MGIDI) (Olivoto and Nardino, 2020) offers a robust solution by quantifying the distance of each accession from a predefined “ideal” genotype based on weighted trait values. Therefore, the present study was undertaken with the objective to screen diverse maize germplasm under natural FAW infestation, evaluate genotypes for leaf damage resistance, biochemical and morphological defense traits, and agronomic performance, and utilize the MGIDI for simultaneous multi-trait selection to identify and recommend superior FAW-tolerant genotypes combining durable host plant resistance with acceptable agronomic performance for breeding programs.

MATERIAL AND METHODS

Twenty maize inbreds were obtained from ANGRAU-Agricultural Research Station, Peddapuram for the current study. The experiment was carried out at ANGRAU-Regional Agricultural Research Station, Lam, Guntur during late *kharif* 2024-25 in a randomized block design with three replications. Each genotype was sown in three rows of 3m length with a spacing of 60×25 cm. Recommended fertilizer application was done timely. Weeds were controlled using herbicides and hand weeding where necessary (Rao et al., 2022).

Fall army worm infestation and scoring: The infestation of FAW was allowed to occur naturally under field conditions during the late *Kharif* season, ensuring realistic pest pressure. Standard agronomic practices were followed without applying insecticides to facilitate natural pest establishment (Asare et al., 2023). Infestation levels were recorded at 7, 14, 21, and 28 days after sowing (DAS) by assessing each plot for visible damage symptoms such as leaf injury, windowing, and whorl feeding, using a standard 1-9 rating scale(Prasanna et al., 2018), where 1 represents no visible damage and 9 corresponds to severe damage and plant death. The overall infestation score for each genotype or treatment was computed as the mean of the scores obtained across all observation intervals, representing the cumulative intensity of natural fall armyworm infestation throughout the crop's early growth period.

Observations: Trichome density (TD) was estimated by collecting leaf samples of 1 cm × 1 cm size from both sides of the midrib. The number of trichomes visible in the defined area was counted and expressed as trichomes per cm² by calculating the average of measurements from both sides of the midrib. Leaf area (LA) of each genotype was calculated as per Elings (2000). Chlorophyll content (SPAD) was measured non-destructively using the SPAD chlorophyll meter. Measurements were taken on the fourth fully expanded leaf from the top at the 2/3 position (two-thirds distance from leaf base to tip) to ensure consistency and accuracy.

Biochemical estimation: Four biochemical parameters namely carbohydrate content (CARB), total soluble sugars (TSS), tannin content (TC) and phenol content (PHE) were estimated from the leaves of each genotype. The total carbohydrate content was estimated using the anthrone method (Hansen and Møller, 1975) and expressed as percentage (%). Total soluble sugars were estimated as per Nielsen (2010), Perveen and Hussain (2021) and expressed as mg/g fresh weight. Tannin content was estimated as per the protocol suggested by Price and Butler (1977) and expressed in tannic acid equivalents per gram (mg TAE/g). Total phenol content was estimated using the Folin-Ciocalteu method (Ainsworth and Gillespie, 2007) and expressed in gallic acid equivalents (mg GAE/g).

Grain Yield (g) (GY): This was recorded at a per plant basis from five randomly selected plant per genotype at 18% moisture after shelling the cobs.

Statistical analysis: Multi trait genotype ideotype distance index (Olivoto et al., 2022) was used for selecting the best five genotypes at a selection intensity of 25% (five out of twenty genotypes). An ideotype was defined as a genotype with high yield, lower FAW infestation score, high tannin and phenol content, with high LAI and SPAD readings. Top five genotypes with MGIDI scores closer to zero were selected and the selection differentials were calculated over the base population. All the analysis were carried out using the 'metan' package (Olivoto and Lúcio 2020) in R version 4.5.1 (R Core Team 2025).

RESULTS AND DISCUSSION

Performance and genetic variability studies: The analysis of variance exhibited presence of ample variation among the genotypes for the studied trait which is reflected in the range of the studied traits (Table 1). Yield ranged from 21.5 g in PL 22351 to 112.2 g in LM14. SPAD values varied from 33.2 in PL 22367 to 45.9 in LM14, while leaf area index ranged between 331.2 in PL 22351 and 502.5 in LM14. Trichome density differed considerably among inbreds, from 57.8/cm² in PL 22348 to 196.0/cm² in PL 22374. FAW infestation rating ranged between 2.9 (PL 22367) to 8.3 (PL 23077). Total soluble sugars exhibited variation from 1.3 (PL 22373) to 4.0 (PL 22348. Carbohydrate content ranged from 53.09 (PL 22374) to 80.0 (PL 22441). Tannin content varied between 1.2 (PL 22390) to 3.5 (PL 22367) while phenolic content showed a range from 1.2 (PL 22348) to 2.7 (PL 22374). The wide ranges observed for grain yield, SPAD and leaf area index indicate substantial genetic variability for productivity. While, variation in trichome density, FAW damage scores, and levels of tannins and phenolics shows that both morphological and biochemical traits contribute to differential resistance and could be exploited to strengthen host plant resistance to FAW.

Correlation studies: Correlation studies among the studied nine traits revealed interactions between traits (Fig. 1). GY was significantly ($p < 0.05$) positively correlated with SPAD, LAI, TC and PHE, while negatively correlated with TSS, CARB and FAW. Tannin content showed positive significant correlation with phenol content. FAW exhibited positive correlation with TSS while it showed negative correlation with rest of the traits. FAW showed high negative correlation against trichome density, tannin content and phenol content. The strong negative correlation between FAW damage and trichome density, tannin and phenolic content highlights their importance as key defenses against infestation and suggests that these traits can serve as useful indicators or indirect selection criteria for breeding FAW-resistant maize (Soujanya et al., 2025)

Multi Trait Genotype Ideotype Distance Index

Factor analysis: Factor analysis of the studied traits divided the total variation into nine PCs, with three PCs having eigen value >1, cumulatively explaining 89.3% of the total variationindicating that most variation was captured in these components. PC_1 explained 55.3%, followed by PC_2 capturing 21.9% of the total variation explained, while PC_3 explained 12.2% of the total variation (Table 2). After varimax rotation, the variation explained by all the traits was captured into first three FAs. The communality ranged between 0.8 (TSS) to 0.97 (LAI) with an average communality of 0.89. Variation explained by traits TD, TSS, TC, PHE and FAW was captured by FA_1, while FA_2 captured the variation explained byGY, SPAD and LAI. FA_3 captured the variation accounted by CARB alone (Table 3).

Genotypes selected and selection gains: At 25% selection intensity, five genotypes namely PL 22389, PL 22339, LM14, PL 22373 and PL 23150 were selected which exhibited

Table 2. Eigen values of the nine PCs obtained from principal component analysis

PC	Eigenvalues	Variance	Cumulative variance
PC1	4.97	55.3	55.3
PC2	1.97	21.9	77.1
PC3	1.1	12.2	89.3
PC4	0.4	4.46	93.8
PC5	0.32	3.53	97.3
PC6	0.14	1.54	98.8
PC7	0.06	0.7	99.5
PC8	0.02	0.27	99.8
PC9	0.02	0.19	100

Table 1. Performance of maize germplasm lines for the nine studied traits

Inbreds	GY	SPAD	LAI	TD	FAW	TSS	CARB	TC	PHE	FAW
PL 22351	21.5	37.2	331.2	157.3	5.9	2.8	79.8	1.7	1.8	5.9
PL 22367	65.9	33.2	331.2	179.0	2.9	2.1	71.4	3.5	2.4	2.9
PL 22409	65.4	37.3	354.8	149.5	5.9	2.9	70.9	1.8	1.7	5.9
PL 22348	66.0	33.7	333.0	57.8	7.9	4.0	54.8	1.3	1.2	7.9
PL 23030	63.9	38.3	344.3	163.5	5.1	2.5	68.0	2.3	1.9	5.1
PL 22394	68.6	34.5	342.9	154.6	4.1	3.4	57.4	2.6	2.1	4.1
PL 23077	53.3	37.8	333.0	102.5	8.3	4.0	64.9	1.7	1.3	8.3
PL 22410	94.4	44.4	484.7	135.9	6.9	2.5	63.9	1.5	1.8	6.9
PL 23012	66.7	34.1	372.7	164.3	7.2	2.2	63.6	1.6	1.5	7.2
PL 23150	88.8	44.0	458.0	127.6	5.5	2.6	77.9	2.1	1.9	5.5
PL 22441	34.4	37.3	333.0	84.6	7.6	3.6	80.0	1.3	1.7	7.6
PL 22373	77.6	42.4	437.5	191.2	3.1	1.3	75.2	3.1	2.5	3.1
LM13	91.9	44.4	482.9	132.1	4.2	2.3	55.9	2.0	2.6	4.2
PL 22344	95.6	45.3	495.5	133.5	5.7	3.0	69.1	2.0	1.8	5.7
PL 22339	80.2	43.7	444.7	182.8	3.5	1.7	77.0	2.8	2.2	3.5
PL 22448	56.5	38.2	342.9	109.0	7.6	3.4	67.7	1.5	1.4	7.6
PL 22389	82.4	43.7	449.4	195.5	3.3	1.9	75.0	2.9	2.3	3.3
PL 22390	74.2	34.6	425.5	83.8	7.6	3.7	68.1	1.2	1.2	7.6
PL 22374	83.2	43.9	452.8	196.0	3.8	2.1	53.1	2.1	2.7	3.8
LM14	112.2	45.9	502.5	149.5	4.8	2.9	73.2	2.5	1.9	4.8
Mean	72.1	39.7	402.6	142.5	5.5	2.7	68.4	2.1	1.9	5.5

GY: Grain Yield (g), SPAD: Chlorophyll Content; LAI: Leaf Area Index; TD: Trichome Density/cm^2; TSS: Total Soluble Sugars (mg/g FW), CARB: Carbohydrate Content (%); TC: Tannin Content (mg TAE/ g); PHE: Phenol Content (mg GAE/g); FAW: Fall armyworm infestation score (1-9).

MGIDI scores closer to zero indicating closer proximity to the defined ideotype with enhanced FAW tolerance (Fig. 2). Selection differential i.e. increase of the mean performance of the selected population over base population was obtained in a desirable direction. TC recorded a SD_{perc} of 24.0% over the base population, followed by GY, TD, PHE, LAI, SPAD, CARB. Highest negative differential was observed for FAW, TSS (Table 4).

Strength and weakness view: The strength-and-weakness view of the MGIDI index (Fig. 3) reveals, for each selected genotype, which latent factors most closely and least closely match the ideotype. PL 22389 and PL 22339 exhibited strong alignment with FA_1 (TD, TSS, TC, PHE, FAW) and FA3 (CARB), but weak alignment with FA_2 (GY, SPAD, LAI). In contrast, LM14 showed strong alignment with FA_2 and FA_3, while aligning weakly with FA_1. PL 22373 demonstrated strengths in FA_1 and FA_2 and a weakness in FA_3. Finally, PL 23150 aligned strongly with FA_3 and FA_2 and showed its weakest alignment with FA_1.

The study revealed significant genotype-level variability observed across all studied traits among the 20 inbred lines highlighting a strong genetic base for selection. Grain yield (GY), SPAD chlorophyll content, and leaf area index (LAI) exhibited broad phenotypic variation with moderate to high

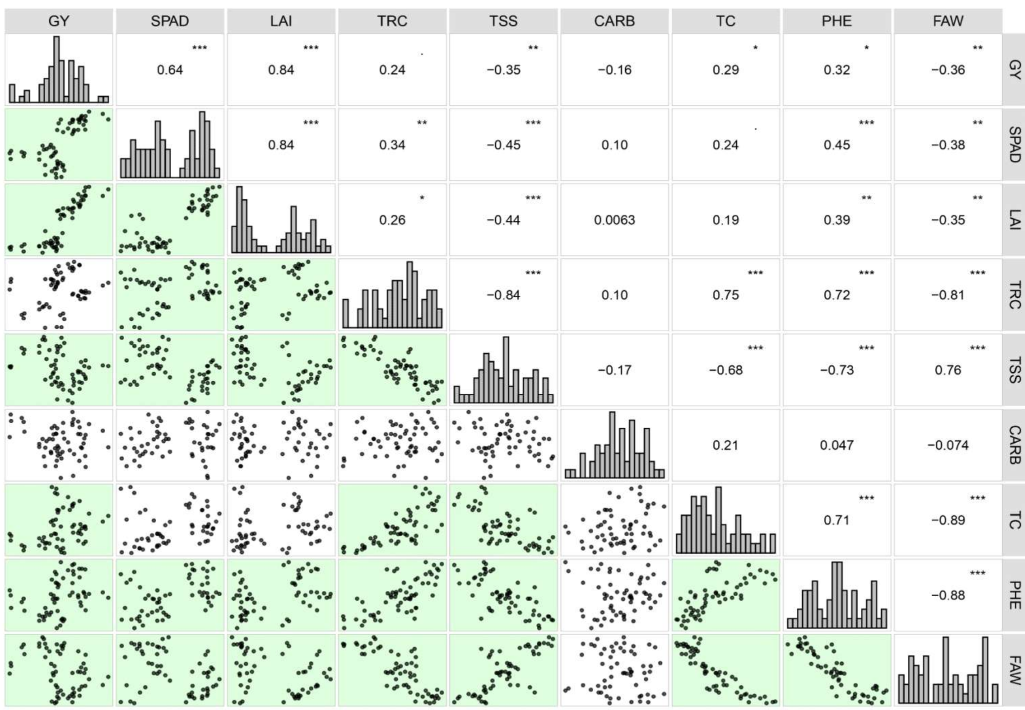

Fig. 1. Correlation coefficients between the nine traits under study

Table 3. Trait loadings after varimax rotation through factor analysis

VAR	FA1	FA2	FA3	Communality	Uniquenesses
GY	-0.2	-0.87	0.31	0.89	0.11
SPAD	-0.21	-0.89	-0.24	0.9	0.1
LAI	-0.15	-0.97	-0.01	0.97	0.03
TD	-0.91	-0.09	-0.16	0.86	0.14
TSS	-0.82	-0.31	-0.16	0.8	0.2
CARB	-0.11	0.01	-0.97	0.96	0.04
TC	-0.93	-0.06	-0.01	0.87	0.13
PHE	-0.89	-0.26	0.03	0.86	0.14
FAW	-0.95	-0.19	0.01	0.94	0.06
	Mean communality			0.89	

See Table 2 for details

Table 4. Selection differential of different traits under selection intensity of 25% over the base population

VAR	Factor	Xo	Xs	SD	SDperc
TD	FA1	143	172	29.6	20.8
TSS	FA1	2.75	2.13	-0.616	-22.5
TC	FA1	2.06	2.56	0.495	24
PHE	FA1	1.89	2.19	0.301	15.9
FAW	FA1	5.54	4.02	-1.52	-27.5
GY	FA2	72.1	88.8	16.7	23.1
SPAD	FA2	39.7	44.2	4.49	11.3
LAI	FA2	403	462	59	14.7
CARB	FA3	68.4	71	2.69	3.94

Xo: Population mean; Xs: Mean of selected genotypes at 25% SI; SD: Selection Differential; SDperc: Selection Differential percentage (%); GY: Grain Yield (g), SPAD: Chlorophyll Content; LAI: Leaf Area Index; TD: Trichome Density/cm^2; TSS: Total Soluble Sugars (mg/g FW), CARB: Carbohydrate Content (%); TC: Tannin Content (mg TAE/ g); PHE: Phenol Content (mg GAE/g); FAW: Fall armyworm infestation score (1-9).

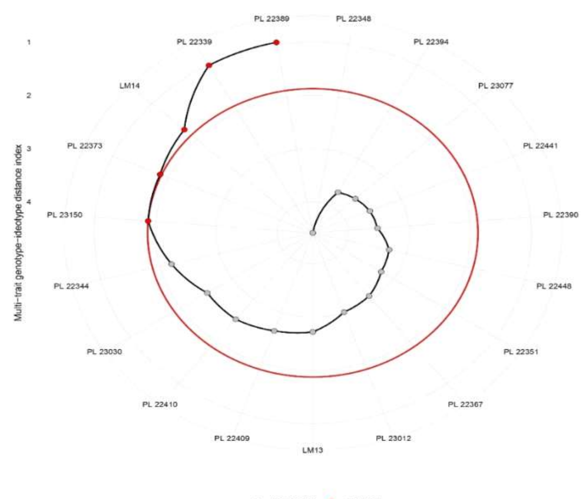

Fig. 2. Genotypes selected using MGIDI selection index at 25% selection intensity

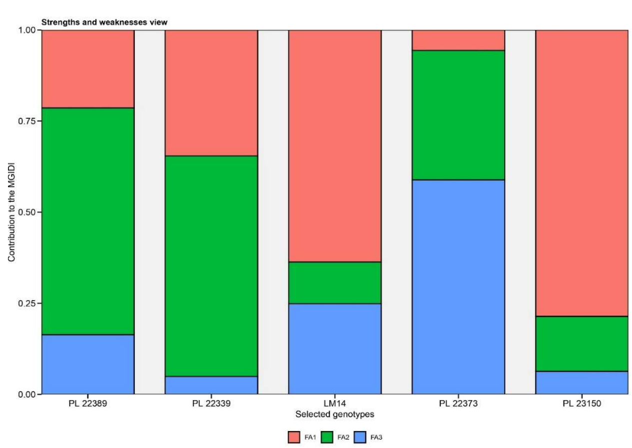

Fig. 3. Strength and weakness view of the selected genotypes for different factors under MGIDI

mean values, indicating substantial potential for improving productivity and photosynthetic capacity. Similarly, biochemical traits such as trichome density (TD), total soluble sugars (TSS), tannin content (TC), phenol content (PHE), and carbohydrate content (CARB) showed wide ranges, reflecting the metabolic diversity important for both nutritional quality and defense mechanisms. The variation in fall armyworm (FAW) infestation scores further emphasizes the differential levels of pest resistance in the germplasm pool.

Correlation analysis revealed positive associations between GY and traits like SPAD, LAI, TD, and PHE, suggesting that yield improvement could be accompanied by enhancements in chlorophyll content, canopy structure, defense metabolites, and structural barriers. Conversely, negative correlations of GY with TSS, CARB, and FAW highlight the trade-off between yield and traits associated with sugar accumulation and susceptibility to pest damage. FAW infestation was negatively correlated with trichome density, tannin, and phenol content, underscoring the critical role of structural defenses and biochemical metabolites in conferring resistance to FAW (Desika et al., 2024). This complex network of trait interactions supports the notion that durable pest tolerance in maize requires integrating multiple morphological and chemical defense strategies. Similar correlation between FAW score and trichome density was reported by Tiwari et al. (2023), and Darshan et al. (2024). Similar correlations between yield and FAW damage were reported byAbubakar et al. (2025), and Bhandari et al. (2025).

The factor analysis effectively condensed the nine studied traits into three major latent factors explaining 89.3% of the total variation. FA1 grouped defense-related biochemical traits (TD, TSS, TC, PHE, FAW), FA2 comprised yield and physiological traits (GY, SPAD, LAI), while FA3 represented carbohydrate content (CARB). High communalities and heritability for traits in FA1 and FA2 indicate strong genetic control, making these traits highly amenable to selection, whereas lower heritability in CARB suggests more modest gains from selection in FA3.Utilizing the MGIDI index at 25% selection intensity, five genotypes (PL 22389, PL 22339, LM14, PL 22373, and PL 23150) were selected that closely resembled the ideotype combining high yield and enhanced FAW tolerance. Crucially, FAW infestation and TSS were reduced by 27.5% and 22.5%, respectively, validating the effectiveness of this bidirectional breeding strategy in simultaneously enhancing resistance and desirable agronomic traits.

The strength-and-weakness profile clarifies the genetic architecture of these genotypes (Olivoto et al., 2022). PL 22389 and PL 22339 excel in FA1 and FA3 but have weaker FA2 performance, indicating biochemical defense and carbohydrate traits are their strengths while physiological traits need improvement. Conversely, LM14 is strong in FA2 and FA3 but weaker in FA1, suggesting good yield and carbohydrate content but poorer pest defense. PL 22373 shows a balance of strengths in FA1 and FA2 but weakness in FA3, whereas PL 23150 has strong FA3 and FA2 but weak alignment with FA1. These patterns provide targeted opportunities for trait-specific breeding to further optimize ideotype conformity. The substantial reduction in FAW damage in selected genotypes supports the presence of effective defense mechanisms, reflected in their significant negative correlation with FAW scores. Incorporation of these tolerant lines into breeding programs can reduce reliance on chemical control, fostering sustainable maize production in FAW-prone regions. In conclusion, this research underscores the utility of MGIDI in breeding maize for complex traits including FAW tolerance, and yield. The identified genotypes represent valuable genetic resources for developing resilient maize cultivars.

CONCLUSION

The five maize in breds viz; PL 22389, PL 22339, LM14, PL 22373 and PL 23150exhibited high yield potential and strong biochemical and morphological defence against fall armyworm under natural infestation. Enhanced phenol and tannin accumulation, along with higher trichome density, contributed to reduced pest injury. These genotypes serve as promising parental lines for developing resistant hybrids and reducing pesticide dependence. However, multi-location and multi-season trials are necessary to confirm the stability of these resistance traits.

AUTHOR'S CONTRIBUTION

Conceptualization and experiment design: CVCM Reddy, Annie Diana Grace; Trial execution and data collection: Syam Raj Nayak; Data curation, statistical analysis and draft preparation: Himakara Datta Mandalapu; Final draft revision and approval: CVCM Reddy, Annie Diana Grace, Syam Raj Nayak and Himakara Datta Mandalapu.

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Resistance to Yellow Leaf Disease in Sugarcane Genotypes as Influenced by Physico-chemical Traits

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Abstract: Field investigation was carried out to evaluate the reaction of sugarcane genotypes to yellow leaf disease (YLD) under natural field conditions to characterize their associated biophysical and biochemical responses. Correlations among disease expression, the vector (aphid) incidence and weather parameters were also assessed. Pooled data of three years (2022-23 to 2024-25) showed that six genotypes viz. 2015A311, 2017A553, CoA20321, CoA20323, CoA20325, and CoV19359 exhibited resistant (R) reactions with disease severity scores between 0.0 and 1.0. Nine genotypes exhibited moderately resistant (MR) reactions with disease severity >1.0–2.0, while others such as CoA19322 and 2001A63 were moderately susceptible (MS). The variety, 2003V46, was highly susceptible (S) with disease severity >3.0. Resistant genotypes typically exhibited semi-erect leaves (22°–28°), medium to medium-wide leaf blades, and light-green foliage with SPAD values of 28–31. They also recorded higher phenol content (33.67–40.34%) and silica levels (1.64–2.41%) than the susceptible check 2003V46, which showed greater leaf droopiness (42°), higher sucrose (17.62%), and reduced phenols (28.32%) and silica (1.30%). DAS-ELISA confirmed SPLCV infection in both resistant and susceptible lines, with absorbance values of 3.693–3.957 in positive samples. Aphids collected from susceptible genotypes alone tested ELISA-positive, confirming vector-mediated transmission. Aphid population and YLD incidence were positively correlated with maximum temperature and relative humidity. Rainfall showed a significant negative correlation, indicating that warm, dry conditions favored aphid activity and disease spread. Overall, the genotypes 2015A311, 2017A553, and CoA20323 were identified as stable YLD-tolerant sources, making them promising candidates for resistant breeding programmes in sugarcane.

Keywords: Sugarcane, Screening, Yellow leaf disease, Vector, Biophysical and Biochemical parameters, Weather

Sugarcane (*Saccharum officinarum* L.) is a major commercial crop in India, cultivated on 5.1 million hectares with a production of 439.9 million tonnes in 2024-25, making the country the world's second-largest producer after Brazil. Uttar Pradesh, Maharashtra and Karnataka contribute over 80% of national output (Government of India 2024). The crop supports more than 50 million livelihoods and plays a central role in India's sugar and bioethanol sectors, contributing Rs.776 billion to the national economy in 2023 (FAO 2023). With the expansion of the ethanol blending program, sugarcane's GDP contribution (1.1%) is projected to nearly triple in the coming years (NITI Aayog 2023, ICAR-SBI 2024).

Despite its economic importance, productivity is threatened by Yellow Leaf Disease (YLD), caused by the Sugarcane yellow leaf virus (SCYLV). The disease is widespread across major cane-growing states, with incidence often reaching 70–100% in susceptible varieties (Viswanathan et al., 2020, Singh et al., 2022). Yield losses range from 35–45% in cane weight to 25–35% in juice recovery, and may exceed 50% in severe infections (Rao et al., 2021, Padmanaban et al., 2022). SCYLV colonizes phloem tissues, inducing midrib yellowing, leaf chlorosis and reduced sucrose accumulation (Lehrer et al., 2010, Muthiah and Rajendran, 2022). The virus is transmitted mainly by the aphid, *Melanaphis sacchari* which efficiently spreads the disease under warm, dry conditions (Vega et al., 2010, Singh and Rao, 2021). Environmental conditions strongly modulate YLD epidemiology through their influence on aphid populations. Ramesh et al.,. (2023) observed a sharp rise in disease incidence during SMW 26–37 under elevated temperatures and increasing aphid density, while Singh et al. (2022) reported significant positive correlations of SCYLV spread with minimum temperature and relative humidity. Such findings highlight the tri-interaction of climate, vector abundance and varietal susceptibility.

Physiological studies show that SCYLV infection alters key functions including photosynthesis, chlorophyll fluorescence and stomatal conductance, reducing stalk weight and juice yield by up to 40 per cent (Viswanathan et al., 2014, Barreto et al., 2021). Given the systemic nature of the virus and limited success of vector management, host plant resistance is considered the most reliable and cost-effective strategy (Medeiros et al., 2018, Muthiah and Rajendran 2022). Recent breeding efforts increasingly incorporate biochemical and morphological markers such as phenolic content, silica levels, SPAD values and leaf architecture (Santiago et al., 2016, Sundar et al., 2020, Ali et al., 2023). Diagnostic advances including DAC-ELISA, DAS-ELISA, qRT-PCR and transcriptomics have further strengthened SCYLV detection and resistance differentiation (Chinnaraja and Viswanathan 2015, Xu et al., 2022). In this context, an integrated study was undertaken to identify promising resistant sources for incorporation into breeding programs and to strengthen the understanding of role of vector as well as physiological and environmental determinants of YLD resistance in sugarcane.

MATERIAL AND METHODS

The research work was carried out at the Regional Agricultural Research Station (RARS), Anakapalle, Visakhapatnam, Andhra Pradesh for three consecutive years from 2022-23 to 2024-25 aimed at investigating resistant sources by correlating YLD severity with biophysical and biochemical attributes and by analyzing the influence of weather parameters, vector population under field conditions. The site is located at 17° 381 N latitude and 83° 011 E longitude at an altitude of 28.62 m above the mean sea level. The location is characterized by tropical semi-arid climate with an average annual rainfall of 900–1100 mm.

Cultivation of sugarcane genotypes: Each of the thirty one genotypes was planted in a plot of five-meter row (four rows) in the month of February with two replications adopting a spacing of 90 cm between rows. All recommended agronomical practices were adopted. The seed rate of 35,000 three budded setts per hectare was used and fertilizers applied were 112 kg N/ha in two equal split doses at 45 and 90 days after planting, 100 kg P_2O_5 and 120 kg K_2O/ha at basal. Irrigation was provided at a week to 15-20 days interval during summer and at monthly intervals during maturity phase. Inter cultivation and weeding were taken up as per need. No plant protection measures were taken up during the entire crop growth period during both the seasons.

Aphid population: Population data for aphids (both adults and nymphs) in the sugarcane was recorded per leaf from ten clumps selected randomly and mean population data on aphid was calculated. Aphid population was recorded standard week-wise from initial appearance till crop maturity.

Yellow leaf disease (YLD) incidence: Characteristic YLD symptoms such as midrib yellowing, laminar discoloration, drying of discolored laminar tissues, bunching of leaves in the crown, progressive decline in the health of the plants were recorded. Ten cane clumps were randomly chosen and the total number of canes exhibiting YLD symptoms had been counted out of total canes and the percentage of disease occurrence was determined (Chinnaraja and Viswanathan 2015). YLD resistance was assessed using a 0–5 disease severity scale. At each observation, a minimum of 25 canes free from other biotic stresses were examined, and severity grades were assigned based on visible symptoms. Absence of disease was represented by a score of 0, indicating no visible symptoms. A score of 1 corresponded to mild yellowing of the midrib on one or two leaves without any bunching. A score of 2 denoted prominent midrib yellowing on all crown leaves but no leaf bunching. Progression of symptoms into the laminar region, accompanied by yellowing of the upper leaf surface and initial bunching, was reflected in a score of 3. Drying of the laminar region from the leaf tip along the midrib, along with typical tuft-like bunching of leaves, corresponded to a score of 4. Severe disease, expressed as stunted cane growth with extensive drying of symptomatic leaves, was captured under a score of 5. Absence of disease was represented by a score of 0, indicating no visible symptoms. Mean values for disease incidence and severity were computed for each genotype across the observation period. Based on these mean severity scores recorded over three years, genotypes were categorized into defined reaction classes: those with scores ≤ 1.0 were considered *resistant*, scores > 1.0–2.0 as *moderately resistant*, scores > 2.0–3.0 as *moderately susceptible*, scores > 3.0–4.0 as susceptible, and those with scores > 4.0–5.0 as highly susceptible (Chinnaraja et al., 2013).

Weather parameters: Data on weather parameters pertaining to minimum and maximum temperature, minimum and maximum percent of relative humidity and rainfall were collected following meteorological standard weeks from the observatory located at RARS, Anakapalle.

Biophysical parameters: The SPAD chlorophyll meter reading was measured on the second fully expanded leaf from the top of the main stem of each plant using an SPAD-502 meter (Jangpromma et al., 2010). The leaf inclination of the third dewlap leaf and the leaf width at the maximum blade width was measured in five random expanded leaves nondestructively and averaged (Castro Nava et al., 2016).

Biochemical parameters: Juice sucrose content was measured using Sucrolyser and the content of phenol, silica and fibre were analyzed following standard protocol as per the methods suggested by Chen and Chou (1977).

Statistical analysis: Using Microsoft Excel software, data on aphid population, yellow leaf disease incidence weather parameters, bio physical and biochemical traits were statistically analyzed for correlation as per Steel and Torry,1980. The correlation coefficients (r) obtained were further tested for statistical significance using the t-test. The calculated t-values were compared with the tabulated values at the 5% level of significance to determine the significance of the correlations.

Direct Antigen-Coated Enzyme-Linked Immune-Sorbent Assay (DAC-ELISA): DAC-ELISA was carried out using the kit obtained from M/s. AC Diagnostics, USA (Code-V093-K1) following the standard protocol land observations were taken visually and the colour change was observed photo metrically at 405 nm using Thermofischer scientific Multi scan- X, ELISA reader and the readings were documented. Two leaf midrib samples from each of the 31 genotypes were collected at the crop maturity stage along with healthy control taken from tissue culture raised sugarcane seedlings 87A298 (*Viswamitra*) and positive control obtained from the AC Diagnostics Ltd., USA in two replications, respectively, and further subjected to DAC-ELISA assay. The sugarcane samples exhibited various symptoms including mild to prominent yellowing of the leaf mid-ribs spreading laterally across the leaf lamina with shortened internodes and leaf-tip necrosis were collected and stored at −80 °C for further detection. DAC-ELISA was performed to detect the association of ScYLV with the YLD of sugarcane samples collected from the experiment (Clark and Bar-Joseph 1984). The assay was performed in 96 well polystyrene microtiter plates (Costar, Sigma, USA). 96 well plates were coated with diseased leaf-midrib extracts diluted 1:4 (w/v) in coating buffer contained 15 mM sodium carbonate, 35 mM sodium bicarbonate, and 2% polyvinylpyrrolidone (PVP-40) with pH 9.6 and incubated at 37 °C for 1 h. After three subsequent washings with PBS-T buffer contained 136 mM NaCl, 1.4 mM KH_2PO_4, 2.6 mM KCl, 8 mM Na_2HPO_4, 0.05% Tween-20, with adjusted pH 7.4, these plates were further blocked with 2% bovine serum albumin (BSA) for 1 h at 37 °C. After three repeated washings with PBS-T, specific antiserum against the coat protein (CP) of sugarcane yellow leaf virus (ScYLV) obtained from the AC Diagnostics Ltd., USA diluted (1:1000) with PBS-TPO contained PBS-T with 2% PVP-40 and 0.2% ovalbumin was loaded to the wells of ELISA plate and incubated at 37 °C for 1 h followed by three washing with PBS-T. Goat anti-rabbit IgG-AP conjugate (Sigma-Aldrich, St. Louis, USA at a dilution of 1:30,000 in PBS-TPO) was added and incubated at 37 °C for 1h. Finally, the plates were washed thrice with PBS-T and para-nitrophenyl phosphate (pNPP) substrate (at 0.5 mg/ml pNPP dissolved in 9.7% diethanolamine buffer, pH 9.6) was added. The OD values at 405 nm were measured by ELISA reader (Thermo Scientific, Multiscan) after 1 h of substrate incubation at 37 °C. DAC-ELISA test results were treated as positive if the absorbance value (OD 405) is more than 0.626 i.e., more than two times the OD 405 value of negative control (OD405 = 0.313), whereas, as negative if absorbance value is less than that value.

RESULTS AND DISCUSSION

Reaction of sugarcane genotypes to YLD: The pooled field evaluation revealed considerable variability in the response of different sugarcane genotypes to YLD under natural conditions (Table 1). Out of the tested genotypes, six entries viz. 2015A311, 2017A553, CoA20321, CoA20323, CoA20325, and CoV19359, exhibited disease grade scores ranging from 0.0 to 1.0, categorizing them as resistant (R). These genotypes showed negligible symptom expression with mild or no leaf chlorosis, indicating effective field tolerance against YLD infection. Majority of genotypes (18 entries) including CoA20322, CoC20336, CoC20337, CoA20326, CoC20338, CoOr20346, CoC19336, CoV19357, CoV18356, CoOr18346, CoA92081, CoC01061, CoOr03151, CoV18358, CoV19359, CoV92102, Co86249, and Co06030 recorded mean disease grade scores between >1.0 and 2.0, and were categorized as moderately resistant (MR). These varieties exhibited mild yellowing and slight midrib discoloration, suggesting partial tolerance and restricted disease progression. Genotypes such as CoA19322, CoC20339, CoA19321, CoA19322, CoA20325, and 2001A63 displayed mean scores in the >2.0 to 3.0 range, falling into the moderately susceptible (MS) group. These showed prominent leaf yellowing and loss of turgidity, especially in lower leaves. Only one genotype, 2003V46, recorded a score between >3.0 to 4.0, indicating a susceptible (S) reaction. None of the evaluated genotypes were found to be highly susceptible (HS) under natural field conditions. These observations confirm the presence of a wide spectrum of resistance in the breeding material, offering opportunities for further use in resistance breeding programs. The frequency distribution of resistance classes suggests that 32% of genotypes screened were resistant, 58% moderately resistant, and only 10% moderately susceptible, demonstrating encouraging progress in

Table 1. Reaction of different genotypes of sugarcane to yellow leaf disease under natural conditions (Pooled)

Disease grade	Reaction	Genotypes
0.0 - 1.0	R	2015A311, 2017A 553, CoA20321, CoA 20323, CoA 20325, CoV 19359
>1.0 – 2.0	MR	CoA 20322, CoC 20336, CoC 20337, CoA 20326, CoC 20338, CoOr 20346, CoC 19336, CoV 19357, CoV 18356, CoOr 18346, CoA 92081, CoC 01061, CoOr 03151, CoV 18358, CoV 19359, CoV 92102, Co 86249, Co 06030
>2.0 – 3.0	MS	CoA 19322, CoC 20339, CoA 19321, CoA 19322, CoA 20325, 2001A 63
>3.0 – 4.0	S	2003V 46
>4.0 – 5.0	HS	- -

breeding for YLD tolerance. This trend is in line with national varietal evaluations in India, where more than one-third of advanced clones have displayed moderate to high resistance under natural infection conditions (Viswanathan et al., 2020, Sundar et al., 2020). Field-based screening remains an effective approach to identify genotypes with durable resistance, as disease expression is strongly influenced by natural vector pressure and agro-climatic factors (Singh and Viswanathan, 2019). Similar patterns of genotypic variation for YLD resistance have been reported from South America, Australia, and China, where selection of resistant cultivars such as SP78-4764 and Q124 led to significant reductions in YLD incidence (Vega et al., 2010, Lehrer et al., 2010). Resistance is often associated with restricted virus accumulation in phloem tissues and low transmission efficiency by*M. sacchari*, (Rott et al., 2008, Chinnaraja et al., 2013). Studies have shown that resistant genotypes express slower symptom development, reduced viral RNA replication, and delayed aphid acquisition (Comstock and Irey 2017). Such combined physiological and molecular defense responses contribute to field-level stability of YLD resistance across locations and seasons.

The current evaluation thus confirms the presence of diverse resistance gradients among sugarcane genotypes, providing a strong base for incorporating durable resistance into elite breeding populations. The identified resistant lines particularly CoA20323 and 2017A553 also performed well for growth and sucrose traits, underscoring the feasibility of combining disease resistance with productivity in breeding programs (Muthiah and Rajendran, 2022, Singh et al., 2022). The observed differences in disease expression further highlight the role of genetic background, vector ecology, and local environmental conditions in shaping YLD dynamics, warranting continued multi-environment screening for long-term varietal stability.

Biophysical and biochemical traits of resistant genotypes: Distinct differences were observed among the YLD-resistant genotypes in terms of their leaf morphology, chlorophyll content, phenol concentration, juice sucrose, and silica content (Table 2). All six resistant genotypes exhibited a semi-erect leaf orientation with medium to medium-wide leaf blades, facilitating improved aeration and possibly reduced vector colonization. Leaf colour varied from light green (2015A311, CoA20321) to medium green (2017A553, CoA20323, CoA20325, CoV19359), indicating a healthy chlorophyll balance even under YLD pressure. The SPAD readings ranged from 28 (2015A311) to 31 (CoA20325 and CoV19359), while the susceptible check 2003V46 recorded a higher SPAD value (36) corresponding with its darker foliage. Although chlorophyll content was high in 2003V46, the excessive leaf droopiness (420 inclination angle) suggested structural weakness and physiological stress, typical of YLD-susceptible types. Among the resistant entries, phenol content varied between 1.8 and 2.0%, with CoA20323 and CoA20325 recording the highest levels. Phenolic compounds are known to play a defensive role in plant-pathogen interactions, possibly contributing to reduced YLD incidence. The juice sucrose percentage ranged between 35.67% (CoA20325) and 40.34% (CoA20323), indicating that YLD resistance did not adversely affect sugar accumulation. Silica content, an important physical defense trait, was relatively higher in resistant types (1.64–2.41%) compared to the susceptible check (1.30%), suggesting an additional barrier to vector feeding or pathogen entry.

Serological detection of YLD Infection through DAC-ELISA: DAC-ELISA analysis confirmed the presence of Sugarcane yellow leaf virus (SCYLV) in leaf and aphid samples from the tested genotypes (Table 3). The positive leaf samples of resistant genotypes recorded high absorbance index values ranging from 3.543 (CoV19359) to 3.893 (CoA20323), while their corresponding aphid samples showed moderate values (1.623–2.194). The susceptible genotype 2003V46 displayed the highest ELISA index values both in leaves (3.957) and aphids (2.507), indicating heavy

Table 2. Biophysical and Biochemical parameters of genotypes exhibiting YLD resistance under natural conditions

Genotype	Leaf colour		Leaf droopiness		Leaf width		Phenols (%)	Juice sucrose (%)	Silica (%)
	Colour	SPAD	Visual	Inclination angle	Width	Width (mm)			
2015A311	Light green	28	Semi erect	23^0	Medium	1.8	38.43	16.10	2.41
2017A553	Medium green	30	Semi erect	25^0	Medium-wide	1.9	39.32	16.21	1.83
CoA20321	Light green	29	Semi erect	22^0	Medium	1.9	37.24	16.43	2.30
CoA20323	Medium green	30	Semi erect	26^0	Medium-wide	2.0	40.34	17.26	1.91
CoA 20325	Medium green	31	Semi erect	24^0	Medium	2.0	35.67	16.62	1.86
CoV19359	Medium green	31	Semi erect	28^0	Medium-wide	1.9	33.67	16.43	1.64
2003V46	Dark green	36	Droopy	42^0	Wide	2.4	28.32	17.62	1.30

Table 3. DAC-ELISA readings of yellow leaf disease infected sugarcane leaves and aphids

Variety	Index values		Leaf sample	Aphid sample
2015A311	+ ve	3.725	1.756	Not applicable
	- ve	0.735		
2017A553	+ ve	3.693	2.005	
	- ve	0.895		
CoA20321	+ ve	3.757	1.975	
	- ve	0.632		
CoA20323	+ ve	3.893	1.623	
	- ve	0.715		
CoA20325	+ ve	3.679	1.735	
	- ve	0.741		
CoV19359	+ ve	3.543	2.194	
	- ve	0.711		
2003V 46	+ ve	3.957	2.507	2.344
	- ve	0.957		

virus accumulation and efficient aphid-mediated transmission. In contrast, negative controls across all genotypes recorded low absorbance values (<1.0), confirming assay reliability. The absence of detectable virus in aphids from the resistant genotypes suggests reduced vector acquisition efficiency or limited virus replication, corroborating the field-level resistance observations. Elevated levels of phenolics and silica are known to contribute to enhanced structural and biochemical defense against SCYLV infection and vector feeding (Santiago et al., 2016, Muthiah and Rajendran, 2022). The juice sucrose percentage remained high (35–40 %), indicating that resistance did not compromise sugar accumulation, a finding consistent with earlier studies linking YLD tolerance and yield stability (Muthiah and Rajendran, 2022).

Correlation between aphid incidence, yellow leaf disease, and weather parameters: Correlation analysis revealed significant interactions between aphid population dynamics, YLD incidence, and prevailing weather factors. Aphid populations exhibited positive correlations with maximum temperature , minimum temperature, and relative humidity I , while a negative correlation was observed with rainfall. Similarly, YLD severity showed positive relationships with minimum temperature, relative humidity II, and maximum temperature, and a negative correlation with rainfall . These findings indicate that warm and humid conditions with low rainfall are conducive to aphid multiplication and YLD spread. Periods of sustained dryness with moderate temperatures likely enhanced vector activity, promoting virus dissemination. Consequently, resistant genotypes maintained stable performance across weather fluctuations. These trends aligning with earlier observations from Brazil and India that identified temperature–humidity interactions as key drivers of YLD epidemics (Vega et al., 2010, Singh and Rao 2021). The stable performance of resistant genotypes across such conditions underscores their resilience and potential suitability for YLD-prone agro-climates. Similar integrative findings have also been reported earlier by Viswanathan et al. (2020) and Singh and Rao (2021), supporting the relevance of these resistant genotypes for deployment in integrated disease management programs.

CONCLUSION

The study demonstrated variability in YLD response among sugarcane genotypes, with a promising proportion exhibiting resistant to moderately resistant reactions under natural field conditions. The resistant lines also displayed favorable biochemical and biophysical traits such as higher phenol and silica content, balanced chlorophyll levels, and stable sucrose accumulation supporting their inherent defensive capacity. ELISA results further confirmed restricted virus accumulation and lower vector acquisition in resistant types. Weather–disease correlations highlighted the role of warm, humid, low-rainfall conditions in accelerating aphid populations and YLD spread, emphasizing the value of climate-resilient resistance. Overall, the genotypes 2015A311, 2017A553, and CoA20323 provide a strong foundation for breeding programs for developing YLD-tolerant, high-yielding cultivars suitable for diverse agro-climatic regions.

AUTHOR'S CONTRIBUTION

R. Saritha conceptualized the study, conducted the experiments, analyzed the data, and prepared as well as revised the original draft. V. Chandrasekhar helped in experimentation, validation, and data analysis. D. Adilakshmi supplied the genotypes used in the study, while B. Bhavani contributed to the conceptualization. The overall supervision of the work was provided by M. Visalakshi.

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Impact of Transgenic and Non-Transgenic Cotton on Insect Pests and Natural Enemies

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Abstract: The present field study was conducted at the Regional Agricultural Research Station in Lam, Guntur, to assess the effects of transgenic cotton on insect pests and associated natural enemies in comparison to non-*Bt* cotton. The findings showed that there was no difference in the egg-laying pattern of *Helicoverpa armigera* between *Bt* (12.68/plant) and non-*Bt* (13.07/plant). However, the number of larvae in the non-transgenic population was higher (6.33 larvae/plant) than in the transgenic population (2.30 larvae/plant). The boll damage caused by pink bollworm was lower in *Bt* cotton (27.68%) than in non-*Bt* cotton (36.33%). Populations of sucking pests, particularly leafhoppers, showed similar trends across Bt (15.82/three leaves) and non-Bt cotton (13.64/three leaves), with no major differences observed for aphids, thrips, or whiteflies. There were no discernible changes between transgenic and non-transgenic cotton in terms of natural enemies. Spider populations on *Bt* and non-*Bt* plants were 4.35 and 5.03 per plant, respectively. In contrast, the numbers of ladybird beetles and chrysopids were 1.12 and 1.39 per plant, respectively, in *Bt* cotton, while they were 0.93 and 1.10 per plant, respectively, in non-*Bt* cotton. The findings suggest that Bt cotton effectively suppresses bollworm infestation without negatively influencing the abundance of natural enemies, thereby supporting its continued role in integrated pest management.

Keywords: *Bt* and non *Bt* Cotton, Dynamics, Insect pests, Natural enemies, Population

Cotton, *Gossypium hirsutum* L. (Family Malvaceae), is an important commercially fiber crop in the world and grown in both tropical and warm temperate regions. About 25% of the world's cotton production comes from India, where cotton (*Gossypium hirsutum* L.) is a significant commercial crop. With 12.07 million hectares of land and 362.18 lakh bales produced per year, India leads the world in both cotton production and area (COCPC 2025). That makes it the world's largest producer of cotton. The cotton pests showed their time to time epidemic appearance and resulted into quantitative and qualitative crop losses in cotton growing states such as Maharashtra, Punjab, Karnataka, Gujrat, Haryana, Rajasthan, Madhya Pradesh, Andhra Pradesh and Telangana (Patil et al., 2004). India's production, however, is only 510 kg/ha, far lower than the global average of 808 kg/ha. This is because plants are under stress from a variety of biotic and abiotic stimuli. Numerous insect pests infest cotton crops at various phenological stages, which is one of the primary factors limiting yield (Sahito et al., 2017).

There are around 1300 plant-feeding insects in cotton systems worldwide, but only a small number of them are common residents and even fewer are economically significant. The large collection of cotton pests is divided into two categories: sucking pests and bollworms. Aphids (*Aphis gossypii*; Glover); leafhoppers (*Amrasca biguttula biguttula*; Ishida); thrips (*Thrips tabaci*; Lind.); and whiteflies (*Bemisia tabaci*; Genn.) are among the sucking pests that are most significant (Williams 2006). Cotton ecosystems also attract a variety of natural enemies that help regulate pest populations (Chi et al., 2021). Key predators include coccinellid beetles such as *Coccinella septempunctata* (Linnaeus) and *Cheilomenes sexmaculatus* (Fabricius), the green lacewing *Chrysoperla carnea* (Stephens), and several species of spiders including the lynx spider (*Oxyopes javanus*), orb spider (*Argiope minuta*), wolf spider (*Lycosa pseudoannulata*), long-jawed spider (*Tetragnatha javana*), *Neoscona theisi*, and *Peucetia viridana* (Stoliczka). Pesticide use has also been linked to detrimental environmental effects, including decreased biodiversity, pesticide resistance, harm to non-target species (such as natural enemies), and the emergence of secondary pests (Singh 2018). The cropping system is the present situation are very diversified and consist of several crops that serve as alternate and collateral hosts of the major insect pests. With the diversifies and multiplicity of cropping patterns the performance and interactions of transgenic crops in different agro-ecosystem are likely to be quite complex (Dhillon and Sharma, 2013). Since many other predators, including parasitoids, in arable systems are susceptible to environmental changes brought about by human involvement, the main worry regarding transgenic crops is their impact on non-target creatures.

Bt cotton has a mixed impact on natural enemies: while reduced insecticide use in Bt fields can lead to higher populations of beneficial insects, some studies indicate potential negative effects from predators consuming Btintoxicated prey. However, most research suggests the overall effect on natural enemy diversity and function is not significantly adverse, and the benefits of reduced broad-spectrum insecticide use often outweigh the drawbacks. In order to understand and compare the diversity of arthropods, including the harm caused by insect pests and their natural enemies, the current field research were conducted.

MATERIAL AND METHODS

The *Bt*-transgenic and non-transgenic cotton hybrids were cultivated under field conditions on deep black soils at the Regional Agricultural Research Station, Lam, Guntur Andhra Pradesh, following normal agronomic practices recommended for raising the crop mentioned in the package of practices of cotton. The *Bt*-transgenic and their non-transgenic versions of Tulasi 171 BGII were planted July with a spacing of 105 cm X 60 cm individually with an area of 500 m^2 each respectively and were divide further in to five sub plots as replicates and leaving the boundary rows to exclude from sampling. The crop was raised under rainfed conditions following suitable agronomic practices as recommended by the university. No plant protection measures were applied during the experimental period in both *Bt* and Non *Bt* cotton fields.

The observations were recorded on the abundance of sucking pests, cotton bollworm, non-target insect pests, and the generalist predators on randomly tagged plants in the middle two rows of each plot at fortnightly intervals starting from 30 days after sowing. Leafhopper and whitefly adults and nymphs were recorded on the under surface of the top five fully expanded leaves, while the rest of the insects were recorded on the whole plant. Numbers of all the insect pests and the generalist predators were expressed as numbers, while the plants infested with aphids were recorded in percentage. The data on total numbers of mature bolls, and those damaged by bollworms were recorded on 15 tagged plants. The data was further subjected to statistical analysis (t-test) using XLSTAT version 16.0.

RESULTS AND DISCUSSION

With respect to oviposition of *H. armigera* there were no significant differences in female moth on *Bt* (12.68) and Non *Bt* cotton (13.07) and the damage due to *H. armigera* and larval population varied significantly with highest in Non Bt (6.33) and in Bt (2.30). The variation in *H. armigera* larval density on Bt and non Bt cotton was significant across the environments. More egg laying by *H. armigera* on *Bt* plants might be because of better crop growth as a result of reduced damage by other insect pests. Similar results were also obtained in earlier studies by Sharma and Pampapathy (2006) and Dhillon and Sharma (2009). Arshad et al. (2011) reported that there was no difference in oviposition between Bt and non Bt cotton. However, Wu et al. (2003) and Vennila et al. (2006) observed significant differences in egg laying. Arshad et al. (2011) who reported that the incidence of *H. armigera* larvae was very low on Bt cotton cultivars compared to their corresponding non *Bt* cultivars.

Larval population of pink bollworm in *Bt* cotton was 2.33 and in its counterpart non Bt was 10.67 larvae per plant, the pink bollworm larval population is generally higher in non-*Bt* cotton than in *Bt* cotton because the *Bt* toxin is engineered to kill the larvae leading to much higher mortality rates and lower overall populations compared to non-*Bt*. *T*he non *Bt* plots attract more bollworms than the *Bt* genotypes, this might have been the reason for the difference in damage of squares (Kumar and Stanley 2006). Marchosky et al. (2001) alsoreported that the BG-I and BG-II hybrids had consistently fewer PBW larvae compared to non Bt cotton.

There was significant differences in the population of leafhoppers, between Bt (15.82and Non Bt cotton (13.64). Similarly, the thrips population was greater on Bt than on non Bt cotton plants (Table 1). There was significant difference among *Bt* and non *Bt* cotton with respect to population of whiteflies. Aggrawal and Dhawan (2009) observed that population of thrips was slightly higher on transgenic cotton in the last two years due to a reduced number of insecticide sprays against lepidopterous pests compared with the

Table 1. Population of major insect pests and natural enemies in Bt and Non Bt cotton

Type of arthropods	Transgenic Bt cotton	Non-transgenic Bt cotton	CD @ 5%
Insect pests			
Helicoverpa armigera eggs	12.68±1.24	13.07±1.30	NS
Helicoverpa armigera larvae	2.30±0.54	6.33±1.10	1.84
Pink bollworm larvae	2.33±0.38	10.67±1.57	2.56
Leaf hoppers/ 3 leaves	15.82±1.85	13.64±0.93	1.10
Thrips/ 3 leaves	31.47±3.15	28.36± 2.73	1.29
Whiteflies/ 3 leaves	5.3±1.10	4.6±0.85	NS
Natural Enemies			
Spiders	4.35±0.55	5.03±0.74	NS
Ladybird beetles	1.12±0.35	0.93±0.26	NS
Chrysopids	1.39±0.28	1.10±0.30	NS
Damage and Yield			
Number of fallen squares (%)	23.67±2.67	24.47±3.45	NS
Square Damage (%)	18.67±1.50	34.33±2.40	6.18
Boll damage (%)	27.68±1.70	36.33±2.85	5.05
Locule damage (%)	6.82±0.25	17.34±1.10	3.26

* Values are means ± SE

number of sprays in the normal cotton. Udikeri et al. (2012) while assessing the impact of Bt cotton on dynamics of aphid in RCH 2 Bt and non-Bt cotton hybrids, reported aphid population range as 8.58 /leaf (34 ISW)-42.15/leaf (50 ISW) in RCH 2 Bt and 6.22-37.08/leaf (46 ISW) in RCH 2 Non-Bt cotton, respectively, indicating no significant variation. Sarwar et al. (2013) explained that in general Bt cotton showed equal or higher sucking pest population than non Bt cotton verities. Mohapatra and Nayak (2014) reported that Sudarshan BGII was found highly susceptible to jassid, harbouring a maximum population of leaf hoppers. Since Bt cotton hybrids are shown to be resistant to the bollworm complex, the increasing prevalence of sucking pest populations may be the result of less interspecific competition among sucking pests. Kaur et al. (2016) reported that population of sucking pests on Bt and non Bt hybrids did not differ significantly.

Spiders, ladybird beetles, and other natural enemies were also observed on Bt and non-Bt cotton plants. The population of natural enemies did not differ statistically, but there were numerical differences between the populations of natural enemies in the Bt and non-Bt cotton ecosystems. Earlier field trials have also demonstrated that by mid-season, the population densities of generalist predators in *Bt*-cotton are significantly higher than in conventional cottons treated with insecticides for control of *H. armigera* (Pray et al., 2002, Sharma et al., 2007). No significant influence of *Bt* cotton on abundance of natural enemies of crop pests *viz.,* chrysopids, ladybird beetles was observed suggesting that there were no adverse effects of *Bt*-cotton on the natural fauna under field conditions (Dhillon and Sharma 2013).

There were no significant differences between *Bt* (23.67) and non *Bt* (24.47) cottons with respect to the shedding of squares, but when the squares were considered with the damage due to boll worm there were significantly more in Non *Bt* (36.33) than in *Bt* cotton (27.68). The bollworm damaged in green bolls between the *Bt* and Non *Bt* cotton was significant. The locule damage was more in Non *Bt* compared to that of *Bt* and differed statistically. In non-*Bt* fields, bollworm populations can grow exponentially, while in *Bt* fields, the survival rate for larvae is very low. Development of transgenic cotton made a significant contribution in reducing the dosage and frequency of insecticide application and reduce the yield losses due to insect pests (Brooks and Barfoot 2008). Bt cotton hybrids exhibited significant reduction in bollworm infestation as against non Bt indicating the superiority of transgenic Bt cotton. These findings are also endorsed by Gujar et al. (2011) and Nadaf and Goud (2015). Chinna Babu Naik et al. (2019) observed that RCH 2 Bt, JK Durga Bt, and Nath baba Bt events had very low incidences of pink bollworm larvae, but they were better than their comparable non-Bt hybrids, which had high incidences of pink bollworm larvae. The population of *H. armigera* was considerably lower in *Bt* cotton than in non-*Bt* cotton, although there were no appreciable variations in the number of eggs laid by H*. armigera*.

CONCLUSION

Target bollworms are effectively controlled by Bt cotton, which greatly reduces the use of insecticides. This benefits natural enemies (predators/parasitoids) by maintaining their populations, resulting in better biological control and a more balanced ecosystem. However, this reduced spraying can occasionally allow secondary pests to flourish, necessitating integrated pest management (IPM) strategies. Bt toxins are specific to certain pests (like bollworms) and generally harmless to beneficial insects, as they lack the required gut receptors. The long-term challenge is managing pest resistance to the Bt toxin.

AUTHORS CONTRIBUTION

L.R.C wrote the draft and designed the study; L.R.C., N.J., R.C., S.B., C.N. and VM analyzed the data and revised the manuscript; NVSSD and SR revised the manuscript; LRC conducted the experiment; L.R.C., N.V.V.S.D and SR reviewed and edited the manuscript.

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Efficacy of Jasmonic Acid Application on Aphid (*Aphis gossypii* Glover) Population in Chilli (*Capsicum annuum* L.)

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***Abstract*:** Studies conducted during 2022–23 at the Insectary, AICRP on Biocontrol, AAU, Jorhat evaluated Jasmonic acid (JA)–induced resistance in chilli against aphids. Two experimental sets were maintained: Set A with a single JA spray at 20 DAT and Set B with two sprays at 20 and 60 DAT, comprising JA at 0.1, 0.5, 1.0 and 1.5 mM along with an untreated control. Results indicated that JA application significantly reduced aphid infestation, with the lowest aphid population consistently observed at 1.0 mM concentration. Two JA applications were more effective than a single spray in suppressing aphid population and enhancing plant recovery from aphid stress. Overall, JA @ 1.0 mM proved most effective in inducing resistance, highlighting jasmonic acid as a promising and sustainable elicitor for aphid management in chilli.

***Keywords*:** *Aphis gossypii*, Chilli, Exogenous application, Induced resistance, Insect herbivory and jasmonic acid

Chilli (*Capsicum annuum* L.) belongs to the Solanaceae family and originated in tropical America (Swamy 2023), cultivated mainly for its pungency due to the alkaloid capsaicin ($C_{17}H_{27}O_3N$) (Chakradhar et al., 2013). *C. annuum* was domesticated in the Tehuacan valley of Mexico around 5000 BC (Ettenberg 2019). Widely grown across tropical, subtropical and temperate regions of India. In 2020-21, global green chilli production reached 36 million tonnes, with India contributing 42% and ranking as the top producer, followed by Bangladesh, Thailand, China, Ethiopia and Indonesia (FAOSTAT 2021). Chilli cultivation is hindered by both biotic and abiotic stresses, with insect pests being a major threat. Several insect species are recognized as major pests of chilli crops. These include the fruit borer (*Helicoverpa armigera*), mites (*Polyphagotarsonemus latus*), whitefly (*Bemisia tabaci*), aphid (*Aphis gossypii*) and jassid (*Amrasca biguttula biguttula*) (Subhashree et al., 2020). These pests have the potential to cause significant damage to the chilli plants, affecting their overall health and productivity. Even with the application of pesticides in substantial quantities, crop damage, particularly from aphids, has been observed. Despite efforts to control pest populations through pesticide use, aphids have exhibited resilience and continued to cause harm to crops.

Jasmonic acid (JA) is a key phytohormone involved in plant defense against herbivores, activating both direct and indirect responses (Shivaji et al., 2010). Jasmonates, cyclopentanone compounds synthesized via the octadecanoid pathway from linolenic acid, regulate multiple defense mechanisms (Wasternack and Hause 2013). Increasing attention has been given to pest and disease management, particularly through host plant resistance (HPR), which is a cost-effective strategy (Walling 2000). Exogenous application of JA and its precursors activate defensive proteins and secondary metabolites in plants (Zhao et al., 2009; Pieterse et al., 2009). Therefore, the current study was conducted to explore the potential of jasmonic acid-induced resistance against aphids.

MATERIAL AND METHODS

The study was conducted at Assam Agricultural University (AAU), Jorhat, Assam, located at 26.72˚N latitude and 94.20˚E longitude. The field experiments were carried out under protected and laboratory conditions in a completely randomized design comprising five treatments with four replications during 2022-23. Based on the frequency of jasmonic acid application, two separate experimental sets Set A and Set B were established, each consisting of 20 pots.

Exogenous application of jasmonic acid: The study evaluated the effect of exogenous jasmonic acid (JA) on inducing resistance to *Aphis gossypii* in chilli (*Capsicum annuum* L., var. BSS918). Seedlings were raised in peat moss, transplanted into pots (soil: FYM, 3:1) and grown under controlled conditions (16 h photoperiod, 32/30°C) in December 2022. JA was applied at four concentrations (0.1, 0.5, 1.0, and 1.5 mM) following Farmer *et al.* (1992). Treatments were replicated four times. Set A received single spray at 40 DAS, while Set B received two sprays (40 and 80 DAS). Aphid counts on the top 10 cm shoot were recorded every five days interval before flowering. Feeding preference was assessed in two experimental sets following using 30 aphids per plant (Aslam et al., 2022).

Statistical analysis: Data were statistically analyzed using SPSS-21 software. Tukey's HSD test was used for post-hoc comparison of treatment means.

RESULTS AND DISCUSSION

The population of *A. gossypii* on leaves of chilli plants was determined in all the treatments after single spray. Different concentrations of jasmonic acid were applied exogenously to chilli leaves and a total of 30 aphids per 10 cm terminal shoot were released on the fifth day after treatment. The number of aphids was recorded at 1, 5, 10, 15, 20, 25 and 30 days after release of aphids in each treatment. Among all the treatments, at fifteen days after spray, JA @ 1.0 mM recorded the minimum aphid population (1.75 aphids), which was statistically at par with @1.5mM (3.50 aphids), while the control maintained a significantly higher population of 30.75 aphids. Complete suppression of aphid population was observed in 1.0mM by 20 days after spray, followed by 1.5mM and 0.5mM by 25 days after spray. In contrast, the control treatment sustained appreciable aphid population throughout the experimental period, recording 8.25 aphids even at 30 days after spray (Table 1). The study showed that exogenous jasmonic acid effectively induced resistance in chilli against *A. gossypii*, with 1.0 mM JA being the most effective treatment. JA-treated plants had significantly fewer aphids than controls. These results agree with earlier studies (Aslam et al., 2022, Bayram and Tonga 2018, El-Wakeil and Volkmar 2012, El-Wakeil et al., 2010).

Feeding preference of *A. gossypii* on chilli plants after two sprays of JA: The chilli plants were again sprayed with different concentrations of jasmonic acid and a total of 30 numbers of aphids per10 cm terminal shoot was released on the fifth day after the second spray of JA at 60 DAT to determine the feeding preference of *A. gossypii* on chilli leaves. Similar observations were taken where the number of aphids was recorded at 1, 5, 10, 15, 20, 25 and 30 days after release of aphids in each treatment. The gradual decrease in the number of aphids per 10 cm terminal shoot was observed from first day in four treatments (0.1, 0.5, 1.0, and 1.5 mM) (Table 2). At 0.1 mM, aphid counts decreased from 25.50 to 5.25 aphids by 20 days and reached zero by 25 days. At 0.5 mM, populations reduced from 24.25– 1.75 aphids by 20 days and became nil by 25 days. Higher concentrations (1.0 and 1.5 mM) showed faster suppression, with aphid numbers declining from 22.00– 3.75 and 23.25–4.50, respectively, to low levels by 10 days and complete absence from 15 days onwards. In contrast, the untreated control maintained comparatively higher aphid populations throughout the observation period, ranging from 32.50–35.50 aphids during the initial stages and persisting at 5.25 aphids. Jasmonic acid (JA) regulates key physiological processes that enhance plant defense. It alters glucose metabolism (Machado et al., 2017) modulates hormones and reduces ROS (Kang et al., 2005) and promotes secondary metabolite production that deters insect feeding (Bruinsma et al., 2007, Qiu et al., 2009). Overall, JA effectively activates defense responses in chilli, making it a promising tool for eco-friendly aphid management.

Table 1. Population of *A. gossypii* on leaves of chilli plants after single spray of jasmonic acid

Treatment	Number of aphids/10 cm terminal shoot after single spray*						
	1 d	5 d	10 d	15 d	20 d	25 d	30 d
JA @ 0.1 mM	28.75^{bc}	24.75^{c}	19.50^{c}	15.50^{c}	8.75^{b}	3.50^{a}	0.00^{a}
JA @ 0.5 mM	26.50^{ab}	21.25^{bc}	14.75^{b}	7.25^{b}	3.50^{a}	0.00^{a}	0.00^{a}
JA @ 1 mM	25.75^{a}	16.75^{ab}	4.75^{a}	1.75^{a}	0.00^{a}	0.00^{a}	0.00^{a}
JA @ 1.5 mM	24.751^{a}	15.50^{a}	5.25^{a}	3.50^{a}	1.50^{a}	0.00^{a}	0.00^{a}
Control	30.75^{c}	33.75^{d}	35.75^{d}	30.75^{d}	27.50^{c}	17.50^{b}	8.25^{b}
CD (p=0.05)	3.12	3.65	3.94	3.58	2.91	2.40	1.85

*Mean within column with same letter do not differ significantly (p≤0.05), Tukey's HSD Test

Table 2. Population of *A. gossypii* on leaves of chilli plants after second spray of jasmonic acid

Treatment	Number of aphids/10 cm terminal shoot after second spray*						
	1 d	5 d	10 d	15 d	20 d	25 d	30 d
JA @ 0.1 mM	25.50^{a}	21.25^{b}	16.75^{c}	10.75^{b}	5.25^{b}	0.00	0.00
JA @ 0.5 mM	24.25^{a}	19.50^{b}	11.25^{b}	6.75^{a}	1.75^{a}	0.00	0.00
JA @ 1 mM	22.00^{a}	13.25^{a}	3.75^{a}	0.00	0.00	0.00	0.00
JA @ 1.5 mM	23.25^{a}	14.00^{a}	4.50^{a}	0.00	0.00	0.00	0.00
Control	32.50^{b}	34.25^{c}	35.50^{d}	27.25^{c}	19.75^{c}	12.00^{b}	5.25^{b}
CD (p=0.05)	2.51	3.92	2.59	1.92	2.14	1.23	0.65

*Mean within column with same letter do not differ significantly (p≤0.05), Tukey's HSD Test

CONCLUSION

The study revealed that two sprays of jasmonic acid (1.0 mM) at 20 and 60 days after transplanting (DAT) significantly reduced aphid populations compared to a single spray at 20 DAT. The dual application enhanced early resistance and improved plant recovery from aphid stress. These results indicate that jasmonic acid is an effective, eco-friendly option for aphid management in chilli cultivation, supporting sustainable and productive agriculture.

AUTHOR'S CONTRIBUTION

SBK and BB conceptualized the research, MSK, SBK and KD conducted the experiment, collected data, MSK and SBK wrote the manuscript, MSK and DS done analysis of data and interpretation.

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Evaluation of Biocontrol Methods and IPM Modules for Management of Fall Armyworm in Maize

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***Abstract*:** The fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), is a serious, voracious and invasive pest that has caused significant yield losses in maize since its first report in Andhra Pradesh during August 2018. Biological control and integrated pest management (IPM) approaches offer sustainable solutions for the management of fall armyworm (FAW) in maize.An ad hoc trial was initiated under ICAR-NBAIR, Bengaluru during 2018–19 to 2020–21 at Acharya N.G. Ranga Agricultural University (ANGRAU), Andhra Pradesh to evaluate the efficacy of egg parasitoids (*Trichogramma pretiosum* and *T. chilonis*) and biopesticides in comparison with the insecticidal check, emamectin benzoate against maize FAW. Further studies were carried out during 2020-21 and 2021-22 to evaluate IPM modules for FAW management. Among the treatments, next to emamectin benzoate, the biocontrol-based approach involving the field release of *T. pretiosum* twice, combined with three sprayings of *Bacillus thuringiensis* (NBAIR Bt 25), or *T. pretiosum* release combined with *Metarhizium anisopliae* (ICAR-NBAIR Ma-35) sprayings, proved effective with lower FAW damage, higher larval mortality, and higher cob yield. Similar efficacy of biocontrol agents and biopesticides was also observed in maize sown with insecticide-treated seed. The biocontrol-based IPM module comprising three releases of *T. chilonis* along with three sprayings of either NBAIR Bt 25 or NBAIR Ma-35 provided a viable, eco-friendly alternative to sole chemical control of FAW in maize.

***Keywords*:** *Spodoptera frugiperda, Trichogramma pretiosum, Trichogramma chilonis, Bacillus thuringiensis, Metarhizium anisopliae,* Maize

The fall armyworm (*Spodoptera frugiperda* Smith) (Lepidoptera: Noctuidae) is a serious invasive pest. Native to the American continent, where it causes devastating damage to several crops and was first reported in India from Karnataka in July 2018 and subsequently in Andhra Pradesh in August 2018. Significant yield losses have been reported from Northern Zimbabwe due to damage on leaves, silks, and tassels (Chimweta et al., 2018). Management of FAW is particularly challenging because of its concealed feeding habit, high reproductive potential, strong migratory ability and wide exposure to chemical pesticides. Ecological pest management practices such as the use of crop spacing have been demonstrated as sustainable, cost-effective, and environmentally safe alternatives (Nivetha et al., 2022).

Currently various approaches including cultural practices, chemical pesticides, natural plant products and development of resistant maize varieties/ hybrids are employed for FAW management (Prasanna 2023). However, indiscriminate insecticide use has led to adverse impacts on soil health, the environment and beneficial organisms, including natural predators and parasitoids (FAO 2018). In this context, biological control and IPM strategies are gaining importance as eco-friendly and long-term solutions. The need to develop sustainable IPM technologies for *S. frugiperda* management in India, with reduced dependence on insecticides has been emphasized (Mallapur et al., 2018, Shylesha et al., 2018, Akutse et al., 2019). Karimou et al. (2024) focused on identifying climate-responsive IPM strategies for long-term control integrating biointensive and judicious insecticide practices. Earlier reports have shown that FAW larvae are susceptible to a range of biocontrol agents, including entomopathogenic bacteria, fungi, nematodes and viruses (Molina-Ochoa et al., 2003, Ríos-Velasco et al., 2010, Visalakshi et al., 2020). Field studies conducted at Regional Agricultural Research Station (RARS), Anakapalle during 2018-2022 evaluated biocontrol agents and entomopathogens both as standalone treatments and as components of IPM modules including the release of *Trichogramma* spp. egg parasitoids against FAW in maize.Although several international studies have demonstrated the potential of biocontrol agents against FAW, field-based evidence from Andhra Pradesh, India is limited. Therefore, the present study was undertaken to evaluate the efficacy of biocontrol agents individually and in IPM modules for the sustainable management of FAW in maize.

MATERIAL AND METHODS

An ad hoc field trial was initiated under ICAR-NBAIR, Bengaluru to evaluate the efficacy of the egg parasitoid *Trichogramma pretiosum* in combination with biopesticide sprayings *viz.*,*Bacillus thuringiensis* NBAIR Bt25, *Metarhizium anisopliae* NBAIR Ma35, *Beauveria bassiana* NBAIR Bb45, *Heterorhabditis indica*, and *Pseudomonas fluorescens* in comparison with pheromone traps alone and the insecticidal check, emamectin benzoate against maize fall armyworm (FAW) during rabi seasons of 2018-19 and 2019-20. The trials were conducted at RARS, Anakapalle, Visakhapatnam district, Andhra Pradesh (East Coast Plains and Hills Zone 11, 17°37′ N latitude, 83°01′ E longitude).The experiments were laid out in a completely randomized block design with eight treatments replicated thrice using maize hybrid Advanta 751. Seeds were sown manually in experimental plots measuring 5 m × 6 m with a spacing of 60 cm × 30 cm and irrigated regularly. Recommended agronomic practices including fertilizer application as per the package of practices of ANGRAU were followed to maintain crop health until harvest. The efficacy of *T. pretiosum* and *T. chilonis* releases along with biopesticide sprayings in maize sown with cyantraniliprole + thiamethoxam treated seed was further studied during four seasons from 2019-20 to 2020-21. Subsequently, field evaluations of IPM modules for FAW management as alternatives to chemical insecticide-based modules were carried out during *kharif* and *rabi* seasons of 2020-21 and 2021-22 at RARS, Anakapalle to identify effective IPM strategies for maize.

Biopesticide formulations were applied at the following doses: *M. anisopliae* NBAIR Ma35 and *B. bassiana* NBAIR Bb45 at 5 g/l (1 × 10^8 CFU/g), *B. thuringiensis* NBAIR Bt25 at 10 ml/l, *H. indica* at 20 g/l, and *P. fluorescens* at 10 g/l. Sprays were initiated at 20 days after sowing (DAS) upon the first incidence of FAW infestation and repeated at 10-day intervals for a total of three applications. Observations were recorded before treatment and five days after each spray. Data on the number of plants infested by FAW (20 plants per replication per treatment), number of damaged whorls, and larval counts (live/dead) were collected up to 50 days after sowing. For larval population estimation, five plants per replication were randomly selected and the number of *S. frugiperda* larvae per plant was counted. Egg masses collected from the field were maintained in glass vials, monitored for parasitoid emergence and percent parasitisation was calculated. The percent reduction in FAW plant damage was computed and crop yield was recorded at harvest. Yield increase (%) in each biocontrol treatment and IPM module was determined relative to the chemical control and untreated control.

Details of the Treatments

Study I: Ad hoc trial on the management of fall armyworm using biocontrol agents and biopesticides

The experiment consisted of eight treatments as follows:(T_1)**:** *T. pretiosum* @ 50,000/acre + *B. thuringiensis* NBAIR Bt25 @ 10ml/l, (T_2)**:** *T. pretiosum* @ 50,000/acre + *M. anisopliae* NBAIR Ma35 @ 5 g/l, (T_3): *T. pretiosum* @ 50,000/acre + *H. indica* @ 20 g/l, (T_4)**:** *T. pretiosum* @ 50,000/acre + *P. fluorescens* @ 10 g/l, (T_5)**:** *T. pretiosum* @ 50,000/acre alone, (T_6)**:** Pheromone traps (*S. frugiperda*) @ 10/acre, (T_7)**:** Insecticidal check - Emamectin benzoate 0.4 SG @ 0.4 g/l, and (T_8)**:** Untreated check. Each treatment was replicated three times in a Randomized **Complete** Block Design (RCBD).

Study II: Management of maize fall armyworm using biocontrol methods

The experiment comprised seven treatments as follows:(T_1) Seed treatment with cyantraniliprole 19.8% + thiamethoxam 19.8% @ 6 ml/kg + release of *T.pretiosum* @ 50,000/acre at 20 DAS (I window) + spraying *B. thuringiensis* @ 10 ml/l at 30, 40, and 50 DAS (II, III, IV windows), (**T_2**) Seed treatment with cyantraniliprole 19.8% + thiamethoxam 19.8% @ 6 ml/kg + release of *T. pretiosum* @ 50,000/acre at 20 DAS (I window) + spraying *Metarhizium anisopliae* @ 5 g/L at 30, 40, and 50 DAS (II, III, IV windows), (T_3) Seed treatment with cyantraniliprole 19.8% + thiamethoxam 19.8% @ 6 ml/kg + release of *T. pretiosum* @ 50,000/acre at 20 DAS (I window) + spraying *Beauveria bassiana* @ 5 g/l at 30, 40, and 50 DAS (II, III, IV windows), (**T_4**) Seed treatment with cyantraniliprole 19.8% + thiamethoxam 19.8% @ 6 ml/kg + release of *T. chilonis* @ 100,000/acre at 20 DAS (I window) + spraying *B. thuringiensis* @ 10 ml/l at 30, 40, and 50 DAS (II, III, IV windows), **(**T_5) Seed treatment with cyantraniliprole 19.8% + thiamethoxam 19.8% @ 6 ml/kg + release of *T. chilonis* @ 100,000/acre at 20 DAS (I window) + spraying *M. anisopliae* @ 5 g/l at 30, 40, and 50 DAS (II, III, IV windows), **(**T_6) Seed treatment with cyantraniliprole 19.8% + thiamethoxam 19.8% @ 6 ml/kg + release of *T. chilonis* @ 100,000/acre at 20 DAS (I window) + spraying *B. bassiana* @ 5 g/l at 30, 40, and 50 DAS (II, III, IV windows), and **(**T_7) Untreated control. Each treatment was replicated three times in a randomized complete block design**.**

Study III: Integrated pest management (IPM) module on fall armyworm in Maize

The experiment comprised ten IPM modules as treatments

Module 1: *T. chilonis* @ 20,000 per acre (3 releases, weekly from one week after sowing) + *B. thuringiensis* @ 10 ml/l (3 sprays from 25 DAS at 10-day intervals).

Module 2: *T. chilonis* @ 20,000 per acre (3 releases, weekly from one week after sowing) + *M. anisopliae* @ 5 g/l (3 sprays from 25 DAS at 10-day intervals).

Module 3: *T. chilonis* @ 20,000 per acre (3 releases, weekly from one week after sowing) + *B. bassiana* @ 5 g/l (3 sprays from 25 DAS at 10-day intervals).

Module 4: *T. chilonis* @ 20,000 per acre (3 releases, weekly from one week after sowing) + Neem formulation @ 5 ml/l (spray at 25 DAS) + Chlorpyriphos @ 2.5 ml/l (spray at 35 DAS).

Module 5: *T. chilonis* @ 20,000 per acre (3 releases, weekly from one week after sowing) + Neem formulation @ 5 ml/l (spray at 25 DAS) + Emamectin benzoate @ 0.4 g/l (spray at 35 DAS).

Module 6: *T. chilonis* @ 20,000 per acre (3 releases, weekly from one week after sowing) + Emamectin benzoate @ 0.4 g/l (spray at 35 DAS).

Module 7: *T. chilonis* @ 20,000 per acre (3 releases, weekly from one week after sowing) + Neem formulation @ 5 ml/l (spray at 25 DAS) + poison baiting in leaf whorls with rice bran (10 kg) + jaggery (2 kg) + thiodicarb (100 g) per acre at 35 DAS.

Module 8: Neem formulation @ 5 ml/l (spray at 10 DAS) + *M. anisopliae* @ 5 g/l (2 sprays from 25 DAS at 10-day intervals).

Module 9: Neem formulation @ 5 ml/l (spray at 10 DAS) + *B. bassiana* @ 5 g/l (2-3 sprays from 25 DAS at 10-day intervals).

Module 10: Farmers' practice (Chemical module) - Neem formulation @ 5 ml/l (spray at 10 DAS) + Chlorpyriphos @ 2.5 ml/l (spray at 20 DAS) + poison baiting in leaf whorls with rice bran (10 kg) + jaggery (2 kg) + thiodicarb (100 g) per acre at 30 DAS + Emamectin benzoate @ 0.4 g/l (spray at 40 DAS).

Each IPM module was replicated three times in a randomized complete block design .

RESULTS AND DISCUSSION

Study I: Ad hoc trial for management of fall armyworm using biocontrol agents and biopesticides

Ad hoc trials were conducted for two consecutive rabi seasons (2018-19 and 2019-20) to evaluate the efficacy of biocontrol agents and biopesticides against the invasive pest, fall armyworm (FAW) in maize. The results revealed that, next to the insecticide treatment emamectin benzoate, the biocontrol treatment consisting of field release of egg parasitoid *T. pretiosum* @ 20,000 parasitoids/acre/release (two releases from 7 days after seedling emergence) + spraying of *B. thuringiensis* (NBAIR Bt-25) @ 10 ml/l (three sprays from 21 days after seedling emergence) was highly effective. This treatment recorded significantly lower FAW damage (48.6%), higher larval mortality (35 dead larvae/plot) and higher cob yield (40.7 q/ha) followed by the treatment comprising two releases of *T. pretiosum* + three sprays of *M. anisopliae* (ICAR-NBAIR Ma-35) which recorded low plant damage (50.38%), high larval mortality (37.62 dead larvae/plot) and higher cob yield (39.27 q/ha) compared to high damage (78.29%) and low yield (22 q/ha) in untreated plots (Table 1).

Good parasitism of FAW eggs by *T. pretiosum* (8.05-15.34 parasitized egg masses/plot) was observed which suppressed FAW damage by 64.49-73.45 per cent compared to untreated control. In contrast, higher reduction in FAW damage was recorded in the insecticidal treatment (86.3%) up to 20 DAS, while pheromone treatment resulted in 69.76% reduction compared to untreated control. The insecticide emamectin benzoate recorded the highest efficacy with significantly lower damage (15.15%), high larval mortality (49.36 dead larvae/plot), maximum reduction in FAW damage (80.65%) and yield increase of 82.27 per cent over untreated check.

Among biocontrol-based treatments, *T. pretiosum* + Bt (NBAIR Bt-25) and *T. pretiosum* + *M. anisopliae* (ICAR-NBAIR Ma-35) showed good reduction in FAW damage up to 60 DAS (37.92% and 35.65%, respectively) and high yield increase (85% and 78.5%, respectively). Their efficacy was found to be comparable to emamectin benzoate. These findings indicate that biocontrol-based approaches particularly integration of *T. pretiosum* with microbial biopesticides can serve as a sustainable alternative to chemical insecticides for the management of FAW in maize.

Study II: Management of Maize fall armyworm using Biocontrol methods

Efficacy studies of biocontrol agents (*T.pretiosum* and *T.*

Table 1. Evaluation of biocontrol methods against Fall armyworm in maize during *Rabi* (2018-19 and 2019-20)

Treatment	Damage at 20 DAS (%)	Number of parasitized egg masses per 40m^2	Damage reduction over control at 20 DAS (%)	Damage at 60 DAS (%)	Number of dead larvae /40m^2	Grain yield (q/ha)	Damage reduction over control at 60 DAS (%)	Increase in yield over control (%)
T1 : TP +Bt	9.23	13.73	64.49	48.60	35.0	40.70	37.92	85.0
T2 : TP+ Ma	9.12	14.70	64.91	50.38	37.62	39.27	35.65	78.50
T3: TP+Hi	7.39	8.05	71.57	52.28	32.68	36.66	33.22	66.64
T4: TP+Pf	6.90	9.0	73.45	62.27	26.51	35.53	20.46	61.50
T5: TP alone	8.10	15.34	68.83	70.53	0.0	31.38	9.91	42.64
T6: Pheromones	7.86	0.0	69.76	74.73	0.0	29.09	4.55	32.27
T7: Insecticidal check	3.56	0.0	86.30	15.15	49.36	40.1	80.65	82.27
T8: Untreated Check	25.99	0.0		78.29	0.0	22.0		
CD (p=0.05)	10.2	6.75		13.75	14.82	8.29		

* Values represent mean of two years

chilonis) and biopesticides (*B. thuringiensis*, *M. anisopliae*, and *B. bassiana*) in maize sown with insecticide-treated seed were conducted during kharif and rabi seasons of 2019-20 and 2020-21.The results showed that T_1:seed treatment + *T. pretiosum*/*T. chilonis* (one release) + three sprays of *B. thuringiensis* (NBAIR Bt-25) was most effective recording significantly lower plant damage (32.95%), higher larval mortality (4.48 dead larvae/plot) and higher yields (44.02 q/ha) compared to untreated control (Table 2). The next best treatment was T_2: seed treatment + *T. pretiosum*/*T. chilonis* release + three sprays of *M. anisopliae*, which resulted in reduced plant damage (34.48%), higher larval mortality (3.92 dead larvae/plot) and good yields (42.35 q/ha). Egg parasitism studies indicated that *T. pretiosum* (6.42-7.91 parasitized egg masses/plot) was statistically on par with *T. chilonis* (6.53-7.78 parasitized egg masses/plot) confirming that both parasitoids performed equally well in parasitizing FAW eggs.

Seed treatment with cyantraniliprole 19.8% + thiamethoxam 19.8% @ 6 ml/kg seed effectively reduced FAW damage up to 20 DAS by 68.67-76.44% over untreated control. The combination of seed treatment + *T. pretiosum*/*T. chilonis* + Bt sprays resulted in 56 per cent reduction in plant damage and yield increases of 68.4 per cent, respectively. The next best integration was seed treatment + parasitoid release + *M. anisopliae* sprays, which recorded 53.97 per cent reduction in damage with yield increases of 62%.These findings confirm that integration of seed treatment with egg parasitoids and microbial biopesticides provides effective, eco-friendly management of FAW in maize corroborating earlier reports on the parasitisation capacity of *Trichogramma* spp. on *S. frugiperda* eggs (Tao Jin et al., 2021).

Study III: IPM module on fall armyworm in maize

The IPM modules evaluated against maize FAW clearly demonstrated the effectiveness of integrating biocontrol agents with biopesticides. The module involving *T. chilonis* releases (three times) + *B. thuringiensis* (NBAIR Bt-25) three sprays recorded significantly lower plant damage (30.46%), higher larval mortality (4.67 dead larvae/20 plants), good egg parasitisation (14%), and higher yield (44.05 q/ha) compared to other treatments (Table 3). Similarly, the module *T. chilonis* three releases + *M. anisopliae* (NBAIR Ma-35) three sprays also proved effective with plant damage of 33.35%, larval mortality of 4.23 larvae/20 plants, parasitisation of 12.08%, and yield of 41.03 q/ha. In contrast, the farmers' practice consisting of neem spray at 10 DAS, chlorpyriphos at 20 DAS, poison baiting at 30 DAS, and emamectin benzoate at 40 DAS recorded high FAW damage (55.42%), low larval mortality (2.7 larvae/20 plants), poor egg parasitism (1.33%), and the lowest yield (26.53 q/ha).The percent reduction in plant damage over farmers' practice was 45.04% in *T. chilonis* + NBAIR Bt-25 module and 39.82% in *T. chilonis* + NBAIR Ma-35 module, resulting in a corresponding yield increase of 66.04% and 54.66%, respectively.

Egg mass parasitisation was observed in the IPM modules with *T. chilonis* releases (12-14%), whereas it was negligible (1.33%) in the farmers' practice. *Trichogramma* egg parasitoids are considered excellent candidates for the biological control of FAW and play a crucial role as a component of integrated pest management (Navik et al., 2023).Cob yields were significantly higher in the IPM modules *T. chilonis* + NBAIR Bt-25 (44.05 q/ha) and *T. chilonis* + NBAIR Ma-35 (41.03 q/ha), compared to the chemical module (66.33 q/acre). The present findings clearly demonstrate the effectiveness of integrating *Trichogramma* releases with microbial biopesticide sprays in IPM modules for FAW management. Such integration minimized crop damage and enhanced yields while reducing dependence on chemical insecticides. These results agree with the

Table 2. Management of maize fall armyworm using biocontrol agents and biopesticides during *Kharif* seasons (2019 and 2020)

Treatments	FAW damage at 20 DAS (%)	Damage reduction) over control at 20 DAS (%)	FAW damage at 60 DAS (%)	Number of dead larvae per plants	Number of parasitized egg masses (no.)/ 40m^2	Grain yield (q/ha)	Damage reduction over control at 60 DAS (%)	Increase in yield over control (%)
T1	6.12	74.84	32.95	4.48	7.91	44.02	56.0	68.40
T2	5.73	76.44	34.48	3.92	6.76	42.35	53.97	62.0
T3	5.30	78.21	35.54	3.62	6.42	39.62	52.55	51.57
T4	7.62	68.67	34.13	4.33	7.78	42.92	54.43	64.20
T5	6.20	74.50	35.30	4.13	6.72	41.60	52.87	59.14
T6	6.16	74.67	36.0	3.39	6.53	33.95	51.94	29.88
T7	24.32		74.9	0.0	1.01	26.14		
CD (p=0.05)	9.81		11.35	1.21	3.34	14.29		

recommendations of Prasanna et al. (2018) on IPM tools for the management of the invasive maize FAW and with the findings of Tiwari and Bopp (2020) on biosafe alternatives against FAW in maize.

Metarhizium anisopliae (ICAR-NBAIR Ma-35) applied as three sprayings showed high larval mortality in ad hoc trials, with an average of 37.62 dead larvae per plot. The effectiveness of *M. anisopliae* as an eco-friendly and sustainable tool for FAW management has also been reported by several researchers (Kumar and Singh, 2020, Keerthi et al., 2023, Sharma and Thakur, 2019, Tavares et al., 2019, Visalakshi et al., 2023). Apart from its entomopathogenic activity, *Metarhizium* is recognized as a highly effective fungus that functions as a plant biostimulant, acting as both an endophyte and a rhizosphere colonizer (Wood et al., 2022).Among the chemical treatments, three sprays of emamectin benzoate applied from 20 days after crop establishment reduced plant infestation by 80.65%, outperforming biocontrol treatments. However, combinations of natural enemies viz., *T. pretiosum* + *B. thuringiensis* (NBAIR Bt 25) reduced infestation by 37.92% and *T. pretiosum* + *M. anisopliae* (NBAIR Ma-35) by 35.65% compared with the untreated control. In terms of yield, the highest increase over control was recorded in *T. pretiosum* + *B. thuringiensis* (85%), followed by emamectin benzoate (82.27%) and *T. pretiosum* + *M. anisopliae* (78.5%).Several studies corroborate the efficacy of emamectin benzoate in controlling FAW and increasing maize yields (Rakat and Bhala, 2018, Ghimire et al., 2020). Nonetheless, despite its high effectiveness, emamectin benzoate poses concerns such as the risk of resistance development, environmental impacts and crop residues. Hence, the value of IPM is increasingly recognized as a sustainable alternative strategy for FAW management in maize.

The cumulative efficacy of the biocontrol agent *T. chilonis* (three releases) in combination with biopesticide applications (*B. thuringiensis* NBAIR Bt 25 or *M. anisopliae* NBAIR Ma-35 three sprays) under the IPM module resulted in a substantial reduction of FAW infestation. This integrated approach recorded high larval mortality and increased egg parasitisation of FAW, ultimately contributing to higher maize yields. A comparative evaluation of different biocontrol strategies and IPM modules against the chemical module/ farmers practice (Neem spray + Chlorpyriphos + poison baiting + Emamectin benzoate) revealed marked differences in FAW damage and maize yields. The combined use of biocontrol agent releases with biopesticide sprayings consistently reduced FAW incidence and improved yields, demonstrating their potential as an effective and eco-friendly alternative to sole reliance on chemical insecticides for FAW management in maize.

The present study represents the first field-level validation of biocontrol agents and biopesticides against maize FAW under Andhra Pradesh conditions. Egg mass parasitisation and increased larval mortality clearly demonstrated the effectiveness of *Trichogramma* releases in combination with biopesticides (*B. thuringiensis* and *M. anisopliae*) in reducing infestation and enhancing maize yield. Integration of seed treatment, parasitoid releases and microbial sprays achieved yields comparable to or even superior to those obtained with chemical modules. These findings strongly highlight that biocontrol-based IPM strategies are not only effective but also yield superior results compared to chemical-based modules. Such strategies can

Table 3. Evaluation of IPM module on fall armyworm in maize during *Kharif* and *RABI* seasons (2019 and 2020)

Treatments	FAW damage (%) at 60 DAS	Dead larvae (no.)/ 20 plants	Parasitized egg masses (no.) /40m^2	Grain yield (Q/ha)	Damage reduction (%) over chemical module at 60 DAS	Increase (%) in yield over chemical module
Module 1	30.46	4.67	14.0	44.05	45.04	66.04
Module 2	33.35	4.23	12.08	41.03	39.82	54.66
Module 3	36.62	4.06	11.50	38.80	33.92	46.25
Module 4	39.82	2.74	5.50	30.94	28.15	16.62
Module 5	41.05	2.88	5.75	34.26	25.93	29.14
Module 6	36.42	4.44	5.69	46.40	34.28	74.93
Module 7	45.17	1.96	5.42	29.02	18.50	9.39
Module 8	45.18	2.37	3.59	27.65	18.48	4.22
Module 9	46.47	2.34	3.11	28.68	16.15	8.10
Module 10	55.42	2.70	1.33	26.53		
CD (p=0.05)	18.52	2.95	4.07	3.72		

*****Values represent mean of two years

therefore be recommended as viable alternatives to chemical insecticides for FAW management in maize as IPM plots consistently showed minimal infestation and significantly higher yields compared to chemical modules.

This study highlights the significance of integrating biological control agents and biopesticides which are highly potent, residue-free and effective in preventing resistance development. Such eco-friendly IPM approaches provide a sustainable alternative to chemical insecticides like emamectin benzoate for the effective management of fall armyworm in maize.

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Bioefficacy of Actinomycetes Secondary Metabolites against *Maruca vitrata* (Geyer) in Pigeonpea

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***Abstract*:** Secondary metabolites of seven actinomycetes isolates were tested for their insecticidal activity against second instar larvae of *Maruca vitrata* using diet impregnation and detached flower bioassay. In diet impregnation bioassay mortality rates recorded by KAI-26, MMA-32, SAI-13, CAI-93, CAI-21, SAI-25 and KG-13 were 90.90%, 90.90%, 81.81%, 63.63%, 54.54%, 51.51% and 18.18%, respectively. In detached flower bioassay mortality rates shown by MMA-32, KAI-26, SAI-13, SAI-25, KG-13, CAI-21 and CAI-93 were 94.44%, 94.44%, 88.88%, 72.22%, 44.44% and 33.33%, respectively. Isolates which showed highest efficacy in both diet impregnation and detached flower bioassay were further evaluated in glass house. Glass house studies revealed that KAI-26, MMA-32 and SAI-13 maintained the same performance with 90.90% mortality. The effective isolates against *M. vitrata* were KAI-26, MMA-32 and SAI-13.

Keywords: Actinomycetes, Secondary metabolites, *Maruca vitrata*, Bioassay, Mortality

Pigeonpea (*Cajanus cajan* L. Millsp.) is an important grain legume crop widely cultivated in tropical and subtropical regions for its high protein content and resilience to environmental stresses. Despite its agronomic importance, productivity is severely constrained by insect pests, among which the legume pod borer, *Maruca vitrata* (Geyer), is one of the most destructive (Shejulpatil et al., 2020). *Maruca vitrata* (Geyer), a widespread tropical insect pest, causes extensive damage to leguminous crops like pigeon pea, cowpea, mung bean, and soybean, posing a serious threat to yields in tropical and subtropical regions worldwide. The larvae feed destructively on flowers, buds, and developing pods, making it a major global pest of grain legumes with severe agricultural and economic consequences (Sharma and Franzmaan 2000).

Actinomycetes are gram-positive, filamentous bacteria that form spores and thrive in diverse environments including soil, rhizosphere, actinorhizal plants, hypersaline soils, limestone, freshwater, marine ecosystems, sponges, volcanic caves, deserts, air, insect guts, earthworm castings, goat faeces and as endophytes (Selim et al., 2021). Some prokaryotic bacteria, particularly *Streptomyces* species, synthesize bioactive secondary metabolites (Berdy 2005), which include antibiotics and anticancer agents that have significantly advanced medicine and pharmaceutical research. Bioactive secondary metabolites offer a sustainable alternative to synthetic insecticides, as they are less toxic and more biodegradable. These metabolites, derived from actinomycetes, can be integrated into pest management strategies as novel biopesticidal formulations (Aggarwal et al., 2016).

The present study investigates the bioefficacy of secondary metabolites derived from actinomycetes against *M. vitrata* in pigeonpea. This research aims to identify potential biocontrol agents capable of reducing pest incidence while promoting sustainable pigeonpea production. This work contributes to developing novel, environmentally safe pest management approaches and expanding the use of microbial metabolites in crop protection.

MATERIAL AND METHODS

The research work was conducted at Microbiology department and Insect rearing unit, International Crop Research Institute for Semi-Arid Tropics (ICRISAT), Patancheru. Whole cultures of 20 actinomycetes isolates were screened against second instar larvae of *M. vitrata*. The isolates which showed highest, medium and lowest mortality were selected for further extracellular metabolite extraction.

Extra-cellular metabolite extraction: Approximately 2–4 loopfuls of actinomycetes cultured on Actinomycetes Isolation Agar (AIA) plate were inoculated into 3 liters of starch casein broth and incubated in a shaker incubator at 120 rpm and 28±2°C for eight days. The extracellular metabolites (ECM) were extracted according to the method described by Khattab et al. (2016). On the eighth day, the broth was centrifuged at 10,000 rpm for 10 minutes. The supernatant and cell mass (pellet) were separated using muslin cloth. The pH of the supernatant was adjusted to 3 to ensure proper extraction, as some lipophilic compounds in the culture filtrate may contain ionizable groups (such as carboxylates) that could hinder organic phase partitioning unless suppressed by acidic conditions.

The supernatant was subjected to solvent partitioning using a separating funnel. Ethyl acetate, in a volume equal to culture filtrate, was added to the filtrate for extraction. The partitioning process was repeated three times to ensure maximum recovery of compounds. The mixture was vigorously shaken for one minute and then allowed to settle until clear separation of the organic (ethyl acetate) and aqueous (culture filtrate) phases occurred. The ethyl acetate layer was carefully separated and pooled. To eliminate any residual moisture or cell debris, anhydrous sodium sulphate was added to the combined organic phase. The solution was then filtered and concentrated through evaporation.

The organic fraction was concentrated using a rotary evaporator at 40°C to form a thin film. The residue adhering to the flask walls was dissolved in methanol (using 10–15 ml of methanol per 3 liters of broth culture) and then transferred to glass screw-cap tubes. These samples were stored at 4°C for subsequent analysis and use.

Diet impregnation bioassay: About 200 ul of ECM was added to the cell well plate containing about 2 ml of dried artificial diet. Later pre-starved second instar larva was added to each individual well. Two replications were used for each treatment (sample) and each replication consisted of 12 larvae. Mortality was observed on 3rd, 5th and 7th DAT. Moribund larvae were also considered as dead. Percentage of mortality for each test isolate was computed. Mortality in methanol control was also recorded and corrected mortality (Abbott 1925) per each treatment was calculated.

$$\text{Per cent mortality} = \frac{\text{Dead larvae}}{\text{Total no. of larvae}} \times 100$$

Detached flower bioassay: About 10 ml of 3% boiled agar was prepared and poured into plastic cups placed at an angle of 45°. After solidification, flower buds which were dipped in ECM for 2-5 min were kept in the cups containing agar. Ten second instar larvae of *M. vitrata* which were pre-starved for 1-2 hours released into each cup containing treated flowers. Two replications were used for each treatment (sample) and each replication consisted of 10 larvae. The insect mortality was recorded on 3rd, 5th and 7th day after treatment (DAT). Moribund larvae were also considered as dead. Percentage of mortality for each test isolate was computed. Mortality in methanol control was also recorded and corrected mortality (Abbott 1925) per each treatment was calculated.

Glass house experiment: Isolates that showed highest efficacy in both diet impregnation assay and detached flower bioassay were selected for glasshouse evaluation on *M. vitrata* in pigeonpea and the larval mortality was recorded. Methanol and water were used as negative controls. Fifty days after seedling emergence, plants were sprayed with secondary metabolite extracts (5ml/plant) and infested with 2nd instar larvae and covered with net bags. Four replications were used for each treatment (sample), and each replication consisted of ten larvae. The larval mortality was recorded on 3rd, 5th and 7th day after treatment. Per cent mortality for each test isolate was computed.

Statistical analysis: The data was subjected to analysis of variance (ANOVA) after arcsine transformation (arc sine) and the means were separated by Duncan's Multiple Range Test (Duncan 1955).

RESULTS AND DISCUSSION

Diet impregnation bioassay: The 3rd day evaluation revealed significant variation in treatment efficacy, with KAI-26 demonstrating superior insecticidal activity (78.78%

Diet impregnation bioassay

Detached flower bioassay

Glass house experiment

mortality). SAI-13 was moderately effective (45.45% mortality), followed by SAI-21 (27.27%) and SAI-25 (22.72%). MMA-32 exhibited limited impact (22.72% mortality), while CAI-93 and KG-13 displayed no detectable mortality at this early evaluation stage.

The bioassay results at 5th DAT revealed a progressive increase in larval mortality across all treatments. MMA-32 and KAI-26 emerged as the most effective isolates, both achieving 81.81% mortality. SAI-13 followed with substantial efficacy (68.18%), while CAI-21 and CAI-93 demonstrated moderate activity (54.54%). SAI-25 showed lower insecticidal potential (36.36%) and KG-13 remained the least effective, with only 9.09% larval mortality. The bioassay results at 7th DAT revealed significant differences in treatment efficacy. KAI-26 and MMA-32 demonstrated the highest larval mortality, 90.90%, followed by SAI-13 with 81.81% mortality. Intermediate efficacy was observed in CAI-93 (63.63%), CAI-21 (54.54%) and SAI-25 (51.51%). In contrast, KG-13 showed markedly lower effectiveness, producing only 18.18% mortality.

High levels of larval mortality observed following exposure to ECM from the selected isolates may be attributed to their production of insecticidal metabolites, with these bioactive compounds potentially enhancing the susceptibility of *M. vitrata* to treatment. Another possible explanation for the mortality is decreased feeding, as either the whole culture (WC) or the produced metabolites could possess antifeedant properties or demonstrate contact toxicity, thereby reducing larval survival. The variation in mortality rates could be attributed to differences in the effective dosage against *M. vitrata*. The above results coincided with Lakshmi et al. (2025) who evaluated the ECM of three isolates against second instar larvae of fall armyworm. Highest mortality was reported in KG-13 (85.19%) followed by CAI-17 (81.48%) and CAI-134 (70.37%).

Detached flower bioassay: At 3 DAT, mortality rates showed clear stratification among treatments, with MMA-32 demonstrating the highest efficacy (61.11%), followed by SAI-13 and KAI-26 (55.55%). SAI-25 exhibited moderate activity (44.44%), while CAI treatments showed limited effectiveness, particularly CAI-93 (16.66%) and KG-13 (0%) displayed no measurable mortality at this early stage. By 5th DAT, mortality patterns became more pronounced, with three treatments SAI-13, MMA-32 and KAI-26, reaching high equivalent efficacy (83.33%). There was an improvement observed in KG-13, from 0% to 66.66% mortality. In contrast, the CAI treatments continued to demonstrate poor performance, with CAI-21 remaining at 33.33% and CAI-93 showing only minimal improvement to 27.77% larval mortality.

At the 7th DAT, treatment efficacy reached its peak, with MMA-32 and KAI-26 achieving the highest mortality rates (94.44%). SAI-13 maintained its strong performance (88.88%), while SAI-25 and KG-13 showed comparable efficacy (72.22%). Notably, the CAI treatments remained the least effective, with CAI-21 reaching only 44.44% and CAI-93 plateauing at 33.33% mortality. The above results align with the findings of Vijayabharathi et al. (2014), who conducted a detached leaf bioassay for the assessment of insecticidal activity of the ECM of 15 isolates on lepidopteran pests. Among them, 100% mortality was reported in BCA-546, BCA-659, CAI-13, CAI-87, CAI-132, CAI-133, CAI-155 and SAI-25 isolates.

Glass house experiment: On 3rd DAT, there was a significant difference in the efficacy of the treatments. Among

Table 1. Efficacy of secondary metabolites (extracellular) of actinomycetes on 2nd instar larvae of *M. vitrata* in diet impregnation bioassay

Treatment	Mean percent mortality at different intervals after treatment					
	3 DAT		5 DAT		7 DAT	
	Mortality (%)	Corrected	Mortality (%)	Corrected	Mortality (%)	Corrected
SAI 13	50	45.45^{bc}	70.833	68.18^{de}	83.33	81.81^{de}
SAI-25	29.16	22.72^{ab}	41.66	36.36^{c}	54.16	51.51^{cd}
MMA-32	25	22.72^{ab}	83.33	81.81^{de}	91.66	90.90^{e}
KAI-26	79.16	78.78^{c}	83.33	81.81^{e}	91.66	90.90^{e}
CAI 21	33.33	27.27^{b}	58.33	54.54^{cd}	58.33	54.54^{cd}
CAI-93	0	0^{a}	58.33	54.54^{cd}	66.66	63.63^{de}
KG-13	0	0^{a}	16.66^{b}	9.09^{b}	25	18.18^{bc}
MC	8.33^{ab}		8.33^{ab}		8.33^{ab}	
NC			0^{a}			

Means followed with the same letters do not differ significantly (0.05) by DMRT (Number of treated larvae, N = 12). DAT = Days after treatment, MC = Methanol, NC= Normal control

Table 2. Efficacy of secondary metabolites (extracellular) of actinomycetes on 2ndinstar larvae of *M. vitrata* in detached flower bioassay

Treatment	Mean percent mortality at different intervals after treatment					
	3 DAT		5 DAT		7 DAT	
	Mortality (%)	Corrected	Mortality (%)	Corrected	Mortality (%)	Corrected
CAI-21	35	27.77^{b-d}	40	33.33^{c}	50	44.44^{cd}
CAI-93	25	16.66^{a-c}	35	27.77^{bc}	40	33.33^{bc}
SAI-13	60	55.55^{cd}	85	83.33^{d}	90	88.88^{ef}
SAI-25	50	44.44^{b-d}	70	66.66^{d}	75	72.22^{de}
MMA-32	65	61.11^{d}	85	83.33^{d}	95	94.44^{f}
KAI-26	60	55.55^{cd}	85	83.33^{d}	95	94.44^{f}
KG-13	5	0.00^{a}	70	66.66^{d}	75	72.22^{de}
MC	10.00^{ab}		10.00^{ab}		10.00^{ab}	
NC	(0.00)^{a}					

Means followed with the same letters do not differ significantly (0.05) by DMRT (Number of treated larvae, N = 12). DAT = Days after treatment, MC = Methanol, NC= Normal control

Table 3. Efficacy of secondary metabolites (extracellular) of actinomycetes on 2ndinstar larvae of *M. vitrata* on pigeonpea under glasshouse conditions

Treatment	Mean percent mortality at different intervals after treatment					
	3 DAT		5 DAT		7 DAT	
	Mortality (%)	Corrected	Mortality (%)	Corrected	Mortality (%)	Corrected
KAI-26	41.66	39.39^{c}	91.66	90.90^{b}	91.66	90.90^{b}
MMA-32	32.91	26.66^{c}	79.16	77.27^{b}	91.66	90.90^{b}
SAI-13	32.08	25.45^{c}	91.66	90.90^{b}	91.66	90.90^{b}
MC	8.33^{a}		8.33^{a}		8.33^{a}	
NC	0.0^{a}					

Means followed with the same letters do not differ significantly (0.05) by DMRT (Number of treated larvae, N = 12). DAT = Days after treatment, MC = Methanol, NC= Normal control

the tested treatments, highest efficacy was recorded in KAI-26 with 39.39% larval mortality. The rest of the two treatments, MMA-32 and SAI-13, exhibited 26.66% and 25.45% larval mortality, respectively. On 5th DAT, there was a rapid improvement in the efficacy of treatments. The larval mortality in KAI-26 and SAI-13 increased to 90.90%, Whereas MMA-32 recorded 79.16% mortality. On 7th DAT, KAI-26 and SAI-13 maintained the same performance, whereas the larval mortality in MMA-32 increased to 90.90%.

The results of the current study align with the findings of Pedaveeti et al. (2022), who assessed the insecticidal effects of three actinobacterial extracts, namely DBT-80, DBT-64 and DBT-59, against second instar larvae of *S. frugiperda* under greenhouse conditions on maize. The mortality percentages recorded 96 hours after treatment were 80.50, 79.50 and 78.25, respectively.

CONCLUSIONS

Among the seven tested isolates KAI-26, MMA-32 and SAI-13 were highly effective isolates in diet impregnation bioassay, detached flower bioassay and glasshouse screening. KAI-26 was identified as a *Streptomyces albus* strain, whereas MMA-32 was a strain of *Streptomyces roseoviolaceus* and SAI-13 was a *Streptomyces* species. The effective isolates against *M. vitrata* were KAI-26, MMA-32 and SAI-13. Among them KAI-26 isolate was quick in action. Future work may be concentrated on dose optimization and development of formulations and compound identification that helps to identify mode of action.

AUTHOR'S CONTRIBUTION

This study was conducted as a part of master's research work in ICRISAT under the supervision of Rajan Sharma and Jaba Jagdish. Study was conceptualized by B. Ratna Kumari. Methodology, data collection and analysis were carried out by M. Keerthana. The first draft of manuscript was written by M. Keerthana and all the authors reviewed the manuscript.

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Enhanced Efficacy of Combined Plant Extracts on Rice Leaf Folder, *Cnaphalocrocis medinalis* (Guenée)

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Abstract: The rice leaf folder, *Cnaphalocrocis medinalis* (Guenée) (Lepidoptera: Crambidae), is a prominent and noxious pest in rice production, particularly in the Cauvery Delta region of Karaikal of Puducherry and Tamil Nadu, India, where rice is cultivated predominantly as a monocrop during the *Kharif* and *Rabi* seasons. Field experiments were conducted during *Kharif* and *Rabi* 2019-20 at PAJANCOA and RI, Karaikal, to evaluate the efficacy of plant extracts against leaf folder. Across both seasons, chemical insecticide treatments, Novaluron and Thiamethoxam resulted in 49.03% and 54.90% reduction in leaf folder damage, respectively. Among the botanical treatments, 5% garlic and chili extract consistently showed the lowest leaf damage, recording 6.27 and 6.49% in *Kharif* 2019 and *Rabi* 2019-2020, respectively. This represents a 40.40 and 40.02% reduction in damage compared to the untreated control. Thus, garlic and chili extract at 5% proved highly effective in minimizing leaf folder incidence under field conditions and offers a sustainable, eco-friendly alternative to chemical insecticides by reducing the risk of resistance development.

Keywords: Botanical extracts, Five leaf extract, Garlic and chilli extract, Leaf folder, Novaluron, Rice

The rice leaf folder, *Cnaphalocrocis medinalis* (Guenee) (Lepidoptera: Crambidae), has emerged as a major threat to rice cultivation in several Asian countries, particularly in tropical and subtropical Asia (SenthilNathan et al., 2006). Rice leaf folder is the most prevalent and economically significant of the eight reported species of rice leaf folders and is the only species capable of surviving by feeding on weeds. In the Puducherry region, stem borers, leaf folders, and leafhoppers are the most destructive pests of rice. Among these insect pests, the leaf folder is a regular and persistent pest in the Cauvery Delta region, where rice is cultivated as the main crop. The leaf folder causes yield losses of about 5–25% (Kulgod et al., 2011).

Chemical pest control using synthetic insecticides such as **o**rganophosphates (e.g., chlorpyrifos), carbamates, and pyrethroids is common in rice cultivation to manage pests like stem borers, brown planthopper, and leaf folder (Pasalu and Katti 2006). While effective initially, the indiscriminate use of these chemicals has led to pest resistance, secondary pest outbreaks, and environmental contamination. Residues of these chemicals accumulate in soil and water, posing health risks including neurotoxicity, carcinogenicity, and endocrine disruption (Aktar et al., 2009). Persistent organochlorines bioaccumulate through the food chain, resulting in long-term ecological hazards (Singh et al., 2018, Rajashekhar et al., 2021). Pesticide runoff further contaminates water bodies, harming aquatic ecosystems. Therefore, reducing chemical pesticide dependency and promoting botanical alternatives is crucial for sustainable rice production and for safeguarding human and environmental health.

Insecticide use can have negative effects on the ecosystem, eliminate beneficial insects, and leave residues in harvested produce; botanicals have long been marketed as substitutes for synthetic chemical insecticides in pest management (Echereobia et al., 2010). Plant-based insecticides derived from a combination of five leaf extracts *Azadirachta indica* (neem), *Vitex negundo* (Indian privet), *Lantana camara* (lantana), *Annona squamosa* (custard apple), and *Clerodendrum inerme* (wild jasmine) have shown promising results in controlling major rice pests such as the rice stem borer, rice leaf folder and brown planthopper. These extracts possess a variety of bioactive compounds, including alkaloids, flavonoids, and terpenoids, which exhibit insecticidal, antifeedant, and growth-regulating effects on pests (SenthilNathan et al., 2006). The foliar applications of these extracts significantly reduce pest infestation and improve rice yield without causing harm to beneficial insects (Kumar et al., 2015). Garlic (*Allium sativum*) and chilli (*Capsicum frutescens*) extracts have demonstrated significant bioefficacy against major rice pests. Garlic extract, rich in organosulfur compounds such as allicin, exhibits insecticidal, antifeedant, and repellent properties that disrupt the metabolic activities of pests, leading to reduced feeding and growth inhibition (Dougoud et al., 2019). Similarly, chilli extract contains capsaicinoids, which exhibit neurotoxic and antifeedant effects, impairing pest behavior and reducing insect proliferation in rice fields (Baidoo and Mochiah 2016). Combined application of garlic and chilli extracts enhances their insecticidal properties due to their synergistic effects, resulting in higher pest mortality and decreased pest infestation. Field trials have shown that foliar application of these extracts reduces pest incidence by up to 60 %, improving overall rice yield and minimizing environmental contamination (Tuan et al., 2014). Considering the importance of eco-friendly pest management and the proven efficacy of plant extract mixtures in rice ecosystems, the present study aimed to evaluate the effectiveness of various botanical extracts against the rice leaf folder. The objective was to assess their potential as sustainable alternatives to chemical insecticides, focusing on their ability to reduce pest infestation while minimizing environmental impact and preserving beneficial organisms.

MATERIAL AND METHODS

Field experiments: To study the effect of botanical extracts, a supervised field experiment I and II was conducted during *Kharif* and *Rabi* 2019-20 (two seasons) on irrigated crop at the eastern farm of PAJANCOA and RI, Karaikal, UT of Puducherry, which lies between 10.95° N latitude and 79.78° E longitude with a height of 4 m above MSL.

The experiment was set up in a randomized block design with eight treatments of three replications. The crop was raised as per recommended agronomic procedures being followed except plant protection measures (Balaji et al., 2018). From each plot 10 plants were randomly selected were observed for insect damage symptoms at weekly intervals from 7 days after treatment (DAT), When pest incidence reached the economic threshold (ETL) of 10% damage, the treatments were imposed. Three foliar applications were given 24, 39 and 54 days after transplanting in experiment I and 27, 43 and 57 DAT in experiment II. Pre-treatment observations one day before application of treatment and post-treatment observations 1, 3, 5, 7, 10 and 14 DAT were recorded. The treatments include, T_1 -Five leaf extract @ 10%; T_2- Garlic and chilli extract @ 5 %; T_3 -Bitter apple leaf extract @ 10 %; T_4 - Ponneem 45% @ 3750 ml/ha; T_5 -Azadirachtin 0.03% @ 2000 ml/ha; T_6 -Thiamethoxam 25 WG @ 100 g/ha; T_7 - Novaluron 10 EC @ 1000 ml/ ha and T_8 -Untreated check

Preparation of the botanical extracts: Five leaf extracts were prepared by using plant materials *viz.* giant milkweed (*Calotropis gigantea* Linnaeus), leaves of neem (*Azadirachta indica*), jatropha (*Jatropha curcas* Linnaeus), chaste tree (*Vitex negundo*) and adhathoda (*Justicia adhatoda* Linnaeus) which were collected from the local area of Karaikal district (10.9221° N, 79.7547° E and 10.9166° N, 79.7548° E), U.T. of Puducherry, India. About 2 kg of fresh leaves from each plant were taken, washed with tap water and diced into small pieces. The diced leaves were macerated individually with an electric blender to form a paste, which was added to 12 litres of cow urine followed by the addition of 3 kg of cow dung and 100 g of turmeric powder. The mixture was then left to ferment for seven days. After fermentation, the solution was filtered through a double-layered muslin cloth, and the filtrate was used for spraying on the rice crop in the trial. For the garlic and chilli extract, the outer layers of garlic were peeled off, and mature green chillies was cleaned to make garlic and chilli extract. To prepare the extract, 200 g of each was combined with one litre of water and ground using an electric blender. An additional one litre of water was used to completely blend this juice. The mixture was then sieved to get a turbidity-free, homogeneous extract (Tuan et al., 2014). Bitter apple leaves, *Citrullus colocynthis* Schrad, were picked locally and rinsed with running tap water to eliminate debris before being cut into small pieces using a sharp knife. In a blender, 500 g of leaves were mixed into a fine paste with 500 ml of water. Before application, all the plant extracts were diluted to the required spray concentration from full-strength (100 %) solution. The total number of leaves and damaged leaves from 10 randomly chosen hills per plot were used to assess *C. medinalis* leaf damage. One day before spraying, pretreatment observations were made and posttreatment observations were taken at 1, 3, 5, 7, 10, and 14 days after spraying. The percentage of leaf damage was calculated.

Statistical Analysis: Statistical analysis of the data was carried out using one-way analysis of variance (SPSS version 22.0, IBM Corporation, New York, USA), and Duncan's multiple range test was used to determine the significant variation (P<0.05).

RESULTS AND DISCUSSION

Efficacy of botanical extracts*:* The efficacy of different botanical was evaluated across three foliar spray applications to assess their impact on the incidence of leaf folder in rice in *Kharif* 2019. The percentage of leaf folder incidence after the 1st, 2nd, and 3rd foliar sprays was recorded (Table 1). After the 1stfoliar spray, significant differences were observed among the treatments. The botanical extracts, including garlic and chilli extract and five leaf extract, resulted in moderate leaf damage (7.72 and 8.12 %). Significant differences were recorded after the 2nd foliar spray, where all treatments demonstrated reduction in leaf folder incidence compared to the untreated control. Among the botanical extracts, the garlic and chilli extract showed reduction, in leaf folder incidence (6.64 %). Among the synthetic insecticides, Novaluron 10 EC recorded the lowest leaf damage (5.86 %). Further reduction in leaf folder incidence was observed after the 3rd foliar spray, with significant differences among treatments. Garlic and chilli extract showed superior efficacy among botanical treatments, reducing leaf damage to 4.45 %. Among the synthetic insecticides, Novaluron 10 EC recorded the lowest incidence (3.41 %), The results indicated that novaluron 10 EC at 400 ml / ac superior among the treatments (49.05 % reduction) and garlic and chilli extract at 5 % (40.40 %) was superior among the botanicals compared to the untreated check.

In *Rabi* 2019-2020, leaf damage 1 day before the first spraying ranged from 10.47 to 11.37 %/hill with non-significant difference. Significant differences were recorded after the 1st spray, Novaluron 10 EC at 400ml/ac recorded the lowest leaf damage of 5.82%. Among the plants, garlic and chili extract was effective at 5 % with 7.74 % leaf damage, followed by five leaf extract at 10 % (8.61 %) compared to untreated controls (10.96 %). After the 2nd spray also significant differences were recorded, the lowest foliar damage of 5.24% was in Novaluron 10 EC at 1000 ml/ha and garlic and chilli extract at 5 % (6.73 %) compared to the untreated control (11.97 %). After the 3rd foliar application, a similar trend was observed as in the first and second foliar applications. Total leaf damage in Novaluron 10 EC at 1000ml/ha was 4.88 % with the highest percentage reduction of 54.90 and followed by garlic and chilli extract at 5 % (6.49 % leaf damage and 40.02 % reduction over control) (Table 2). The repeated foliar sprays significantly reduced leaf folder incidence in treated plots compared to the untreated control. The five-leaf extract and bitter apple leaf extract also contributed to pest suppression but were relatively less effective.

Ginger-garlic chili extract was 10% devoid of leaf folder larvae on the treated plants 6 hours after release and the percentage of leaf area fed was 13.03% 48 hours after release (Rani 2013). Similarly, karanj oil followed by chili-garlic solution proved to be the most effective treatment, (Niyati and Gajbhiye 2017). Tuan et al (2014) found that the combination of chili and garlic was effective against diamondback. Baidoo and Mochiah (2016) reported that garlic and hot pepper, *Capsicum frutescens*, control cabbage pests *P. xylostella*, *Hellula undalis* and *T. ni*, reducing mortality by 10.76 to 55.94%. The plant product garlic + green chili was most effective against the defoliants *Spodoptera litura* and *Chrysodeixis acuta* in soybeans (Kushram et al., 2017). Narayanasamy et al. (2009) shown that calotropis leaf extract combined with onion, garlic and chilli powder had the maximum mortality for the brinjal fruit and shoot borer, pumpkin caterpillar and tapioca whitefly. Biorationals treatments, ginger + garlic + green chilli extracts 5 % was effective against leafhopper, *Amrasca biguttula biguttula* in okra (Kanimozhi et al., 2020). The botanical treatments, garlic and chilli extract (5 %) proved to be the most effective against rice yellow stem borer (Nishanthini and Kandibane 2021). Ladji et al. (2011) observed that combination of garlic chilli aqueous (2 %) and garlic chilli kerosene (0.5 %) showed the highest percentage of larvae population decrease (46.85 %) against *H. armigera*. Rahman et al. (2022) observed that garlic and chilli extracts exhibited strong repellent and antifeedant properties against *Chilo suppressalis*. The effectiveness of vitex, pongamia, and calotropis extracts against rice planthoppers provided sustainable pest control while reducing the risk of pesticide resistance (Alam et al., 2019). Garlic and chilli extract showed over 50 % mortality of *Helicoverpa armigera* larvae in chickpea fields, supporting its role as an

Table 1. Efficacy of botanical extracts against the leaf folder, *C. medinalis* during *Kharif* 2019

Treatments	Conc. %/ml/g per hectare	Mean per cent leaf damage/hill during *Kharif* 2019				Overall mean	Percent reduction over control
		Pretreatment count	1st Foliar spray#	2nd Foliar spray#	3rd Foliar spray#		
Five leaf extract	10	10.81[a]	8.12d	7.15 (15.51)[d]	4.93 (12.84)[d]	6.74	35.93
Garlic and chilli extract	5	11.06[a]	7.72 (16.13)[c]	6.64 (14.94)[c]	4.45 (12.18)[c]	6.27	40.40
Bitter apple leaf extract	10	10.77[a]	9.27 (17.72)[g]	8.34 (16.79)[g]	6.02 (14.20)[g]	7.88	25.10
Ponneem 45%	3750	11.01[a]	8.67 (17.12)[e]	7.61 (16.01)[e]	5.29 (13.29)[e]	7.19	31.65
Azadirachtin 0.03%	2000	10.98[a]	9.02 (17.48)[f]	7.94 (16.37)[f]	5.65 (13.75)[f]	7.54	28.33
Thiamethoxam 25 WG	100	10.53[a]	7.08 (15.43)[b]	6.21 (14.43)[b]	3.75 (11.17)[b]	5.68	46.01
Novaluron 10 EC	1000	11.05[a]	6.81 (15.13)[a]	5.86 (14.00)[a]	3.41 (10.64)[a]	5.36	49.05
Untreated check	-	10.75[a]	11.40 (19.74)[h]	11.88 (20.16)[h]	8.27 (16.71)[h]	10.52	

- Observed on pretreatment, 1, 3, 5, 7, 10, and 14 days following treatment
In a column mean followed by a common letter not substantially different by DMRT (*P*<0.05)

Table 2. Efficacy of botanical extracts against the leaf folder, *C. medinalis* during *Rabi* 2019-2020

Treatments	Conc. %/ml/g per hectare	Mean per cent leaf damage/hill during *Rabi* 2019				Overall mean	Percent reduction over control
		Pretreatment count	1st Foliar spray#	2nd Foliar spray#	3rd Foliar spray#		
Five leaf extract	10	11.06[a]	8.61 (17.07)[d]	7.66 (16.07)[d]	5.75 (13.88)[d]	7.34	32.16
Garlic and chilli extract	5	10.97[a]	7.74 (16.16)[c]	6.73 (15.03)[c]	4.99 (12.91)[c]	6.49	40.02
Bitter apple leaf extract	10	11.37[a]	9.70 (18.14)[g]	9.10 (17.56)[g]	7.91 (16.33)[g]	8.91	17.65
Ponneem 45%	3750	10.62[a]	8.86 (17.31)[e]	8.16 (16.59)[e]	6.24 (14.46)[e]	7.76	28.28
Azadirachtin 0.03%	2000	10.47[a]	9.33 (17.78)[f]	8.60 (17.05)[f]	6.90 (15.23)[f]	8.28	23.48
Thiamethoxam 25 WG	100	11.15[a]	6.47 (14.74)[b]	5.98 (14.16)[b]	4.46 (12.20)[b]	5.64	47.87
Novaluron 10 EC	1000	10.72[a]	5.82 (13.96)[a]	5.24 (13.23)[a]	3.57 (10.90)[a]	4.88	54.90
Untreated check	-	10.90a	10.96 (19.33)[h]	11.97 (20.24)[h]	9.52 (17.97)[h]	10.82	32.16

- Observed on pretreatment, 1, 3, 5, 7, 10, and 14 days following treatment
In a column mean followed by a common letter not substantially different by DMRT (P<0.05)

eco-friendly alternative to synthetic insecticides (Borah et al., 2022). Similarly, combination of garlic and chilli extracts effectively suppressed populations of major rice pests, including leaf folders and planthoppers (Zhang et al., 2020).

CONCLUSION

The foliar application of botanical extracts resulted in lower leaf damage compared to the control, particularly, garlic + chilli extract (5%) combination, against the rice leaf folder was observed. Among the conventional insecticides, Novaluron 10 EC at 1000 ml/ha, recorded minimum leaf damage and maximum percent reduction, signifying its higher efficacy. The findings emphasize that botanical insecticides, particularly garlic and chilli extract, offer an eco-friendly and effective alternative for managing rice leaf folder, reducing dependence on synthetic chemicals, preserving natural enemies and supporting sustainable rice production.

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Effect of Botanicals against *Callosobruchus maculatus* (Fabricius) in Stored Mung Bean

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***Abstract*:** The study evaluated three botanical biopesticides *viz*., azadirachtin (10,000 ppm), acorus oil and acorus powder for their efficacy against the pulse beetle, *Callosobruchus maculatus* (Fabricius 1775) in stored mung bean (*Vigna radiata* L.), with spinosad as a chemical check. Experiments were conducted under controlled laboratory conditions for a storage period of five months. The botanicals completely inhibited oviposition and adult emergence, resulting in zero insect damage and seed weight loss, while spinosad and untreated seeds showed progressive increases in oviposition, adult emergence, up to 44 per cent seed damage and 9 per cent weight loss. Seed quality parameters, including germination percentage (85-87%), seedling length (22.36 -21.14 cm), seedling dry weight (0.15- 0.14 gm) and vigour indices (S.V.I I-1953.95-1833.73, S.V.I II- 13.38-12.42) were significantly better preserved in botanical treatments compared to spinosad (39%) and control (32%). The results highlight the potential of azadirachtin @ 0.6%, acorus oil @ 2.5% and acorus powder @ 5g kg^{-1} as eco-friendly alternatives to synthetic insecticides for safe and sustainable management of pulse beetles in stored mung bean.

***Keywords*:** Mung bean, Pulse beetle, Seed quality, Seedling vigour, Storability, Storage Insects

Pulses are important sources of protein, dietary fibre and other essential nutrients. However, their production is severely constrained by insect pests, which cause significant quantitative and qualitative losses both in the field and during storage. Among these, pulse beetles (*Callosobruchus* spp.; Coleoptera: Bruchidae) are the most destructive storage pests. Economically important species include the adzuki bean weevil, *Callosobruchus chinensis* (Linnaeus), the cowpea bruchid, *Callosobruchus maculatus* (Fabricius) and the pulse weevil, *Callosobruchus analis* (Fabricius) (Singh and Boopathi 2021), with hosts ranging from mung bean, adzuki bean, rice bean, cowpea, pigeon pea, lablab, common bean, lentils, chickpeas to peanuts (Tuda et al., 2005, 2006). Adult females lay eggs singly on the smooth surface of seeds (Senthilraja and Patel 2024). The larvae develop inside the seeds, consuming the endosperm and upon completing the larval stage, metamorphose into pupae and adults emerge by boring through the seed coat, completing the life cycle and initiating new infestations. Pulse beetles can cause 30–40% loss within six months, which may escalate to complete loss if left unmanaged (Paikaray et al., 2022, Bhattarai et al., 2024).

The growing incidence of insecticide resistance in storage pests, coupled with concerns over harmful residues in food and the environment, has greatly limited the dependence on chemical insecticides and fumigants. In view of these problems, along with WTO regulations, there is a pressing need to restrict their use globally and to implement safer alternative methods of insect management. Botanical products, which are already being utilized in many countries, offer a promising solution. Plant-derived essential oils have demonstrated ovicidal, larvicidal, and repellent effects against a wide spectrum of insect pests and are increasingly recognized as environmentally safe alternatives to synthetic chemicals (Isman 2000, Cetin et al., 2004). Neem-based formulations, in particular, have shown considerable potential as natural grain protectants under tropical conditions (Saxena et al., 2018). *Acorus calamus* Linn. (Acoraceae), a perennial herb with insecticidal properties, has traditionally been used for stored-product pest management (Koul et al., 2008). Its rhizome-derived products, such as essential oil and powder contain α, β and γ asarone, which contribute to its insecticidal activity (Juan et al., 2009a, 2009b, Liu et al., 2013, Swamy and Wesley 2017). Similarly, spinosad, a biopesticide derived from the soil actinomycete *Saccharopolyspora spinosa* Mertz and Yao (Bacteria: Actinobacteridae) (Sparks et al., 1998), is increasingly adopted for the management of stored-product pests in several countries (Vayias et al., 2009, Mondal et al., 2018). Despite extensive research on botanical insecticides, comparative studies on their long-term efficacy in maintaining both pest control and seed quality in stored mung bean are limited. Hence, the present study was undertaken to evaluate the effectiveness of azadirachtin (10,000 ppm), acorus oil and acorus powder in comparison with spinosad against *C. maculatus* under laboratory storage conditions.

MATERIAL AND METHODS

The present study was carried out at the Entomology Laboratory, S.V. Agricultural College, Tirupati, Acharya N.G. Ranga Agricultural University, Andhra Pradesh, India during 2024-2025.

Insect collection: The initial mother culture of pulse beetle, *C. maculatus* adults were collected from pulse storage godown, Regional Agricultural Research Station, Tirupati. The collected pulse beetles were brought to the laboratory, Department of Entomology, S.V. Agricultural College, Tirupati and were mass multiplied on mung bean seed under laboratory conditions at 25± 2°C and 75% RH.

Maintenance of *C. maculatus* insect culture: The mass multiplication of *C. maculatus* was carried out in the plastic containers (11cm x 8 cm) containing mung bean seed. The adult beetles of mixed sexes were released and the container was covered with muslin cloth and secured with rubber band. The plastic jars were kept undisturbed till the emergence of adults and the freshly emerged F1 population was used for storage studies. Fresh seed lot of mung bean seed with high germination of > 99% was used for storage studies. Commercial neem formulation, neem azal *i.e.,* azadirachtin (10,000 ppm), acorus oil, acorus powder and spinosad (Tracer 45% SC) were purchased from local market in Tirupati.

Mung bean seeds were treated with azadirachtin (10,000 ppm), acorus oil (2.5%) and acorus powder (5g/kg) along with spinosad (Tracer 45% SC, 0.5 ml/kg) serving as the chemical check and untreated control was maintained without any seed treatment. The experiment was laid out in a Completely Randomized Design with five treatments and four replications. To achieve equal distribution treated mung bean seed in the containers was shaken for 5 minutes. The treated mung bean seed was shade dried and then 10 adult pulse beetles of mixed sex were released into the containers with 1 kg of mung bean seed. The containers were closed with muslin cloth for sufficient ventilation and were placed in continuous dark conditions in the laboratory. Insect damage (%), weight loss (%), F1 adult emergence, germination (%), oviposition, seedling length, seedling dry weight were recorded at two months intervals up to five months. Seedling vigour indices were calculated as follows:

Seedling vigour index-I= Per cent germination x Seedling length in cm (root length+ shoot length)

Seedling vigour index-II= Per cent germination x Seedling dry weight in grams

The initial germination of mung bean seed recorded was 100 % without any insect damage and maintained good seedling vigour indices I and II at 2469.94 and 19.22 respectively.

Statistical analysis: Percentage data were angular-transformed before analysis. Data was analyzed with SPSS and treatment means compared using Duncans Multiple Range Test (p≤0.05).

RESULTS AND DISCUSSION

Effect of Botanicals on Pulse Beetle, *C. maculatus* Damage of Stored Mung Bean

Oviposition: All the plant products viz., azadirachtin (10,000 ppm), acorus oil and acorus powder were found to be effective against *C. maculatus* in treated mung bean seeds up to 5 months of storage. No oviposition was observed on mung bean seeds treated with azadirachtin (10,000 ppm), acorus oil and acorus powder indicating complete inhibition of egg laying and development of *C. maculatus*. In contrast, spinosad and untreated control recorded progressive increase in egg deposition after one (5 and 6 eggs/100 seeds), three (197 and 212 eggs/100 seeds) and five months (310 and 319 eggs/ 100 seeds) of treatment respectively during the storage period (Table 1). These results are in line with works of earlier researchers who confirmed the strong deterrent and ovicidal properties of neem and acorus oils against *Tribolium castaneum* (Rani 2022) and *Rhyzopertha dominica* in rice (Anu 2023).

Adult emergence: Significant reduction in adult emergence (0%) was observed with azadirachtin (10,000 ppm), acorus oil and acorus powder up to five months of storage as nil egg laying was observed compared to untreated control with the emergence of 986 adults/ kg seed. The chemical check

Table 1. Effect of botanicals against pulse beetle, *C. maculatus* on oviposition, F1 adult emergence, grain damage and weight loss of stored mung bean

Treatment	Dose	Oviposition * (no. of eggs laid/ 100 seeds)			F1 adult emergence * (no./ per kg seed)			Pulse beetle damage (%)*			Weight loss (%)*
		1M	3M	5M	1 M	3M	5M	1M	3M	5M	5M
Azadirachtin 0.6%	5 ml/kg	0.0 b	0.0 c	0.0 b	0.0 b	0.0 c	0.0 c	0.0 b	0.0 c	0.0 c	0.0 c
Acorus oil 2.5%	5 ml/kg	0.0 b	0.0 c	0.0 b	0.0 b	0.0 c	0.0 c	0.0 b	0.0 c	0.0 c	0.0 c
Acorus powder	5 g/kg	0.0 b	0.0 c	0.0 b	0.0 b	0.0 c	0.0 c	0.0 b	0.0 c	0.0 c	0.0 c
Spinosad 0.05 %	5 ml/kg	5.00 a	197.00 b	310.00 a	37.00 a	619.00 b	939.00 b	2.07 a	29.75 b	42.11 b	8.70 b
Untreated control		6.00 a	212.33 a	319.00 a	40.00 a	644.00 a	986.00 a	2.20 a	33.41 a	44.46 a	9.00 a

*Data was recorded at 1,3 and 5 months after storage
Initial insect damage in mung bean seed- nil
Means followed by same letters are not significantly different (p ≤ 0.05) by DMRT

spinosad @ 0.5 ml /kg was found to be ineffective in suppressing the pulse beetles with the highest number of adult emergence on par with untreated control (939 beetles/ kg). The bruchid emergence was increased with increase in storage period with 37, 619 and 939 adults per kg mung bean seed treated with spinosad recorded after 1, 3 and 5 months of storage which is on par with untreated control (40, 644 and 986 adults) at 1, 3 and 5 months, respectively indicating decrease in residual toxicity of spinosad over the storage period as reported by Ammar et al. (2024) in stored cow pea against *C. maculatus*. The results also showed increased egg laying, insect damage, decreased vigour and germination over the storage period in cow pea seed treated with spinosad.

Insect damage: There was no insect damage with different plant products like azadirachtin, acorus oil and acorus powder and in mung bean seed treated with spinosad 42.11% damage was observed five months of storage of treated mung bean which is almost equal in untreated control (44.46 %). The lower efficacy of the spinosad might be due to the resistance developed by pulse beetle to the spinosad. Sarada et al. (2021) also reported the lower efficacy of malathion 50% EC against pulse beetle. The lower persistence of malathion against pulse beetle was reported because of high degradation of malathion by hydrolysis, photolysis and high temperature (Raghu et al., 2016).

Weight loss: The five months after storage about 9 % weight loss was recorded with untreated control followed by spinosad (8.7%). All the plant products *viz*., azadirachtin (10,000 ppm), acorus oil and acorus powder under study protected the mung bean seed for prolonged periods of storage without any insect damage and weight loss of mung bean seed.

Effect of Botanicals on Seed Viability and Vigour of Stored Mung Bean

Germination percent: Irrespective of the seed treatment, germination percentage declined with the increase in storage period. The seed quality parameters*, viz.* seed germination, seed vigour, seed moisture and seed storability declined progressively with the increase in storage period (Sarkar et al., 2012). But the germination was maintained above minimum seed certification standards (MSCS) of 80 per cent in mung bean seed treated with plant products *viz*., acorus oil (85.67%), azadirachtin (87.33%) and acorus powder (86.67%) after five months of storage. The chemical check, spinosad recorded very poor germination of mung bean (38.67%) which was on par with the untreated control (32.00%) which could be due to the high pulse beetle damage to mung bean seed (Table 3). Sanon et al. (2010) also revealed that spinosad (seed coating) reduced adult emergence and seed perforation in cowpea for up to 6 months; >80% reduction in emerging insects in contrary to current study. Raheem (2011) evaluated the residual and relative toxicity of spinosad against *C. chinensis* in mung bean seeds and after one month of storage, the germination percentage is high (98%), but later on it is decreased to 50.33% after five months of storage which is similar to the current study. They also observed that adult emergence is low during first month of storage but after five months of storage there is an increased adult emergence. The seed damage recorded was around 28.66% after five months of storage. They concluded that the spinosad is effective only for shorter periods but was ineffective during longer storage periods.

Seedling shoot length and root length: Seedling shoot length of mung bean was decreased with increase in storage period (Table 3). After five months of storage the highest shoot length was observed in azadirachtin (14.96 cm) and there are no significant differences found between the other treatments. The root length recorded during the different storage intervals exhibited significant reduction with the increased period of storage. After fifth month, highest root length was recorded with azadirachtin (7.40 cm) followed by acorus powder which was on par with acorus oil compared to untreated control (5.38 cm) and chemical check, spinosad (5.83 cm). Similar results were also reported by Rajasri and

Table 2. Effect of botanicals on root length, shoot length and total seedling length of mung bean seedlings at different storage intervals

Treatment	Dose	Root length (cm)*			Shoot length (cm)*			Seedling length (cm)*		
		1M	3M	5M	1 M	3M	5M	1M	3M	5M
Azadirachtin 0.6%	5 ml/ kg	8.96 [ab]	7.90 [a]	7.40 [a]	17.08	16.57 [a]	14.96	26.03	24.47 [a]	22.36 [a]
Acorus oil 2.5%	5 ml/ kg	8.06 [b]	7.30 [b]	6.70 [b]	16.46	16.00 [b]	13.76	24.87	23.57 [c]	21.64 [a]
Acorus powder	5 g/ kg	10.01 [a]	7.93 [a]	6.86 [ab]	16.92	16.03 [b]	14.28	26.93	23.97 [b]	21.14 [a]
Spinosad 0.05%	5 ml/ kg	9.55 [a]	6.70 [c]	5.83 [c]	17.62	14.83 [c]	12.69	27.17	21.53 [d]	18.51 [b]
Untreated control		7.80 [b]	6.67 [c]	5.38 [c]	16.80	14.73 [c]	13.71	24.60	21.40 [d]	19.09 [b]

See Table 1 for details

Table 3. Effect of botanicals on germination percentage, dry weight and seedling vigour indices of stored mung bean at different storage intervals

Treatment	Dose	Germination percentage*			Seedling vigour index I *			Dry weight (g)*			Seedling vigour index II *		
		1M	3M	5M	1 M	3M	5M	1M	3M	5M	1M	3M	5M
Azadirachtin 0.6%	5 ml/ kg	97.67 ^{b}	91.33 ^{a}	87.33 ^{a}	2543.45 ^{ab}	2234.60 ^{a}	1953.95 ^{a}	0.19 ^{b}	0.17 ^{a}	0.15 ^{a}	18.26 ^{b}	15.83 ^{a}	13.38 ^{a}
Acorus oil 2.5%	5 ml/ kg	97.00 ^{b}	90.00 ^{a}	85.67 ^{a}	2412.97 ^{b}	2121.27 ^{b}	1855.00 ^{a}	0.18 ^{b}	0.16 ^{b}	0.15 ^{a}	17.65 ^{c}	14.70 ^{b}	13.13 ^{a}
Acorus powder	5 g/ kg	99.33 ^{a}	91.00 ^{a}	86.67 ^{a}	2675.11 ^{a}	2180.97 ^{a}	1833.73 ^{a}	0.19 ^{a}	0.16 ^{b}	0.14 ^{b}	18.87 ^{a}	14.86 ^{b}	12.42 ^{a}
Spinosad 0.05%	5 ml/ kg	97.67 ^{b}	55.33 ^{b}	38.67 ^{b}	2653.19 ^{a}	1191.43 ^{c}	713.11 ^{b}	0.17 ^{b}	0.13 ^{c}	0.10 ^{c}	16.60 ^{d}	7.37 ^{c}	3.87 ^{b}
Untreated control		96.33 ^{b}	50.67 ^{c}	32.00 ^{c}	2368.89 ^{b}	1084.27 ^{d}	608.81 ^{c}	0.17 ^{b}	0.13 ^{c}	0.10 ^{b}	16.05 ^{e}	6.59 ^{d}	3.20 ^{b}

*Data was recorded at 1, 3 and 5 months after storage
Initial germination percentage- 100%, S.V.I 1-2469.94, S.V.I II- 19.22, Dry weight- 0.21g
Means followed by same letters are not significantly different ($p \leq 0.05$) by DMRT

Rao (2012) with chick pea treated with neem formulations protected the seed from pulse beetle damage for longer period without any loss in seed germinability and vigour.

Seedling vigour indices: In general, with increase in storage duration, the seedling dry weight was decreased among different treatments. After five months of storage, highest seedling dry weight of 0.15gm was recorded with azadirachtin (10,000 ppm), acorus oil followed by acorus powder (0.14 gm) compared to lowest dry weight of 0.10 gm with chemical check spinosad and untreated control. Irrespective of the seed protectants used for seed treatment, seedling vigour index I declined progressively over the period of storage. Gradual decrease in vigour was observed from first to fifth month after storage; azadirachtin (2543.45 to 1953.95), acorus oil (2412.97 to 1855.00), acorus powder (2675.11 to 1833.73), spinosad (2653.19 to 713.11) and control (2368.89 to 608.81). After five months of storage higher seedling vigour was observed in seeds treated with azadirachtin (1953.95) followed by acorus oil and acorus powder. The least was in spinosad (713.11) on par with the control (608.81) (Table 3). Similarly, the seedling vigour index II was also declined with increase in storage period. Five months after the storage, azadirachtin (13.38), acorus oil (13.13) and acorus powder (12.42) treated mung bean maintained highest vigour. All the bio pesticide treatments were found superior to untreated control (3.20). The chemical check spinosad has shown least seedling vigour (3.87) which is on par with the untreated control. Similar studies were conducted by Rajasri and Rao (2012) with neem products like neem oil and commercially available neem formulations *viz*., Econeem plus®, Neemindia ® and Neemazal ® for the control of pulse beetle, *C. chinensis* in stored Bengal gram and were compared with deltamethrin treatment as a chemical check and the results indicated that the neem formulations *viz*., Neemazal, Econeem plus and Neemindia were found to be very effective against *C. chinensis* in stored Bengal gram maintaining high viability and vigour of seed up to twelve months of storage. The lower germination and vigour in spinosad treatment may be due to higher seed perforations caused due to higher number of pulse beetles and spinosad @ 0.05% was found ineffective in managing the pulse beetle damage in mung bean whereas botanicals found to be superior to control the bruchid damage in mung bean and also maintained the vigour and viability of seed up to five months of storage.

CONCLUSION

Botanical biopesticides *viz.,* azadirachtin, acorus oil and acorus powder completely inhibited oviposition and adult emergence of *C. maculatus* in stored mung bean up to five months. These treatments also maintained seed germination and seedling vigour above minimum certification standards, whereas spinosad and untreated control recorded heavy seed damage and loss in quality. The safer and ecofriendly botanical pesticides *viz.,* Azadirachtin (10000 ppm), acorus oil @ 2.5% and acorus powder 5g/kg can be used for long term storage of pulses without any quantitative and qualitative losses due to hidden bruchid infestation. Further studies on large-scale validation under farmer storage conditions and seed godowns are warranted.

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Artificial Domiciliation, Foraging Behaviour and Biology of *Xylocopa fenestrata* F.

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Abstract: This study demonstrated that *Xylocopa fenestrata* F. exhibited specific nesting and foraging preferences. The bees selectively utilized dry bamboo nodes for nesting, constructing linear nest patterns. The preference was shown for bamboo nodes with diameters of 1.5 cm. Xylocopa bees were active pollinators of several crops, including sunhemp, pigeonpea, sesbania and drumstick. Foraging activity varies throughout the day, with peak visitations observed in sunhemp and drumstick during the mid-afternoon and bimodal activity (morning and afternoon) on pigeonpea flowers. *X. fenestrata* was found to be the dominant pollinator on both sesbania and drumstick.

Keywords: Pollinators, Foraging activity, Nesting behaviour, *Xylocopa fenestrata*

With the proliferation of monotonous agricultural landscapes that diminish biodiversity and reduce bee forage availability, research on wild and/or managed non-*Apis* bees can yield valuable insights into complementary pollinator species that could aid in food crop pollination in regions where honey bee colony maintenance is hindered or affected (Javorek et al., 2002, Hoehn et al., 2008, Brittain et al., 2013). The ability of giant carpenter bees (*Xylocopa* Latreille 1802, Hymenoptera: Apoidea) to pollinate has drawn attention in recent years. Reports indicate the successful use of giant carpenter bees in Australia and Israel for pollinating honeydew melons and greenhouse tomatoes (Hogendoorn et al., 2000, Sadeh et al., 2007, Keasar 2010). Carpenter bees belong to the family Apidae, genus , and Xylocopa subfamily Xylocopinae (Michener 2000). These species are important pollinators of numerous crops. In some crops where honey bees fail to effect pollination, carpenter bees act as efficient alternatives. Additionally, unlike honey bees, they may forage effectively under inclement weather conditions. They contribute significantly to the pollination of fruit, vegetable, and ornamental plants, thereby enhancing crop productivity and ensuring healthy seed set. There are two types of carpenter bees: small carpenter bees (*Ceratina* spp.) and large carpenter bees (*Xylocopa* spp.), the latter characterized by robust, hairy bodies.

The name *Xylocopa* is derived from the Greek word *xylokopos*, meaning 'wood cutter' (Scott et al., 1993). The primary characteristics of *Xylocopa* spp. include a large body size, elongated marginal cells, long prestigma, absence of stigma, and a robust, papillate distal portion of the wing (Kacchawa et al., 2020). Nesting behaviour and biology vary among species, ranging from solitary to semi-social or primitively eusocial forms, wherein the eldest female (mother or sister) feeds both young females and males via trophallaxis (Lucia et al., 2015). Large carpenter bees possess considerable potential for pollination of horticultural and agricultural crops due to their polylactic foraging habits, buzz pollination capability, year-round activity, adult hibernation, ability to forage under low-light conditions, and adaptability to artificial nesting substrates (Buchmann 2004, Keasar 2010).

Researchers worldwide have concluded that large carpenter bees are efficient pollinators of various crops, including eggplant, tomato, sunflower, squash, and passion fruit (Gerling et al., 1989, Sihag 1993, Mardan 1995). Carpenter bees were also observed actively foraging on drumstick, sweet orange, sesbania, pigeon pea, sunhemp, and acid lime at the Agricultural Research Station, Vijayarai, and surrounding farmers' fields. However, information on standardizing rearing techniques for *Xylocopa* spp. and other non-*Apis* pollinators remains limited. Hence, the present study was undertaken to address this gap.

MATERIAL AND METHODS

Floral rewards (nectar or pollen) by *Xylocopa* spp. during each floral visit was observed. Observations like extending their proboscises to the base of the corolla was visually checked for nectar collection while as during pollen gathering. Surveys of pollinating insects visiting the target crop were conducted throughout the flowering season once in three days. On each sampling date, insect activity was monitored continuously from the beginning of observable pollinator foraging in the morning until activity declined in the evening. Within each day of observation, standardized counts of pollinators were made at three predetermined time points (09:00, 13:00, and 15:00) to capture temporal variation in visitation rates. The foraging activity of *X. fenestrata* was recorded during flowering seasons of the crop during 2023-24. The foraging behavior was recorded at random spots of 1 m^2 area in a total area of 6 acres of the flowering species. The collected pollinators were preserved and were sent to ZSI, Kolkata for authentic identification.

Artificial domiciliation: For studying the nesting behaviour and standardization of rearing methodology of *X. fenestrata*, at three locations pandals were erected at ARS, Vijayarai with hollow bamboo nodes of different diameters *i.e.*, 1.0-2.70 cm and the most preferred diameters of bamboo nodes were observed and length of 2.0-2.5 m were kept for nest construction in four different directions *i.e.*, north, west, south and east. The data regarding nest preference was analyzed using ms excel.

The hollow bamboo nodes used for nesting were periodically monitored to observe the development of *X. fenestrata*. Nests were carefully opened to document the egg, larval, and pupal stages. The duration of each life stage (egg, larva, pupa) was recorded. After the emergence of adult bees, the nests were dissected to study their internal structure, including the number of brood cells, provision mass of the emerging bees.

RESULTS AND DISCUSSION

Foraging behaviour of *X. fenestrata*: The highest number of *X. fenestrata* visits was recorded at 3:00 pm (0.68 visits per 2 min) on sunhemp (*Crotalaria juncea*), coinciding with the highest number of flowers available (2.94 flowers per 2 min). The minimum time spent per flower was observed at 09:00 am (5.33 s) on sunhemp. Rahman and Deka (2013) reported the lowest visitation frequency during the morning hours (09:00–10:00 am). Similarly, on red gram (*Cajanus cajan*), the minimum visitation occurred at 09:00 am, while peak activity was observed at 09:00 am and 3:00 pm, with the highest number of flowers visited at 09:00 am (1.16 flowers per 2 min).

In drumstick (*Moringa oleifera*) and *Sesbania bispinosa*, *X. fenestrata* was the dominant pollinator, recording 0.73 and 0.59 visits per 2 min, respectively, and visiting a greater number of flowers (3.51 and 3.25 flowers per 2 min). The highest visitation rate of *X. fenestrata* on drumstick was observed at 3.00 pm (0.59 visits per 2 min), whereas the maximum number of flowers visited occurred at 09:00 am (3.65 flowers per 2 min) (Table 1).

Nest preference of *X. fenestrata*: *X. fenestrata* preferred bamboo as nesting material. The nests were built in an angled position in the shadow which might be due to convenience and protection from rain. The nests offered shelter for progeny and there was strong nest defence by *Xylocopa* sp. Despite a range of bamboo node diameters (1.0−2.70 cm) being provided, *X. fenestrata* showed a preference for nodes with diameters of 1.5, 1.6, and 1.7 cm for nest construction. The highest mean acceptance rate was in 1.5 cm nodes (41.75%), followed by 1.6cm with the lowest acceptance in 1.7cm nodes (22.87%). (Plate 2).

Biology: The adult female *X.fenestrata* lays eggs in nests provisioned with pollen and nectar. The developmental periods for the egg, larval, and pupal stages of *X. fenestrata* were 2, 10 and 26 days, respectively. The female scrapes the inner surface of the bamboo node and mixes the wood shavings with saliva to form individual brood cells. This masticated material is used to construct partitions, sealing each egg within its own cell. Each brood cell constructed by *X. fenestrata* females is provisioned with a mass of pollen and nectar that serves as a food source for the developing larva prior to pupation. Single egg is laid on the pollen-nectar

Table 1. Foraging activity of carpenter bees on flowers of different plant species

Time	Carpenter bee activity		
	No. of bees / 2 min	No. of flowers visited / 2 min	Time spent (sec)
On sunhemp			
9.00 AM	0.58	2.14	5.33
1.00 PM	0.58	2.49	6.03
3.00 PM	0.68	2.94	7.40
On pigeonpea			
9.00 AM	0.57	1.16	6.56
1.00 PM	0.46	0.82	3.79
3.00 PM	0.57	0.86	6.70
On sesbania			
9.00 AM	0.41	2.00	6.25
1.00 PM	0.46	2.25	6.98
3.00 PM	0.73	3.51	8.68
On drumstick			
9.00 AM	0.75	3.65	8.04
1.00 PM	0.62	2.25	6.06
3.00 PM	0.59	3.25	7.53

Table 2. Mean percentage distribution of different diameters of Bamboo nodes

Diameter of bamboo nodes	Mean percentage (%)
1.5 cm	41.75
1.6 cm	35.36
1.7 cm	22.87
CD (p=0.05)	08.74

provision. Female *X. fenestrata* typically constructs seven to eight brood cells within a single bamboo node. This process is repeated sequentially, resulting in a linear arrangement of cells within the bamboo tunnel. The total developmental period from egg to adult was approximately 38 days duration (Plate 1).

In 2023, nesting activity of *X. fenestrata* was recorded in November and December, with bamboo nodes containing eggs, larvae, and pupae, demonstrating active oviposition and brood development. In contrast, in 2024 the active breeding period shifted earlier, occurring from April to July with similar developmental stages present. This temporal shift in nesting activity across years indicates that *X. fenestrata* is multivoltine, producing multiple generations annually, and suggests that environmental or phenological factors may influence the onset and duration of breeding seasons. Developmental stages of *X. fenestrata* (Plate 1) in bamboo node at, ARS, Vijayarai at 2023-24.

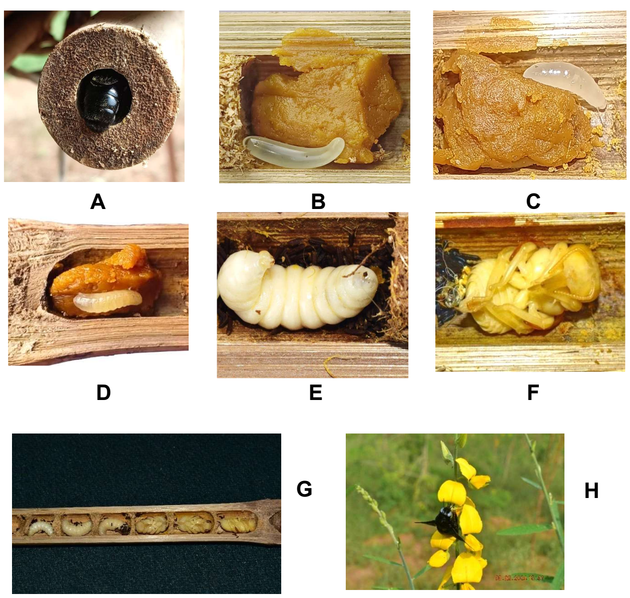

Plate 1. A: *Xylocopa fenestrata* nesting in 1.5 cm bamboo node, B: Egg laid in provisioned food (pollen+ nectar) C: Hatched egg, D: Grub, E: Pre-pupa, F: Pupa, G: Foraging of *X. fenestrata* on sunhemp, H: Different grub stages of *X. fenestrata*

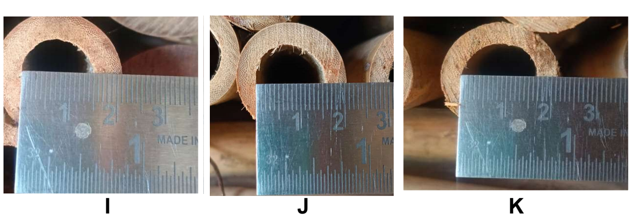

Plate 2. I: 1.5 cm diameter, J: 1.6 cm diameter, K: 1.7 cm diameter

CONCLUSION

X. fenestrata bees showed preference for dry bamboo nodes for nesting, constructing linear nest patterns. The preference was shown for bamboo nodes with diameters of 1.5 cm. Xylocopa bees were active pollinators of several crops, including sunhemp, pigeonpea, sesbania and drumstick. Foraging activity was observed in sunhemp and drumstick during the mid-afternoon and bimodal activity (morning and afternoon) on pigeonpea flowers. *X. fenestrata* was dominant pollinator on both sesbania and drumstick. For many agricultural crops, giant carpenter bees, *Xylocopa* sp. serve as highly efficient pollinators.

AUTHOR'S CONTRIBUTION

Mohan Rao K contributed to investigation, data curation, implementation, and writing/editing of the manuscript. Alekhya G assisted in literature collection, review, and editing. Kumar Naga provided supervision and validation. Sachin Suresh Suroshe was involved in conceptualization, project administration, and validation. Srinivas T contributed to review and editing. All authors have read and approved the final manuscript.

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Foraging Activity and Nesting Behaviour of Leafcutter Bees, *Megachile lanata* (F.) and *Megachile disjuncta* (F.)

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Abstract: This study investigated the nesting behaviour, nest architecture, substrate acceptance, and foraging activity of *Megachile lanata* and *Megachile disjuncta* during 2023–2024 at the Agricultural Research Station, Vijayarai, Andhra Pradesh, India. Both species exhibited distinct temporal foraging patterns and differential visitation rates across crops. Nesting occurred in pre-existing cavities, with both species constructing linear series of brood cells i.e., *M. lanata* used leaf material and red earth, whereas *M. disjuncta* employed wax-propolis mixtures. Mid-range substrate diameters (0.8–1.0 cm) were preferentially accepted, with species-specific differences in optimal diameters. Overall, this research helps to fill significant knowledge gaps in the nesting ecology of *M. lanata* and *M. disjuncta*, and supports further studies on their role as pollinators in diverse ecosystems.

Keywords: Nesting, Pollinators, Cells, Domiciliation, *Megachile lanata, Megachile disjuncta*

Megachilid genera are most commonly known as mason bees and leafcutter bees within the family Megachilidae (Hymenoptera) reflecting the materials from which they construct their nest cells i.e., soil or leaves respectively. Due to their long tongue, oligolectic foraging behaviour, faster foraging trips, and scopa on ventral side for collecting pollen, non- Apis bees are regarded as more effective pollinators than Apis pollinators of a large number of cultivated and wild flowering plants (Raina et al., 2023). *Megachile* species are solitary and highly adaptive and build their nests in pre-existing cavities, e.g., wooden logs, hollow stems of bamboo and roses, burrows in the soil, cracks and crevices, and slits in rocks or man-made structures. Some species use plant resins in nest construction and are correspondingly called resin bees which are also recognized as potential pollinators of the number of crops. Globally, the family Megachilidae is one of the largest families of bees, comprising over 50 subgenera and more than 3,000 angiosperm host species. Their ecological role and high pollination efficiency highlight the importance of conservation. The late 1950s saw the recognition of the benefits of employing leaf cutter bees as pollinators (Stephen et al., 1969, Bohart 1972). The genus *Megachile* and the family Megachilidae include several non-native imported bees, many of which are well represented in terms of species numbers. This is largely because they can be readily transported within vegetative portions as they nest in stems, twigs, and wood cavities (Russo 2016). *Megachile* is known to build its nest in bamboo reeds and use a mud and resin mixture to seal the cells (Osaka Museum collection 2017).

Each female constructs cells made from pieces of leaves and petals, hence the name leafcutter bee. These cells are placed in any of a wide variety of situations such as in hollow weed stalks, in curled leaves, or in holes in the ground. They may occur singly or in series, placed end to end. Each cell is provisioned with a viscous mass of honey and pollen, sufficient to provide food for the entire larval development. An egg is then laid on top of the food mass and the cell is closed with a cap made from additional pieces of petals and leaves. There are two types of favorable habitats which cause concentrations of the bees. One is called a nesting habitat as it provides nesting sites and pollen sources as well as nectar. So far as is known, all plants utilized for pollen also provide nectar, bees thrust their proboscices into the flowers to suck nectar while collecting pollen. The others called a nectar habitat, which provides flowers that are highly attractive as nectar sources but are not used for pollen, and may not have nesting sites in the vicinity (Young et al., 2016). Within this context, the present study focuses to document the nesting biology of *M. lanata* and *M. disjuncta* including describing the structure of their nests, the materials employed for construction of brood cells, and record the pollen resources used by females.

Pollination services provided by bees are vital for terrestrial ecosystems and agricultural productivity (Roig Alsina, 2008). However, intensification and expansion of agriculture remain two of the greatest global threats to biodiversity (Donald and Evans, 2006). Habitat destruction, fragmentation, reduced floral diversity, and the introduction of competing species pose significant challenges to native bee populations (Kremen et al., 2002, Silveira, 2004, Freitas et al., 2009, Medan et al., 2011). Studies from agro-ecosystems, such as those in the Inland Pampa (Durante and Torretta 2010), highlight the need for ecological research on bee diversity and nesting biology of leaf cutter bees.

MATERIAL AND METHODS

Study area: The study was conducted during 2023-2024 at Agricultural Research Station(ARS), Vijayarai (16.8121^{0}N and 81.0327^o E). A total of three pollinator sheds were erected at different locations at ARS, Vijayarai (Fig. 1). Bamboo nodes and *Saccharum spontaneum* sticks with diameters ranging from 0.5-1.5 cm and lengths ranging from 3-4 feet were installed in the pollinator sheds (Fig. 1). The bundles of Saccharum sticks and Bamboo nodes were stacked in a bundle of twenty-five each and were placed in pollinator shed (Table 2). The percent acceptance of *Saccharum* sticks and bamboo nodes by *M. disjuncta* and *M. lanata* was standardized and recorded. The observations on foraging activities of all the pollinators were recorded on sunny days undernormal temperature conditions. The activity of *M. lanata* and *M. disjuncta* was observed in the pollinators sheds to understand the nest preference by leaf cutter bees. The number of bees entering into and exiting out of bamboo nodes and saccharum sticks were recorded at three different intervals in a day i.e., 9 am, 1 pm and 3 pm. The sticks were cut longitudinally to observe various stages of young ones and to study the pattern of cell construction.

Floral hosts: The foraging activity of *M. lanata* and *M. disjuncta* was recorded during monthly visits to the study area (3–4 days per visit) by observing the foraging activity of adults on flowers of diancha (*Sesbania spinosa*), niger (*Guizotia abyssinica*) and sunhemp (*Crotalaria juncea*) at ARS, Vijayarai. These observations were made between 9:00 h and 16:00h on sunny days undernormal temperature on days when conditions were favorable for bee activity. The data for foraging activities of leaf cutter bees were recorded from initiation to cessation of blooms at three different intervals in a day *i.e*., 9 am, 1 pm and 3 pm. Furthermore, all plant species having entomophilous flowers were recorded during each visit.

RESULTS AND DISCUSSION

Foraging Activity of *Megachile lanata* and *Megachile disjuncta* on Various Crops

Foraging activity on Sesbania: *M. lanata* showed peak foraging activity at 1:00 PM, with an average of 0.62 visits per 2 minutes. However, the maximum number of flowers visited was at 3:00 PM, with 1.41 flowers visited per 2 minutes. Similarly, *M. disjuncta* also exhibited its highest foraging

a

b c

Fig. 1. a. Pollinators' shed with systematically arranged *Saccharum* sticks and Bamboo nodes to serve as nesting structures for leaf cutter bees; b. Bamboo nodes; c: Saccharum sticks

activity at 1:00 PM (0.62 visits/2 min), but demonstrated significantly greater flower visits, visiting 3.52 flowers/2 min at the same hour. This indicates that *M. disjuncta* is potentially a more efficient forager on Diancha than *M. lanata* during peak activity periods.

Foraging activity on Niger: For *M. lanata*, both peak foraging activity (0.67 visits/2 min) and maximum flower visits (2.89 flowers/2 min) occurred at 3:00 PM, suggesting a strong preference for afternoon foraging on this crop. *M. disjuncta* also exhibited its highest foraging rate on Niger at 3:00 PM, with 0.83 visits/2 min. Interestingly, the number of flowers visited was relatively low at this time, with only 0.46flowers/2 min. (Table 1).

Foraging activity on Sunhemp: *M. lanata* displayed peak activity at 1:00 PM (0.33 visits/2 min), while the highest flower visitation was recorded at 9:00 AM (1.60 flowers/2 min**).** This suggests a possible early morning preference for floral rewards, despite more frequent activity later in the day. *M. disjuncta* showed its highest activity at 9:00 AM (0.31 visits/2 min), with the number of flowers visited peaking at 3:00 PM (2.21 flowers/2 min). These findings indicate a broader temporal foraging range for *M. disjuncta* compared to *M. lanata*, especially on sunhemp (Table 1).

Overall, *M. disjuncta* demonstrated higher flower visitation rates than *M. lanata* on diancha and sunhemp, while *M. lanata* showed greater efficiency on Niger (Fig. 2). These patterns suggest crop-specific preferences and temporal variations in foraging behavior between the two species, which could be influenced by floral morphology, nectar availability, and environmental conditions.

Nest, cell structure and biology of *M. lanata*: The nests of *Megachile lanata* were constructed in alinear series, with each occupied *Saccharum* stick or bamboo node containing six to eight brood cells. Cell construction typically began at

Table 1. Foraging activity of *Megachile* sp. on sesbania, niger and sunhemp flowers at ARS, Vijayarai

Time	No of bees / 2 min	No of flowers visited / 2 min	Time spent (sec)	No of bees / 2 min	No of flowers visited / 2 min	Time spent (sec)
	Megachile lanata			*Megachile disjuncta*		
Sesbania						
9.00 AM	0.14	0.62	2.20	0.31	1.33	4.41
1.00 PM	0.62	1.33	4.45	0.56	3.52	6.60
3.00 PM	0.35	1.41	4.20	0.54	2.54	6.02
Niger						
9.00 AM	0.25	1.23	2.96	0.50	1.44	2.71
1.00 PM	0.41	2.21	4.87	0.55	2.25	6.12
3.00 PM	0.67	2.89	6.33	0.83	3.46	6.80
Sunhemp						
9.00 AM	0.29	1.60	1.41	0.31	2.21	4.96
1.00 PM	0.33	1.29	1.08	0.16	0.58	0.50
3.00 PM	0.18	0.62	0.75	0.12	0.31	0.56

Table 2. Percent acceptance of Saccharum and bamboo nodes of different diameters *M. disjuncta* and *M. lanata*

Megachile disjuncta			*Megachilelanata*		
Treatments	Percent acceptance		Treatments	Percent acceptance	
	Saccharum	Bamboo		Saccharum	Bamboo
T1 (0.7-0.8cm)	12.51	21.35	T1 (0.8-0.9 cm)	23.38	19.33
T2 (0.8-0.9 cm)	28.15	28.97	T2 (0.9 to 1 cm)	31.94	25.21
T3 (0.9 to 1 cm)	20.43	16.40	T3 (1.0 to 1.1 cm)	19.82	19.53
T4 (1.0 to 1.1 cm)	17.60	10.76	T4 (1.1 to 1.2 cm)	12.43	14.51
T5 (1.1 to 1.2 cm)	10.80	9.29	T5 (1.2 to 1.3 cm)	6.56	8.57
T6 (1.2 to 1.3 cm)	7.72	7.64	T6 (1.3 to 1.4 cm)	3.63	7.79
T7 (1.3 to 1.4 cm)	3.36	5.52	T7 (1.4 to 1.5 cm)	2.20	5.01
CD (p=0.05)	2.66	2.65	CD (P=0.05)	4.96	4.01

the nodal septum of the nesting substrate. Nests were built using both leaf material and red earth, with plant species such as redgram (*Cajanus cajan*), roselle (*Hibiscus sabdariffa*), sunhemp (*Crotalaria juncea*), and rose (*Rosa* spp.) serving as leaf sources. In nests where red earth was used for construction, the nestentrance was sealed with a mixture of red earth and saliva. All nests, regardless of the building material, were ultimately closed using this red earth–saliva mixture. Each brood cell measured between 0.9 to 1.4 cm in length and 0.4 to 0.5 cm in diameter. The developmental stages included: Early stage grub hatched from egg in 03 days, the grub period was 9 days and pupal period was 22 days (Fig. 3).

Nest, cell structure and biology of *M. disjuncta:* Nests of *Megachile disjuncta* were also arranged in a linear series, with each *Saccharum* stick or bamboo node containing six to eight cells. Like *M. lanata*, construction generally began at the nodal septum of the nesting substrate. However, unlike *M. lanata*, the nest entrances of *M. disjuncta* were left open, without any form of sealing. The cells were constructed using

Fig. 2. D. Foraging activity of *M. lanata* on flowers of Sunhemp; E. Foraging activity of *M.* F *disjuncta* on flowers of sesbania; F. Foraging activity of *M. disjuncta* on flowers of Niger

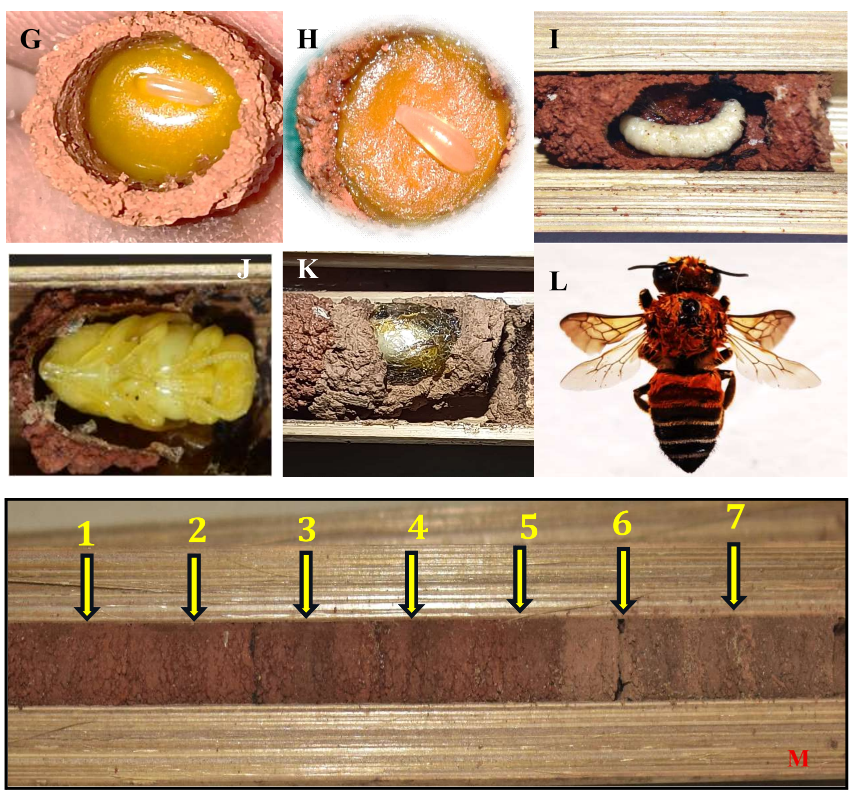

Fig. 3. Biology of *Megachile lanata* in Saccharum sticks& Bamboo nodes. G. Egg laid in provisioned food (pollen + nectar); H. Hatched egg; I. Grub; J. Pupa (inside view); K. Pupa (outside view); L. *Megachile lanata* (adult); M. Cells made of red earth constructed by *M. lanata*

a mixture of wax and propolis, and the interior walls of the sticks were polished with wax, giving them a smoother finish. Each brood cell measured 0.5-0.6 cm in length and 0.4-0.5 cm in diameter. The developmental stages followed the same pattern as in *M. lanata* (Fig. 4).

Pollen provisions: The pollen provisions inside the brood cells were yellow, moistened with nectar, and typically occupied about half of the cell volume. The egg was deposited in a slanting position on the pollen mass. After pupation, the cocoon filled the entire inner dimension of the cell and was composed of a thin silk layer embedded within a thicker, dark brown matrix. In cells constructed with red earth, brown fecal material was observed adhering to the external surface of the cocoon (Eickwort et al., 1981).

Nest Substrate Preferences of *M. lanata* and *M. disjuncta*

Percent acceptance of *Saccharum* sticks with different diameters: The selection of *Saccharum* sticks of varying diameters by leafcutter bees was assessed during 2023–24 to determine substrate preferences for nesting. For *Megachile disjuncta*, the highest acceptance was observed in T2 (0.8–0.9 cm diameter) sticks, with acceptance of 28.15%, followed by T3. In *Megachile lanata*, the highest preference was for T2 (0.9–1.0 cm), with an acceptance rate of 31.94%, followed by T1. These results suggest that *M. disjuncta* prefers slightly narrower sticks (0.8–0.9 cm), whereas *M. lanata* shows a higher preference for slightly wider sticks (0.9–1.0 cm). This difference may be attributed to variations in body size and nesting behavior between the two species (Table 2).

Percent acceptance of bamboo nodes with different diameters: Similar trends were observed in the acceptance of bamboo nodes as nesting substrates. For *Megachile disjuncta*, the highest acceptance was in T2 (0.8–0.9 cm) nodes with 28.97%, followed by T1. For *M. lanata*, the highest acceptance was again in T2 (0.9–1.0 cm) at 25.21%, followed by T3. These findings indicate that while both species show a strong preference for mid-range diameters (0.8–1.0 cm), *M. lanata* tends to prefer slightly larger diameters than *M. disjuncta*. The preference could be influenced by nesting requirements such as space for brood cells, ease of entry, or thermal insulation (Table 2). Mid-range diameters between 0.8 to 1.0 cm appear to be most suitable for both *M. lanata* and *M. disjuncta*. The slight variation in optimal diameters between the two species should be considered in conservation strategies and artificial nesting programs, especially if these species are to be used for pollination services in agricultural landscapes.

Kunjwal et al. (2021) reported that *Megachile (Eutricharea) studiosa* Bingham females constructed 1–6 brood cells per nest and used leaf pieces of three different sizes to build each cell. Female emergence occurred after 29 days. Kunjwal et al. (2021) observed that *M. disjuncta*, visited 30 species for nectar/pollen and 19 species for leaf material from 17 plant families. Dos Santos et al. (2020) analyzed the larval diet of *Megachile zapotlana* and concluded that the species was polylectic, with pollen sourced from 19 plant species, predominantly from the families of Asteraceae, Rubiaceae, Plantaginaceae, and Fabaceae. Similar nest-lining behaviors was observed in *Megachile cephalotes*, where females apply resin and other secretions to fortify cell walls and protect brood from desiccation and pathogens (Akram et al., 2022). Heroldovê et al. (2021) and Bogo et al. (2024) also reported the use of plant-derived materials in other groups, such as *M. ligniseca* and *M. sculpturalis*, both

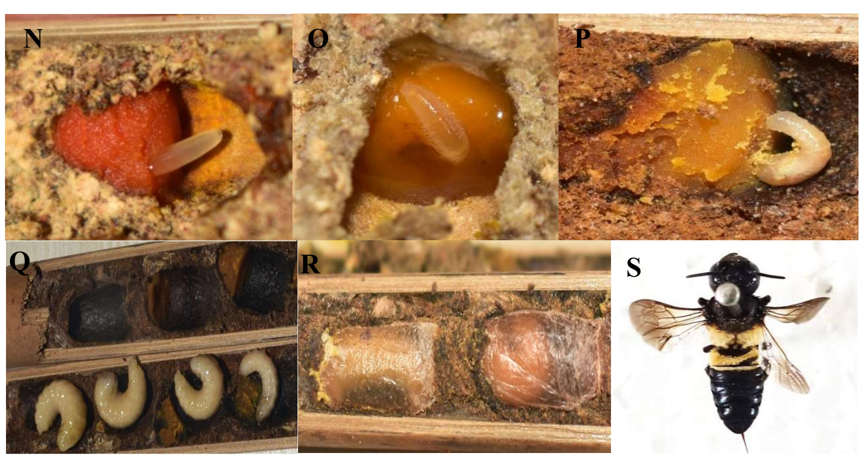

Fig. 4. Biology of *Megachile disjuncta* in Saccharum sticks and Bamboo nodes. N. Freshly laid Egg; O. Hatched egg; P. *M. disjuncta* grub feeding upon provisioned food(pollen + nectar);Q. Various grub stages; R. Pupal stages of *M. disjuncta;*S. *M. disjuncta* (Adult)

of which exhibit species-specific nest-building behaviors that enhance brood protection and structural stability. The brood-cell dimensions recorded in the present study (0.5–0.6 cm length, 0.4–0.5 cm diameter) fall within the lower size range reported for smaller-bodied *Megachile* species. Dos Santos et al. (2020) documented similarly compact cells in *M. zaptlana*, whereas larger species such as *M. sculpturalis* construct substantially wider and deeper cells due to their greater body size (Bogo et al., 2024). These variations demonstrate the strong morphological constraints that shape nest architecture across the genus. Comparable larval and pupal durations have also been reported in *M. cephalotes* and *M. zaptlana*, although slight variations occur depending on temperature, resource availability, and cell size (Dos Santos et al., 2020, Akram et al., 2022).

CONCLUSION

This study elucidated distinct foraging and nesting patterns in *M. lanata* and *M. disjuncta*. *M. disjuncta* generally showed higher visitation rates on *Sesbania* and sunhemp, while *M. lanata* displayed greater efficiency on Niger, indicating species−specific and temporally variable foraging behaviour. Both species built linear nests in Saccharum sticks and bamboo nodes, but differed in construction materials and brood cell dimensions. *M. lanata* used leaf fragments and red earth with sealed entrances, whereas *M. disjuncta* used wax propolis mixtures with open entrances. Brood cell provisioning and development patterns were consistent with those reported in other *Megachile* studies, in which linear brood chambers are provisioned with pollen and nectar mixtures and eggs are laid on the provision mass. The preference for mid−range nesting diameters (0.8–1.0 cm) reflects species−specific nesting requirements potentially linked to body size, a pattern also seen in related research where cavity diameter corresponded to bee morphology. These findings enhance understanding of the reproductive ecology of these leafcutter bees and necessitate conservation and artificial nesting strategies aimed at sustainable pollination services in agricultural landscapes.

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AUTHOR'S CONTRIBUTION

Mohan Rao K contributed to investigation, data curation, implementation, and writing and editing of the manuscript. Alekhya G assisted in investigation, literature collection, review, and editing. Kumar Naga provided supervision and validation. Sachin Suresh Suroshe was involved in conceptualization, project administration, and validation. Srinivas T contributed to review and editing. All authors have read and approved the final manuscript.

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Safety Assessment of Certain Newer Insecticides to Western Honey Bee, *Apis mellifera* L.

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Abstract: The widespread use of insecticides in agriculture has raised concerns about their potential impacts on non-target pollinators, particularly the European honey bee, *Apis mellifera* L which plays a key role in ecosystems and pollination services. The current study aimed to evaluate newer generation insecticides including neonicotinoids such as sulfoxaflor, flupyradifurone and pyrifluquinazon with respect to their effects on the honey bees. Laboratory bioassays were conducted to assess both acute and sublethal effects on worker bees including mortality. The results revealed that acephate and sulfoxaflor were highly toxic to honey bees causing the highest mortality in less time followed by chlorantraniliprole.

Keywords: Mortality, Honey bee, Safety, Insecticides, Toxicity

Excessive use of pesticides in modern agriculture, though vital for reducing crop losses and ensuring food security, poses a critical threat to pollinators. This has resulted not only in the contamination of agroecosystems and agricultural produce but also in the contamination of nectar and pollen, causing heavy losses to honey bees and other pollinators. Unfortunately, crop protection practices and pollinator conservation are not always compatible, as honey bees are susceptible to many commonly used pesticides (Sundararaju 2003, Brittain et al., 2010). Pollinators provide ecosystem services that are crucial for crop production and wild plant biodiversity. Hence, the conservation of honey bees for crop pollination is vital for sustaining agricultural productivity. The honey bee, a major pollinator, is experiencing global declines, raising concerns about ecological impacts, food security and human welfare. Multiple studies have focused on honey bees because their biochemistry and neurophysiology are better understood than those of other pollinators and bees can also serve as models for assessing pesticide risks to other insect pollinators. Among the major stressors affecting bee health, pesticides remain paramount particularly under prolonged or multiple exposures leading to increased mortality. Although neonicotinoids have been extensively studied, their use is increasingly restricted due to harmful effects on bees and rising pest resistance. Consequently, newer pesticides such as flupyradifurone, sulfoxaflor, pyrifluquinazon, fenpyroximate, and afidopyropen have recently entered the market, yet evidence indicates that these too may be detrimental to bees. A planned pollination strategy integrating the use of bee attractants and safer insecticides is crucial for enhancing crop productivity. Hence, the present study was undertaken to investigate the safety of novel insecticides to *Apis mellifera* L.

MATERIAL AND METHODS

The safety of certain newer insecticide molecules *viz*, sulfoxaflor 21.8% SC, flupyradifurone 17.09% SL, pyrifluquinazon 20% WG, fenpyroximate 5% EC, afidopyropen 4.89% DC, chlorantraniliprole 18.5% SC, flonicamid 50% WG and acephate 75% SP was evaluated against *A. mellifera* at Agricultural college, Bapatla (15.9039° N and 80.4671° E) Andhra Pradesh, India. The experiment was carried out under laboratory conditions by exposing a definite number (n=10) of bees to thin dry film of insecticide inside the plastic jars.

Bioassay using dry film method: The toxicity of the test insecticides to honey bees was assessed using the dry film method. Recommended doses of the insecticide solutions were prepared by diluting the required quantity of each commercial formulation in one liter of distilled water. From this, one ml of each of the insecticide solutions was applied as a thin film to the inner surface of clean dry rearing jar of size 10 x 7 cm diameter and the jar was gently rotated and left for drying so that a thin dry film of the insecticide was formed inside the jar. Forager honey bees were collected at the entrance of the hive with a cone-type muslin hand net (30 cm diameter) and transferred into plastic jars and were immobilized by refrigeration for approximately 5 min. Ten forager bees were released into each treated jar at intervals *i.e.*,0, 12 and 24 hours after dry film formation following the method of Ratnakar (2015). Since bees were exposed to insecticides any time after their spray in the field, these intervals were considered to understand the residual toxicity of the insecticides. A cotton pad soaked in sugar solution (20%) was provided inside the jar as food for bees and the jars were covered using muslin cloth. Each treatment was replicated thrice and a jar with a dry film of distilled water alone was served as untreated control.

RESULTS AND DISCUSSION

Mortality of honey bees exposed to insecticides immediately (zero hours) after treatment: Mortality data of *A. mellifera* workers exposed to insecticide dry films (Plate 2) at different intervals (Table 1). Immediately (zero hours) after the treatment, no mortality was observed in any treatment. However, 2 h after exposure, significant differences were evident among treatments. Acephate (56.66%) and sulfoxaflor (53.33%) caused the highest mortality, followed by chlorantraniliprole and flupyradifurone . Pyrifluquinazon and afidopyropen caused equal mortality (13.33%), while fenpyroximate (10.00%) and flonicamid (6.66%) recorded the lowest values. The order of toxicity was acephate > sulfoxaflor > chlorantraniliprole > flupyradifurone > pyrifluquinazon = afidopyropen > fenpyroximate > flonicamid.

At 4 h, acephate increased mortality to 76.66%, followed by sulfoxaflor (53.33%), chlorantraniliprole (30.00%), flupyradifurone (23.33%) and were statistically on par with pyrifluquinazon and fenpyroximate. Afidopyropen and flonicamid recorded the lowest mortalities. The toxicity order remained similar to the 2 h observations. At 6 h, acephate further increased mortality to 96.29%, followed by sulfoxaflor, chlorantraniliprole, caused moderate mortality. The flupyradifurone and pyrifluquinazon and fenpyroximate were on par. afidopyropen and flonicamid. By 12 h, acephate reached 100% mortality, followed by sulfoxaflor and chlorantraniliprole. Pyrifluquinazon, flupyradifurone, fenpyroximate and afidopyropen were statistically comparable. The lowest mortality was recorded in flonicamid (19.44%).

At 24 h, acephate and sulfoxaflor both caused 100% mortality. Chlorantraniliprole (59.72%) followed, while pyrifluquinazon (43.98%), fenpyroximate (46.75%), and flonicamid (43.17%) were statistically on par. Flupyradifurone and afidopyropen (31.94% each) recorded the lowest values.

At 48 h, acephate and sulfoxaflor continued to cause 100% mortality. Chlorantraniliprole recorded 95.23% mortality, followed by pyrifluquinazon (71.42%). Fenpyroximate (56.66%), afidopyropen (63.33%), and flonicamid (64.28%) were on par, while flupyradifurone recorded the lowest mortality (35.71%).

Overall, Acephate proved highly toxic, causing 100% mortality within 12 h, followed by sulfoxaflor which reached 100% mortality at 24 h. Chlorantraniliprole exhibited delayed but high toxicity (95.23% at 48 h). Pyrifluquinazon, fenpyroximate, and flonicamid showed a gradual increase in mortality, while flupyradifurone and afidopyropen consistently caused lower mortality across all intervals.

Mortality of honey bees exposed after 12 hours of insecticide treatment: After 2 h of release, Sulfoxaflor caused the highest mortality (33.33%), followed by chlorantraniliprole and acephate (Table 2). Flupyradifurone resulted in 13.33% mortality, while pyrifluquinazon, fenpyroximate, afidopyropen, and flonicamid caused no mortality. The order of toxicity was sulfoxaflor > acephate = chlorantraniliprole > flupyradifurone > pyrifluquinazon = fenpyroximate = afidopyropen = flonicamid.

After 4 h, sulfoxaflor again caused the highest mortality

Table 1. Effect of insecticides at recommended dose on mortality of *A. mellifera* exposed immediately after dry film formation

Treatment	Dose (ml or g/l)	0 h	2 h	4 h	6 h	12 h	24 h	48 h
Sulfoxaflor 21.8% SC	0.75 ml/l	0.0 (0.0)	53.33 (32.25)	53.33 (32.25)	66.64 (41.87)	79.16 (52.36)	100 (90.05)	100 (90.05)
Flupyradifurone 17.09% SL	0.5 ml/l	0.0 (0.0)	23.33 (13.50)	23.33 (13.50)	25.92 (15.03)	27.77 (16.13)	31.94 (18.64)	35.71 (20.93)
Pyrifluquinazon 20% WG	1.0 g/l	0.0 (0.0)	13.33 (7.66)	13.33 (11.54)	25.92 (15.03)	36.11 (21.18)	43.98 (21.10)	71.42 (45.60)
Fenpyroximate 5% EC	0.6 ml/l	0.0 (0.0)	10.00 (5.74)	10.00 (11.54)	22.22 (12.84)	27.77 (16.13)	46.75 (27.89)	56.66 (34.53)
Afidopyropen 4.89% DC	2.0 ml/l	0.0 (0.0)	13.33 (7.66)	13.33 (7.66)	14.81 (8.52)	24.07 (13.93)	31.94 (18.64)	63.33 (39.31)
Chlorantraniliprole 18.5% SC	0.3 ml/l	0.0 (0.0)	26.66 (15.47)	26.66 (17.47)	33.33 (19.48)	47.68 (28.49)	59.72 (36.69)	95.23 (72.27)
Flonicamid 50% WG	0.3 g/l	0.0 (0.0)	6.66 (3.82)	6.66 (3.82)	7.40 (4.25)	43.51 (25.80)	43.98 (25.59)	64.28 (40.02)
Acephate 75% SP	1.2 g/l	0.0 (0.0)	56.66 (34.53)	56.66 (50.07)	96.29 (74.38)	100 (90.05)	100 (90.05)	100 (90.05)
Untreated Control	-	0.0 (0.0)	0.0 (0.00)	0.0 (0.0)	10.00 (5.74)	13.33 (7.66)	13.33 (7.66)	26.66 (15.47)
CD (p=0.05)		-	10.43	14.76	17.59	16.20	22.21	22.10

Figures in parentheses are angular transformed values

(33.33%), followed by chlorantraniliprole and acephate which were statistically similar. No mortality was recorded in bees treated with pyrifluquinazon, fenpyroximate, and afidopyropen. The order of toxicity was sulfoxaflor > chlorantraniliprole = acephate > flupyradifurone > flonicamid > pyrifluquinazon = fenpyroximate = afidopyropen.

After 6 h, sulfoxaflor caused the highest mortality (53.33%), followed by acephate, chlorantraniliprole and flupyradifurone. No mortality was observed in pyrifluquinazon and fenpyroximate. The order of toxicity was sulfoxaflor > acephate > chlorantraniliprole = flupyradifurone > flonicamid > afidopyropen > pyrifluquinazon = fenpyroximate. After 12 h, similar trend was observed The order of toxicity was sulfoxaflor > acephate > chlorantraniliprole > flupyradifurone > flonicamid > afidopyropen > fenpyroximate > pyrifluquinazon.

After 24 h, sulfoxaflor recorded the highest mortality (91.66%), followed by acephate and flupyradifurone, pyrifluquinazon, chlorantraniliprole and afidopyropen with non-significant differences. Fenpyroximate recorded the lowest (11.57%). The order of toxicity was sulfoxaflor > acephate > flupyradifurone > pyrifluquinazon > chlorantraniliprole = afidopyropen > flonicamid > fenpyroximate.

After 48 h, cent percent mortality was recorded in sulfoxaflor and acephate treatments. Chlorantraniliprole caused 91.66% mortality, followed by flupyradifurone, pyrifluquinazon and fenpyroximate. Afidopyropen caused the least mortality (37.50%). The order of toxicity was sulfoxaflor = acephate > chlorantraniliprole > flupyradifurone > pyrifluquinazon = fenpyroximate > flonicamid > afidopyropen.

Overall, sulfoxaflor and acephate consistently showed high toxicity, with 100% mortality at 48 h. Chlorantraniliprole was moderately toxic, while flupyradifurone and flonicamid caused delayed but considerable mortality. Pyrifluquinazon, fenpyroximate, and afidopyropen exhibited negligible effects up to 6-12 h but showed moderate mortality after 24-48 h.

Mortality of honey bees exposed after 24 hours of insecticide treatment: No mortality was observed immediately (0 h) after bee release in any treatment. At 2 h after release, acephate caused the highest mortality (43.33%), whereas chlorantraniliprole (3.33%) and flupyradifurone (6.66%) were the least toxic (Table 3). Pyrifluquinazon, fenpyroximate, afidopyropen, and flonicamid caused no mortality. At 4 h, acephate remained the most toxic (43.33%). Chlorantraniliprole and flupyradifurone (6.66% each) and afidopyropen (10%) showed low mortality, while pyrifluquinazon, fenpyroximate, and flonicamid recorded no mortality. After 12 h, acephate caused the highest mortality (59.25%), followed by pyrifluquinazon and flonicamid (33.33%). Fenpyroximate (29.62%) and sulfoxaflor (25.92%) showed moderate effects, whereas afidopyropen and chlorantraniliprole (11.11% each) were comparatively low. Flupyradifurone recorded the least mortality (7.44%). At 24 h after release, acephate again recorded the highest mortality (90.47%), followed by flonicamid, pyrifluquinazon, fenpyroximate and sulfoxaflor.

Table 2. Effect of insecticides at recommended dose on mortality of *A. mellifera* exposed 12 hours after dry film formation

Treatment	Dose (ml or g/l)	2 h	4 h	6 h	12 h	24 h	48 h
Sulfoxaflor 21.8% SC	0.75 ml/l	33.33 (19.48)	33.33 (19.48)	53.33 (32.25)	77.77 (51.08)	91.66 (66.47)	100.00 (90.05)
Flupyradifurone 17.09% SL	0.5 ml/l	13.33 (9.40)	16.66 (9.60)	26.66 (15.47)	33.33 (19.48)	44.44 (25.39)	76.18 (49.65)
Pyrifluquinazon 20% WG	1.0 g/l	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	39.81 (23.47)	66.66 (41.83)
Fenpyroximate 5% EC	0.6 ml/l	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	3.70 (2.12)	11.57 (4.52)	66.66 (41.83)
Afidopyropen 4.89% DC	2.0 ml/l	0.0 (0.0)	0.0 (0.0)	10.00 (5.74)	11.11 (6.38)	36.11 (21.18)	37.50 (22.04)
Chlorantraniliprole 18.5% SC	0.3 ml/l	23.33 (13.50)	26.66 (15.47)	26.66 (15.47)	29.62 (17.24)	36.11 (50.24)	91.66 (66.47)
Flonicamid 50% WG	0.3 g/l	0.0 (0.0)	13.33 (7.66)	16.66 (9.60)	18.51 (10.67)	19.07 (11.00)	45.83 (27.29)
Acephate 75% SP	1.2 g/l	0.0 (0.0)	26.66 (15.47)	33.33 (19.48)	37.03 (21.75)	67.59 (42.55)	100.00 (90.05)
Untreated Control	-	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	10.00 (5.74)	23.33 (9.60)	20.00 (11.54)
CD (p=0.05)		8.08	10.94	20.62	17.20	25.02	20.69

Figures in parentheses are angular transformed values

Table 3. Effect of insecticides at recommended dose on mortality of *A. mellifera* exposed 24 hours after dry film formation

Treatment	2 h	4 h	6 h	12 h	24 h	48 h
Sulfoxaflor 21.8% SC	13.33 (7.66)	16.66 (9.60)	16.66 (11.54)	25.92 (15.03)	30.35 (17.68)	42.85 (25.39)
Flupyradifurone 17.09% SL	6.66 (3.82)	6.66 (3.82)	6.66 (3.82)	7.40 (4.25)	17.26 (9.94)	33.32 (19.47)
Pyrifluquinazon 20% WG	0.0 (0.0)	0.00 (0.0)	0.0 (0.0)	37.03 (21.75)	38.69 (22.77)	61.90 (38.26)
Fenpyroximate 5% EC	0.0 (0.0)	0.00 (0.0)	0.0^{d} (0.0)	29.62 (17.24)	34.52 (20.20)	61.89 (38.26)
Afidopyropen 4.89% DC	0.0 (0.0)	10.00 (5.74)	10.00 (5.74)	11.11 (6.38)	19.90 (11.48)	66.66 (41.83)
Chlorantraniliprole 18.5% SC	3.33 (1.91)	6.66 (3.82)	6.66 (3.82)	11.11 (6.38)	17.26 (9.94)	42.85 (25.39)
Flonicamid 50% WG	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	29.67 (17.27)	39.28 (23.14)	61.89 (38.26)
Acephate 75% SP	43.33 (25.69)	43.33 (25.69)	43.33 (25.69)	59.25 (36.35)	90.47 (64.82)	100 (90.05)
Untreated Control	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	23.33 (13.50)	30.00 (17.47)
CD (p=0.05)	6.60	6.60	6.60	8.20	14.39	34.02

Figures in parentheses are angular transformed values

Flupyradifurone and chlorantraniliprole were the least toxic (17.26% each).

At 48 h after release, cent percent mortality was observed in acephate-treated bees followd by flupyradifurone, afidopyropen, pyrifluquinazon fenpyroximate and flonicamid. Chlorantraniliprole and sulfoxaflor recorded the lowest mortalities (42.85% each).

Overall, acephate consistently caused the highest mortality, reaching 100% by 48 h. Flupyradifurone and afidopyropen showed delayed but substantial toxicity. Sulfoxaflor induced moderate mortality over time, whereas chlorantraniliprole, pyrifluquinazon, fenpyroximate, and flonicamid showed lower or delayed effects. These results indicate that residual toxicity varies considerably among newer insecticides and exposure timing is a critical factor in honey bee safety. Among organophosphates, acephate was found to be moderately to highly toxic, causing 37.05-100% mortality within 4-12 h of exposure. These findings are consistent with observations of Reddy and Reddy (2006), and Stanley et al. (2015). Chlorantraniliprole, a diamide, indicated low to moderately toxic, with mortality ranging from 3.33-95.23% at 2–48 h and is likely due to limited interaction with honey bee ryanodine receptors when in aqueous solutions (Dinter et al., 2010). Similar observations were reported by Hasanab et al. (2013), Stanley et al. (2015), Dinter and Samel (2015), Dai et al. (2017), Wade (2019) and Anwar et al. (2022) indicating diamides are generally safer for bees.

Flonicamid (pyridine group) exhibited low toxicity in the present study, with 6.66-64.28% mortality at 6-48 h. Anwar et al. (2022) and Meikle and Weiss (2022) also reported minimal effects on colony growth, behavior and worker longevity under field-realistic exposures. Pyrifluquinazon (pyridine azomethine derivative) was considered non-toxic to low-moderately toxic with mortality ranging 0-71.42% after 12-48 h. Wilson et al. (2019) also reported low toxicity of this compound to *A. mellifera*. Fenpyroximate (mitochondrial complex I electron transport inhibitor) showed moderate toxicity, with 0-66.66% mortality over 6-48 h. Similar trends were reported by Leite et al. (2018) and Dahlgren et al. (2012) indicating acaricides of this class can affect worker bee survival. Afidopyropen (pyropene group) caused moderate toxicity with mortality of 0-66.66% within 6-48 h. Recent studies indicate chronic exposure can result in mortality and nutritional deficiency in bees (Peng et al., 2023) and moderate toxicity to silkworms and earthworms (Wei et al., 2023, Hu 2008). Sulfoxaflor (sulfoximine) was highly toxic, causing 20-100% mortality over 6-48 h which in agreement with Li et al. (2021) and Chakrabarti et al. (2020), highlighting severe risk to honey bees. Flupyradifurone (butenolide group) exhibited low toxicity, with 6.66-71.98% mortality at 24-48 h. Chakrabarti et al. (2020) also reported limited lethality following contact exposure.

CONCLUSIONS

The study demonstrates that the toxicity of newer insecticides to *Apis mellifera* varies with chemical class and residual exposure time. Acephate and sulfoxaflor exhibited the highest toxicity, whereas flupyradifurone, pyrifluquinazon, fenpyroximate, flonicamid, and afidopyropen were relatively safer, showing low to moderate effects on honey bee mortality. These findings highlight the importance of selecting pollinator-friendly insecticides in integrated pest management programs and emphasize the need for further studies to develop sustainable strategies that minimize risks to honey bees and other essential pollinators.

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Population Dynamics and Eco-friendly Management of Root Grub and Root-knot Nematode using Entomopathogenic Nematode and Fungi in Small Cardamom

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***Abstract*:** The present investigation was undertaken to study the seasonal fluctuations and eco-friendly management of root grub, *Basilepta fulvicorne* (Jacoby) and plant-parasitic nematodes (PPN), *including Meloidogyne javanica* (Treub) in small cardamom from January 2022 to December 2023. This study documented that the *B. fulvicorne* incidence was negligible during November to January, with no grubs recorded from February to April 2022 and March to April 2023. Populations increased thereafter and peaked during September 2023. Plant-parasitic nematodes (PPN) populations followed a similar pattern, with minimum densities in February 2022 and January 2023, reaching a maximum during August 2023. Pearson correlation analysis showed a strong positive association between *B. fulvicorne* and PPN populations and significant correlations with rainfall, rainy days and relative humidity. The combined application of *Heterorhabditis indica* (ICRI EPN-18), *Metarhizium anisopliae* (ICRI MA RG-3), and *Purpureocillium lilacinum* resulted in complete suppression of *B. fulvicorne* and reduced root-knot nematode galling by more than 85 per cent, offering an effective eco-friendly management strategy for small cardamom.

***Keywords*:** Root-knot nematode, Cardamom, PPN, Entomopathogenic nematode root grub

Small cardamom, *Elettaria cardamomum* (L.) Maton belongs to the family Zingiberaceae and popularly known as the "Queen of spices" is grown under forest ecosystem. In India, it is cultivated over an area of about 73,795 hectares, primarily confined to the Western Ghats regions of Kerala, Karnataka, and Tamil Nadu (Narayana et al., 2017). Soil pests on small cardamom include cardamom root grub, *Basilepta fulvicorne* (Jacoby) and root knot nematodes (*Meloidogyne* spp.), which are considered as seasonal pests (Varadarasan et al., 2011). Among the root-knot nematodes (RKN), *Meloidogyne incognita* and *M. javanica* are of major importance, causing significant damage to the crop. Additionally, *Radopholus* sp. and *Pratylenchus* sp. are also recorded when cardamom is grown as an intercrop with arecanut, coffee, or banana (Praveena et al., 2013). In recent years, the excessive use of pesticides to manage *B. fulvicorne* and *Meloidogyne* spp. has led to the accumulation of chemical residues in cardamom soils, degrading soil health and leaving harmful residues on capsules, ultimately compromising the export quality of cardamom. The use of entomopathogenic fungi (EPF) such as *Metarhizium* and *Purpureocillium,* in combination with entomopathogenic nematodes (EPN) belonging to the genera *Steinernema* and *Heterorhabditis*, offers a promising alternative to chemical pesticides. The forest-based agroecosystem in which cardamom is cultivated provides a favourable environment for the survival and persistence of EPN populations (Poinar, 1990, Grewal and Georgis 1998). Among EPN species, *Heterorhabditis indica* (Josephrajkumar et al., 2005, Varadarasan et al., 2011), and *Oscheius* spp. (Pervez et al., 2016) has been reported to be effective biocontrol agents against *B. fulvicorne*. India has a great potential to exploit these beneficial nematodes, EPNs for the suppression of insect pests, however, the technology has yet to be developed and adopted at the farmer level. The seasonal incidence of *B. fulvicorne* and plant-parasitic nematodes (PPNs) in small cardamom remains poorly documented, yet is critical for understanding pest dynamics and designing effective management strategies. As cardamom is an export-oriented crop, minimizing pesticide residues in capsules is essential. Therefore, this study investigates the population dynamics of key soil pests and evaluates the combined efficacy of EPNs and EPFs for their eco-friendly management.

MATERIAL AND METHODS

Study area: The study was conducted at the research farm, Indian Cardamom Research Institute (ICRI), Spices Board India, Myladumpara, Idukki Dt., Kerala (longitude of 9^{0}8'E and latitude of 77^{0}2'N at an altitude 1050 MSL) from January 2022 to December 2023 in small cardamom ecosystem. Field experiments were conducted during June - November for two consecutive years 2022-23 and 2023-24 in naturally infested soil.

Population dynamics of *B. fulvicorne* and PPNs: The five-year-old Njallani Green Gold cultivar plot was selected for the study and population of grubs of *B. fulvicorne* and plant parasitic nematodes (PPN) were counted from randomly selected five plants in an acre which were maintained without pesticide application at monthly intervals throughout study period. For *B. fulvicorne*, the number of grubs per 15 cm^3 of soil was recorded as the mean of five samples (ICRI 2008 and Varadarasan et al., 2011). Similarly, for PPN, the number of nematodes per 200 cc of soil was determined during 2022-23 (Thomas and Goddard 1986, Giné et al., 2014). The population of *B. fulvicorne* and PPN was documented and then correlated with various weather factors, specifically maximum temperature (X_1), minimum temperature (X_2), relative humidity (X_3), rainfall (X_4) and rainy days (X_5). Subsequently, the obtained data was regressed for the prediction of the *B. fulvicorne* and PPN population. Statistical analyses were performed using the "Agricolae" package version 1.4.0 (Mendiburu 2015) and the correlation matrix with scatter plots graphs was prepared using "Performance Analytics" package for (Peterson et al., 2018) in R Studio 2025.09.2+418.

Culturing of EPN and EPF: Infective juveniles (IJs) of native isolate of EPN *Heterorhabditis indica*, a strain ICRI EPN - 18 (Vardarasan et al., 2011) and an isolate ICRI MA RG-3 of *Metarhizium anisopliae* (Metschn.) Sorokin were isolated in the grubs of *B. fulvicorne* from Cardamom Hill Reserve (CHR), Idukki district, Kerala (Fig. 1) were bio-assayed and both are found effective against cardamom *B. fulvicorne*. The EPN strain ICRI EPN -18 and an isolate ICRI MA RG-3 of Entomopathogenic fungi (EPF) were mass multiplied (Sydhic 2005 and Thiyagarajan et al., 2023) at ICRI, Myladumpara and used for field study.

Field experiments: The experiments consisted of eight treatments implemented in a randomized block design with three replications. Five-year-old 'Njallani Green Gold', a popular small cardamom cultivar was used, with each replication consisting of 12 plants. All standard agronomic practices were followed except pesticide applications. Based on preliminary studies, an EPN strain ICRI EPN -18 @ 4 lakhs IJs, native isolate ICRI MA RG - 3 of *M. anisopliae* @ 25g/plant and *Purpureocillium lilacinum*, previously known as *Paecilomyces lilacinus* @ 25g/plant which was collected from Cardamom Research Station, Kerala Agricultural University, Pampadumpara, Kerala were used along with vermicompost @ 2kg/plant. The treatments of bio-control agents consisted of eight treatments including untreated check (Table1). Two applications were given at 90 days intervals, first application during onset of monsoon (June) and second application during September (post monsoon). EPN infected *Galleria* cadavers were implanted in 7.5 cm away from the plant base at a depth of about 5cm. Care was taken to ensure adequate moisture before application of EPN and EPF. The data were recorded at 30 and 90 days after

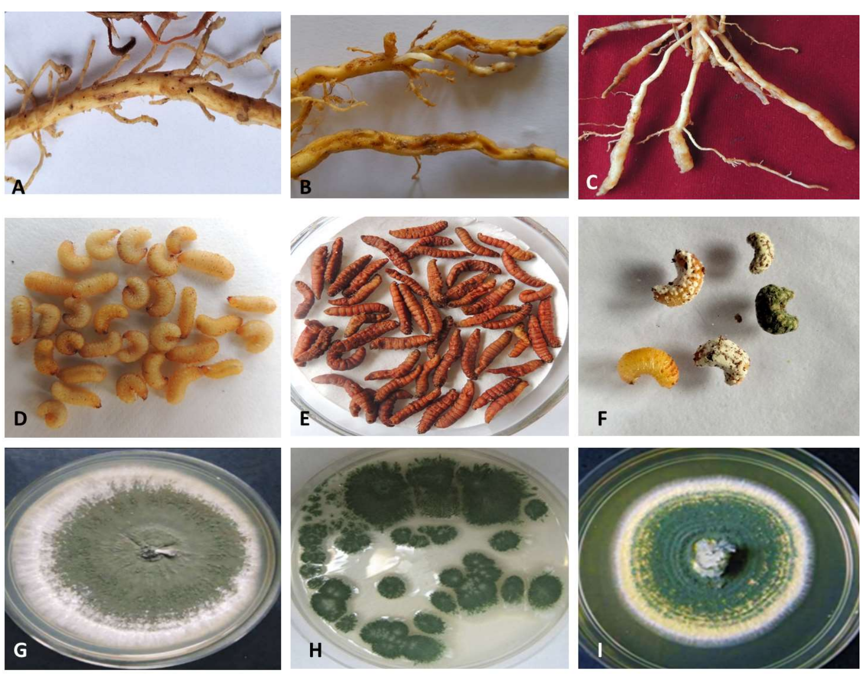

Fig. 1. A. Healthy cardamom root B. Root grub damage C. RKN damage D. Grub of root grub E. ICRI EPN - 18 strain F. Different growth stages of *M. anisopliae* on root grub G. *M. anisopliae* (ICRI MA RG -1) H. *M. anisopliae* (ICRI MA RG -2) I. *M. anisopliae* (ICRI MA RG -3)

treatment application from the randomly selected five plants of each plot. For *B. fulvicorne*, the population of grubs of *B. fulvicorne* counted in the soil in depth of 15cm^3 / plant (Varadarasan et al., 2011). For nematodes, number of galls (RKN) per 5g root were recorded and the initial nematode population per 200cc soil was recorded just before applying the treatments and 30 days and 90 days after treatment (Narayana et al., 2017) (Fig. 1). The percentage reduction (PR) of both root grub and nematodes over the untreated control was calculated as PR [(Control count - Treatment count/Control count) x 100] for each treatment following each application. Data were analysed using randomized block design in SPSS software version 16, and means were separated using Tukey's HSD test at $p \leq 0.05$.

RESULTS AND DISCUSSION

Population dynamics of *B. fulvicorne* and PPNs: Root grub, *B. fulvicorne* incidence remained negligible, with no grubs recorded from February to April 2022 and from March to April 2023 (Fig. 2). The highest population occurred in September 2022 and 2023, with 5.4 and 6.2 grubs, respectively and declining in the subsequent months. PPN populations fluctuated in a similar manner, and this showed that the prevailing weather conditions support their coexistence with the *B. fulvicorne* populations (Fig. 2). The lowest population density of PPN was recorded in February 2022 (12.4/200 cc) and January 2023 (12.6/200 cc). From may onwards, nematode populations increased steadily and peaked during the monsoon months. The highest PPN population was recorded in August 2023 (350.8/200 cc), with similarly high values in September 2022 (328.6) and other monsoon months (Fig. 3). Both *B. fulvicorne* and PPNs are more during rainy months due to adequate moisture in soil. Pearson correlation analysis showed a strong positive correlation between *B. fulvicorne* and PPN populations, exhibiting that both populations respond similarly to changes in environmental conditions. Both *B. fulvicorne* and PPN were also positively correlated with rainfall, the number of rainy days and relative humidity. These findings revealed that rainfall, humidity, and rainy days are the significant environmental factors that promote the populations of *B. fulvicorne* and PPN in the study area (Fig. 4). Similar trend was observed in the studies of Bora et al. (2023) and Dutta and Phani (2023) in large cardamom and other crops, where

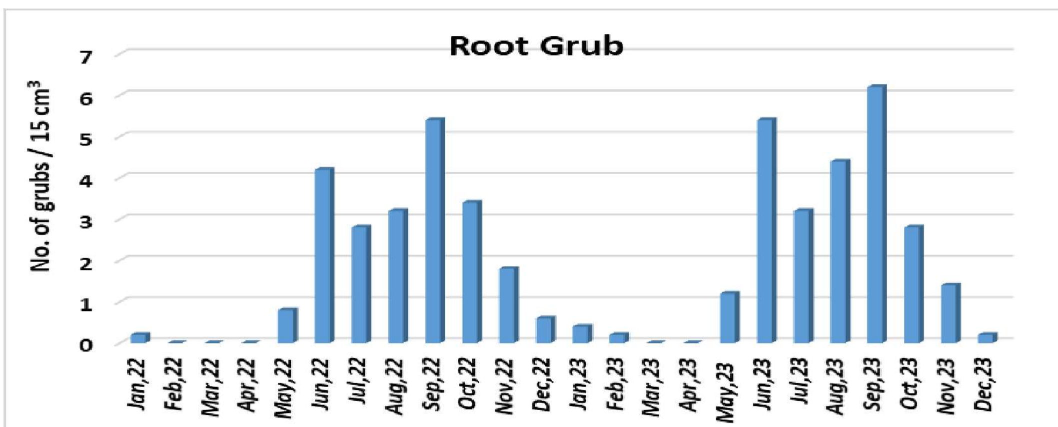

Fig. 2. Monthly variation in the incidence of *B. fulvicorne* on small cardamom during 2022-23

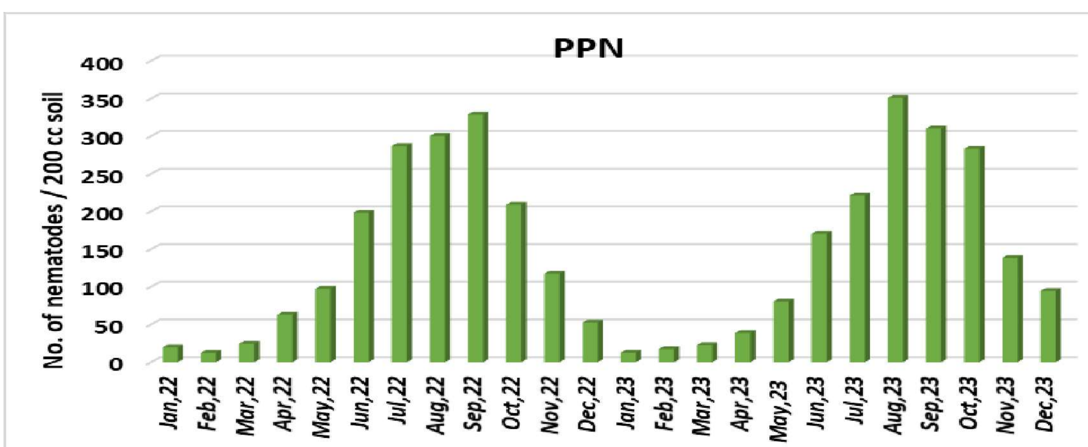

Fig. 3. Monthly variation in the incidence of PPNs on small cardamom during 2022-23

nematode abundance is closely linked to soil moisture, temperature, and rainfall.

The multiple regression analyses provided the linear equation for prediction of *B. fulvicorne* and PPN populations as $Y = -46.596+0.584(X_1)-0.502(X_2)+0.423(X_3)-0.004(X_4)+0.229(X_5)$ and $Y = -1094.874+18.516(X_1)-15.045(X_2)+9.150(X_3)+0.084(X_4)+9.548(X_5)$, respectively. The coefficient of determination (R^2) was recorded to be 47 per cent, and all the weather parameters together had a significant impact on *B. fulvicorne* and PPN populations, respectively. The seasonal fluctuations in *B. fulvicorne* and PPN populations in small cardamom appeared to be largely influenced by weather parameters and edaphic factors, both of which play a significant role in pest management and crop productivity (Varadarasan and Nagarajan 2014, Dutta and Phani 2023).

Field experiments: The pooled results from 2022–23 and 2023–24 showed that root grub populations increased in the untreated control but declined significantly across all treatments after application (Table 1). Among them, T7 consistently produced the highest suppression, *reducing B. fulvicorne* to near-zero levels after the second application, followed by T4. T1 also improved notably after the second application, while T3 alone resulted in only modest reductions. A similar pattern was observed for *M. javanica*. Nematode populations rose in the untreated control but were reduced most effectively by T7 (86.74% at 90 DAT), followed by T5 (Table 2). The ranking for gall reduction showed a clear superiority of T7 over all other treatments (Table 3). The enhanced performance of combined bioagents, particularly T7, indicates strong synergistic effects between EPNs and EPFs. Further, T7 also produced the highest capsule yield (900.90 kg/ha), substantially outperforming the untreated control. Varadarasan et al. (2011) observed 71-93%

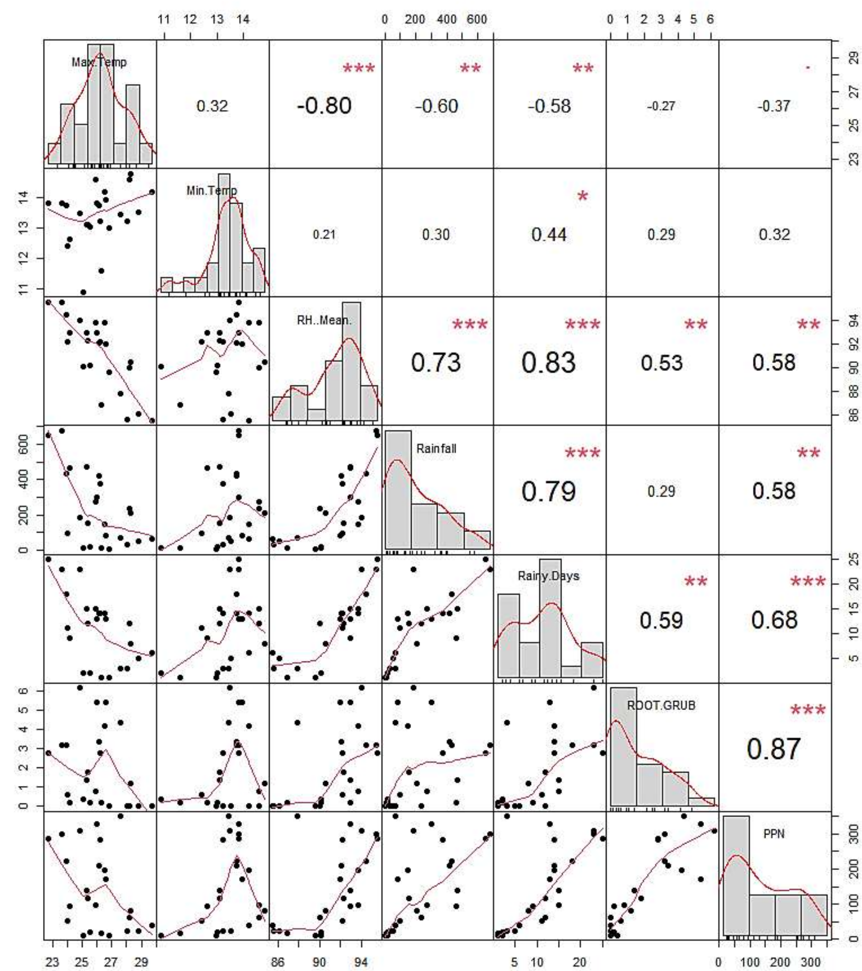

Fig. 4. The population of root grub and PPN in response to weather parameters.
(Graph's diagonal displays the distribution of weather parameters and RG & PPN population. On below, scatter plots with fitted lines. Above, correlation values and significance levels are provided; Each significance level is represented by p-values of 0.001 are denoted as "***", 0.01 as "**", 0.05 as "*" and 0.1 as ".", 1 as " ").

reduction of *B. fulvicorne* using EPN-infected *Galleria* cadavers, and Varadarasan and Nagarajan (2014) demonstrated that EPN-infected cadavers of *H. indica* were more effective than gel formulations in small cardamom. Similar observations by Pervez et al. (2016) highlighted *Heterorhabditis* sp. and *O. gingeri* as promising EPNs for

Table 1. Effect of EPN & EPF on incidence of *B. fulvicorne* in small cardamom

Treatments with Dosage / Plant	PTC	Mean grub population (15 cm^3 / Plant)					
		1 Application			2 Application		
		30 DAT	90 DAT	PR	30 DAT	90 DAT	PR
T_1 - EPN @ 4 lakhs IJs	3.07	2.66^c	0.73^c	76.08	0.60^c	0.13^b	92.00
T_2 - *M. anisopliae* @ 25g	3.13	2.73^d	1.06^d	65.21	0.66^c	0.20^b	88.00
T_3 - *P. lilacinum* @ 25g	3.20	3.73^f	2.26^e	26.08	4.80^d	1.20^c	28.00
T_4 - EPN @ 4 lakhs IJs + *M. anisopliae* @ 25g	3.00	1.80^b	0.46^b	84.78	0.33^b	0.06^{ab}	96.00
T_5 - EPN @ 4 lakhs IJs + *P. lilacinum* @ 25g	3.07	2.46^e	0.66^c	78.26	0.53b^c	0.13^b	92.00
T_6 - *M. anisopliae* @ 25g + *P. lilacinum* @ 25g	3.00	2.73^d	1.00^d	67.39	0.66^c	0.20^b	88.00
T_7 - EPN @ 4 lakhs IJs + *M. anisopliae* @ 25g + *P. lilacinum* @ 25g	3.20	1.60^a	0.26^a	91.30	0.06^a	0.00^a	100.00
T_8 - Untreated control	3.13	4.46^g	3.06^f	-	6.46^e	1.66^d	-

PTC: Pre-Treatment Count, DAT: Days After Treatment, PR: Percent Reduction Over Control
In column, means followed by common letters are not significantly different at (P=0.05) by DMRT

Table 2. Effect of EPN & EPF on population of PPNs in small cardamom

Treatments with Dosage / Plant	PTC	Number of nematodes/200g soil					
		1 Application			2 Application		
		30 DAT	90 DAT	PR	30 DAT	90 DAT	PR
T_1	175.30	152.00^f	212.30^f	30.15	212.30^f	75.30^f	37.56
T_2	176.00	171.60^g	242.60^g	20.17	243.60^g	87.00^g	27.90
T_3	174.60	129.00^d	145.60^d	52.08	102.00^d	34.60^d	71.27
T_4	175.00	138.30^e	188.30^e	38.04	191.60^e	72.00^e	40.33
T_5	174.30	112.60^b	119.60^b	60.63	84.00^b	28.30^b	76.51
T_6	175.60	124.00^c	143.00^c	52.96	98.60^c	31.00^c	74.30
T_7	175.00	109.30^a	104.30^a	65.67	80.00^a	16.00^a	86.74
T_8	174.00	201.60^h	304.00^h	-	325.30^h	120.60^h	-

See Table 1 for details

Table 3. Effect of EPN and EPF on incidence of root galls of *M. javanica* in small cardamom

Treatments with Dosage / Plant	PTC	Number of galls/5g root					
		1 Application			2 Application		
		30 DAT	90 DAT	PR	30 DAT	90 DAT	PR
T_1	14.33	11.33^e	17.66^f	27.39	20.33^f	14.00^f	31.14
T_2	14.66	13.66^f	19.33^g	20.54	23.00^g	15.66^g	22.95
T_3	14.00	9.33^d	11.66^d	52.05	10.66^d	5.66^d	72.13
T_4	14.00	11.33^e	16.00^e	34.24	19.00^e	13.00^e	36.06
T_5	14.33	8.00^b	10.33^b	57.53	8.33^b	5.00^b	75.40
T_6	14.66	9.00^c	11.00^c	54.79	8.66^c	5.33^c	73.77
T_7	14.00	7.66^a	8.66^a	64.38	7.00^a	3.00^a	85.24
T_8	14.00	15.00^g	24.33^h	-	28.66^h	20.33^h	-

See Table 1 for details

managing *B. fulvicorne*, while the pathogenicity of *M. anisopliae* against root grub was earlier confirmed under laboratory and field conditions (Sydhic 2005, Varadarasan et al., 2002). These results corroborate earlier findings of Narayana et al. (2017), where *P. lilacinum* and other bioagents showed high efficacy against root-knot nematodes in cardamom. Studies in other crops further support the present results that PPN suppression by *Steinernema rarum* and *H. bacteriophora*, while increased EPN application rates enhanced PPN and RKN, *M. incognita* suppression in tomato (Perez and Lewis 2002, Caccia et al., 2012, Khan et al., 2016). The present study has shown that two rounds application with combination of bio-control agents, EPN @ 4 lakhs IJs + *M. anisopliae* @ 25g + *P. lilacinum* @ 25g/plant was proved to be most effective against for reducing the population of both *B. fulvicorne* and *M. javanica* in cardamom soil besides encouraging microbial load in soil, which are also earlier reported by workers on small cardamom and other crops, that confirm the current investigation.

CONCLUSIONS

The current findings demonstrate that both root grub, *B. fulvicorne* and PPNs in small cardamom are closely associated with seasonal rainfall patterns, peaking during monsoon periods. Notably, the combination of bio-agents approach utilizing *Heterorhabditis indica* @ 4 lakhs IJs, *Metarhizium anisopliae* @ 25g, and *Purpureocillium lilacinum* @ 25g /plant offers excellent suppression of both pest's population and root gall formation. In light of these results, it is recommended that this eco-friendly pest management strategy be adopted in cardamom cultivation, with further trials conducted under diverse agro-climatic conditions to refine the protocols for maximum efficacy and farmer acceptance.

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AUTHOR'S CONTRIBUTION

All authors contributed significantly to the development of this work. P. Thiyagarajan contributed for population dynamics and supervised the research process. K. A. Saju and Arthra Ancy Joseph involved for characterization and multiplication of multiplication of *Metarhizium*. L. Gopianand performed the analysis the data and interpretation. A. B. Rema Shree edited, and approved the final version of the manuscript.

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Efficacy and Economic Evaluation of Various Biopesticides against *Helicoverpa armigera* in Chickpea

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Abstract: The field experiment conducted at Govind Ballabh Pant University of Agriculture and Technology, Pantnagar evaluated the efficacy of various biopesticides, including *Beauveria bassiana*, *Bacillus thuringiensis*, neem seed kernel extract (NSKE), and neem leaves extract, alongside the chemical insecticide chlorantraniliprole 18.5% SC against *Helicoverpa armigera* in chickpea during the *Rabi* 2024-25 season. Chlorantraniliprole consistently suppressed larval populations most effectively, achieving the lowest larval density (1.07 larvae/plant at 3 days after first spray) and maintaining superior control through subsequent observations. Among biopesticides, *B. bassiana* and NSKE recorded moderate larval control. In terms of pod damage and yield, chlorantraniliprole recorded the lowest pod damage (14.8%) and highest grain yield (789.67 kg/ha), while *B. bassiana* and neem seed kernel extract showed moderate pod damage (23.75% and 32.06%) with significant yield increase (718.31 kg/ha and 632.45 kg/ha). Biopesticide *B. bassiana* showed the highest incremental cost-benefit ratio (6.98), indicating greater economic efficiency compared to chlorantraniliprole (ICBR 5.57).

Keywords: *Beauveria bassiana*, Biorational, Chickpea, Incremental cost-benefit ratio, Management

Chickpea (*Cicer arietinum* L.), commonly known as Bengal gram is one of the most vital grain legumes worldwide, especially in underprivileged regions due to its significant nutritional value (Kumara Charyulu and Deb, 2014). Globally, chickpea ranks third among pulse crops, following peas and soybeans, representing about 15% of the global pulse production (Noreen et al., 2024). In addition to its dietary importance, chickpea supports sustainable agriculture by improving soil fertility when included in cereal-based crop rotation systems. India is a leading chickpea producer, with production reaching 13.75 million tonnes over 10.91 million hectares in 2021-22, yielding 12.6 q/ha (DES 2023, MOAF&W, GoI). Chickpea contributes nearly half of India's total pulse production with Maharashtra, Madhya Pradesh, Rajasthan, Gujarat, and Uttar Pradesh as the principal cultivating states. Rajasthan, in particular, cultivates chickpea on 2.25 million hectares, producing 2.66 million tonnes at 1177 kg/hectare productivity (E&S Division, DA&FW, 2022).

However, chickpea yields face threats from various biotic and abiotic stresses, including diseases such as *Ascochyta* blight, *Botrytis* gray mold, fusarium wilt, root rot, and stunt, along with insect pests like *Helicoverpa armigera*, aphids, black cutworm, bruchids, semiloopers, and leaf miners (Gurjar et al., 2011). Among these, *H. armigera* (Hübner), the gram pod borer, stands out as the most destructive pest, causing 30–40% pod damage on average, which can escalate to 80–90% in severe infestations, leading to yield reductions exceeding 75% (Patil SB et al., 2017). Over the past decade, several outbreak events have resulted in yield losses of 10–80%, translating into approximately US$328 million in economic losses annually in semi-arid tropics chickpea production (Patil et al., 2017). On a global scale, *Helicoverpa* damage to cotton, legumes, vegetables, and grains exceeds US$2 billion yearly, with over US$1 billion spent on control measures (Mahmood et al., 2021). The larvae damage tender leaves, flower buds, and pods, causing crop defoliation and yield losses of up to 400 kg/ha. Field surveys consistently identify *Helicoverpa* infestation as a primary constraint to chickpea productivity and quality, where one larva can destroy up to 40 pods during its lifecycle (Taggar and Singh, 2011, Ojha et al., 2017).

Insecticides remain the predominant method for controlling *H. armigera* globally; however, persistent challenges such as widespread resistance development have led to the pest's classification as a national threat in India (Golla et al., 2018). The repeated use of conventional insecticides has resulted in resistance to multiple chemical classes and disrupting natural crop ecosystem making pest management increasingly difficult and unsustainable. Consequently, there is an urgent need for insecticides that leave minimal residues and pose lower environmental risks. This study aims to evaluate and compare the efficacy of selected biopesticides against recommended insecticides through cost-benefit analysis to identify effective and environmentally safer management options for controlling gram pod borer, *H. armigera*, in chickpea.

MATERIAL AND METHODS

Field experiments on chickpea were conducted at G.B.

Pant University of Agriculture & Technology, Pantnagar, Uttarakhand, India, during the *Rabi* season of 2024-25. The chickpea variety PG-186 was sown in the first week of November with a row-to-row spacing of 30 cm and a plant-to-plant spacing of 10 cm. Seeds were planted in uniformly sized plots measuring 5 meters by 4 meters, and the crop was managed following recommended agronomic practices. Randomized block design with three replications was used for the trials to ensure statistical accuracy. Six treatments, including a control, were tested: *Beauveria bassiana* (400 g/ha), neem seed kernel extract (NSKE) at 5% (25 kg/ha), neem leaf extract (prepared fresh from 200 g leaves steeped overnight and diluted to 4 liters to achieve a 5% concentration), *Bacillus thuringiensis* (1 l/ha), Chlorantraniliprole 18.5% SC (30 g active ingredient/ha or 0.3 ml/l, the recommended insecticide), and an untreated control. All formulated treatments were sourced commercially from the market except for the neem leaf extract, which was freshly prepared. For neem leaf extract, 200 grams of neem leaves were weighed and mixed with distilled water, steeped overnight, and filtered through muslin cloth, followed by dilution to 4 liters with distilled water to achieve a 5% concentration.

Two foliar sprays were applied, the first at the economic threshold level of (one larva/meter row) and the second 15 days later. Larval populations of *H. armigera* were recorded 24 hours before spraying and again at 3, 7, and 10 days after each spray from five randomly selected plants per plot. Pod damage was assessed by calculating the percentage of damaged pods out of the total pods, and yield increases were calculated as a percentage increase over the control yield (El Fakhouri et al., 2022). The collected data were statistically analyzed using R softwere and SPSS version 16 to ensure the reliability of the results.

RESULTS AND DISCUSSION

The pre-treatment data revealed that the mean larval population of *H. armigera* per plant did not differ significantly among the various treatments and the untreated control, one day prior to the first spray during *Rabi* 2024–25 season, indicating a uniform pest distribution across the experimental plots. There were significant differences in larval populations among the treatments, beginning from 3 days after the first spray (3 DAFS) (Table 1). At 3 DAFS, chlorantraniliprole 18.5% SC recorded the lowest mean larval population (1.07 larvae/ plant), followed by *B. bassiana*, *B. thuringiensis* NSKE) and Neem leaves extract. The untreated control recorded the maximum larval population (2.27 larvae/plant). At 7 DAFS, chlorantraniliprole 18.5% SC continued to maintain the lowest larval population (0.93 larvae/plant) At 10 DAFS, chlorantraniliprole 18.5% SC again recorded the minimum larval density (1.33 larvae/plant), followed by *B. bassiana*, NSKE, *B. thuringiensis* and neem leaves extract. All treatments were significantly superior to the untreated control (5.13 larvae/plant).

The second spray was done after 15 DAFS, and the larval population of *H. armigera* was recorded 24 hours before the second spray, the larval population ranged from 3.20 to 5.53 larvae/plant, At 3 days after second spray, chlorantraniliprole 18.5% SC was significantly more effective than all other treatments, recording the lowest larval population, followed by *B. bassiana*, NSKE, *B. thuringiensis*, and neem leaves extract. In contrast, the maximum larval density was recorded in the untreated control (6.80 larvae/plant). At 7

Table 1. Efficacy of biopesticides and chlorantraniliprole against *H. armigera* in chickpea during 2024-25

Treatments	1st Spray				2nd Spray				Pod damage (%)**	Pod damage reduction over control (%)
	Mean population of *H. armigera/* Plant*				Mean population of *H. armigera/* Plant*					
	Pre Count	3 DAS	7 DAS	10 DAS	Pre Count	3 DAS	7 DAS	10 DAS		
Beuveria bassiana	0.33	1.27 (1.13)	2.20 (1.48)	2.40 (1.55)	3.20 (1.79)	3.73 (1.93)	3.53 (1.88)	2.73 (1.65)	23.75 (29.13)	70.85
Neem seed kernel extract	0.40	1.87 (1.37)	2.80 (1.67)	3.20 (1.79)	4.27 (2.07)	3.93 (1.98)	4.00 (2.00)	4.20 (2.05)	35.80 (36.75)	56.04
Neem leaves	0.33 (0.58)	1.60 (1.26)	3.67 (1.91)	3.80 (1.95)	4.60 (2.14)	4.27 (2.07)	5.67 (2.38)	5.87 (2.42)	57.56 (49.33)	29.33
Bacillus thuringiensis	0.27	1.80 (1.34)	3.13 (1.77)	3.53 (1.88)	4.00 (2.00)	4.13 (2.03)	4.27 (2.07)	4.80 (2.19)	38.26 (38.19)	53.03
Chlorantraniliprole 18.5% SC	0.33	1.07 (1.03)	0.93 (0.97)	1.33 (1.15)	3.47 (1.86)	2.33 (1.53)	1.53 (1.24)	2.40 (1.55)	14.80 (22.61)	81.83
Control	0.40	2.27 (1.51)	4.80 (2.19)	5.13 (2.27)	5.53 (2.35)	6.80 (2.61)	7.90 (2.81)	8.00 (2.83)	81.45 (64.50)	--
CD (p=0.05)	NS	(0.08)	(0.08)	(0.12	(0.18)	0.075	0.106	0.125	2.72	--

Values in parenthesis are *√x+0.5 transformed, and **angular transformed values;
Means followed by same alphabet in columns did not differ significantly (p=0.05) by DMRT

DAS, reduction in larval population was observed in chlorantraniliprole 18.5% SC-treated plots (1.53 larvae/plant), was statistically superior to all other treatments. The next best performance was *B. bassiana* (3.53 larvae/plant), followed by NSKE, *B. thuringiensis*, and neem leaves. At 10 DAS, a slight increase in the larval population was recorded across treatments. Chlorantraniliprole 18.5% SC maintained the lowest larval density (2.40 larvae/plant), followed by *B. bassiana* and NSKE. *B. thuringiensis* (4.80 larvae/plant) and neem leaves extract were statistically comparable and significantly superior to the untreated control .

In terms of pod damage and yield chlorantraniliprole 18.5% SC recorded the lowest pod damage percentage (14.80%) and the highest pod damage reduction over control (81.83%) (Table 1, 2) and recorded the maximum average grain yield (789.67 kg/ha), representing a 139.22% yield increase over control, indicating efficacy in protecting the crop and enhancing productivity. Among the biocontrol and botanical treatments, *B. bassiana* and NSKE were statistically at par, resulting in moderate pod damage (23.75% and 32.06%) and yield increases of 117.60% and 91.59% over control, respectively. *B. thuringiensis* showed similar effectiveness to NSKE. Neem leaves were less effective, showing higher pod damage (57.56%) and a lower yield (479.23 kg/ha). The control showed the highest pod damage (81.45%) and lowest grain yield (330.10 kg/ha).

In terms of ICBR value, *B. bassiana* recorded the highest ICBR value of 6.98 and a net gain of Rs. 19,183 over the control. Although the chemical insecticide chlorantraniliprole 18.5% SC resulted in the maximum grain yield of 789.67 kg/ha and the highest net gain of Rs. 22,015.33, its ICBR was lower at 5.57 due to the greater input cost involved. Among the other biopesticides, *B. thuringiensis* and NSKE achieved similar ICBR and the neem leaves treatment lowest ICBR. These findings showed that bio-pesticides, particularly *B. bassiana*, provided a higher return per unit cost compared to the chemical option, emphasizing their efficiency and economic advantage in pest management strategies and are much safer for the pollinators and natural enemies.

In the management of *H. armigera*, several studies have highlighted the potential of entomopathogenic fungi and biopesticides as effective and sustainable alternatives to chemical insecticides. Kalvnadi et al. (2018) reported that *B. bassiana* strain DC2 significantly reduced populations of second-instar larvae. This efficacy was further supported by Petlamul et al. (2019), who observed 100% mortality of *H. armigera* larvae at a spore concentration of 10^{10} conidia/ml. Similarly, Fite et al. (2020) confirmed that three *B. bassiana* strains at 10^{8} conidia/ml effectively controlled third-instar larvae. Laboratory bioassays align with these findings, showing 84-91% mortality for various *B. bassiana* formulations at 1×10^{7} times conidia/ml against third-instar larvae (Malinga and Laing, 2024). Field trials demonstrated efficacy of 50-60% within 7-10 days of foliar spray application (Malinga & Laing 2024). The efficacy of *B. bassiana* in chickpea was further supported by Deepthi and Yadav (2022). In addition to biopesticides, synthetic insecticides such as chlorantraniliprole have demonstrated sub-lethal effects on *H. armigera* populations (Depalo et al., 2017) but remain the most economically advantageous control tool for gram pod borer in chickpea, with superior benefit-cost ratios reported by Reddy and Kumar (2022). Akhtar et al. (2022) corroborated the superior yield and economic efficiency of chlorantraniliprole 18.5% SC in green gram, while neem oil (5%) and neem seed kernel extract efficacy were supported by Reza et al. (2016).

Table 2. Economic evaluation of biopesticides and chlorantraniliprole application for the management of *H. armigera* in chickpea during *rabi* 2024-25

Treatments	Dose (g/l or ml/l)	Cost of insecticide (Rs/ha)	Labour	Total cost (Insecticide + labour) (A)	Grain yield	Additional yield over control	MSP	Cost of grains (Rs)	Value of increased yield (Rs/ha) (B)	Net gain over control (C) (Rs.) (B-A)	ICBR (C/A)
Beuveria bassiana	5 ml/l	750	2000	2750	718.313	388.21	56.5	40584.70	21933.87	19183.87	6.98
Neem seed kernel extract	100 ml/l	1000	2000	3000	632.45	302.35	56.5	35733.61	17082.78	14082.78	4.69
Neem leaves	50 g/l	500	2000	2500	479.22	149.12	56.5	27076.31	8425.47	5925.47	2.37
Bacillus thuringiensis	2 ml/l	650	2000	2650	597.33	267.23	56.5	33749.15	15098.31	12448.31	4.70
Chlorantraniliprole 18.5% SC	0.15 ml/l	1950	2000	3950	789.66	459.56	56.5	44616.17	25965.33	22015.33	5.57
Control	--	--	--	--	330.10	--	56.5	18650.84	--	--	--

ICBR: Incremental Cost Benefit Ratio; MSP of whole pigeon pea: ₹.56.50/kg; Total spray solution used per treatment-: 6.0 liters; Number of applications: 02; Labourers required (02 per spray) : 4; Labour cost @ ₹.500/day.

Cost of biopesticides: *Beuveria bassiana:* ₹ 300/kg, *Bacillus thuringiensis:* ₹ 650/kg, Neem seed kernel extract: ₹ 1000, Neem leaves: ₹ 500; Cost of Chlorantraniliprole *:* ₹ 13000/l

Younas et al. (2023) demonstrated that both *B. bassiana* (at 3.21×10^6 conidia/ml) and chlorantraniliprole significantly reduced larval populations and pod infection in chickpea fields over successive years, contributing to increased crop yield. Moreover, *B. thuringiensis* based biopesticides, combined with *B. bassiana*, achieved high larval mortality rates in laboratory conditions and acceptable efficacy in the field (Malinga and Laing 2024). Collectively, these studies affirm the effective role of biopesticides like *B. bassiana*, *B. thuringiensis*, and botanicals such as neem leaf and seed extracts, alongside selected insecticides like chlorantraniliprole, in integrated pest management strategies for sustainable and economically viable control of *H. armigera*.

CONCLUSION

The study showed the effectiveness of biorational pesticides, particularly *B. bassiana*, in managing *H. armigera* in chickpea. Although chemical insecticides like chlorantraniliprole 18.5% SC achieved the highest yield, pod damage reduction, and larval suppression, *B. bassiana* provided effective pest control and recorded the highest ICBR among all the treatments. This indicates greater economic efficiency despite a slight reduction in yield when compared to chemical control. The superior ICBR of *B. bassiana* highlights its potential as a safer, environmentally sustainable alternative that conserves natural enemies and reduces chemical residue risks. Thus, integrating biorational options like *B. bassiana* into pest management programs can enhance both the economic and ecological sustainability of chickpea production systems.

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Efficacy of Biorational and Insecticides against *Helicoverpa armigera* (Hübner) in Pigeonpea

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***Abstract*:** The field experiment conducted at Norman E. Borlaug Crop Research Centre (N.E.B.C.R.C.), Govind Ballabh Pant University of Agriculture and Technology, Pantnagar during *Kharif* 2024–25 evaluated the efficacy of six biorational insecticides against the gram pod borer, *Helicoverpa armigera*, infesting pigeonpea. All treatments significantly reduced the larval population compared to the untreated control. Chlorantraniliprole 18.5% SC was most effective in reducing larval population, recording as low as 0.33 larvae/5 plants at 10 days after second spray, with pod damage reduction of 77.44% and a substantial grain yield of 797 kg/ha, representing a 97.11% increase over the untreated control. Spinetoram and azadirachtin also provided significant larval suppression and pod damage control, achieving pod damage reductions of 71.43% and 40.60%, and grain yields of 745.67 kg/ha and 652.50 kg/ha, respectively. *Bacillus thuringiensis* var. kurstaki demonstrated effective pest suppression with 45.86% pod damage reduction, a 72.51% yield increase to 697.50 kg/ha, and the highest incremental cost-benefit ratio (ICBR) of 8.20, underscoring superior economic efficiency. *Metarhizium anisopliae* displayed moderate efficacy with 29.32% pod damage reduction and a 42.70% yield increase. These findings highlight the potential of *Bt* as a highly effective and economically viable component of integrated pest management strategies, capable of reducing chemical pesticide reliance while sustaining pigeonpea productivity and profitability.

***Keywords*:** Biorational, Management, Insect pests, Insecticides, Pigeonpea

Pigeonpea (*Cajanus cajan* L.) is a vital grain legume crop in India, ranking second in cultivated area among pulse crops. It serves as a staple food, consumed both as green peas and dry seeds (Kumar et al., 2016, Agale et al., 2021). Predominantly grown in marginal lands or as part of mixed cropping systems with cotton, sorghum, and soybean, pigeonpea often receives limited farmer attention (Sharma et al., 2011). The crop's yield has stagnated over the last three decades, primarily due to damage caused by diverse insect pests (Basandrai et al., 2011). During reproductive phase, pigeonpea is vulnerable to biotic stresses, with pests attacking flowers, pods, and developing grains. In recent years, there has been a notable shift in pest dynamics on pigeonpea. Among the multiple insect pests infesting pigeonpea, the pod borer complex comprising the gram pod borer (*Helicoverpa armigera* Hübner), the legume pod borer (*Maruca vitrata* Geyer) which attacks during flowering and pod formation stages, and the pod fly (*Melanagromyza obtusa* Malloch) at the pod maturation stage pose the major biotic constraints to achieving higher productivity in the crop (Veeranna et al. 2023). *Helicoverpa armigera* larvae cause significant yield losses in pigeonpea by feeding aggressively on leaves during the early instar stages and later attacking developing pods and seeds, leading to an estimated annual grain loss of up to 250,000 tonnes and economic losses exceeding 3750 million rupees (Sardar et al., 2018). Damage to pigeonpea pods caused by the pod borer complex has been reported in range of 20 to 72 per cent (Priyadarshini et al., 2013). Besides the pod borers, other pests such as the leaf webber *Grapholita critica (*Meyr.) and several sucking pests including *Clavigralla gibbosa* Spinola, *Reptortus dentipes* Fabricius, *Anoplocnemis curvipis* (Fabricius), *Nezara virudula* (Linnaeus), and the green leafhopper *Empoasca kerri* (Pruthi), have emerged as significant threats, causing substantial economic losses (Rachappa et al., 2018). While chemical insecticides have been effective in controlling this pod pest complex, their indiscriminate application has led to adverse consequences including pest resurgence, development of insecticide resistance, disruption of natural enemy populations, health risks to humans and animals, and environmental contamination. Given these challenges, there is an urgent need to adopt eco-friendly and sustainable pest management strategies (Sahoo, 2002, Kumar & Muthukrishnan, 2017, Dokekar et al., 2025). The use of insecticides that are selective, target-specific, biodegradable, and safe for beneficial organisms is imperative. In this context, biorational insecticides, microbial pesticides, and botanical extracts have gained prominence owing to their efficacy in pest suppression and their role in maintaining ecological and economic balance (Chethan et al. 2024). The present study was undertaken to evaluate the efficacy of various insecticides and biorational insecticides against pod borer, particularly *Helicoverpa armigera*, within the pigeonpea agro-ecosystem.

MATERIAL AND METHODS

The field experiment was carried out at the N.E.B.C.R.C., Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, during the *Kharif* season of 2024-25. The study was in a randomized block design comprising six treatments, including an untreated control, each replicated three times. The pigeonpea variety PA 291 was cultivated using standard agronomic practices with a spacing of 70 × 20 cm in plots measuring 4 × 5 m². The treatments included foliar application of liquid formulations of *Bacillus thuringiensis* var. *kurstaki* (0.5% WP) @2.5 g/L, *Metarhizium anisopliae* (2 × 10^8 CFU/ml) @5 ml/l, azadirachtin (1500 ppm) @5 ml/l, spinetoram 11.7% SC @54 g a.i/ha (0.9 ml/l), chlorantraniliprole 18.5% SC @30 g a.i/ha (0.3 ml/l) (recommended insecticide), along with an untreated control were evaluated against *H. armigera.* The first foliar spray was applied at the 50% flowering stage, followed by a second application 10 days later. Insecticide treatments were applied using a manually operated foot sprayer equipped with a hollow cone nozzle. For recording observations on the larval population of *H. armigera*, five plants were randomly selected from each plot. The selected plants were carefully examined, and the number of *H. armigera* larvae was counted before the first spray and at 3, 7, and 10 days after each spray (AICRP, 2024). At harvest, 100 pods were randomly collected from each net plot. The percentage of pod damage was calculated based on these counts. The seed yield of pigeonpea from each net plot was recorded and extrapolated to yield per hectare.

Statistical analysis: Statistical analysis was carried out using SPSS software (version 16.0) using Duncan's Multiple Range Test (DMRT), with critical difference values calculated at the 5% level of significance.

RESULTS AND DISCUSSION

Cumulative Impact of biorational insecticide on larval population of *H. armigera:* The pre-treatment observations revealed that the mean larval population of *H. armigera*/5 plants did not differ significantly among the various treatments and the untreated control, one day prior to the first spray during *Kharif* 2024–25, indicating a fairly uniform distribution of the pest across treatments. At three days after the first spray (DAFS), significant differences in mean larval populations were observed among the treatments (Table 1). Chlorantraniliprole 18.5% SC proved to be the most effective, recording the lowest larval population (0.87 larvae/5 plants), followed by Spinetoram 11.7% SC , Azadirachtin 1500 ppm , *Bt.* var. *kurstaki* and *Metarhizium anisopliae* (over untreated control (1.60 larvae/5 plants). At seven DAFS, the lowest larval population (1.03 larvae/5 plants) was in Chlorantraniliprole 18.5% SC, which was statistically at par with Spinetoram 11.7% SC. Similar trends persisted at 10 DAFS, where the lowest larval population (1.10 larvae/5 plants) was observed in Chlorantraniliprole followed by Spinetoram (1.13 larvae/5 plants). Treatments with Azadirachtin 1500 ppm, *Bt* var*. kurstaki,* and *M. anisopliae* also recorded lower larval populations compared to the control (Table 1).

Prior to the second spray, the larval population of *H. armigera* ranged between 1.17 and 1.87 larvae/5 plants. At three days after the second spray (DASS) spray, Chlorantraniliprole 18.5% SC was significantly more effective than the other treatments in reducing larval numbers, with an average of 0.70 larvae/5 plants, and was statistically on par with Spinetoram. Among the biorational control options evaluated for pod borer suppression, Azadirachtin 1500 ppm demonstrated the highest efficacy, recording the lowest *H. armigera* population (1.07 larvae/5 plants) and showing parity with *Bt* var. *kurstaki*. Overall, Azadirachtin 1500 ppm ranked next in effectiveness to the chemical insecticide treatments. At 7 DASS, a marked reduction in larval population was noted, ranging from 0.47 to 2.07 larvae/5 plants across treatments. The minimum population in Chlorantraniliprole 18.5% SC, which was significantly superior to all other treatments and the untreated control. Spinetoram was the next most effective treatment, followed by Azadirachtin 1500 ppm, which was statistically comparable to *Bt* var. *kurstaki*. At 10 DASS, a substantial decline in larval population was observed across all treatments. Chlorantraniliprole 18.5% SC remained the most effective treatment, maintaining the lowest larval density of 0.33 larvae/5 plants. This was statistically at par with Spinetoram, followed by Azadirachtin 1500 ppm. *Bt* var. *kurstaki* and *M. anisopliae* were also found to be statistically comparable (Table 1).

The present findings are consistent with earlier studies emphasizing the effectiveness of Chlorantraniliprole against *H. armigera* in pigeonpea. Patel (2015), identified Chlorantraniliprole 18.5% SC as the most potent treatment for managing pod borer infestations in pigeonpea. Kumar et al. (2016), also reported that the *Bacillus thuringiensis* strain NBAII-*Bt* G4 at 2% was the next most effective treatment after the chemical insecticide spray, recording an average surviving larval population of *H. armigera* (1.01 larvae/plant) and *M. vitrata* (1.10 larvae/inflorescence). Warad et al. (2021) also highlighted Chlorantraniliprole 18.5% SC as the most effective treatment for pod borer management in pigeonpea. Veeranna et al. (2023) observed that Chlorantraniliprole 18.5% SC at 0.3 ml/l, followed by Emamectin benzoate 5% SG at 0.4 g/l, provided superior control of *H. armigera.* These findings collectively reinforce the superior efficacy of Chlorantraniliprole based treatments in reducing larval populations and minimizing pod damage under field conditions, thereby confirming its reliability as a key component in integrated pest management strategies for pigeonpea.

Efficacy of biorationals on pigeonpea pod damage and grain yield and Comparative evaluation of Incremental cost benefit ratio (ICBR): All the treatments significantly reduced pod damage caused by *H. armigera* compared to the untreated control. Among the treatments, Chlorantraniliprole 18.5% SC recorded the lowest pod damage (10.00%), the highest percent reduction in pod damage over control (77.44%), and the maximum grain yield (797.00 kg/ha), representing a 97.11% increase in yield over the untreated control. Spinetoram also performed well, resulting in 71.43% reduction over control, grain yield of 745.67 kg/ha, and an 84.42% yield increase. *Bt.* var. *kurstaki* resulted 45.86% reduction. Azadirachtin and *M. anisopliae* were comparatively less effective. The untreated control had the highest pod damage (44.33%) and lowest grain yield (404.33 kg/ha).

The comparative evaluation of ICBR (Table 2) revealed that although Chlorantraniliprole 18.5% SC achieved the highest grain yield and maximum pod damage reduction incremental cost-benefit ratio (ICBR) was 6.95, which is lower than that of several biorational treatments. *Bt var. kurstaki* recorded an ICBR of 8.20, the highest among all treatments, followed closely by Spinetoram (ICBR 6.91). Although *M. anisopliae* and Azadirachtin resulted in moderate yield increases and pod damage reduction, their ICBR values (4.53 and 5.40, respectively) were lower than *Bt*

Table 1. Efficacy of biorational insecticides against gram pod borer*, H. armigera* infesting pigeonpea

Treatment	Before spray	Mean number of *H. armigera* larvae/5 plants (days after spray)							Pod damage (%)	Pod damage reduction over control (%)
		1st Spray			Before spray	2nd Spray				
		3	7	10 DAF		3	7	10		
Bt. var. *kurstaki*	1.57^{a}	1.20^{bc}	1.27^{ab} (1.13)	1.33^{ab} (1.15)	1.50^{a} (1.22)	1.13^{bc} (1.06)	1.00^{bc} (1.00)	0.90^{c} (0.95)	24.00^{b}	36.09
Metarhizium anisopliae	1.67^{a}	1.33^{c} (1.15)	1.37^{b} (1.17)	1.43^{b} (1.20)	1.48^{a} (1.22)	1.20^{c} (1.10)	1.10^{c} (1.05)	0.97^{c} (0.98)	31.33^{b}	29.32
Azadirachtin 1500 ppm	1.60^{a}	1.13^{abc} (1.06)	1.20^{ab} (1.10)	1.30^{ab} (1.14)	1.37^{a} (1.17)	1.07^{bc} (1.03)	0.93^{bc} (0.97)	0.67^{b} (0.82)	26.33^{b}	48.87
Spinetoram 11.7% SC	1.70^{a} (1.30)	0.93^{ab} (0.97)	1.17^{ab} (1.08)	1.13^{a} (1.06)	1.23^{a} (1.11)	0.90^{ab} (0.95)	0.73^{ab} (0.86)	0.53^{ab} (0.73)	12.67^{a}	67.67
Chlorantraniliprole 18.5% SC	1.67^{a} (1.29)	0.87^{a} (0.93)	1.03^{a} (1.02)	1.10^{a} (1.05)	1.17^{a} (1.08)	0.70^{a} (0.84)	0.47^{a} (0.68)	0.33^{a} (0.58)	10.00^{a}	80.45
Control	1.53^{a} (1.24)	1.60^{d} (1.26)	1.73^{c} (1.32)	1.87^{c} (1.37)	1.87^{a} (1.37)	1.97^{d} (1.40)	2.07^{d} (1.44)	2.13^{d} (1.46)	44.33^{c}	

Means in the same column followed by the same letter are not significantly different from each other at the 5% probability level according to the Duncan's Multiple Range Test (DMRT).

Table 2. Comparative economic evaluation of biorational application over untreated control for the management of *H. armigera* in pigeonpea

Treatment	Quantity used (g/l or ml/l) in water	Cost of Insecticide (₹/ha)	Total cost (insecticide+ labour) (A)	Grain yield (kg/ha)	Percent increase in yield over control (%)	Cost of grains (₹)	Additional yield over control	Value of increased yield (₹/ha) (B)	Net gain over control (C) (₹) (B-A)	ICBR (C/A)
Bt. var. *kurstaki*	2.5	550	2550	697.50	72.51	55800	293.17	23453.33	20903.33	8.19
Metarhizium anisopliae	5	496	2496	577.00	42.70	46160	172.67	13813.33	11317.33	4.53
Azadirachtin 1500 ppm	5	1100	3100	652.50	61.38	52200	248.17	19853.33	16753.33	5.40
Spinetoram 11.7% SC	0.9	1450	3450	745.67	84.42	59653.33	341.33	27306.66	23856.66	6.91
Chlorantraniliprole 18.5% SC	0.3	1950	3950	797.00	97.11	63760	392.67	31413.33	27463.33	6.95
Control	-	-	-	404.33	-	32346.7	-	-	-	-
CD (p=0.05)	-	-	-	0.83	-		-	-	-	-

ICBR: Incremental Cost Benefit Ratio; MSP of whole pigeon pea : ₹.80.00/kg. Total spray solution used per treatment-: 6.0 liters; Sprays done-02; Labours required : 02 per spray =4; Labour cost @ ₹.500/day/labour.; Cost of *Bt.* var. *kurstaki* - *₹440/kg,* Cost of *Metarhizium anisopliae* - *₹200/kg,* Cost of *Azadirachtin 1500 ppm* - ₹440/l, Cost of *Spinetoram 11.7% SC* - ₹3235/l, Cost of *Chlorantraniliprole* - ₹13000/l *var. kurstaki* and Spinetoram. Prajapati and Patel, (2025) also reported that at both the green pod stage and harvest, plots treated with Chlorantraniliprole 0.006% exhibited the lowest pod damage (6.60%). Agale et al. (2021) reported that the application of Spinosad 45% SC was significantly effective, recording the lowest pod and seed damage by *H. armigera* . Taggar and Singh (2015) reported that the highest grain yield with Spinosad 45% SC, followed by *Bacillus thuringiensis* formulation at 1.5 kg/ha and a combination of *B. thuringiensis* with *Beauveria bassiana* at 3.0 g/l. Das et al. (2022) identified *B. thuringiensis* and Azadirachtin as effective options for managing the pod borer complex in pigeonpea. Veeranna et al. (2023) observed Chlorantraniliprole 18.5% SC in managed both *H. armigera* and *M. vitrata*.

CONCLUSION

B. thuringiensis var. kurstaki is an effective and economically advantageous option for managing *H. armigera* in pigeonpea, showing substantial pod damage reduction and yield increase with the highest incremental cost-benefit ratio (ICBR) among tested treatments. Although chemical insecticides such as Chlorantraniliprole have showed higher efficacy in reducing pest population and increasing yield, high cost and potential environmental risks make biorational pesticides a more sustainable and cost-effective alternative for long-term pest management. Spinetoram, Azadirachtin, and *Metarhizium anisopliae* also provided moderate control levels and yield improvements, supporting their use as complementary components in integrated pest management (IPM) strategies. The integration of Bt with these biorational and selective chemical options can enhance sustainability, reduce chemical residues, and conserve natural enemies, thus ultimately promote eco-friendly and profitable pigeonpea production systems.

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Management of Pink Bollworm, *Pectinophora gossypiella* (Saunders) through Agronomic Interventions in Cotton

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Abstract: An experiment to investigate the effect of agronomic interventions in the management of pink bollworm, *Pectinophora gossypiella* in *Bt* cotton (hybrid Platinum) under closer spacing (90 x 30 cm) was conducted at RARS, Lam, ANGRAU, Guntur during *kharif* ,2024-25. Eight treatments in combination with mepiquat chloride application at 45 and 60 days after sowing detopping at 60 DAS, with recommended chemical pink bollworm management compared with conventional method of spacing (105 x 60 cm) , were evaluated. Infestation levels of PBW measured in terms of green boll damage (%), green locule damage (%), number of larvae per 10 bolls, and rosette flowers (%). The lowest green boll damage, green locule damage, no. of larvae/ 10 bolls and rosette flowers due to pink bollworm were recorded in the treatment closer spacing + detopping + recommended PBW chemical management (17.33, 12.5, 4.33 and 11.00 respectively), next best treatment was closer spacing + MPC @ 45 ppm at 45–60 DAS + recommended PBW chemical management (18, 18, 4.33 and 12 respectively) and highest infestation was recorded in Conventional method of spacing (36.67, 36, 4.93 and 24.67 respectively). Closer spacing + recommended PBW chemical management alone recorded 22.67 green boll damage, 14.89 green locule damage, 4.33, and 16.33 rosette flowers. Integrating closer spacing, growth regulation, and recommended PBW chemical management effectively reduced PBW infestation in *Bt* cotton.

Keywords: *Bt* cotton, Closer spacing, Detopping, Mepiquat chloride, Rosette flowers, Pink bollworm

India is a leading cotton producer, with approximately 112.95 lakh hectares of area during the 2024-25 season and an estimated production of around 301 lakh bales of 170 kg each (Cotton Association of India 2024). The introduction of genetically modified *Bt* cotton in the early 2000s significantly reduced bollworm infestations and reliance on chemical insecticides with enhanced yields. Despite its vital contribution to the global economy, cotton production is consistently challenged by a wide spectrum of insect pests. Among these pests, the pink bollworm (*Pectinophora gossypiella* Saunders) is particularly destructive, feeding internally on floral parts and developing bolls, causing substantial yield losses and reducing fibre quality. The field populations of pink bollworm have developed resistance to both Cry1Ac and Cry2Ab proteins in dual-gene *Bt* cotton varieties, resulting in pest resurgence in key cotton-growing regions (Dhurua et al., 2011, Mukhtar et al., 2023). This highlights the need for integrated management strategies. The IPM strategies include refugia strategy, short statured high density planting systems with agronomic interventions, off-season management of the pest etc

Agronomic interventions such as detopping, foliar application of the growth regulator mepiquat chloride (MPC), and optimized plant spacing have been explored to complement *Bt* cotton and improve crop resilience. Detopping redistributes the assimilates to reproductive organs, promoting flowering and boll formation (Maiga et al., 2024). MPC regulates excessive vegetative growth, maintains optimal canopy architecture, and improves light interception (Abbas et al., 2022). MPC, limits vegetative growth by reducing gibberellic acid, shortening internodes, and producing a compact canopy that promotes early and uniform fruiting Optimized spacing ensures uniform crop growth and modifies the microclimate within the canopy, indirectly reducing pest incidence (Bhanderi et al., 2024).

The present study was undertaken to evaluate the effects of detopping, MPC application, and closer spacing, along with recommended pink bollworm management strategies on the incidence of pink bollworm and its damage.

MATERIAL AND METHODS

A field experiment was conducted at the Regional Agricultural Research Station (RARS), Lam, Guntur during *kharif* 2024-25 with Bt hybrid, Platinum under closer spacing. The study comprised eight treatments: conventional spacing of 105 × 60 cm under unprotected conditions, conventional spacing (105 x 60 cm) with recommended PBW chemical management; closer spacing (90 × 30 cm) as untreated control; closer spacing with recommended PBW chemical management; closer spacing with detopping; closer spacing with detopping along with recommended PBW chemical management; closer spacing with foliar application of MPC @ 45 ppm at 40–60 DAS during square initiation and closer spacing with MPC @ 45 ppm along with recommended PBW chemical management. Detopping was carried out by removing the apical shoot tip when plants attained 15 nodes to restrict vertical growth and encourage early boll formation. Foliar application of MPC @ 45 ppm was imposed between

40–60 DAS during square initiation. Recommended PBW management involved rotation of insecticides starting from 75 DAS at 15-day intervals, including chlorpyriphos 20% EC @1250 ml/ ha, quinalphos 25% EC@1000 ml/ ha, cypermethrin 25% EC @500 ml/ ha, lambda-cyhalothrin 5 EC @500 ml/ ha and profenophos 50 EC @ 1000 ml/ha.

Observations on pink bollworm (*P. gossypiella*) incidence were recorded at 75, 90, 105, 120, 135, and 150 days after sowing (DAS) across all treatments. The infestation levels were measured in terms of per cent rosette flowers (50 flowers/ plot), per cent green boll damage (GBD), green locule damage (GLD), no.of larvae (10 bolls/ plot by destructive sampling), open boll and locule damage at the time of harvest by collecting data from open bolls from 5 plants/ plot. Per cent GBD and GLD were calculated by destructive sampling of 10 bolls per treatment. The original per cent mean values were transformed into arc sine values and no. of PBW larvae converted into square root values. The transformed data is subjected to ANNOVA

RESULTS AND DISCUSSION

The mean green boll damage (%) during the *kharif* 2024-25 season ranged from 17.33 to 36.67. The lowest damage was recorded in the treatment combining closer spacing with detopping at 60 DAS and recommended PBW management (17.33%), which was statistically superior to both conventional and closer spacing untreated plots (Table 1). Similarly, the mean green locule damage (%) ranged from 12.53 to 25.35, with the lowest damage (12.53%) also observed in the treatment combining closer spacing and detopping with recommended PBW management. This combination of agronomic interventions resulted in a significant reduction in both GBD and GLD. These findings are in accordance with earlier reports where terminal shoot removal reduced fruiting body damage (bolls and squares) by *Helicoverpa armigera* (Vennila et al., 2000) Reddy and Rabindrababu (1999) also confirmed the reduction of *H. armigera* eggs by nipping at 18-20 nodes.

The lowest mean larval incidence (2.13 per 10 green bolls) and lowest mean rosette flowers (%) damage (11.00) were both recorded in treatments that combined closer spacing with MPC application and recommended PBW chemical management. Zummo et al. (1984), also confirmed that MPC not only controls excessive vegetative growth but also contributes to increased resistance against bollworms. The MPC application led to a reduction in bollworm survival and growth, suggesting enhanced antibiosis and feeding deterrence. This effect was partially attributed to the increased synthesis of secondary metabolites such as tannins and terpenoids, which are known to reduce pest feeding and improve plant resistance. Therefore, the use of MPC not only improves canopy structure but also plays an important role in integrated pest management (IPM) by enhancing the plant's natural defence mechanisms against bollworm infestation.

Table 1. Effect of agronomic practices on the incidence of pink bollworm and damage in cotton during *kharif,* 2024–25 at RARS Lam

Treatment Details	Green boll damage (%)	Green locule damage (%)	Rosette flowers (%)	No. of larvae	Open boll damage (%)	Open locule damage (%)	Seed cotton yield (q/ha)
T_1: Conventional method of spacing (105 x 60 cm)	32.00 (34.32)*	21.77 (27.80)*	23.33 (28.87)*	4.40 (2.31)**	49.83 (44.88)*	39.20 (38.71)*	11.62
T_2: Conventional method of spacing (105 x 60 cm) + recommended PBW management	20.67 (27.02)	13.91 (21.86)	15.33 (23.03)	2.53 (1.85)	36.58 (37.09)	21.09 (27.33)	17.87
T_3: Closer spacing (90 x 30 cm) (untreated control)	36.67 (37.22)	25.35 (30.20)	24.67 (29.75)	4.93 (2.43)	50.63 (45.35)	41.41 (39.99)	12.67
T_4: Closer spacing + recommended PBW management	22.67 (28.35)	14.89 (22.62)	16.33 (23.81)	2.80 (1.95)	38.35 (38.24)	22.39 (28.23)	18.64
T_5: Closer spacing + detopping	30.00 (33.17)	19.50 (26.17)	19.00 (25.79)	3.80 (2.19)	42.57 (40.68)	27.81 (31.81)	12.12
T_6: Closer spacing + detopping + recommended PBW management	17.33 (24.50)	12.53 (20.66)	12.00 (20.21)	2.33 (1.83)	30.40 (33.38)	19.65 (26.3)	20.19
T_7: Closer spacing + mapiquat chloride @ 45ppm at 30 DAS or square initiation stage	30.66 (33.60)	19.01 (25.81)	17.33 (24.59)	4.47 (2.34)	42.67 (40.76)	24.94 (29.95)	11.4
T_8: Closer spacing + MPC @ 45ppm at 30 -45 DAS or square initiation + recommended pbw management	18.00 (25.07)	13.44 (21.32)	11.00 (19.35)	2.13 (1.77)	29.48 (32.79)	18.83 (25.67)	20.87
CD (p=0.05)	3.95	4.03	2.22	0.38	4.16	3.53	3.89
CV (%)	7.33	9.29	5.14	10.44	6.00	6.44	14.03

·ARC SINE transformed values, **SQRT x +1 transformed values

At harvest, this integrated approach continued to show its effectiveness. The lowest open boll damage (OBD) of 29.48% and open locule damage (OLD) of 18.83% were recorded in the closer spacing treatment with MPC and recommended PBW chemical management (Table 1). The damage in close spacing without protection was maximum, with 50.63% OBD and 41.41% OLD. This highlights that through closer spacing favours pest build-up, an integrated approach with detopping, MPC application, and insecticide management could control PBW effectively. These results are supported by Udikeri et al. (2004), who reported that shoot nipping effectively reduced bollworm populations and minimized fruiting body damage. Renou et al. (2011) also confirmed that manual topping significantly reduced the incidence of *Helicoverpa armigera* and *Earias* species. Similarly, Surilivelu *et al.* (1998) demonstrated that topping, when integrated with insecticide applications guided by economic thresholds, significantly reduced bollworm infestation. Collectively, these studies indicate that although closer plant spacing may promote pest proliferation, the combined implementation of detopping, MPC application and insecticide management constitutes an essential and effective approach within the framework of Integrated Pest Management.

The highest seed cotton yield (20.87 q/ha) was achieved under closer spacing (90 × 30 cm) with mepiquat chloride (45 ppm at 45 DAS) and recommended PBW chemical management, comparable to treatments combining closer spacing with PBW management or detopping, whereas MPC alone produced the lowest yield (11.40 q/ha) (Table 1). These findings align with Alam et al. (2024), who reported significant yield and fiber quality improvements from detopping at 80-95 DAS. Grundy et al. (2012) stated that Integrating canopy management, MPC application and PBW control optimizes plant architecture and maximizes yield potential.

CONCLUSION

The present study demonstrated that by integrating closer spacing with detopping and recommended PBW management proved most effective, recording the lowest green boll ,locule damage. Similarly, closer spacing with mepiquat chloride (MPC) application and PBW chemical management significantly reduced larval incidence and rosette flowers, open boll and open locule damage, while achieving the highest seed cotton yield . These findings highlight those cultural practices such as detopping and canopy regulation through MPC, when combined with recommended chemical management, can substantially suppress PBW infestation while improving productivity. The results reinforce the importance of adopting integrated agronomic and chemical interventions for sustainable management of pink bollworm in cotton.

AUTHORS CONTRIBUTION

Conceptualization and experiment design: Annie Diana Grace, Trial execution and data collection: Ms. Hima Bindu; Data curation, statistical analysis and draft preparation**:** V. Hima Bindu**,** G. Annie Diana Grace, B. Ratna Kumari, Rani Chapara. Final draft revision and approval: V. Hima Bindu**,** G. Annie Diana Grace, B. Ratna Kumari, Rani Chapara.

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Incidence of Major Sucking Pests in Cotton as Influenced by Plant Spacing

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Abstract: The study was carried out at Regional Agricultural Research Station (RARS), Lam, Guntur during *kharif,* 2024**.** An experiment was conducted using *Bt* cotton hybrid Siri NCS-8899 BG-II in two spacing regimes: normal spacing (105 × 60 cm; 15,873 plants/ha) and closer spacing (90 × 30 cm; 37,037 plants/ha). The mean leafhopper population was significantly higher under closer spacing (with peak incidence observed during the 44^{th} standard meteorological week (SMW) Aphid incidence ranged from 2.72 to 15.02/3 leaves (normal) and 2.92 to 17.2/3 leaves (closer), with no significant differences. Thrips population ranged from 0.45 to 11.32/3 leaves (normal) and 0.72 to 13.34/3 leaves (closer), with significantly higher populations under closer spacing during the early vegetative stage (38^{th} – 42^{nd} SMW). Whitefly incidence ranged from 0.90 to 2.96 (normal) and 0.98 to 3.01/3 leaves (closer) with no significant difference between the two spacing regimes.

Keywords: *Bt* cotton, Closer spacing, Standard metrological week, Sucking pests

Cotton (*Gossypium hirsutum* L.) is the major fiber and cash crop globally, cultivated in tropical as well as sub-tropical regions across more than seventy countries. Cotton plays a significant role in the agricultural and industrial economies globally. India ranks first in area and second in production on global basis. It is cultivated on 12.47 million ha with a production of 32.31 million bales and with the average productivity of 440.52 kg lint per ha (CICR 2024). Despite of the large area, the productivity in India is very low. In Andhra Pradesh, cotton is grown in an area of 0.43 million ha with a productivity of 461 kg lint per ha, with a total production of 1.16 million bales (AICRP 2024-25). Around 60% of fiber to Indian textiles is derived from cotton. However, cotton production is often hampered by various biotic stresses, among which insect pests pose a major threat. Among the insect pests, sucking pests such as leafhopper (*Amrasca biguttula* Ishida), whitefly (*Bemisia tabaci* Gennadius), aphids (*Aphis gossypii* Glover), and thrips (*Thrips tabaci* Lindeman) are of particular concern. To enhance the cotton productivity while minimizing input costs has been a key challenge for Indian agriculture, especially under resource-limited and rainfed conditions. One promising agronomic approach to improve yield potential is the adoption of closer spacing. Closer spacing in cotton refers to the reduction in plant-to-plant and row-to-row distances, thereby increasing the plant population per unit area. Under this system, short-duration, compact varieties are planted at a higher plant population per unit area.

The concept of closer spacing in cotton began gaining popularity in the early 2000s, but it was during the post-*Bt* cotton era (after the introduction of *Bt* hybrids around 2002-2004). Traditional cotton hybrids have a longer crop duration and indeterminate growth habit, often leading to excessive vegetative growth under wider spacing. In contrast, *Bt* cotton, with a shorter crop duration and more synchronized flowering, responded well to closer spacing due to better canopy structure and resource utilization. It aims to maximize the capture of solar radiation, reduce weed competition, and enhance the land-use efficiency (Venugopalan et al., 2011, Reddy et al., 2010) and Rathinavel and Dhivya (2013) reported an increased incidence of sucking pests under high-density planting, especially during early growth stages. This presents a significant trade-off between achieving higher yields and managing pest pressure effectively. Despite this, closer spacing has shown potential to increase yield under rainfed and resource-constrained ecosystems by increasing the number of productive bolls per unit area, even though individual plant performance may decline. Therefore, the present study was undertaken to assess the impact of plant spacing on the incidence and population dynamics of major sucking pests in *Bt* cotton under field conditions. The findings are expected to provide understanding into optimizing plant density to balance yield advantages with effective pest management in *Bt* cotton.

MATERIAL AND METHODS

The field experiment was laid out at Regional Agricultural Research Station, Lam, Guntur which is located in upland coastal area of the Krishna Agro Climatic Zone of Andhra Pradesh during *kharif,* 2024. Two bulk plots were maintained with 100 m^2 area each to study the incidence of sucking pests under normal (105 × 60 cm) and closer planting system (90 ×

30 cm) under unprotected conditions. The cotton hybrid Siri (NCS 927 BG 11) was sown manually by dibbling at normal (105 × 60 cm) and closer spacing (90 × 30 cm) during last week of July. Gap filling was done twice within seven to ten days interval after sowing to maintain uniform plant population. Observations on number of leafhoppers, thrips, aphids and whiteflies per three leaves one each from top, middle and bottom of plant was recorded. Thrips were observed and counted by using magnifying lens. About 20 plants were selected randomly in each bulk plot. Weekly observations were recorded from 30 days after sowing and data was subjected to square root transformation and subjected to two sample 't' test assuming unequal variances to compare the pest incidence between normal and closer spacing treatments.

RESULTS AND DISCUSSION

The leafhopper population was observed throughout the season and the first appearance of leafhoppers was observed from 35th SMW (end of August) in both the spacings. The incidence was moderate to high up to 49th SMW (December first week), thereafter declined and reached to a minimum number of 0.95 no.s /3 leaves at 1st SMW in normal spacing and 1.05 to 15.02 /3 leaves in closer spacing. The incidence of leafhopper population ranged from 0.95 to 11.48 /3 leaves in normal spacing and from 1.05 to 15.02 per three leaves in closer spacing. Peak population was observed with 11.48 / 3 leaves during 39th standard week (October 14th- 20th) under normal spacing and 15.02/ 3 leaves during 46th SMW (October 28th – November 3rd) under closer spacing. The overall population was slightly low under normal spacing when compared to closer spacing. The seasonal mean population of leafhoppers was 2.50 /3 leaves in normal spacing as against 2.79 /3 leaves in closer spacing. The computed t-statistics for differences between the above two mean values was statistically different indicating that the leafhopper population was significantly higher in closed spacing than the normal spacing. Mahalakshmi and Prasad (2018) also observed that the leafhopper population was significantly higher in high-density planting system (HDPS) (closer spacing) compared to recommended spacing in cotton. The increased canopy density in HDPS likely provides a more favorable microclimate for leafhopper multiplication. Pandagale et al. (2020) also observed that the leafhopper population was higher in narrow row spacing (45 × 10 cm) compared to wider row spacing (75 × 10 cm), attributing it to greater plant density (Table 1).

Aphid population in normal spacing conditions ranged from 2.72 to 15.02 per three leaves, while under closer spacing, the population varied from 4.01 to 17.2 no. per three leaves throughout the crop growth period. During 44th to 47th SMW, the aphid incidence was at peak level and there was significant difference between both the spacings with higher aphid incidence recorded in closer spacing than normal spacing**.** However, aphid population never crossed ETL (30 aphids per three leaves) in normal and closer spacing. Kalaichelvi (2008) also documented maximum aphid incidence between 43rd and 48th SMW in *Bt* cotton fields. Although higher aphid counts were observed under HDPS, the values remained below ETL and the differences were not statistically significant.

Thrips population ranged from 0.45 to 11.32 no.s /3 leaves during the crop growth period in normal spacing, whereas in closer spacing it was 0.72 to 14.50 /3 leaves. The population of thrips was high from September (38th SMW) to the end of October (42th SMW). In both normal and closer spacings, thrips population never crossed ETL throughout the season. Although slightly higher thrips populations were observed under closer spacing than normal spacing, the difference was statistically non-significant. The present findings are in conformity with those of Rajasekhar et al. (2018) where thrips population was initially higher in HDPS during the early vegetative phase, particularly up to 90 days after sowing and the difference in population between closer and normal spacing was not statistically significant in later stages. Rajesh and Dhakad (2016) also observed that closer spacing favored slightly higher thrips populations, especially in the early vegetative phase, but the population remained below ETL throughout the season.

The incidence of whitefly population ranged from 0.28 to 2.96 no.s per three leaves in normal spacing and 0.38 to 3.01 no.s in closer spacing during crop growth period. No significant difference was found between both the spacings throughout the cropping period (30 to 150 DAS). Rajasekhar et al. (2018) also reported that whitefly populations were not significantly affected by plant spacing. The variations in population were more strongly linked to prevailing weather conditions and inter-pest competition, especially when other sucking pests like leafhoppers and thrips were more dominant. Mahalakshmi and Prasad (2018), also observed that whitefly incidence remained statistically non-significant between HDPS and recommended spacing in *Bt* cotton.'

CONCLUSION

Closer spacing (90×30 cm) led to slightly higher populations of sucking pests, particularly during the vegetative phase, due to denser canopy and modified microclimate. However, pest levels largely remained below ETL throughout the crop growth period, except for occasional peaks. Significant impact of spacing was observed only for

Table 1. Effect of spacing on major sucking pest complex in cotton during *kharif,* 2024

SMW	Leafhoppers/3 leaves/plant *			Aphids/3 leaves/plant *			Thrips/3 leaves/plant *			Whiteflies/3 leaves/plant *		
	Normal spacing (105X60)	Closer spacing (90X30)	t-test	Normal spacing (105X60)	Closer spacing (90X30)	t-test	Normal spacing (105X60)	Closer spacing (90X30)	t-test	Normal spacing (105X60)	Closer spacing (90X30)	t-test
35	3.48 (1.86)	3.75 (1.93)	NS	2.72 (1.64)	2.92 (1.70)	NS	1.38 (1.17)	1.98 (1.40)	NS	1.52 (1.23)	1.95 (1.39)	NS
36	5.13 (2.26)	5.52 (2.34)	NS	6.30 (2.51)	6.51 (2.55)	NS	1.92 (1.38)	2.26 (1.50)	NS	1.44 (1.20)	1.98 (1.40)	NS
37	7.13 (2.67)	7.85 (2.80)	NS	6.80 (2.60)	6.93 (2.63)	NS	11.32 (3.36)	13.34 (3.65)	S	0.35 (0.59)	0.38 (0.61)	NS
38	8.98 (2.99)	9.02 (3.00)	NS	7.50 (2.73)	7.62 (2.76)	NS	10.95 (3.30)	14.50 (3.80)	S	0.28 (0.52)	0.49 (0.70)	NS
39	11.48 (3.38)	11.98 (3.46)	NS	8.25 (2.87)	8.54 (2.92)	NS	10.05 (3.17)	13.01 (3.60)	S	0.41 (0.64)	0.56 (0.74)	NS
40	10.60 (3.25)	10.75 (3.27)	NS	7.09 (2.66)	7.42 (2.72)	NS	7.86 (2.80)	8.12 (2.84)	NS	2.08 (1.44)	2.72 (1.64)	NS
41	11.02 (3.31)	11.31 (3.36)	NS	8.15 (2.85)	8.92 (2.98)	NS	3.8 (1.94)	3.95 (1.98)	NS	1.52 (1.23)	1.72 (1.31)	NS
42	10.62 (3.25)	11.06 (3.32)	NS	8.35 (2.88)	9.21 (3.03)	NS	4.81 (2.19)	4.92 (2.21)	NS	2.96 (1.72)	2.04 (1.42)	NS
43	9.38 (3.06)	13.72 (3.73)	S	9.40 (3.06)	12.23 (3.49)	S	2.45 (1.56)	2.50 (1.58)	NS	1.60 (1.26)	1.76 (1.32)	NS
44	8.25 (2.87)	14.68 (3.83)	S	13.21 (3.61)	15.26 (3.90)	S	2.30 (1.51)	2.47 (1.57)	NS	2.84 (1.68)	2.04 (1.42)	NS
45	6.13 (2.47)	13.95 (3.73)	S	13.05 (3.61)	16.84 (4.10)	S	1.92 (1.38)	2.12 (1.45)	NS	1.24 (1.11)	1.92 (1.38)	NS
46	5.82 (2.41)	12.92 (3.59)	S	15.02 (3.87)	17.20 (4.14)	S	1.84 (1.35)	2.01 (1.41)	NS	2.94 (1.71)	3.01 (1.73)	NS
47	7.62 (2.76)	9.81 (3.13)	S	14.98 (3.87)	15.98 (3.99)	S	1.22 (1.10)	1.95 (1.39)	NS	2.38 (1.54)	2.92 (1.70)	NS
48	5.98 (2.44)	6.15 (2.47)	NS	13.10 (3.61)	14.59 (3.81)	NS	1.38 (1.17)	1.40 (1.18)	NS	2.04 (1.42)	2.32 (1.52)	NS
49	4.96 (2.22)	5.13 (2.26)	NS	10.24 (3.20)	10.92 (3.30)	NS	0.49 (0.70)	0.55 (0.74)	NS	2.56 (1.60)	2.92 (1.70)	NS
50	4.16 (2.03)	4.92 (2.21)	NS	7.75 (2.78)	8.20 (2.86)	NS	0.40 (0.63)	0.47 (0.68)	NS	0.88 (0.93)	1.20 (1.09)	NS
51	3.35 (1.83)	3.85 (1.96)	NS	7.02 (2.64)	7.64 (2.76)	NS	1.2 (1.09)	1.49 (1.22)	NS	0.92 (0.95)	0.98 (0.98)	NS
52	2.05 (1.43)	2.84 (1.68)	NS	4.68 (2.16)	5.12 (2.26)	NS	0.81 (0.90)	0.95 (0.97)	NS	2.91 (1.70)	2.96 (1.72)	NS
1	0.95 (0.97)	1.05 (1.02)	NS	3.62 (1.34)	4.01 (2.00)	NS	0.45 (0.60)	0.72 (0.84)	NS	2.4 (1.54)	2.71 (1.64)	NS

*Figures in parentheses are square root transformed values. NS: Non-significant; S - Significant

leafhoppers, which were more abundant in closer spacing likely due to a denser canopy and favorable microclimatic conditions.

AUTHORS CONTRIBUTION

K. Pavan Sathish conducted the field investigations, collected the data, and performed the data analysis. N. V. V. Durga Prasad and B. Ratna Kumari designed the study and coordinated the research work. S. Prathibha Sree critically reviewed, edited, and finalized the manuscript. L. Rajesh Chowdary contributed to the preparation of the initial manuscript draft. All authors read and approved the final version.

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Bio-Ecology of Maize Spotted Stem Borer, *Chilo partellus* (Swinhoe) and Biorational Approaches for Sustainable Management

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Abstract: The maize spotted stem borer, *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) is a key pest causing 25–80 per cent yield losses in maize across Asia and Africa. Its wide host range, rapid development and climatic adaptability make management challenging. This review summarizes current understanding of its bio-ecology and sustainable biorational control options. Microbial agents like *Bacillus thuringiensis*, *Beauveria bassiana* and *Metarhizium anisopliae* provide effective larval suppression and yield improvement. Insect growth regulators, pheromone-based mass trapping and recent tools including RNA interference and nanobiopesticides further strengthen eco-friendly management. Integrating these interventions within maize IPM modules reduces pest incidence besides conserving beneficial fauna. Continued progress in host resistance, formulation technologies and predictive decision-support tools will enhance long-term resilience. Collectively, the reviewed evidence highlights the potential of biorational-based IPM as a sustainable alternative to conventional insecticides for managing *C. partellus* in maize.

Keywords: Biorational management, Biopesticides, *Chilo partellus*, RNAi, Semiochemicals

Chilo partellus (Swinhoe) remains a major stem borer of maize (*Zea mays* L.) across tropical and subtropical Asia and Africa despite decades of management efforts (Panwar 2005). Originally documented from the Indian subcontinent (Kfir et al., 2002) and taxonomy is now well resolved, with molecular assessments placing it within a diverse genus (Regier et al., 2012) comprising numerous species distributed globally. Although the recent invasion of *Spodoptera frugiperda* (J.E. Smith) has shifted maize crop pest dynamics in many regions, *C. partellus* continues to inflict substantial whorl and stem damage, particularly under rainfed, late-sown, and climate-stressed production systems (Hailu et al., 2021). Dual infestations of *C. partellus* and *S. frugiperda* are increasingly reported in South Asia, with the former dominating early crop stages and in dry, low- to mid-altitude ecologies where warming trends favour its development (Mutamiswa et al., 2022, Mir et al., 2022). These patterns affirm its continued relevance as a key pest, warranting sustained surveillance, research and integrated management attention.

Distribution, spread and phytosanitary risk: *Chilo partellus* is considered to have originated in the India-Pakistan region but has since established across major maize-growing regions of Africa and Asia. It is widely reported throughout eastern, central and southern Africa, including Kenya, Uganda, Ethiopia, Tanzania, Zambia, Zimbabwe and South Africa and is similarly widespread in Asian countries such as Afghanistan, Bangladesh, India, Nepal, Pakistan and Sri Lanka (Jalali and Singh 2003, EPPO 2014). Within India, its presence across nearly all maize-growing states reflects broad ecological adaptability. Although traditionally dominant in low- and mid-altitudes (<1500 m), recent field observations and modelling studies indicate ecological range expansion into temperate and highland zones, supported by phenotypic plasticity and thermal tolerance (Mutamiswa et al., 2022). Establishment in the temperate Kashmir valley further demonstrates adaptation to cooler climates (Mir et al., 2022). Recent detection in southeastern Türkiye confirms its spread into the Mediterranean basin (Tonga 2023), emphasizing its invasive potential.

From a regulatory standpoint, *C. partellus* is listed by EPPO (code “CHILZO”) and recognized within the CABI Crop Protection Compendium as a high-impact stem borer. Several sub-Saharan African countries classify it as a quarantine concern under the International Plant Protection Convention (IPPC) and national Plant Protection Acts.

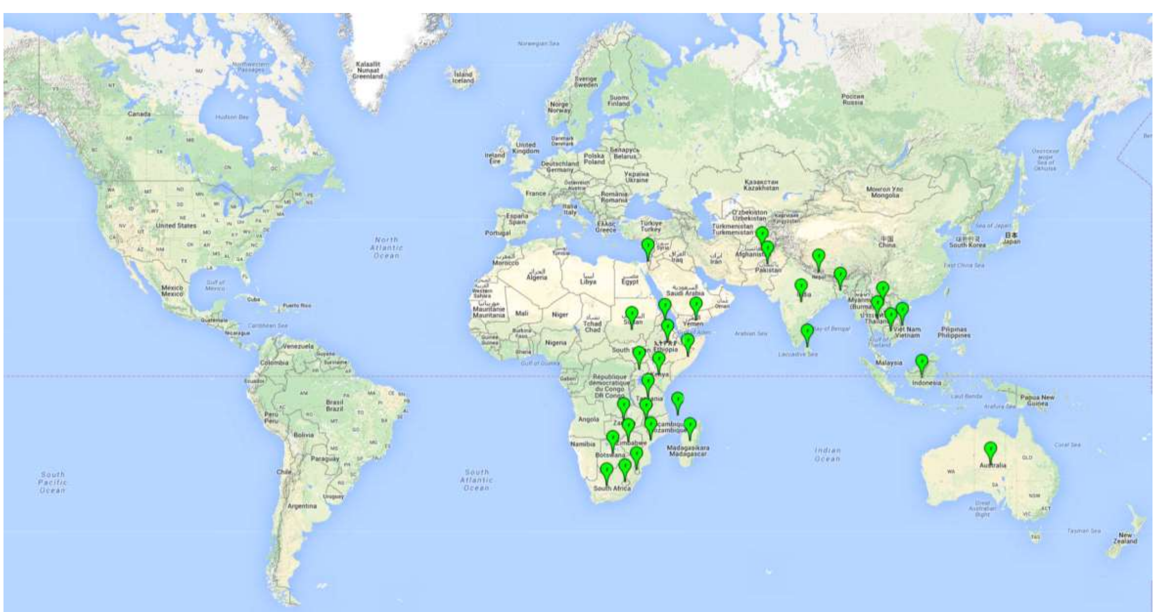
Life history and biology: *Chilo partellus* exhibits high fecundity, rapid development and strong ecological adaptability, traits that sustain its prominence in maize production systems. Adults are crepuscular, mate shortly after emergence and oviposit over several nights, placing egg batches along the leaf midrib during the whorl stage. Females typically lay several hundred eggs, influenced by host genotype and environmental conditions (Bhoi et al., 2020). Adult longevity averages 5-6 days, with premating, mating and oviposition periods well described (Siddalingappa et al., 2010). Egg incubation ranges from 4-10 days depending on temperature. Larvae initially feed in the whorl before boring into the stem and complete development through six instars, with instar durations and total larval periods (20-51 days) detailed by Siddalingappa et al. (2010). Thermal constant estimates (~580-600 degree-days) support 5-7 generations per year in tropical regions (Tamiru et al., 2012). A facultative larval diapause occurs at high elevations or during dry seasons, whereas populations in warm lowlands develop continuously (Ong'amo et al., 2016). Recent physiological studies highlight metabolic adjustments under cold stress, indicating diapause-linked plasticity (Sau et al., 2023).

Mortality factors and life table studies: Life-table studies on *C. partellus* consistently show that early larval stages experience the highest mortality due to predation, parasitism, disappearance losses and abiotic stress ((Jalali et al., 2003, Midega et al., 2005). Seasonal dynamics reveal positive population growth during warmer kharif periods, with declines toward rabi, highlighting strong climatic regulation. Host-based life tables emphasise the role of maize cultivar and environmental stress in shaping larval survival and generational survivorship, with marked reductions across successive generations (Suneel Kumar and Madhumati 2018). Key-factor analyses identify larval disappearance and parasitism, particularly by *Cotesia flavipes*, as major contributors to density-dependent regulation (Suneel Kumar and Madhumati 2018).

Recent studies highlight the increasing influence of climate variability on mortality patterns. Elevated temperatures and low humidity reduce larval survival and suppress adult emergence (Mutamiswa et al., 2022). Temperature-dependent host-parasitoid interactions show reduced parasitoid efficiency at extreme temperatures (Mutamiswa and Nyamukondiwa 2020). Thermal-based demographic modelling indicates that the intrinsic rate of increase (r_m) peaks near 30 °C but declines beyond upper thermal limits (Khadi et al., 2023). Together, these findings show that while biological control remains vital, heat and moisture fluctuations are emerging as dominant mortality drivers under changing climates.

Extent of yield losses due to stem borer, C. *partellus* in maize: Yield losses caused by *C. partellus* vary widely across agro-ecologies, hybrids and seasons, depending on crop stage, infestation intensity and environmental stress (Vinay Kumar 2024). Larval attack during 10-20 days after emergence results in the greatest losses due to dead-heart formation, reduced photosynthesis and stunting. Field studies report yield reductions typically ranging from 22-48%, with higher losses under late sowing, moisture stress or warmer environments (Kumar et al., 2021). Protected-unprotected trials in India further demonstrate substantial reductions (70.0 to 31.55 q/ha), reaffirming the significance of early-season damage (Suneel Kumar et al., 2017b). Economic injury level studies indicate that infestations exceeding 2-3 larvae per plant produce statistically significant yield penalties (Suneel Kumar et al., 2017a).

Climate-responsive analyses suggest heightened risks under warming and extended dry spells, with modelling predicting increased developmental suitability and higher yield losses in transitional and mid-altitude zones (Mutamiswa et al., 2022, Khadi et al., 2023). Field



Source: Ong'amo et al. (2016), reproduced from Pest Distribution and Risk Atlas for Africa (CIP, Peru)

Fig. 1. Global distribution of *C. partellus* (Green points indicate countries with confirmed pest establishment)

assessments also report 25-42% losses under late-sown or water-stressed conditions (Mir et al., 2022). Overall, yield losses may vary from 25-80% depending on hybrid susceptibility, sowing window, infestation pressure and local climatic variability.

Bio-efficacy of biorationals for *C. partellus* management in maize: Growing concerns over pesticide residues, environmental impact and declining efficacy of conventional insecticides have strengthened the focus on biorational alternatives for sustainable *C. partellus* management in maize.

Botanical insecticides: Neem- and karanj-based botanicals continue to serve as core components of stem borer management owing to their ovicidal, antifeedant and growth-regulatory effects (Isman 2020). Classical studies demonstrated that neem oils, seed kernel extracts (NSKE) and azadirachtin formulations effectively deter larval feeding and reduce dead-heart incidence in maize (Jalali and Singh 2004, Sinha et al., 2005). Field evaluations further confirmed moderate-to-high suppression, with NSKE (5-10%), neem oil (0.5-1%) and azadirachtin products lowering dead hearts by 46-70% and causing 50-60% larval mortality (Jat et al., 2014, Chaudhary et al., 2016).

Synergistic enhancements are increasingly reported. For example, combining neem oil with *Metarhizium anisopliae* resulted in 68.5% reduction in leaf injury (Rathod et al., 2018), while karanj oil (1%) reduced dead hearts by >40% (Sharanabasappa et al., 2019). Phytochemical-rich botanicals such as *Melia azedarach* and *Annona squamosa* exhibit strong oviposition deterrence and larval toxicity due to high terpenoid content (Adati et al., 2021). Integrative approaches such as neem- or karanj-based formulations used with bioactive insecticides (spinetoram 25 SC, Spinosad 45 SC) have recorded 65-69% larval reduction and substantial yield gains (Singh et al., 2022). Similarly, azadirachtin (1500 ppm) in combination with entomopathogenic fungi such as *Beauveria bassiana* significantly improves larval suppression (71.3%) and enhances grain yield (Patil et al., 2023).

Recent advances in micro-emulsified neem and karanj formulations have demonstrated 58-72% larval reduction and 0.8-1.1 t/ha yield improvement with higher field stability and improved penetration (Sharma and Singh 2024). Botanicals particularly when integrated with microbial agents or selective biorational insecticides provide scalable, eco-safe and economically viable strategies for *C. partellus* management in maize (Abhishek and Yadav 2024).

Microbial Insecticides

Bacteria: *Bacillus thuringiensis* (*Bt*) remains one of the most reliable microbial tools for *C. partellus* management in maize. Early studies established the pathogenicity of *Bt* var. kurstaki against larvae, confirming strong efficacy on neonates and early instars (Jalali and Singh 2006, Deepthi et al., 2008). Commercial *Bt* formulations such as Dipel®, Biobit® and Delfin® consistently reduce dead hearts and stem tunnelling, providing moderate but reliable yield protection (Saini et al., 2020).

Synergistic combinations have gained importance in recent years. Integrating Bt with entomopathogenic fungi such as *B. bassiana* or *M. anisopliae* enhanced larval mortality to 55-72% and reduced tunnelling more effectively (40-60%) than single agents, an approach increasingly validated under field conditions (Kumela et al., 2022). *Bt*-botanical blends, particularly with azadirachtin (0.15-0.3%) have shown improved residual activity, enhanced feeding deterrence and higher early-instar mortality (Kaur et al., 2023) and enhancing yield by 1.2-1.8 q/ha (Feng et al., 2023, Irshad et al., 2023). Within agroecological systems such as push-pull, *Bt* interventions have been reported to achieve 86% reduction in infestation and significant yield gains (Midega et al., 2018). Transgenic Bt maize expressing *Cry* proteins continues to offer high levels of protection in regions permitting its cultivation, often achieving near-complete suppression of leaf and stem injury (Murenga et al., 2016, Gichuru et al., 2019). Advances in *Bt* formulations, synergistic microbial-botanical integrations and *Bt*-transgenic platforms reaffirm *Bt* as a cornerstone of sustainable *C. partellus* management.

Fungi: Entomopathogenic fungi, particularly *B. bassiana* and *M. anisopliae*, remain important microbial agents for *C. partellus* management. Earlier work confirmed their pathogenicity and larval susceptibility (Tefera and Pringle 2004), and recent research has strengthened evidence of their field-scale utility (Adhikari et al., 2021). Across multiple agro-ecologies, oil-based and aqueous formulations have consistently achieved 45-80% larval reduction, attributable to improved conidial persistence and environmental stability (Dhaliwal et al., 2018). A major advancement is the demonstration that *B. bassiana* and *M. anisopliae* can colonize maize endophytically, reducing larval feeding, delaying development and inducing systemic resistance (Tefera et al., 2016).

Compatibility with botanicals and other biocontrol agents enhances their integration within IPM programmes. Neem-based products show synergistic effects with entomopathogenic fungi (Togbe et al., 2014), while integration with egg parasitoids such as *Trichogramma chilonis* improves early-instar suppression (Deepthi et al., 2008). Synergy with Bt formulations further enhances larval mortality, especially under moderate infestation levels.

Physiological benefits such as enhanced plant vigor and activation of defense pathways have also been reported (Irshad et al., 2023). Overall, *B. bassiana* and *M. anisopliae* are promising eco-compatible tools for *C. partellus* management, with advances in endophytic delivery and formulation technologies strengthening their role in climate-resilient maize IPM systems.

Baculovirus: Nucleopolyhedroviruses (NPVs) have been explored as highly specific and environmentally safe biorational options against *C. partellus* (Sinha and Mohan 2014). Laboratory assays with *C. partellus* NPV (CpNPV) isolates demonstrate strong virulence, producing characteristic baculoviral pathology and achieving LC_{50} values of 1×10^5-10^7 OB/ml for neonates, with >90% mortality at 1×10^8 OB/ml (Kumar et al., 2011, Sinha 2014). Time-mortality studies further indicate that higher viral doses shorten larval survival periods, with LT_{50} values typically within one week (Ghosh and Chakraborty 2016). However, field efficacy is substantially lower due to rapid UV and temperature-induced degradation of occlusion bodies. Improved oil-based and UV-protectant formulations enhance viral persistence by 20-25%, extending residual activity from 2 to 5 days and improving practical effectiveness (Patel et al., 2017).

Granuloviruses (GVs) associated with *Chilo* spp. have also shown cross-pathogenicity to *C. partellus*, with 60-80% mortality at 1×10^7 OB/ml in feeding assays (Manjunath et al., 2018). Despite encouraging laboratory results, widespread deployment of CpNPV and GV formulations remains constrained by inconsistent field performance and limited commercial standardization. Advancements in UV-stable formulations, scalable production and multi-location field validation are essential for integrating viral biopesticides into climate-resilient maize IPM programmes.

Insect growth regulators (IGRs): Insect growth regulators (IGRs) offer an effective biorational option for *C. partellus* management by disrupting chitin synthesis or endocrine regulation, with generally low non-target effects. Field evaluations show that benzoylureas such as teflubenzuron and lufenuron, particularly when integrated with neem, reduce stem tunnelling and dead-heart incidence by 48-62% while conserving parasitoids like *Cotesia flavipes* (Muzeyi, 2005). Similarly, diflubenzuron (0.0125%) achieved 59% reduction in dead hearts and increased grain yield by 21.4 q/ha (Sadanandane et al., 2012).

Laboratory bioassays further demonstrate dose-dependent larval mortality, prolonged development and reduced adult emergence with lufenuron, while pyriproxyfen induces abnormal pupation and partial sterility (Hameed et al., 2016). Juvenile hormone analogues disrupt endocrine pathways associated with metamorphosis, suppressing adult emergence (Venkat Rao et al., 2016). Among ovicidal IGRs, hexaflumuron (200 mg/l) causes complete egg mortality, whereas lufenuron (1000 mg/l) delays hatching and produces >50% mortality of developing embryos (Achiri et al., 2017). Lufenuron and pyriproxyfen further reduce egg hatchability to 37.7% and 60.6%, respectively, often yielding malformed larvae and incomplete pupation (Aboelhadid et al., 2018). Integration of IGRs with *Trichogramma chilonis* releases increases parasitisation by 18-27% and reduces dead hearts by 20-35% (Patil et al., 2020, Ghosh et al., 2021). Population modelling indicates that lufenuron significantly lowers intrinsic rate of increase and adult longevity (Feng et al., 2023). Under field conditions, sequential applications of lufenuron (50 g a.i./ha) or diflubenzuron (25 g a.i./ha) reduced larval density by 64.9% and enhanced yield by 27% (Hameed et al., 2024). Collectively, IGRs alone or within IPM modules provide reliable, ecologically compatible alternatives to conventional neurotoxic insecticides for sustainable suppression of *C. partellus* in maize.

Semiochemicals and pheromones: Semiochemicals particularly sex pheromones are now integral to monitoring and decision-support systems for *C. partellus*. Pheromone trap catches closely reflect field population dynamics, enabling accurate forecasting, early warning and threshold-based interventions. Molecular studies on pheromone-binding proteins (PBPs) highlight their role in signal recognition and their potential for designing novel pheromone analogues through sequence analysis and molecular docking (Pedda Kasim et al., 2018).

Advances in pheromone chemistry and behavioral ecology have significantly enhanced application efficacy. Synthetic lures developed for *Chilo* spp. support mass trapping and IPM integration, achieving 60-90% suppression of infestation across cropping systems (Chen et al., 2013). Optimized lure ratios, dispenser types and release rates tailored to agro-climatic zones ensure consistent trap performance. Semiochemical-based surveillance also improves intervention timing, reducing unnecessary insecticide sprays and residues (Taneja et al., 2020). Electrophysiological and field evaluations confirm that the blend of (Z)-11-hexadecenal and (Z)-11-hexadecenol in a 100:100 ratio elicits maximum male attraction (Guleria et al., 2023). Maize-derived kairomones have further been shown to synergize pheromone response, supporting the development of hybrid kairomone-pheromone lures with enhanced sensitivity under low-density infestations (Guleria et al., 2021). Efforts should prioritize standardized trap densities, improved controlled-release dispensers and integration of pheromone surveillance with biological control, resistant cultivars and climate-responsive IPM models.

Emerging biorationals (RNAi and nanobiopesticides): Advances in molecular biotechnology and nano-formulations are expanding biorational options for managing *C. partellus*. RNA interference (RNAi) has shown promising gene-specific suppression, with transgenic maize expressing dsRNA against the chitinase gene (*CpCHI*) achieving 57-82% transcript knockdown and nearly 53% larval mortality (Adeyinka et al., 2023). Targeting chitin-synthase and metabolic genes similarly reduced larval growth and survival and induced deformities during pupation (Rana 2020). However, RNAi efficiency in lepidopterans is constrained by dsRNA instability and delivery barriers, encapsulation in nanoparticles or polymeric matrices enhances oral uptake, persistence and silencing efficiency (Nitnavare 2021, Lu 2023).

Nanobiopesticides have likewise advanced the performance of botanical and microbial agents. Nano-encapsulated azadirachtin formulations exhibit improved UV protection, stability and residual activity, resulting in stronger feeding deterrence and mortality compared with conventional formulations (Pasquoto-Stigliani et al., 2017). Nano-formulated fungal and plant-based biopesticides show 20-40% higher larvicidal activity and improved persistence under controlled trials (Lu 2023). Nanocarriers such as liposomes and clay nanosheets also protect dsRNA from degradation, enabling hybrid RNAi-nanotechnology platforms with enhanced delivery and efficacy (Nitnavare 2021).

CONCLUSION

Maize stem borer, *C. partellus* remains a key constraint to maize production across tropical and subtropical regions, with its polyphagy, overlapping generations and climatic resilience necessitating sustainable management approaches. Improved understanding of its bio-ecology and seasonal dynamics now supports more accurate forecasting and targeted interventions. Biorational tactics provide effective, environmentally compatible alternatives to conventional insecticides and their integration within robust IPM frameworks strengthened by digital advisory systems and extensive field validation offers a viable pathway for long-term management of *C. partellus* while conserving beneficial fauna and overall agro-ecosystem health. This review calls for further research on developing synergistic biorational consortia (microbial, botanical and pheromone-based), strengthening decision-support tools for precise application timing and evaluating long-term impacts on natural enemies. Policy support for residue-free maize and organic certification will further enhance adoption. Multi-location validation across diverse Indian agro-ecologies remains critical for achieving durable, scalable IPM solutions for *C. partellus.*

AUTHOR'S CONTRIBUTION

G. V. Suneel Kumar conceptualized the review, developed the framework, supervised literature synthesis and finalized the manuscript. S. V. S. Gopala Swamy organized and interpreted relevant findings and critically reviewed the content for accuracy and completeness. C. Kathirvelu conducted the literature search and assisted in drafting. All authors approved the final version.

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Evaluation of Integrated Pest Management Strategies for Major Insect Pests of Mungbean (*Vigna radiata* L.)

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***Abstract*:** An integrated pest management (IPM) module was developed and tested on mungbean (*Vigna radiata* L.) at Regional Agricultural Research, Lam, Guntur from 2018 to 2022 to reduce dependency on calendar-based insecticide sprays while maintaining acceptable pest control and profitability. The IPM package combined seed treatment (imidacloprid 600 FS @ 5.0 ml/kg), cultural measures (maize guard rows), monitoring (yellow and blue sticky traps), botanical sprays (neem oil 10,000 ppm @ 1.5 ml/l at 20 DAS), *Bacillus thuringiensis* formulations at flowering and need-based application of selective insecticides (flonicamid 50 WG and chlorantraniliprole 18.5 SC at recommended stages). IPM plots recorded mean populations of whitefly (2.6/3 leaves), thrips (3.4/3 leaves) and *Maruca* larvae (1.1/plant) with pod damage of 8.8%, yield 1,293 kg/ha and cost: benefit ratio 1:2.23 compared with farmers' practice which indicated lower natural enemy counts, higher input cost and yield 1,423 kg/ha with B:C 1:1.89. The results confirm that adoption of IPM provides comparable pest control with reduced number of insecticide sprays and improved natural enemy abundance while maintaining better returns making it a sustainable option for mungbean cultivation.

Keywords: IPM, Mungbean, Neem oil, Pod borer, Sticky traps, Sucking insects

Mungbean (*Vigna radiata* L.) is a vital legume crop in India, renowned for its nutritional value and adaptability to diverse agro-climatic conditions and is the third most important pulse crop of India after the chickpea and pigeon pea. India stands as the leading producer of mungbean, occupying an area of 5.01 million hectares with a production of 2.92 million tonnes contributing 18.5 % of the total pulses area and 11.9 % to the total pulses production during 2023-24. In Andhra Pradesh, greengram grown in an area of 0.06 million ha with a production of 0.06 million tonnes and a productivity of 973 kg ha during 2023-24 (*Rabi* price policy report 2025-26, www.cacp.da.gov.in). Mungbean production often constrained by sucking pests (whitefly, thrips, aphids) and pod-borers such as *Maruca vitrata* (Geyer) which cause yield losses and reduce seed quality. Reliance on calendar or frequent insecticide sprays is common among farmers, leading to environmental problems, natural enemy mortality and development of resistance. Integrated pest management (IPM) strategically combining cultural, biological, botanical and selective chemical tools offers a sustainable alternative and has shown promise for legumes under Indian conditions. Previous evaluations of IPM packages for blackgram/greengram recorded better suppression of sucking pests and viral disease incidence compared with sole chemical use (Khajuria et al., 2015). Botanical products such as neem oil and microbial agents provide low-toxicity options compatible with beneficials, while seed treatments (neonicotinoids like imidacloprid) can reduce early-season establishment of sucking pests and protect seedlings. Integration of seed treatment with imidacloprid 48 FS and selective newer insecticides like indoxacarb and thiamethoxam proved highly effective in suppressing both sucking pests and pod borers in mungbean (Abhijit Kar et al., 2018). The present study aimed to develop and evaluate an integrated pest management module for mungbean under southern Andhra Pradesh conditions, emphasizing pest suppression, natural enemy conservation, yield sustainability, and economic viability compared with farmers' practice.

MATERIAL AND METHODS

The trials were conducted at Regional Agricultural Research station, Lam, Guntur, Andhra Pradesh, India during five *Rabi* seasons from 2018-19 to 2022-23. Two main management approaches were compared.

Integrated Pest Management: The IPM strategy involved a combination of preventive, cultural, and need-based control measures. Seeds were treated with imidacloprid 600 FS at 5.0 ml/ kg seed prior to sowing. To minimize pest immigration, four guard rows of maize were planted around the mungbean plots as a cultural barrier. Monitoring of white fly and thrips were carried out using yellow and blue sticky traps, respectively installed at a density of 50 traps per hectare. Botanical insecticide i.e. neem oil (10,000 ppm) at 1.5 ml/l was applied at 20 days after sowing (DAS). Subsequent insecticidal applications were made based on pest scouting and threshold levels, employing a rotational use of selective insecticides to avoid resistance build-up. Flonicamid 50 WG was applied at 75 g a.i. / ha around 25 DAS for sucking pests, chlorantraniliprole 18.5 SC at 20 g a.i./ ha during pod initiation (approximately 55 DAS) for pod borers, and *Bacillus thuringiensis* (Bt) formulations were used from flowering to pod maturity to manage lepidopteran larvae. Throughout the crop period, conservation of natural enemies was emphasized by minimizing the use of broad-spectrum insecticides.

Farmers' Practice (FP): The farmers' practice typically consisted of calendar-based or weekly insecticidal sprays, with 4–8 applications per season depending on pest pressure. These sprays were applied without seed treatment, use of botanicals, or incorporation of bio-agents. The choice of insecticides and their frequency varied among across years, largely based on local availability and their preferences rather than pest monitoring or threshold-based decision-making.

Experimental design and observations: Mungbean plots under IPM and FP were sown separately each in 500 m^2 area with spacing of 30 X 10 cm and maintained with all the recommended agronomic practices (except pest management). Regular scouting was done at fortnight intervals and recorded pest incidence as numbers of whiteflies (per 3 leaves), thrips (per 3 leaves), *Maruca* larvae per plant, percent pod damage, and natural enemy counts per plant. Economic parameters (cost of cultivation, gross and net returns, B:C ratio) were computed from recorded input costs and market prices of produce. Individual year data were pooled (2018-19 to 2022-23) for analysis and pooled data were subjected to statistical analysis using t-test (p=0.05).

RESULTS AND DISCUSSION

Pest incidence and natural enemy activity: The pooled results from five seasons (2018-19 to 2022-23) revealed that the incidence of major sucking pests viz., whitefly (*Bemisia tabaci*), thrips (*Thrips tabaci*) and the pod borer *M. vitrata* was effectively managed under both IPM and farmers' practice (FP) modules (Table 1). Mean whitefly and thrips populations were 2.6 and 3.4 per three leaves in the IPM plots compared with 1.9 and 2.6 in FP, respectively. Similarly, the mean number of *Maruca* larvae per plant was 1.1 under IPM and 0.8 under FP. Pod damage varied between 5.5 % and 12.9 % across years, with pooled means of 8.8 % (IPM) and 7.4 % (FP). The differences in pest incidence were statistically non-significant indicating that substantial reduction in pesticide use under IPM did not compromise pest control efficacy. In contrast, the population of natural enemies was significantly higher in IPM plots (0.5 per plant) than in FP (0.2 per plant). Enhanced abundance of predators such as coccinellids, chrysopids, and spiders under IPM can be attributed to the reduced use of broad-spectrum insecticides and adoption of botanicals, which are compatible with natural enemies (Khajuria et al., 2015, Singh et al., 2020). These findings support the ecological advantage of IPM in sustaining beneficial arthropod populations and maintaining pest–predator equilibrium.

Yield performance and economic returns: FP recorded a slightly higher mean yield (1,423 kg / ha) than IPM (1,293 kg/ ha). Although yield differences were statistically small, they were not agronomically significant in relation to cost savings. The lower cost of cultivation in IPM (₹ 29,700 per ha) compared with FP (₹ 38,550 per ha) contributed to a higher

Table 1. Incidence of major insect pests and yield of mungbean under IPM and farmers' practice

Particulars	2018		2019		2020		2021		2022		Pooled (2018-2022)		
	IPM	FP	IPM	FP	IPM	FP	IPM	FP	IPM	FP	IPM	FP	T test
No. of whiteflies/3 leaves	0.3	0	0.5	0	0.42	0.27	5.4	5.1	6.5	4	2.6	1.9	NS (P = 0.40)
No. of thrips per three leaves	0.6	0	1.15	0	0.93	0.18	4	5	10.5	7.8	3.4	2.6	NS (P = 0.44)
No.of Maruca larvae/plant	-	-	-	-	0.41	0.16	1.8	1.7	1.1	0.6	1.1	0.8	NS (P= 0.25)
Pod damage (%)	-	-	-	-	5.55	2.15	11.94	12.87	9	7.3	8.8	7.4	NS (P=0.37)
Natural enemies/plant	0.5	0.1	0.4	0.1	0.5	0.1	0.6	0.35	0.6	0.35	0.5	0.2	S (P=0.0016)
Cost of cultivation (Rs./ha)	25500	29000	22000	27000	32250	53500	32250	39500	36500	43750	29700	38550	S (P= 0.034)
Yield (kg/ha)	1250	1300	1280	1400	1140	1430	1448	1525	1350	1460	1293	1423	S (P=0.019)
Gross returns Rs./ha)	50000	52000	64000	70000	62700	78650	79640	83875	74250	80300	66118	72965	S (P=0.027)
Net returns (Rs./ha)	24500	23000	42000	43000	30450	25150	47390	44375	37750	36550	36418	34415	
CB ratio	1:2.8	1:1.4	1:2.9	1:2.6	1:2.9	1:2.5	1:2.5	1:2.1	1:2.0	1:1.8	1:2.23	1:1.89	

NS- Non Significant S- Significant

cost: benefit ratio (1:2.23 vs 1:1.89). The superior economic efficiency of IPM is attributed to reduction in pesticide sprays from 6–8 to 3–4 per season corresponds to a 40–50% reduction in insecticide load, aligning with national IPM objectives. Similar observations were made in blackgram and cowpea where IPM practices reduced chemical sprays by nearly half while sustaining yields and improving profitability (Khajuria et al., 2015, Swamy et al., 2021). These results highlight that judicious, need-based pest management is more cost-effective than calendar spraying. The economic advantage of IPM aligns with reports from other pulse systems where partial substitution of synthetic insecticides with neem oil and microbial agents improved benefit–cost ratios and reduced pesticide residue load (Singh et al., 2020, Kumar et al., 2022). The advantages of IPM in controlling both sucking pests and pod borers resulting in enhanced productivity and profitability were further emphasized Rajabaskar and Natarajan (2018).

Performance of module components: The effectiveness of the IPM package stems from its integrated components. Seed treatment with imidacloprid 600 FS @ 5 ml/kg provided early protection against sucking pests and reduced initial infestation pressure, also observed by Swamy et al. (2021) in mungbean and by Khajuria et al., (2015) in blackgram. Comparable reductions in thrips incidence from neem-based formulations have been reported in mungbean and vegetable ecosystems (Singh et al., 2020, Sundar and Rani 2019). Selective insecticides such as flonicamid (against sucking pests) and chlorantraniliprole (against *M. vitrata*) were effective when applied at threshold levels. These molecules are known for their specificity and low toxicity to beneficial fauna. Bt formulations applied during flowering–pod initiation further aided suppression of *Maruca* larvae. The integration of chemical, botanical and biological tactics thus achieved efficient pest suppression with minimal ecological disturbance. Sasmal et al. (2018) demonstrated that an IPM module integrating seed treatment, traps and selective insecticidal sprays provided superior pest suppression and improved yields. Similarly, Singh et al. (2018) confirmed the efficacy of IPM in minimizing whitefly populations.

Khajuria et al. (2015) reported reduced whitefly infestation and lower yellow mosaic virus incidence under IPM modules compared with chemical control in blackgram. The observed higher natural enemy activity and improved cost-benefit ratio in the current IPM trials reinforce the sustainability of integrated approaches. Reduction in pesticide frequency not only lowers production costs but also delays pest resistance development and minimizes health and environmental hazards. Swamy et al. (2021) also highlighted that combined use of seed treatment, neem products and selective insecticides enhanced mungbean yield while reducing pest incidence and chemical dependence.

CONCLUSIONS

The five-year field evaluation demonstrated that the IPM strategy integrating seed treatment with imidacloprid, neem-based botanicals, trap-based monitoring, microbial biopesticide sprays and threshold-based use of selective insecticides was as effective as farmers' calendar sprays in managing whiteflies, thrips and *Maruca* pod borer in mungbean. Although yields under IPM were marginally lower than farmers' practice, pest levels remained below economic thresholds without compromising productivity. Notably, higher natural enemy abundance under IPM confirmed its ecological compatibility and reduced disruption to beneficial fauna. Economically, IPM proved more advantageous due to reduced pesticide use by nearly half and lower input costs, resulting in a superior cost–benefit ratio highlights its sustainability. The findings establish IPM as a more sustainable and profitable alternative to pesticide-intensive practices, with added benefits of resistance management and environmental safety. Thus, the study validates IPM as a profitable, eco-friendly, and scalable approach for mungbean pest management.

AUTHOR'S CONTRIBUTION

This work was carried out in collaboration among all the authors. The authors Mounika, D and Kamakshi, N prepared the Manuscript. Sandhya Rani C, Rani Chapara and Kishore Varma, P corrected the manuscript. All the authors contributed and approved the final manuscript.

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Sustainable Management of Fall Armyworm (*Spodoptera frugiperda*) in Maize through Integrated Approaches

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***Abstract*:** Frontline demonstrations were conducted in twenty locations in various adopted villages of Krishna district, Andhra Pradesh to evaluate the efficacy of Integrated Pest Management (IPM) practices against fall armyworm (*Spodoptera frugiperda*) in maize during *rabi*, 2022-23 and 2023-24. The pooled results of two consecutive seasons revealed that IPM treated plots comprising erection of pheromone traps, spraying of *Bt* formulations and need based spraying of recommended insecticides had resulted in 66.9 & 70.03 per cent reduction in plant damage and 57.8 & 62.8 per cent reduction in cob damage due to fall armyworm incidence in maize during 2022-23 and 2023-24, respectively. The yield gain was observed to be 17.05 and 9.3 per cent with BC ratio of 1.79: 1 and 1.96: 1 during 2022-23 and 2023-24, respectively,

Keywords: Fall armyworm, IPM, Net returns, Per cent plant damage, Pheromone traps

Maize, a vital staple food in India next to rice, plays a crucial role in ensuring food security and supporting the livestock and agro-industrial sectors serving as a raw material for feed, in making of beverages and various industrial products. The invasion of the fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith), a polyphagous lepidopteran pest native to the Americas, has severely disrupted maize cultivation since its first report in India during 2018 (Sharanabasappa et al., 2018). In Andhra Pradesh, it was reported for the first time in agency areas of Visakhapatnam in July, 2018 (Ramesh et al., 2020). FAW attacks maize at all growth stages, from seedlings to cobs, causing severe yield losses, particularly in southern and northeastern states. The high fecundity (up to 1,200 eggs per female) and ability to migrate facilitated by monsoon winds contribute to rapid population buildup, with 4-6 generations per year in tropical climates (Mousafa et al., 2023). Management of fall army worm in maize with sole dependence on chemicals alone often leads to pesticide residues in the crop produce, pest resurgence, secondary pest outbreak besides environmental pollution and severe health hazards. Hence, adoption of Integrated Pest Management (IPM) strategies will ensure management of fall army worm in more economical, sustainable and eco-friendly manner (Lakshmi Narayanamma et al., 2023). Therefore, frontline demonstrations (FLDs) were conducted in different adopted villages of Krishna district for two consecutive seasons during *rabi*, 2022-23 and 2023-24 to demonstrate the practical benefits, economic advantages and adoption potential of IPM practices for sustainable management of fall armyworm in maize under farmers' field conditions.

MATERIAL AND METHODS

Study area and experimental details: Frontline demonstrations were conducted in farmers' fields of adopted villages located in Ghantasala, Mopidevi, Movva and Challapalli mandals of Krishna district, Andhra Pradesh for two consecutive years during *rabi* seasons of 2022-23 and 2023-24. The demonstrations were conducted in ten locations each year with an objective of evaluating IPM strategies for the effective management of fall armyworm in maize.

Each treatment was implemented in an area of 0.4 ha area in farmers' fields with popular maize hybrids. The crop was grown following all the recommended package of practices. Regular field scouting was carried out for monitoring of pest population through pheromone traps and recording pest incidence. The pheromone traps were installed randomly covering the entire demonstration field and need based sprayings were applied whenever the pest population exceeded the economic threshold level (ETL) i.e., 5 % leaf damage or 15% whorl infestation (Manisha et al., 2024), using recommended insecticides.

Observations and data recording: Data was recorded on per cent plant infestation by randomly selecting 20 plants from each treatment (demonstration plot) leaving the border plants all around the field. The number of healthy and fall army worm damaged plants were counted to arrive per cent plant infestation in the treated plots and in farmer's practice. Similarly, the data on per cent cob damage was estimated by sampling hundred randomly selected cobs and the no. of healthy cobs and cobs damaged by fall army worm were counted at the time of harvest. Yield data were recorded from each treatment and economic parameters including cost of cultivation, gross and net returns, benefit cost (B:C) ratio were also calculated.

Statistical analysis: Data was analysed using using SPSS statistical package tools.

RESULTS AND DISCUSSION

The adoption of IPM practices against fall armyworm in maize significantly reduced pest damage. The mean per cent plant damage in IPM plots was 14.1 and 9.5 corresponding to 66.9 and 70.03 % reduction of plant damage over farmers practice during 2022-23 and 2023-24, respectively. Similarly, per cent cob damage in IPM demonstrated plots was 18.6 and 14.7 % during 2022-23 and 2023-24, respectively, as against higher damage levels of 44.1 and 39.5 during 2022-23 and 2023-24, respectively, under farmers practice (Table 2). Sharanabasappa et al. (2020) also reported that chlorantraniliprole followed by emamectin benzoate and spinetoram were found effective in managing fall armyworm in maize. Aarthi Helen (2021) with *Bt* formulations were effective against all armyworm instars. Palanivel et al. (2024) reported that the combined use of azadirachtin, *Metarhizium anisopliae* and emamectin benzoate in IPM treated plots reduced fall armyworm infestation from 49 to 17 per cent with 67.3 per cent control efficiency.

The implementation of IPM practices against fall armyworm in maize resulted in reduction of cost of cultivation and increase in net returns with higher BC ratio (Table 3). During 2022-23, the cost of cultivation in IPM was Rs. 74,875 per ha with net returns of Rs. 96,800 per ha and a BC ratio of 2.29: 1, whereas, farmers' practice incurred a higher cost of Rs. 80,475 per ha with net returns of Rs. 64,222 per ha and a BC ratio of 1.79: 1. Similarly, during 2023-24, IPM plots recorded a cost of cultivation of Rs. 76,125 per ha with net returns of Rs. 1,02,403 per ha and a BC ratio of 2.34: 1 whereas, famers' practice had as cost of cultivation of Rs. 84,590 per ha, net returns of Rs. 78,858 per ha and a BC ratio of 1.93: 1. These results demonstrate that IPM not only effectively reduces FAW incidence but also lowers production costs and improves profitability, emphasizing the practical and economic benefits of adopting integrated management strategies under farmers' field conditions.

In the present study, the reduction in per cent infestation by fall armyworm in IPM-demonstrated plots can be attributed to the integration of pheromone traps, which effectively trapped male adult moths and facilitated monitoring of pest population dynamics, enabling timely insecticidal applications (Kumar et al., 2022, Sisay et al., 2024). The erection of pheromone traps proved beneficial not

Table 1. Treatment details along with GPS coordinates of locations

Treatment	Details	Location with GPS (2022-23)	Location with GPS (2023-24)
Integrated Pest Management (IPM)	Seed treatment with Cyantraniliprole 19.8% + Thiamethoxam 19.8% FS @ 6 ml/kg seed; installation of pheromone traps (*S. frugiperda*) @ 10 traps/ha; collection and destruction of egg masses; spraying of 5% neem seed kernel extract (NSKE) or azadirachtin 10000 ppm (500 ml/ha) if adult activity and egg masses are noticed; spraying of *Bacillus thuringiensis* formulations @ 2g/l at 5-10% infestation, and need based spraying of recommended insecticides: Chlorantraniliprole 18.5 % SC @ 0.3 ml/l; Spinetoram 11.7 % SC @ 0.5 ml/l; Emamectin benzoate 5% SG @ 0.4g/l.	L1: 16.1239°N, 80.8907°E L2: 16.1211°N, 80.8710°E L3: 16.1830°N, 80.9269°E L4: 16.1766°N, 80.8578°E L5: 16.2969°N, 80.8206°E L6: 16.1073°N, 80.8904°E L7: 15.4312°N, 81.3112°E L8: 16.1912°N, 80.9226°E L9: 16.1976°N, 80.8456°E L10: 16.1373°N, 80.8938°E	L1: 16.4969°N, 80.6390°E L2: 16.1024°N, 80.8914°E L3: 16.2182°N, 80.0836°E L4: 16.2356°N, 80.0376°E L5: 16.2577°N, 81.1454°E L6: 16.1809°N, 81.1303°E L7: 16.1712°N, 80.3112°E L8: 16.1159°N, 80.9779°E L9: 16.0526°N, 80.9396°E L10: 16.1749°N, 80.9516°E
Farmers practice	Chemical based management involving multiple sprays of insecticide mixtures such as Novaluron 5.25% + Emamectin benzoate 0.9% SC, Profenophos 50%EC, Flubendiamide 480SC and Chlorantraniliprole 18.5% SC after noticing the fall armyworm incidence at 4-5 days interval.		

Table 2. Effect of integrated pest management on fall armyworm infestation and yield in maize

Year	No. of locations	Mean No. of insects trapped		Mean Per cent plant damage (%)		Per cent reduction over check	Mean Per cent cob damage (%)		Per cent reduction over check	Yield (kg/ha)		Per cent increase in yield (%)
		IPM	FP	IPM	FP		IPM	FP		IPM	FP	
2022-23	10	11.3	-	14.1	42.6	66.9	18.6	44.1	57.8	8750	7475	17.05
2023-24	10	8.4	-	9.5	31.7	70.03	14.7	39.5	62.8	8542	7815	9.3
t value	-	-	-	4.05*		-	4.24*		-	4.77*		-

* - Significant at 5 per cent level of significance (P = 0.05); IPM- Integrated Pest Management; FP- Farmers' Practice

Table 3. Economic analysis of maize under integrated pest management and farmers' practice

Year	Average cost of cultivation (Rs/ha)		Average gross returns (Rs/ha)		Average net returns (Rs/ha)		BC ratio	
	IPM	FP	IPM	FP	IPM	FP	IPM	FP
2022-23	74,875	80,475	1,71,675	1,44,698	96,800	64,222	2.29: 1	1.79:1
2023-24	76,125	84,590	1,78,528	1,63,334	1,02,403	78,858	2.34: 1	1.93: 1
Mean	75,500	82,475	1,75,101.5	1,54,016	99601.5	71540	2.32: 1	1.86: 1

IPM- Integrated Pest Management; FP- Farmers' Practice

only for monitoring but also for mating disruption, resulting in comparatively lower egg laying in IPM- demonstrated plots than under the farmers' practice. The application of neem-based formulations during periods of adult activity likely exerted a repellent effect, thereby reducing oviposition. Spraying of selective insecticides further suppressed subsequent pest populations, minimized the development of resistance and reduced residual effects. Overall, the integrated approach was more effective than the farmers' conventional practice of relying solely on insecticides.

CONCLUSION

Fall armyworm is a major destructive pest of maize causing significant economic losses due to reduction in yield by damaging leaves, tassels and cobs. Adoption of IPM practices like seed treatment, installation of pheromone traps, spraying of neem, *Bt* formulations and need based spraying of selective insecticides viz., Chlorantraniliprole, Spinetoram and Emamectin benzoate effectively reduced fall armyworm infestation. Implementation of these IPM strategies led to increased maize yield and higher net returns compared to conventional farmers' practice. The findings also indicate that farmers are adopting the suggested IPM practices to suppress the fall armyworm incidence and to enhance the yield, highlighting the practical relevance and economic benefits of integrated management under field conditions.

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Field Efficacy of Novel Insecticide Afidopyropen against Leafhopper, *Amrasca biguttula biguttula* and Whitefly, *Bemisia tabaci* in Cotton

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Abstract: Field trials were conducted to assess the efficacy of the novel insecticide afidopyropen against major sucking pests of cotton, *Amrasca biguttula biguttula* (Ishida) and *Bemisia tabaci* (Gennadius) during the 2020 and 2021 cropping seasons at Hisar (Haryana). Two foliar sprays of each treatment, including standard checks, were applied, and observations on target pests were recorded at 1, 3, 5, 7, and 10 days after each spray. Afidopyropen @ 50 g a.i./ha significantly reduced the target pest populations in both years, recording the lowest leafhopper (0.80 and 0.86 nymphs/leaf) and whitefly (21.13 and 2.88 adults/leaf) densities, along with the highest seed cotton yields (26.86 and 22.29 q/ha) in 2020 and 2021, respectively. Populations of natural enemies, including coccinellids and spiders, were not significantly affected, and no phytotoxic symptoms were observed on cotton. These findings reveal that afidopyropen is a highly effective, selective, and crop-safe insecticide suitable for inclusion in integrated pest management programs for sustainable cotton cultivation.

Keywords: Afidopyropen, Cotton, Efficacy, Novel insecticide, Natural enemies, Sucking pests

Cotton is one of the most important cash and fibre crops in India, which is grown over an area of 12-13 million hectares with production of approximately 35-38 million bales. Haryana is one of the important cotton-growing states in India which occupied 6.48 lakh hectares area under its cultivation in 2022 (Department of Agriculture & Farmers Welfare, Haryana 2022). The majority of farmers grow *Bt* cotton which was commercialized to protect the crop from the attack of bollworms. On the other hand, *Bt* cotton suffers due to the ravages of sucking insect-pests, namely cotton leafhopper/jassid, whitefly and thrips. They damage cause substantial yield losses and degrade cotton fiber quality, increasing the need for targeted pest management practices despite the advantages offered by *Bt* cotton against chewing pests (Ali and Farooq 2018). Although several insecticides have been recommended for their management from time to time. But frequent and indiscriminate use of these insecticides led to the tolerance and development of resistance among sucking pest populations (Mahalanobish et al., 2022), highlighting the urgent need for novel chemistries with unique modes of action.

Afidopyropen, a novel insecticide, is a derivative of pyripyropene A, which is produced by the filamentous fungus *Penicillium coprobium* has strong insecticidal activity against aphids and is currently used as a control agent of sucking pests worldwide (Ryo et al., 2022). Afidopyropen modulates the transient receptor potential vanilloid (TRPV) channels in insect chordotonal organs (Horikoshi et al., 2025, Li et al., 2022), thereby disrupting feeding behavior in sap-sucking insects (Saito et al., 2014, Matsuda et al., 2020) and showed excellent insecticidal activities against common aphid species, such as green peach aphid (*Myzus persicae*), cotton aphid (*Aphis gossypii*) and bean aphid (*A. craccivora*), that damage a variety of vegetables, fruit trees, tea trees and ornamentals by sucking sap from leaves (Zhou et al., 2023, Zha et al., 2024,). Furthermore, it showed good activities against whiteflies *(Trialeurodes vaporariorum* and *B. tabaci*), mealybugs (*Pseudococcus comstocki)*, leafhoppers (*Empoasca onukii*) and psyllids and exhibited good efficacies against these insect pests in field trials, while decreasing crop damage (Ryo et al., 2022). In addition, afidopyropen shows low toxicity levels against honeybees and natural enemies, as well as against mammals. Because of environmental dynamics, afidopyropen is expected to be an eco-friendly tool for sustainable agriculture. Therefore, the present study was devised to evaluate afidopyropen 50 g/l DC formulation for its bioefficacy against leafhopper and whitefly infesting cotton and safety against natural enemies and phytotoxicity on cotton crop during *kharif* 2020 and 2021.

MATERIAL AND METHODS

The field experiments on bioefficacy of afidopyropen 50 g/l DC against leafhopper and whitefly on cotton were conducted for two consecutive years during *Kharif* 2020 and 2021 at Research Area, Department of Genetics and Plant Breeding (Cotton Section), CCS HAU, Hisar. The experiments were conducted in Randomized Block Design with six treatments and four replications. Afidopyropen 50 g/l

DC was evaluated at its three different doses (25, 35 and 50 g a.i./ha) against leafhopper and whitefly. Thiamethoxam 25% WG (25 g a.i./ha) and dimethoate 30% EC (225 g a.i./ha) were kept as standard checks for leafhopper and whitefly whereas one untreated control was also kept. One additional treatment was also kept for recording the observations on phytotoxicity of afidopyropen 50 g/l DC @ 100 g a.i./ha with three replications. The plot size was kept as 21.87 sq. m and plant spacing was maintained at 67.5×30 cm (row×plant). Non-Bt cotton crop variety, H 1098i (*Gossypium hirsutum*) was sown on May 9, 2020 and May 12, 2021 and the crop was maintained by following recommended Package of Practices except for insect-pest management. The insecticide application was initiated after crossing the economic thresholds for leafhopper (2 nymphs/leaf) and whitefly (6-8 adults/leaf) using battery operated knapsack sprayer and spray volume was kept @ 500 liters/ha. Cotton crop was sprayed with respective treatments on 16th and 28th July during 2020 and 7th and 19th August during 2021.

The observations on leafhopper nymphs and whitefly adults were recorded before spray and 1, 3, 5, 7 and 10 days after each spray from three leaves (upper, middle and lower canopy) each of five randomly selected and tagged plants per replication. The observations on natural enemies including coccinellids and spiders were also recorded on above five tagged plants. Phytotoxicity observations like chlorosis, necrosis, wilting, scorching, hyponasty and epinasty were also recorded after first spray in afidopyropen 50 g/l DC @ 50 and 100 g a.i./ha and untreated control. Picking of seed cotton was done at appropriate boll opening stage and yield was recorded in kg/plot and converted into q/ha. The population data was subjected to square root transformation before processing for analysis of variance using OPSTAT software (Sheoran et al., 1998).

RESULTS AND DISCUSSION

Efficacy against leafhopper, *A. biguttula biguttula:* Based on the mean of all sprays, the population of leafhopper varied from 0.80 to 3.15 nymphs/leaf and 0.86 to 3.45 nymphs/leaf during 2020 and 2021, respectively (Table 1). During both years, the population of leafhoppers showed non-significant differences among the treatments before spray. All the insecticide treatments significantly suppressed the population of leafhoppers at 1, 3, 5, 7 and 10 days after spray during both years. Treatment with afidopyropen 50 g/l DC @ 50 g a.i./ha resulted in the significantly lowest population of leafhopper, *i.e.,* 0.80 and 0.86 nymphs/leaf during 2020 and 2021, respectively.

Efficacy against whitefly, *B. tabaci:* The mean population of whitefly varied from 21.13 to 44.10 adults/leaf and 2.88 to 9.29 adults/leaf during 2020 and 2021, respectively (Table 1). Before spray, the whitefly population did not vary significantly across the treatments during both the years. All the insecticide treatments significantly suppressed the population of whitefly at 1, 3, 5, 7 and 10 days after spray during both years. Among the treatments, the lowest population of whitefly was recorded in afidopyropen 50 g/l DC @ 50 g a.i./ha*i.e.,* 21.13 and 2.88 adults/leaf during 2020 and 2021, respectively.

The superior efficacy of afidopyropen may be attributed to its rapid feeding cessation and prolonged residual activity, which effectively suppresses pest resurgence. Its unique mode of action targeting TRPV channels likely confers efficacy even against insect populations showing resistance to conventional neonicotinoids and organophosphates (Saito et al., 2014, Matsuda et al., 2020). Field evaluations confirmed that afidopyropen significantly suppressed *A. biguttula biguttula* (Kumar et al., 2022) and whitefly populations in cotton, comparable to or better than other insecticides (Sharma et al., 2019, Kumar et al., 2022). Sharma et al. (2019) also support the superior efficacy of afidopyropen among newer insecticides against sucking pests of cotton.

Effect on natural enemies: Natural enemies including coccinellids and spiders were recorded after each spray on cotton during both years and the pooled data are presented in

Table 1. Effect of afidopyropen and other insecticidal treatments against leafhopper, whitefly and seed cotton yield

Treatments	Dose (g a.i./ha)	Leaf hopper (No. of nymphs/leaf)			Whitefly (No. of adults/leaf)			Seed cotton yield (q/ha)		
		2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
Afidopyropen 50 g/l DC	25	1.95	1.82	1.86	34.58	5.89	20.23	21.95	19.20	20.58
Afidopyropen 50 g/l DC	35	1.40	1.38	1.39	27.49	5.17	16.33	24.01	20.12	22.06
Afidopyropen 50 g/l DC	50	0.80	0.86	0.83	21.13	2.88	12.01	26.86	22.29	24.58
Thiamethoxam 25% WG	25	1.52	1.74	1.63	33.14	6.06	19.6	22.41	20.00	21.20
Dimethoate 30% EC	225	1.82	1.94	1.88	30.24	5.05	17.65	22.52	19.89	21.20
Untreated control	-	3.15	3.45	3.30	44.10	9.29	26.69	20.35	18.06	19.20
CD (p=0.05)		0.05	0.07	0.06	0.17	0.08	0.13	1.99	1.72	1.73

Table 2. Effect of afidopyropen and other insecticidal treatments on the population of natural enemies in cotton

Treatments	Population of spiders (per plant)	Population of coccinellids (per plant)
Afidopyropen 50 g/l DC @ 25 g a.i./ha	0.48	0.32
Afidopyropen 50 g/l DC @ 35 g a.i./ha	0.42	0.28
Afidopyropen 50 g/l DC @ 50 g a.i./ha	0.40	0.29
Thiamethoxam 25% WG @ 25 g a.i./ha	0.35	0.27
Dimethoate 30% EC @ 225 g a.i./ha	0.40	0.33
Untreated control	0.53	0.39
CD (p=0.05)	(NS)	(NS)

Table 2. Non-significant differences were observed in the population of spiders and coccinellids before and after 1, 3, 5, 7 and 10 day(s) of spray during both years. Patil et al. (2017) reported that afidopyropen was not only effective in reducing whitefly incidence but also compatible with natural enemies, making it a suitable candidate for use in integrated pest management (IPM) programs. The lower population levels observed in the current study, particularly in 2021, may also be attributed to favourable environmental conditions for insecticide performance and timely applications. The non-significant differences in coccinellid and spider populations before and after insecticidal sprays indicate that afidopyropen is selective in its activity and does not adversely affect non-target beneficial arthropods. Patil et al. (2017) also observed that afidopyropen was safe to key predators such as coccinellids and spiders when applied in cotton fields, highlighting its suitability for integrated pest management (IPM) programs for sustainable cotton production.

Seed cotton yield: Maximum seed cotton yield was obtained with afidopyropen 50 g/l DC @ 50 g a.i./ha during 2020 (26.86 q/ha) and 2021 (22.29 q/ha), which was significantly superior over rest of the treatments. Rest of the treatments except afidopyropen 50 g/l DC @ 25 g a.i./ha resulted in non-significant increase in yield over untreated control during both years.The significantly higher seed cotton yield recorded with afidopyropen 50 g/l DC @ 50 g a.i./ha in both years can be attributed to its superior efficacy in suppressing key sap-sucking pests like leafhoppers and whiteflies. This reduction in pest pressure likely minimized crop damage and improved plant vigor and boll retention, leading to better yield outcomes. Kumar et al. (2022) also reported a significant increase in cotton yield following afidopyropen application due to its quick action and prolonged protection. Sharma et al. (2019) observed a positive correlation between the reduction in sucking pest population and seed cotton yield enhancement.

Phytotoxicity: Phytotoxicity studies revealed that there were no phytotoxicity symptoms such as chlorosis, necrosis, wilting, scorching, hyponasty and epinasty were observed at either afidopyropen 50 g/l DC @ 50 or 100 g a.i./ha at 1, 3, 5, 7 and 10 day(s) after first spray on cotton during both years. The absence of phytotoxicity symptoms throughout the observation period clearly indicated the crop safety of afidopyropen at both tested doses. No adverse effects on cotton plants were observed even at higher application rates, suggesting a wide margin of safety for this insecticide. Sharma et al. (2019) also reported no visible phytotoxic effects of afidopyropen in cotton trials conducted across multiple locations. Additionally, the phytotoxicity evaluations conducted by Saito et al. (2014) in other crops supported afidopyropen's favorable environmental and plant safety profile.

CONCLUSION

Afidopyropen 50 g/l DC @ 50 g a.i./ha consistently provided the most effective control of *A. biguttula biguttula* and *B. tabaci*, resulting in the lowest pest densities and highest seed cotton yields. Its high selectivity, absence of phytotoxicity, and compatibility with natural enemies highlight its potential as a sustainable insecticidal option within integrated pest management (IPM) frameworks for cotton.

AUTHOR'S CONTRIBUTION

AJ: Methodology, performed experiments: AJ and PR: Data analysis, wrote original draft, AJ, AKR, KSM, SL: Conceptualization, designed the research, Supervision and Review, AJ, SL, PR: Review, editing. All authors read and approved the manuscript.

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Evaluation of Hermetic Bags for Storage of Sesame seed against *Tribolium castaneum* (Herbst)

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Abstract: Sesame (*Sesamum indicum* L.), commonly referred as the "queen of oil seeds," is valued for its nutritional richness and widely cultivated. Traditional storage in polypropylene and jute bags predisposes sesame seeds to insect infestation particularly by the red flour beetle, *Tribolium castaneum (*Herbst) and often necessitates chemical treatments that pose environmental risks. The present study conducted during 2022-23 and 2023-24, evaluated Purdue Improved Crop Storage (PICS) bags, Super GrainPro bags (SGP) for maintaining seed quality over 90 days in comparison with polypropylene bags, jute bags and jute bags treated with deltamethrin 2.8 EC @ 2ml/L. Results revealed that PICS bag, jute bags treated with deltamethrin and SGP bag recorded the lowest *T. castaneum* populations (3.9, 4.3and 4.4 per 100 grams of seed) compared with polypropylene bag (29.0) and jute bags (32.0) after 90 days of storage. Grain damage was significantly less in PICS (4.1%), deltamethrin treated jute bags (4.38%) and SGP bags (4.52%) than in polypropylene (19.2%) and jute bags (20.3%). Consequently, higher thousand seed weight was recorded in PICS bags (3.08 g) followed by insecticide treated jute bags (3.07g) and SGP bags (3.06 g) in comparison to polypropylene bags(2.41 g) and jute bags (2.38 g). Similarly, seed germination remained highest in PICS bags (88.0%), insecticide treated jute bags (87.0%) and in SGP bags (86.0%) compared to polypropylene bags and jute bags (61% each). The findings confirm that PICS bags and SGP bags effectively maintain pest free conditions and preserve seed quality without reliance on synthetic chemicals. Being eco-friendly and sustainable, hermetic storage solutions need to be promoted among sesame growers for safe and long-term seed storage.

Keywords: Sesame, Postharvest quality, *Tribolium*, Hermetic bags

Sesame (*Sesamum indicum* L.), commonly referred as the "queen of oil seeds", is an ancient oilseed crop belonging to the family Pedaliaceae, with high nutritional and economic value. Sesame seeds are rich in folic acid, oil, protein, unsaturated fatty acids, vitamins, and minerals, making them an important raw material for oil and meal production as well as food, confectionery, and beverage industries. (Kapoor et al., 2014). Globally, sesame ranks eighth among oilseed crops, cultivated in 14.8 million hectares with a production of 6.8 million tons, valued at 3.4 trillion dollars. Consumption is projected to reach 7244.9 million dollars by 2026 (Anonymous 2022). India holds the largest share in sesame area (45%), production (36%) and export (45%) with 1.95 million hectares under cultivation and 0.81 million tonnes of production in 2022–23, recording a productivity of 4.15 q/ha (Anonymous 2023).

Like other oilseeds, sesame is prone to storage pests due to its high protein and fat content. Major insect pests reported in India include sesame seed bug (*Elasmolomus sordidus* Fabricius), red flour beetle (*Tribolium castaneum Herbst*) and rice moth (*Corcyra cephalonica Stainton)* (Rajendran and Devi 2004). *Tribolium castaneum* is particularly destructive, feeding on broken grains, germ portion and milled products causing quality deterioration, foul odor and reduced dough quality. Being a cosmopolitan and polyphagous pest, it significantly reduces seed weight, germination and quality while raising storage temperature and moisture content of the grains (Faroni and Sousa 2006). Management of storage pests traditionally relies on synthetic chemicals, which, apart from posing environmental and health hazards, also threaten export potential due to pesticide residues. Post-harvest losses are substantial, with over 25% of seeds in warehouses deteriorating annually due to insect damage and biochemical degradation (Kumar and Kalita 2017). Although indigenous eco-friendly storage structures exist (Swamy and Wesley 2020), their durability and effectiveness are limited. In this context, hermetic storage technologies have emerged as a sustainable alternative, offering protection against pests without chemical inputs. Hence, the present study was undertaken to assess the performance of different types of storage bags including traditional (polypropylene, jute) and hermetic bags (PICS and Super GrainPro) for storing sesame seed against red flour beetle infestation.

MATERIAL AND METHODS

The experiment was conducted at Agricultural Research Station, Yellamanchili, Andhra Pradesh during 2022–23 and 2023–24 to evaluate different storage bags for storage of field harvested sesame seed over a 90-day period. The experiment was formulated adopting completely randomized block design with five treatments, replicated four times. The five treatments included, Purdue Improved Crop Storage (PICS) bags, Super GrainPro bags (SGP) in comparison to polypropylene (PP) bags, jute bags and jute bags treated with deltamethrin 2.8EC @ 2ml/l (chemical check). The hermetic bags (PICS and SGP) were obtained online from India Mart and the polypropylene (PP) and jute storage bags were procured from local market. The PICS bags contain three layers, while the SGP bags had a single layer of 78 µm polyethylene film.

Sesame seed produced during *Rabi* 2022 and 2023 under recommended practices was homogenized, divided into 40 kg lots and were attributed to every four storage bags; PICS bags, SGP bags, PP bags, and jute bags. PICS and SGP bags act as hermetic storage technologies, while PP and jute bags represent traditional storage materials used by small farmers. The jute bag treated with deltamethrin 2.8 EC @ 2ml/l served as chemical check. Each treatment of the storage bag was filled with 10 kg of sesame seeds, sealed using the twist-tie method after expelling excess air and stored under ambient room conditions. The natural build-up of red flour beetle in the field harvested sesame seed was monitored at 30-day intervals by sampling 100 g seed sample. After 90 days, the bio-physical parameters *viz.* per cent grain damage, seed index (thousand seed weight) and per cent germination were recorded after opening the bags. For seed index, 1000 seeds per replication were weighed. Percentage of seed damage was estimated (Boxall 1998):Germination was tested using the blotter method with 100 seeds per replication placed in filter-paper lined 100 mm petri plates. The plates were incubated at 25°C in a germination chamber with fluorescent lights that cycled on and off for 12 h (Alemayehu et al., 2020). Plates were moistened daily with distilled water and germination percentage was recorded after one week.

Statistical analysis: The data collected regarding various parameters were analysed using AGRES software. The critical differences (CD) were tested at 5 per cent probability level and the percentage values were arc-sin and square root transformed wherever necessary.

RESULTS AND DISCUSSION

The results obtained from the evaluation of different storage bags for sesame revealed significant variation in their effectiveness against red flour beetle (Table 1). The PICS bags, SGP bags, and jute bags treated with deltamethrin 2.8 EC effectively suppressed insect infestation compared to untreated controls. At 90 days after storage (DAS), insect population was lowest in PICS bags (3.9 adults/100 g), followed by insecticide treated jute bags (4.3 adults/100 g) and SGP bags (4.4 adults/100 g) corresponding to 87.8%, 86.56% and 86.25% reduction over the untreated jute control, respectively. In contrast, the traditional packaging materials (polypropylene and untreated jute bags) harbored significantly higher insect populations, reaching 29.0 and 32.0 adults/100 g at 90 DAS, respectively. Accordingly, their protection efficacy was very low, with polypropylene bags achieving only 9.37% reduction, while untreated jute bags with maximum infestation.

Seed quality parameters were also strongly influenced by storage bag. Germination percentage was highest in in PICS bags (90.0%) followed by insecticide treated jute bags (87.0%) and SGP bags (86.0%). In contrast, polypropylene and untreated jute bags recorded significantly reduced germination (61.0%). Similarly, 1000-seed weight was highest in PICS bags (3.20 g), while untreated jute bags recorded the lowest (2.38 g). Seed damage followed a similar trend, with PICS (4.12%), SGP (4.38%) and treated jute bags (4.52%) performing far better compared to polypropylene (19.17%) and untreated jute bags (20.30%), where heavy infestation occurred. Similarly, Germination percentage was highest in PICS bags (90.0%) followed by insecticide treated jute bags (87.0%) and SGP bags (86.0%). In contrast, polypropylene and untreated jute bags recorded significantly reduced germination (61.0%).

The study demonstrated the superiority of hermetic storage bags (PICS and SGP) and insecticide-treated jute

Table 1. Effect of storage methods on red flour beetle infestation and seed quality in sesame

Treatment	No. of adults /100 g*			Reduction over control (%)	1000-seed weight (g)	Seed damage (%)$	Germination (%)$
	30 DAS	60 DAS	90 DAS				
Purdue Improved crop storage bags	0.0 (1.0)	2.3 (1.8)	3.9 (2.0)	87.80	3.20	4.12 (11.86)	90.0 (69.13)
Super grain pro bags	0.0 (1.0)	2.5 (1.9)	4.4 (2.2)	86.25	3.07	4.38 (12.07)	86.0 (68.62)
Jute bag treated with deltamethrin 2.8 EC @ 2 ml/l	0.0 (1.0)	2.3 (1.9)	4.3 (2.1)	86.56	3.06	4.52 (12.27)	87.0 (68.71)
Polypropylene bags	12.6 (3.7)	17.0 (6.2)	29.0 (8.4)	9.37	2.41	19.17 (25.96)	61.0 (52.04)
Jute bag	14.6 (4.3)	22.0 (7.3)	32.0 (9.1)	--	2.38	20.30 (26.12)	61.0 (52.04)
CD (p=0.05)	0.4	0.3	0.4		0.10	1.16	3.73

DAS: Days after Storage; Values in the parentheses are *square root and $angular transformed values bags over conventional materials for effective protection of seeds against storage pests. PICS bags consistently outperformed other treatments by maintaining lower insect populations, highest germination percentage, maximum seed weight and minimum insect damage, aligning with earlier reports that hermetic storage suppresses insect multiplication by limiting oxygen availability and increasing CO_2 concentration (Gebregergis et al., 2024). The comparable performance of SGP bags and insecticide-treated jute bags indicates that both hermetic storage and chemical protection can restrict insect infestation. However, chemical treatments may pose environmental and health concerns, making PICS bags a more sustainable alternative. Traditional storage structures like polypropylene and untreated jute bags failed to prevent infestation due to their porous nature and lack of insecticidal protection. The sharp decline in germination percentage and seed weight in these treatments can be attributed to continuous insect feeding and damage, which also resulted in the highest percentage of seed damage.

The findings corroborate earlier studies of Musuya et al., (2022) who reported significantly lower insect proliferation, minimal seed moisture changes, and drastically reduced aflatoxin contamination in sesame stored in PICS and SGP bags over six months compared to polypropylene and conventional bags, in both tropical and semi-arid environments. Similar results were obtained by Sudini et al. (2015) and Baoua et al. (2014) who demonstrated near-complete control of *T. castaneum, Cryptolestes* spp. in hermetically sealed bags. Sharma et al. (2023) confirmed that sesame stored in high-density polyethylene (HDPE) hermetic bags retained more than 88 per cent germination after eight months, while plain jute and PP bags often fell below 60 per cent. Hassan et al. (2023) also observed reduction in insect damage significantly higher 1000-seed weight and viability in PICS bags throughout storage. Chemical control through deltamethrin-treated jute bags offered comparable protection to hermetic bags in the short term. However, previous reports caution that efficacy declines after 2–3 months and pesticide residues raise food safety and seed quality concerns (Rani and Singh 2018; Channaveerayya et al., 2019, Kavitha et al., 2018) making hermetic options preferable for seed material intended for planting.

Storage of sesame in untreated jute and polypropylene bags was consistently inferior. High permeability to air and moisture facilitated rapid insect multiplication, leading to greater seed damage, reduced seed weight, and lower germination. These findings align with earlier reports of 20–25% seed damage and significant viability loss in sesame stored in conventional bags under ambient conditions (Punnuri et al., 2018, Kumar et al., 2020, Bhagirath et al., 2021, ICAR-IIOR 2024).

Across multiple studies, a consistent pattern emerges in which hermetic storage systems such as PICS and SGP bags preserve seed viability, limit insect infestation (<5%), and maintain original seed moisture Musuya et al. (2022) far better than conventional packaging (Ghosh et al., 2023, ICAR-IIOR 2024). Meta-analyses by Nduku et al. (2020) and Sudini et al. (2015) also confirm the superiority of triple-layer hermetic storage bags in maintaining seed quality of sesame and other oilseeds across different environments. Drouin et al. (2021) and Thakur et al. (2022) also confirmed the superiority of PICS bags across multiple parameters including insect population dynamics, seed viability, mass retention, and insect damage.

CONCLUSION

Hermetic storage technologies particularly PICS and SGP bags effectively preserve sesame seed viability and grain quality, outperforming conventional bags. While insecticide-treated jute bags provide similar protection, their environmental and health risks make hermetic bags a more sustainable choice. Hence, adoption of PICS or SGP bags is strongly recommended to minimize post-harvest losses, maintain higher seed germination in sesame and thereby promoting food security.

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Effect of Different Diet Formulations on Adult Emergence of *Corcyra cephalonica* (Stainton)

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***Abstract*:** Experiment was conducted to evaluate the efficacy of various diet formulations on the adult emergence of *Corcyra cephalonica,* an important factitious host used in biological control programs. Ten different diets, including five solo grains (sorghum, maize, bajra, ragi, and broken rice) and five additive-enriched combinations (with groundnut powder and yeast), were tested under controlled conditions. Data on adult emergence were recorded weekly for five weeks. Among the diets, bajra and sorghum with additives resulted in the highest moth emergence (1294.3 adults), followed by bajra alone (1156.7) and maize + sorghum + additives (1007.0), whereas broken rice yielded the lowest moth emergence. These results confirm that dietary additives significantly enhance the reproductive performance of *C. cephalonica* and can be recommended for cost-effective mass rearing in biocontrol programs.

***Keywords*:** Additives, Adult emergence, *Corcyra cephalonica*, Host diet, Mass rearing, Biocontrol

Biological control has been employed for over a century to manage various insect pests (Dhawan 2007, Sampaio 2010 and Dhaliwal et al., 2010). It is widely recognized as an eco-friendly and sustainable alternative to chemical control, especially in light of the environmental and health hazards associated with the indiscriminate use of pesticides. In recent years, the adoption of biological control has gained significant momentum, particularly with the increased emphasis on Integrated Pest Management (IPM) strategies (Dhawan 2007, Dhaliwal et al., 2010, Dhawan et al., 2013, Stenberg 2017). Among the multiple approaches to biological control, augmentative release preceded by laboratory mass rearing has been proven effective in several cropping systems, including protected cultivation (Van Lenteren 2012, Brodeur et al., 2018). Successful implementation of these programs requires efficient mass production and conservation of beneficial organisms (Padhy et al., 2020). In India, the rice meal moth, *C. cephalonica* (Stainton), is extensively used as a factitious host for mass rearing of egg parasitoids such as *Trichogramma spp*. (Bernardi et al., 2000, Gauraha and Deole 2016). Various cereal grains including rice, maize, wheat, sorghum, and pearl millet have been evaluated for their suitability in rearing *C. cephalonica,* with differing opinions reported in earlier studies (Pathak et al., 2010, Gauraha and Deole 2016, Nasrin et al.,2016, Jhala et al., 2019 , Jitendra Kumar et al., 2025). The nutritional composition of the larval diet plays a crucial role in determining the quality and quantity of host eggs produced, which directly influences the field performance of released parasitoids (Hunter 2003). Hence, diet optimization is critical for both host production and the performance of natural enemies. In this context, the present study was conducted undertaken under laboratory conditions to assess the impact of different diet formulations, comprising solo grains and grain mixtures with nutritional additives on the adult emergence of *C. cephalonica*.

MATERIAL AND METHODS

The experiment was conducted under laboratory conditions at the Centre for Biological Control (CBC), National Institute of Plant Health Management (NIPHM), Rajendranagar, Hyderabad duirng 2022. Ten dietary treatments were evaluated consisting of five solo cereal grains: sorghum, maize, bajra, ragi, and broken rice and five combinations with additives. Each combination included two grains mixed in a 1:1 ratio and each supplemented with 40 g groundnut kernel powder and 5 g dry yeast per kg of diet. The treatments were sorghum, maize, bajra, ragi, broken rice, bajra + sorghum + additives, maize + sorghum + additives, sorghum + broken rice + additives, ragi + bajra + additives and bajra + broken rice + additives. Each treatment was replicated three times. The grains were cleaned, coarsely ground to 2–3 fragments, and sterilized at 100°C for one hour to eliminate microbial contaminants. After cooling, 1 kg of each diet was placed in individual plastic tubs. Additive mixtures were incorporated into the relevant diet treatments before infestation.

Each tub was inoculated with *C. cephalonica* eggs at a rate of 800 eggs (0.05 cc) per kg of diet, obtained from the insect culture maintained at Prof. Jayasankar Telangana State Agricultural University (PJTSAU), Hyderabad. The tubs were covered with muslin cloth secured with rubber bands and arranged on iron racks under laboratory conditions (temperature: 25±1ºC; RH: 70±5%; photo period: 14:10 h L:D). Adult moth emergence was monitored daily beginning on the 34th day after inoculation. Emerged moths were collected using specimen tubes, transferred to ovipositional cages and weekly cumulative emergence data were recorded for five consecutive weeks. Data were analyzed and treatment means were separated with Tukey's HSD using SPSS statistical software.

RESULTS AND DISCUSSION

The adult emergence of *C. cephalonica* was recorded weekly across all ten treatments for five consecutive weeks. The results showed significant differences in moth emergence among diets. During the first week, the highest adult emergence was observed in bajra + sorghum + additives with 86.00 moths, followed closely by bajra (83.3 adults) and maize + sorghum + additives (82.7 adults). The lowest adult emergence was observed in broken rice (13.0) and ragi (19.0).

In the second week, again bajra + sorghum + additives recorded the highest emergence (245.67), followed by maize + sorghum + additives and sorghum + broken rice + additives. Broken rice recorded lowest emergence (21.00). Similar trends continued in the subsequent weeks, with bajra + sorghum + additives consistently producing the maximum number of adults, peaking at 405.7 moths in the third week followed by bajra , maize + sorghum + additives, and sorghum + broken rice + additives . Broken rice and Ragi consistently yielded the fewest adults.

Adult emergence during the fourth week was highest in bajra (375.00) and bajra + sorghum + additives (364.33), followed by maize + sorghum + additives, sorghum + broken rice + additives, maize, and sorghum. In the fifth week, bajra + sorghum + additives recorded the maximum emergence (192.67 moths), followed by Bajra , maize + sorghum + additives, and sorghum + broken rice + additives (155.67). In contrast, broken rice consistently registered the lowest adult emergence across all five weeks. The daily emergence pattern over the 35-day period indicates the superior performance of bajra + sorghum + additives and bajra as reflected in their linear trend lines compared with the other diet treatments (Fig. 1).

The pooled analysis across five weeks further confirmed the superiority of additive-enriched diets. bajra + sorghum + additives with maximum cumulative emergence (1294.33 moths), followed by bajra, maize + sorghum + additives with 1007.00, and sorghum + broken rice + additives. Solo grain cereal diets such as sorghum and maize recorded moderate

Table 1. Weekly adult emergence of *C. cephalonica* on different diet formulations

Treatment	Adult emergence in different weeks (Numbers)					Total
	Week '1'	Week '2'	Week '3'	Week '4'	Week '5'	
T1 - Sorghum (S)	36.33^{c} (6.01)	173.33^{bc} (13.16)	230.67^{c} (15.11)	213.33^{b} (14.59)	147.33^{b} (12.12)	801.00^{d} (28.27)
T2- Maize (M)	54.33^{b} (7.33)	174.67^{bc} (13.19)	208.00^{c} (14.41)	241.33^{b} (15.53)	145.67^{bc} (12.07)	824.00^{d} (28.70)
T3- Bajra(B)	83.33^{a} (9.04)	183.00^{bc} (13.51)	344.00^{ab} (18.51)	375.00^{a} (19.36)	171.33^{ab} (13.08)	1156.67^{b} (34.01)
T4 – Ragi (R)	19.00^{d} (4.35)	32.33^{e} (5.68)	97.67^{d} (9.88)	102.00^{d} (10.10)	74.33^{e} (8.53)	325.3f (18.01)
T5 - Broken Rice (BR)	13.00^{d} (3.60)	21.00^{e} (4.53)	83.00^{d} (9.10)	75.67^{e} (8.69)	58.00^{e} (7.61)	250.67^{g} (15.83)
T6 - B+ S + Additives	86.00^{a} (9.27)	245.67^{a} (15.67)	405.67^{a} (20.13)	364.33^{a} (19.07)	192.67^{a} (13.84)	1294.33^{a} (35.97)
T7 - M+S+ Additives	82.67^{a} (9.09)	202.67^{b} (14.21)	334.33^{b} (18.28)	224.33^{b} (14.97)	163.00^{ab} (12.76)	1007.00^{c} (31.72)
T8 - S+BR+ Additives	42.67^{bc} (6.50)	195.67^{b} (13.99)	323.00^{b} (17.96)	216.33^{b} (14.71)	155.67^{ab} (12.47)	933.33^{c} (30.55)
T9 – R+B + Additives	31.67^{c} (5.62)	157.33^{cd} (12.53)	212.67^{c} (14.55)	166.00^{c} (12.87)	111.67^{d} (10.56)	679.33^{e} (26.06)
T10 - B+BR + Additives	41.00^{bc} (6.39)	141.00^{d} (11.87)	188.67^{c} (13.72)	141.33^{c} (11.88)	114.00^{cd} (10.68)	626.00^{e} (25.01)
'p-Value'	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
'Tukey HSD at 5%'	1.658	1.119	1.632	1.006	1.409	1.675

Figures in the parentheses are arc sin transformed values. Column values with same superscripts do not differ significantly

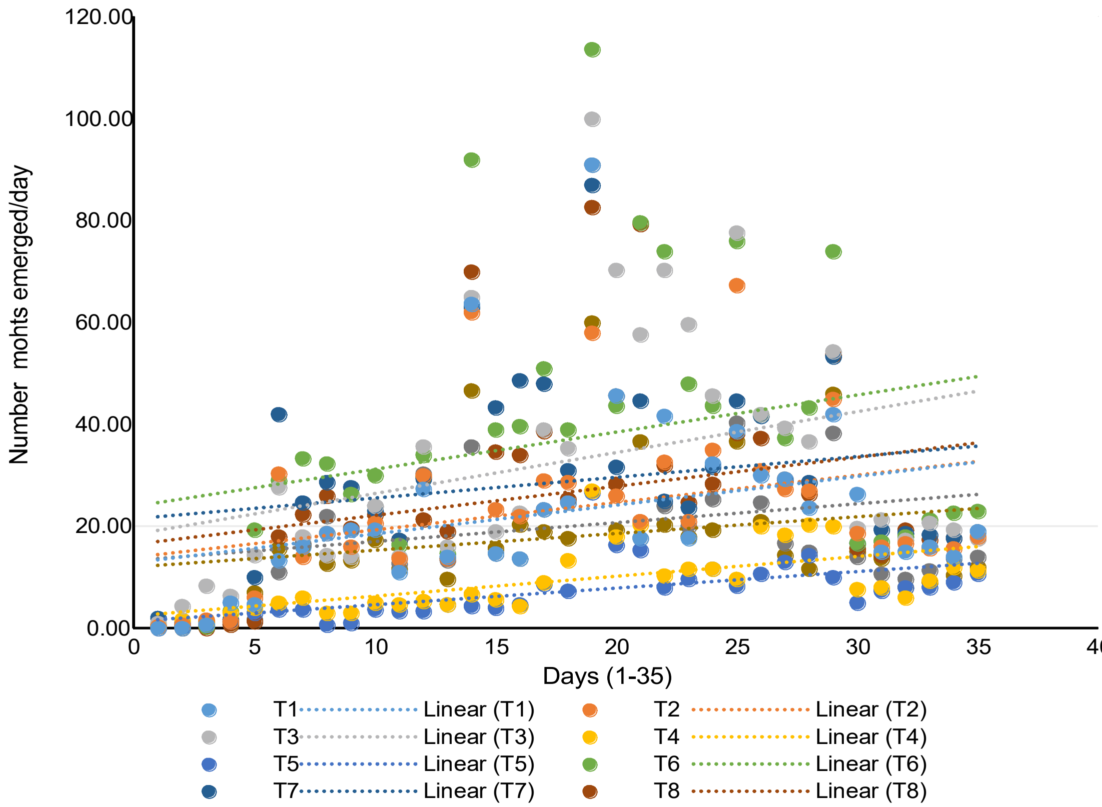

Fig. 1. Moth emergence in treatments during study period (day wise)

performance and were statistically at par. The lowest emergence was observed in broken rice with 250.67 moths and was significantly inferior.

The results suggest that diets containing additives significantly improved the emergence and development of *C. cephalonica*. Nutrient-enriched media likely improved moth performance by supplying essential proteins, vitamins, and micronutrients necessary for larval growth and successful pupation. Bait additives, groundnut powder and yeast provide essential amino acids, fatty acids, and B-complex vitamins needed for larval development. These additives enhance digestibility and assimilation of nutrients, improving feed conversion efficiency. The balanced nutrition reduces larval mortality, accelerates growth, and supports successful pupation. Lipids and sterols from groundnut and yeast also aid hormone synthesis required for metamorphosis, thereby ensuring better adult survival and emergence (Nasrin et al., 2016, Jhala et al., 2019, Kaur et al., 2024). The superior performance of Bajra + Sorghum + additives can be attributed to the synergistic nutritional effects of bajra, sorghum, groundnut powder and yeast. Conversely, the inferior performance of broken rice may be due to the low non-starch polysaccharide (NSP) content in broken rice, which affects nutrient utilization and digestibility.

The findings corroborate earlier reports that highlighted the positive influence of protein-rich and yeast-supplemented diets on the reproductive output of *C. cephalonica* (Sathpathy et al., 2003, Pathak et al., 2010, Kumar et al., 2019, Jitendra Kumar et al., 2025). Arun Kumar et al. (2018) and Mehendale et al. *(*2014) also recorded enhanced emergence and fitness in moths reared on sorghum and additive-based media.

CONCLUSION

Among the tested diets, bajra + sorghum supplemented with groundnut kernel powder and yeast proved to be the most effective formulations for supporting adult emergence of *C. cephalonica*. Diets enriched with nutritional supplements significantly outperformed solo cereals, indicating their potential use in large-scale and cost-effective mass rearing for biological control programs.

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Food Preferences and Bait-Based Management of Cockroaches in Urban Households

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Abstract: Cockroaches are major urban pests due to their synanthropic behavior and ability to transmit pathogenic microorganisms, posing significant public health risks. This study assessed the seasonal prevalence, habitat distribution, and feeding preferences of three dominant species *viz.,* German cockroach (*Blattella germanica*), Brown-banded cockroach (*Supella longipalpa*), and American cockroach (*Periplaneta americana*) in domestic settings at Hyderabad. Highest cockroach abundance in urban households occurs in winter, driven by cooler indoor conditions. Kitchens and storage areas show more infestation due to food and moisture availability. Laboratory based multi-choice assays showed a strong preference for carbohydrate-rich foods, particularly banana, among German and Brown-banded cockroaches, likely reflecting their nocturnal foraging activity and high energy demands. In contrast, American cockroaches exhibited opportunistic omnivory, favoring bread, likely due to their larger body size and adaptability to varied, often moist, microhabitats. A banana-based gel bait containing 0.05% fipronil recorded 88% population reduction in five weeks, with efficacy comparable to commercial gel baits. These findings highlight the potential of food preference based bait formulations as effective tools in integrated cockroach management.

Keywords: Urban pest management, *Blattella germanica, Supella longipalpa, Periplaneta americana*, Feeding preferences, Fipronil

Cockroaches are among the most ubiquitous and resilient urban pests globally, with approximately 30 species closely associated with human habitats out of over 4,600 known species (Bell et al., 2007). These insects pose significant public health risks due to their ability to mechanically transmit a wide range of pathogenic microorganisms, contaminate food, and elicit allergic reactions. In India, urban cockroach fauna is dominated by the German cockroach (*B. germanica*), Brown-banded cockroach (*S. longipalpa)* and American cockroach (*P. americana*), each occupying distinct ecological niches with specific biological and physiological adaptations (Prabakaran 2010, Luz et al., 2011). German cockroach populations in particular display high infestation rates, reaching up to 70% in residential settings, reflecting their remarkable adaptability and close synanthropic association (Yuan Pan et al., 2020).

Effective cockroach management requires a comprehensive understanding of species-specific seasonal dynamics, microhabitat preferences, and feeding ecology. Such knowledge is essential for developing optimized bait formulations with enhanced attractiveness and efficacy. Fipronil-based gel baits are widely recognized as highly effective against cockroaches due to their cascading effect, whereby the toxicants are disseminated among individuals through contact, necrophagy, and coprophagy, leading to a rapid and substantial colony-wide reduction in the population (Metha et al., 2020, Rahayu1 et al., 2021). Beyond biological factors, socio-economic and regulatory frameworks significantly influence pest control outcomes, highlighting the need for coordinated efforts between public health authorities and private pest management services to implement sustainable urban cockroach control strategies (Li et al., 2023). This study was undertaken to address gaps in understanding cockroach species distribution in urban Indian households, particularly kitchens, to assess species-specific food preferences through controlled laboratory bioassays, and to evaluate the field efficacy of banana based fipronil gel bait compared to commercially available preparations.

MATERIAL AND METHODS

Survey of cockroach incidence: A household survey on cockroach incidence was conducted among 120 urban households from residential apartments located in Kukatpally (17^{0}29' 29.9724” N and 78^{0}23'31.1388”E) Hyderabad during 2020. To ensure accurate identification of cockroach species by respondents, colored photographs alongside mounted specimens of the common cockroach species were shown, reducing errors due to lack of awareness. This questionnaire-based approach assessed seasonal prevalence, species occurrence and preferred habitat sites.

Collection and maintenance of cockroaches: Adult German, Brown-banded, and American cockroach specimens were collected from infested apartments in an urban residential setting. Each cockroach species was housed individually @10 individuals in a plastic box measuring 40x10x10 cm provided with folded cardboard pieces as shelter. Cockroaches were provided with carbohydrate-rich foods such as bread, biscuit pieces, and banana slices to meet nutritional requirements. Water was supplied using containers fitted with sponges to prevent drowning while ensuring constant moisture availability. The insect were reared at 25 ± 2 °and 70 ± 5% RH with a 12h light and 12hr dark cycle, replicating natural circadian rhythms. This standardized setup provided stable conditions for further experimental observations and behavioral assessments.

Laboratory food preference assays: Multi-choice feeding assays were conducted to quantitatively assess dietary preferences of three cockroach species under controlled laboratory conditions. Each test consisted of 0.2 g portions of representative food items *viz.,* bread (plain, with butter, or jam), boiled potato (with or without sugar or butter), banana (alone or combined with butter or prawn), cornflakes, and prawns offered simultaneously to cohorts of ten adult cockroaches per species housed in individual plastic chambers (40 cm × 10 cm × 10 cm). The environmental parameters were meticulously maintained at 25 ± 2 °C, RH 70±5% with a 12:12 h photo period, to simulate natural diurnal rhythms, factors known to influence cockroach behavior and feeding activity. Prior to feeding assays, cockroaches were starved for 24 h to standardize hunger levels. Food consumption was recorded daily for 5 consecutive days, with three independent replicates per species.

Preparation of banana based fipronil gel bait: Ripe banana pulp (100 g) was used as the bait base. Technical-grade fipronil (98%) obtained from Bhagiradha Chemicals& Industries Ltd., was incorporated to achieve a 0.05% (w/w) concentration. Sodium benzoate (e.g., 0.1% w/w) was added as a preservative. The mixture was thoroughly homogenized to form a uniform gel bait. The bait was stored in airtight containers in the dark until use.

Field evaluation of gel baits: Nine kitchens with medium-to-high cockroach infestation (≥50 individuals per night as determined by pre-survey visual counts and sticky traps) were selected for field evaluation. The randomized design was used. Three kitchens received banana-based 0.05% fipronil gel bait, three received a commercial fipronil gel, and three served as untreated controls without any bait application. Gel baits were uniformly applied at 3 drops per linear meter along cracks and crevices, based on consistent infestation levels. Cockroach populations were systematically monitored through weekly visual counts complemented by sticky traps placed near baited sites over five consecutive weeks post-application to accurately assess bait efficacy

Statistical analysis: Food preference data were analyzed using SPSS-22.0 software for Tukey HSD pairwise comparisons ($p < 0.05$). Field efficacy data comparing commercial and banana-based gel baits were analyzed using independent samples t-tests at each time point to evaluate differences in control performance.

RESULTS AND DISCUSSION

Survey data from 120 respondents showed highest cockroach problems in winter (39%) and in many cases, persisted across all seasons (35%). German cockroach predominated (68%), with infestations concentrated behind stoves, drains, and sinks (Fig. 1). Respondents acknowledged cockroach-related health risks and reported a preference for chemical sprays as their primary control method. These findings corroborate earlier reports on the persistence of *B. germanica* in diverse indoor habitats and their role as mechanical vectors of multiple pathogens including bacteria, fungi, and viruses (Yuan Pan et al., 2020). Food preference assays revealed distinct variations among the three cockroach species (Table 1). All species showed significant preference for carbohydrate and starch rich foods such as banana, boiled potato, and bread, recording the highest mean consumption values. German and Brown-banded cockroaches exhibited strong preferences for these three foods particularly banana, which was the most preferred item by *B. germanica* (31.8 mg) and *S. longipalpa* (30.2 mg) which is consistent with earlier observations that carbohydrate-rich foods with suitable texture enhance bait palatability (El-Sharabasy et al., 2014). In contrast, the American cockroach (*P. americana*) displayed broader feeding preferences, with bread (32.3 mg) followed banana, boiled potato and cornflakes forming the top-ranked group,

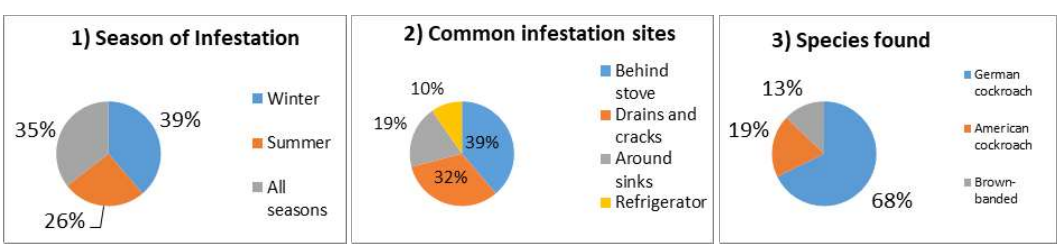

Fig. 1. Cockroach seasonal infestation, habitat and species present in urban dwellings

reflecting its omnivorous feeding habits and opportunistic feeding behavior (Anil 2022).

Additives such as butter, jam, or sugar generally reduced food consumption across species, indicating possible deterrent effects or reduced palatability. The combination of bread + butter recorded the lowest feeding response in *B. germanica* (1.3 g), while *P. americana* exhibited minimal interest in potato + sugar (2.8 mg) and bread + jam (2.4 mg). Among proteinaceous foods, prawn alone elicited moderate feeding (8.2–9.4 mg), whereas banana + prawn mixtures improved consumption slightly in *P. americana* (14.1 mg). The results indicate that banana and boiled potato serve as highly attractive and consistently preferred food substrates across species, suggesting their potential as effective phagostimulant bases for developing gel bait formulations for domestic cockroach management.

Table 1. Food preference of cockroach species (mg) (Mean ± SD)

Treatment	German cockroach	Brown-banded cockroach	American cockroach
Bread	24.7 ± 13.3^{a}	19.9 ± 4.8^{a}	32.3 ± 13.1^{a}
Bread + Butter	1.3 ± 0.8^{b}	11.6 ± 4.1^{b}	3.0 ± 1.4^{c}
Bread + Jam	8.0 ± 3.9^{b}	5.4 ± 2.6^{b}	2.4 ± 0.9^{c}
Boiled Potato	31.0 ± 13.8^{a}	26.6 ± 15.9^{a}	22.9 ± 13.8^{a}
Potato + Sugar	15.4 ± 5.5^{b}	3.9 ± 2.3^{b}	2.8 ± 1.0^{c}
Potato + Butter	4.3 ± 3.1^{b}	8.7 ± 2.7^{b}	6.9 ± 3.5^{c}
Banana	31.8 ± 13.1^{a}	30.2 ± 15.0^{a}	30.5 ± 11.9^{a}
Banana + Butter	9.5 ± 4.4^{b}	9.7 ± 4.0^{b}	12.8 ± 4.4^{b}
Banana + Prawn	8.6 ± 2.8	6.1 ± 1.4^{b}	14.1 ± 3.3^{b}
Cornflakes	4.5 ± 1.7^{b}	1.6 ± 0.6^{b}	18.6 ± 2.5^{a}
Prawn	8.2 ± 2.9^{b}	6.5 ± 3.5^{b}	9.4 ± 4.0^{b}

Figures with same letter in column do not differ significantly ($p<0.05$)

The efficacy of commercial and banana-based fipronil gel baits was assessed against cockroach infestations over a five-week period, combining both population counts and percentage control data to provide a comprehensive evaluation. Initial cockroach densities in treated kitchens ranged from 55 to 58 individuals, while control kitchens averaged approximately 52 individuals (Fig. 2). Field evaluation demonstrated significant and sustained reductions in cockroach populations with both gel baits, as evident from the progressive decline in counts to approximately 5–15 individuals by the end of the treatment period. In contrast, populations in untreated control kitchens progressively increased, surpassing 70 cockroaches by week five.

The commercial fipronil gel bait consistently achieved high control percentages with an overall mean reduction of 92.17%.The banana-based gel bait also demonstrated robust efficacy, with mean reduction of 88.69%. Independent samples t-tests revealed statistically significant differences favoring the commercial gel bait at day 1 followed by week 1, 3 and 4. However, weeks 2 and 5 showed no significant differences. Overall, commercial gel bait demonstrated marginally greater efficacy than the banana-based formulation, though both maintained effective control exceeding 85% (Table 2)

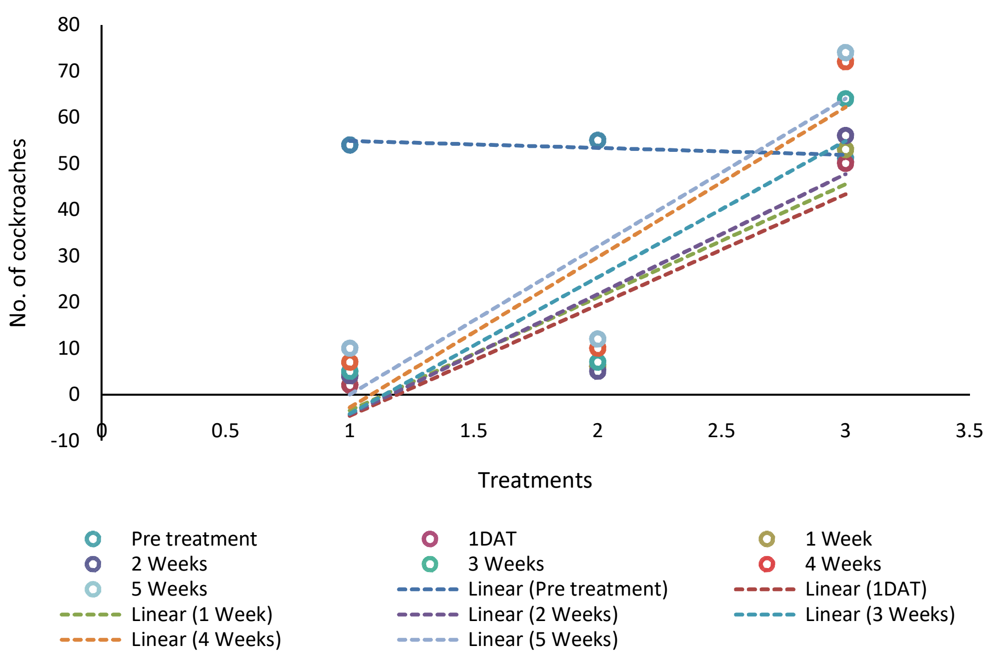

Fig. 2. Efficacy of treatments agaisnt cockroaches

Table 2. Field efficacy of commercial and banana based fipronil gel baits against cockroaches (Percent reduction) (Mean ± SD)

Time point	Commercial gel bait	Banana-based gel	t-value	p-value
Day 1	96.2 ±1.5	88.9 ±1.4	5.12	<0.01
Week 1	92.9 ±1.2	89.5 ± 1.3	3.67	0.01
Week 2	93.3 ± 1.3	91.7 ± 1.1	1.82	0.10
Week 3	92.6 ± 1.5	89.9 ± 1.2	3.12	0.02
Week 4	90.8 ± 1.4	87.1 ± 1.3	4.07	<0.01
Week 5	87.2 ± 1.7	85.0 ± 1.5	1.90	0.09
Overall mean	92.1 ±1.43	88.6 ± 1.31	4.21	<0.01

These results suggest that banana-based gel bait prepared with locally available materials can serve as a cost-effective alternative to commercial products within integrated urban pest management programs. This aligns with IPM strategies that emphasize minimizing insecticide resistance and environmental impact through innovative, eco-friendly bait matrices. Importantly, the survey revealed that most households relied on chemical sprays for cockroach control, indicating a need for greater awareness and education on the advantages of gel baits, including their safety, ease of use, and long-term efficacy. Promoting such awareness could significantly enhance community adoption and implementation of gel bait–based approaches within urban pest management frameworks (Yuan Pan et al., 2020, Li et al., 2023).

CONCLUSION

This study highlights species-specific distributions and feeding preferences of cockroaches in urban households, emphasizing the dominance of German cockroach in kitchens and exhibiting distinct seasonal infestation trends. The laboratory and field evaluations demonstrated that the banana-based fipronil gel bait formulated using locally available materials was highly effective and comparable to commercial products in suppressing cockroach populations. Integrating such cost-effective baits with improved sanitation, habitat management and public awareness initiatives can improve efficacy of urban pest control thereby reducing associated health risks.

AUTHORS CONTRIBUTION

N.Srinivasa Rao conceptualized, planned, and supervised the study. P. Saktivel conducted the experiments and prepared the manuscript. K. Praveen Kumar provided critical comments and suggestions for improvement during the study. A. Padmavathi assisted in data compilation and statistical analysis. All authors have read and approved the final version of the manuscript.

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Floral Preference of Butterflies in Agricultural and Horticultural Ecosystems of Coastal Tamil Nadu

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Abstract: Butterflies, belonging to the order Lepidoptera, represent the second-largest group of insects and play a crucial role in ecosystems, including agricultural and horticultural systems. In Tamil Nadu, however, their roles within the crop ecosystem remain insufficiently studied. Information on feeding preferences, host selection, and pollination contributions is limited and inconsistent. To address this gap, the present investigation explores the butterfly diversity of crop ecosystems and ecology of selected coastal areas of Tamil Nadu. The survey was carried out in six coastal areas during the seasons, *Rabi* 2022-23 and *Summer* 2023 by sweep net and visual observations, in order to the study the relationship between the proboscis length and the flower morphology. A total of 25 nectar yielding plant species were recorded in the study area. Butterfly species recorded exhibited a preference for readily available larval host plants from five families such as Annonaceae, Rhamnaceae, Malvaceae, Fabaceae and Poaceae within the survey area. Statistical analysis employing a multiple linear regression model revealed no significant correlation between proboscis length and floral characteristics, including corolla length, flower color, and corolla type. The findings hold the potential to not only inform conservation strategies and promote sustainable agricultural practices, but also unveil the hidden value of these fluttering ambassadors, paving the way for a more harmonious relationship between butterflies and the agricultural landscapes they grace.

Keywords: Agricultural ecosystem, Butterfly, Floral preference, Horticultural ecosystem, Morphology

The order Lepidoptera is one of the most well-known and well-liked insect orders that include both butterflies and moths. Lepidoptera, which means "scaly-winged" insects, was coined by Linnaeus. Members of this order are distinguished by the presence of dense, wide scales that contain pigments. The scales that give butterflies and moths their stunning and distinctive colour patterns are simply flattened, modified hairs. Lepidoptera are classified into 4 suborders, 139 families, 15,578 genera, and 1,57,424 species that have been described so far (Sidhu 2023). According to Kristenson et al. (2007), suborders of Lepidoptera includes Zeugloptera, Glossata, Aglossata and Heterobathmiina. Recently, the order was divided into two suborders *viz*., Rhopalocera (Butterflies) and Heterocera (Moths), of which 17,000-20,000 taxa are butterflies (Nieukerken Van et al., 2011).

All the butterfly species are grouped under six families, *viz*. Papilionidae, Nymphalidae, Pieridae, Lycaenidae, Riodinidae and Hesperiidae (Bhattacharjee 2020). They serve as bio-indicators of environmental variety and quality that reflect a specific set of ecological conditions or suggest larger consequences of environmental changes, and they are an important component of biodiversity and ecologically vital due to their involvement in the food chain (Singh 2011).

Ganvir et al. (2017) probed that butterflies contribute to the ecology in particular by recycling the N, P, and K needed by crops. The insect community claims that butterflies are important pollinators and herbivores with a long history of coevolving with plants. Owing to their crucial role in pollinating both crop and wild plants worldwide, butterflies have proven useful to those, commonly known as Psychophily. Agricultural fields have multiple agricultural areas with key crops that attract butterflies for a variety of reasons. Butterflies are dependent on nectar and pollen as their food while the caterpillars are dependent on specific host plants for foliage. The presence of weed-eating butterfly species in agroecosystems has made a significant contribution to natural weed suppression (Kathirvelu et al., 2022). Butterflies are thought to be reliable indicators of the condition of any particular terrestrial environment. Bergerot et al. (2010), observed that pollinators employ a variety of characteristics as cues, including flower colour, aroma produced by pollen and nectar composition, flower size, plant size, and flower design. The nectar that the flowers provide, which controls the physiological processes of butterflies, and the compatibility of the flowers with their feeding structures determine how butterflies and flowers interact. The diversity, abundance, and species richness of butterflies are decreasing as more highways, buildings, and green spaces are developed. This is because habitat degradation has decreased the variety of plant species, lowered the water quality, and increased air pollution (Kanagaraj and Kathirvelu 2018). In Tamil Nadu, there is little evidence on butterfly feeding preference, host selection, and pollination in crop ecosystems. Therefore, the present study was conducted in the agricultural and horticultural fields of Coastal areas of Tamil Nadu to examine the floral preferences of butterflies.

MATERIAL AND METHODS

"The study on floral preference of butterflies in agricultural and horticultural ecosystems of Coastal, Tamil Nadu" was conducted at the Department of Entomology, Annamalai University, from November 2022 – 2023 (*Rabi*) to June 2023 (*Summer*).

Study Area: Butterflies and their floral preference were observed in the following villages located in the coastal areas of the Cuddalore district from the crop ecosystems (agricultural and horticultural ecosystems) including agricultural land, fruit orchards, vegetable gardens, flower fields and associated lands. Survey of butterfly and their floral preference were made in two seasons from November 2022 - 2023 (*Rabi*) to June 2023 (*Summer*) in selected localities of Cuddalore district (Fig. 1). The study areas include Annamalainagar, Bhuvanagiri, Parangipettai, Sivapuri, Kavarapattu and Kodiyampalayam. They were systematically surveyed every week over the course of two distinct seasons. Each week, two specific areas were selected for observation. During the visits, the different butterflies visiting flowers were collected using sweep net and preserved for morphometry study.

Proboscis morphometry: The proboscises of butterflies, which were coiled, were carefully uncoiled by separating the heads from preserved butterfly specimens. Subsequently, each butterfly head was inverted and positioned on a slide coated with resin or double-sided adhesive tape. A gradual and precise process involved using sharp needles or forceps to uncoil the proboscis, securing it onto the adhesive surface of the slide. Following the complete uncoiling of the proboscis, a transparent cellophane tape was employed to encase the proboscis on the slide, thus preventing any inadvertent recoiling. Subsequently, the slide was appropriately labelled with the butterfly's name for identification purpose. To determine the proboscis length, the "Image J" software was employed. A photograph of the slide containing the proboscis was captured, and the software was utilized to set the measurement units to millimeters (mm). Subsequently, the software was used to analyze the photograph, and the measurements obtained were recorded for further analysis.

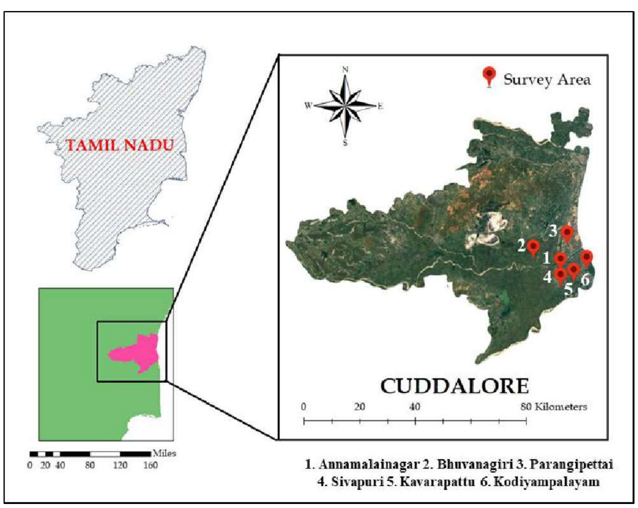


Fig. 1. Study area map

Floral morphometry: A sample of flowers from the chosen plant species is meticulously gathered. These specimens were in pristine condition, free from any physical impairments. To ensure precision and consistency, appropriate measuring instruments, such as rulers or callipers with millimeter (mm) gradations, were employed. The selected flower was placed on a stable, level surface, mimicking its natural positioning when approached by a nectar-seeking butterfly. The specific point on the flower, where a butterfly's proboscis would naturally reach the corolla's base (typically where nectar is located), was determined. Accurate measurements were carried out using the ruler or calliper, documenting the distance from the chosen point to the corolla base in millimetres (mm). Additionally, corolla type (Tubular or non-tubular) and flower colour for each plant species were documented (Subedi et al., 2020).

Data Analysis: STATISTICA version 13.0 was used to explore the connection between proboscis length and the floral characteristics of nectar.

RESULTS AND DISCUSSION

Butterflies in the agricultural and horticultural ecosystems: Butterflies present in the agricultural and horticultural ecosystems during the seasons, *Rabi* 2022-23 and *Summer* 2023 were recorded (Table 1). Butterflies showed clear crop-specific associations. In agricultural fields, rice ecosystems supported the highest richness, with nine species, including *Ampittia dioscorides* Fab., *Borbo cinnara* Wall., and *Junonia orithya* Linn. Sesame fields showed relatively higher diversity with seven species, such as *Chilades pandava* Hors., *Eurema brigittia* Stoll, and *Hupolimnas bolina* Linn. Pulses, maize and castor fields each recorded three species, while sugarcane was represented by a single species (*Catochrysops strabo* Fab.). In horticultural landscapes, *Graphium agamemnon* Linn., and *Delias eucharis* Drury were recorded from trees. The vegetable yard exhibited the greatest diversity with thirteen species, including *Catopsilia pyranthe* Linn., *Pachliopta* *hector* Linn., and *Papilio polytes* Linn.. The fruit orchard supported five species, while the flower yard had three species (*Leptosia nina* Fab., *Pareronia hippie* Fab., *Zizeeria karsandra* Moore). Overall, butterfly communities showed clear habitat preferences, with the greatest diversity observed in vegetable yards and rice fields. In a study conducted by Kanimozhi et al. (2020) in the Namakkal district of Tamil Nadu, they found that out of 60 butterfly species observed in agroecosystems, 49 were found in pulse fields, 60 in rice fields, 59 in vegetable yards, 52 in groundnut fields, and 53 in sugarcane fields. These results align with the findings of the present study.

Floristic inventory associated with butterflies: Butterfly species showed clear host plant associations across crop, weed, and tree ecosystems. Papilionidae members were primarily associated with Rutaceae, Annonaceae, and Aristolochiaceae. Most Lycaenidae were closely linked with Fabaceae hosts, with some extending to Rhamnaceae, Amaranthaceae, and Verbenaceae. Notably, *Spalgis epius* differed by acting as a predator of mealybugs. In the Nymphalidae family, butterflies generally prefer weed hosts over crops and Malvaceae being the most frequently utilized plant family. In Pieridae, most species feed on weeds, except *Pieris brassicae* and *P. canidia*, which prefer Brassicaceae. Other species utilizes Fabaceae as the primary host family, followed by Salvadoraceae and Cleomaceae (Table 2, Plate 1).

Dwari and Mondal (2015) listed the larval host plants of different butterfly families in the Howrah district, West Bengal. Larval food plants of Nymphalidae, Pieridae and Hesperiidae are found in agricultural fields but same in case of Papilionidae and Lycaenidae are different, larval food plants of these groups are absent in agricultural fields of the Howrah district. Papilionidae exhibited a preference for Asteraceae, Pedaliaceae, and Brassicaceae hosts as larval feed. Lycaenidae, on the other hand, favored plants of Poaceae, Malvaceae, Asteraceae, Fabaceae, Pedaliaceae and Cleomaceae. Nymphalidae preferred Asteraceae, Poaceae, Brassicaceae, Lamiaceae, and Euphorbiaceae plants, as their larval hosts and Family Hesperiidae preferred plants of Poaceae, Lamiaceae and Asteraceae as their preferred hosts. The above findings affirm the results accurately.

Proboscis length (mm) of the butterflies surveyed: The maximum proboscis length was recorded in *Papilio polymnester* from Papilionidae at 36.9 mm, followed by 27.4 mm in *Pareronia hippia* from Pieridae and 25.6 mm in *P. conidia*. The shortest proboscis length observed was 4.5 mm in *Pseudozizeeria maha* from Lycaenidae (Table 2). The results are in accordance with the findings of Venkata Ramana (2010) recorded the proboscis lengths of various butterfly species in which *Papilio polymnestor* had the highest proboscis length of 30-32 mm, while *Leptsotia nina* exhibited the smallest proboscis at 5-6 mm in the study sites.

Floral morphometry and Nectar flora preference by butterfly families: A total of 25 nectar plant species were identified, and their flower characteristics, including color, corolla length, and type, were observed and categorized based on distinctive features (Table 3). Flowers were classified into two groups, Tubular (≥ 25 mm) and Non-tubular (< 25 mm), based on corolla length. Twelve species fell into the "Tubular" category, and 13 into "Non-tubular." Both categories were further divided by color (Red, Yellow, Blue, White) (Plate 2). Nectar plant preference differed

Table 1. Butterflies in agricultural and horticultural ecosystems of the survey area

Ecosystem	Species
Rice	*Ampittia dioscorides* Fabricius, *Borbo cinnara* Wallace, *Junonia orithya* Linnaeus, *Melanitis leda* Linnaeus, *Potanthus nesta* Evans, *Prosotas dubiosa* Semper, *Pseudozizeeria maha* Kollar, *Tirumala limniace* Cramer, *Zizula hylax* Fabricius
Pulse	*Graphium doson* Felder, *Euchrysops cnejus* Fabricius, *Lampides boeticus* Linnaeus
Maize	*Junonia iphita* Cramer, *Papilio polymnestor* Cramer, *Zizina otis* Fabricius
Sugarcane	*Catochrysops strabo* Fabricius
Sesame	*Chilades pandava* Horsfield, *Eurema brigittia* Stoll, *Eurema hecabe* Linnaeus, *Hypolimnas bolina* Linnaeus, *Junonia almanac* Linnaeus, *Junonia hierta* Fabricius, *Neptis hylas* Linnaeus
Castor	*Acraea violae* Linnaeus, *Ariadne merione* Cramer, *Junonia lemonias* Linnaeus
Trees	*Graphium agammemnon* Linnaeus, *Delias eucharis* Drury
Vegetable yard	*Castalius rosimon* Fabricius, *Catopsilia pyranthe* Linnaeus, *Cepora nerissa* Fabricius, *Everes lacturnus* Godart, *Freyeria putli* Kollar, *Ixias marianne* Cramer, *Ixias pyrene* Linnaeus, *Mycalesis perseus* Fabricius, *Pachliopta hector* Linnaeus, *Pachliopta aristolochiae* Fabricius, *Papilio polytes* Linnaeus, *Pieris brassicae* Linnaeus, *Pieris canidia* Linnaeus
Fruit orchard	*Colotis amata* Fabricius, *Euploea core* Cramer, *Euthalia aconthea* Cramer, *Hypolimnas misippus* Linnaeus, *Papilio demoleus* Linnaeus
Flower yard	*Leptosia nina* Fabricius, *Pareronia hippie* Fabricius, *Zizeeria karsandra* Moore

Table 2. Floristic inventory associated with butterflies of crop ecosystems and proboscis length

Scientific name	Proboscis length (mm)*	Crop host plant	Weed / Tree host plant	Host family
Graphium agammemnon	14.5±0.31	*Annona squamosa*	-	Annonaceae
		-	*Polyalthia longifolia*	Annonaceae
Graphium doson	10.6±0.31	*Murraya koenigii*	-	Rutaceae
Pachiliopta aristolochiae	16.5±0.21	-	*Aristolochia bracteolata*	Aristolochiaceae
Pachiliopta hector	19.8±0.25	-	*Aristolochia bracteolata*	Aristolochiaceae
Papilio demoleus	24.5±0.30	*Citrus aurantiifolia*	-	Rutaceae
		Murraya koenigii	-	Rutaceae
Papilio polymnestor	36.9±0.30	-	-	-
Papilio polytes	23.1±0.61	*Citrus aurantiifolia*	-	Rutaceae
		Citrus limon	-	Rutaceae
		Murraya koenigii	-	Rutaceae
Spalgis epius	5.5±0.16	Mealybugs*		-
Castalius rosimon	5.8±0.07	-	*Ziziphus* sp.	Rhamnaceae
Castalius strabo	6.4±0.08	*Vigna radiata*	-	Fabaceae
		Vigna unguiculata	-	Fabaceae
Chilades pandava	4.6±0.13	*Vigna* sp.	-	Fabaceae
		-	*Acacia* sp.	Fabaceae
Freyeria putli	5.0±0.07	-	*Pongamia pinnata*	Fabaceae
		-	*Tephrosia purpurea*	Fabaceae
Euchrysops cnejus	6.8±0.08	*Vigna radiata*	-	Fabaceae
Everes lacturnus	8.2±0.10	-	*Trifolium* sp.	Fabaceae
		-	*Desmodium* sp.	Fabaceae
Lampides boeticus	8.9±0.26	*Vigna* sp.	-	Fabaceae
Prosotas dubiosa	4.5±0.10	-	*Mimosa pudica*	Fabaceae
		-	*Acacia* sp.	Fabaceae
Pseudozizeeria maha	4.5±0.01	-	*Tephrosia purpurea*	Fabaceae
Zizeeria karsandra	5.3±0.07	-	*Amaranthus spinosus*	Amaranthaceae
Zizina otis	4.8±0.13	-	*Clitoria* sp.	Fabaceae
		-	*Vicia* sp.	Fabaceae
Zizula hylax	6.8±0.11	-	*Lantana camara*	Verbenaceae
Acraea violae	11.5±0.24	*Nerium oleander*	-	Apocynaceae
Danaus chrysippus	11.6±0.12	-	*Calotropis gigantea*	Apocynaceae
Danaus genutia	12.4±0.15	-	*Calotropis gigantea*	Apocynaceae
Euploea core	11.7±0.35	*Nerium oleander*	-	Apocynaceae
Tirumala limniace	12.7±0.10	-	*Calotropis* sp.	Apocynaceae
Ariadne merione	10.2±0.13	*Ricinus communis*	-	Euphorbiaceae
Euthalia aconthea	13.5±0.29	*Mangifera indica*	-	Anacardiaceae
Neptis hylas	8.6±0.19	-	*Thespesia populnea*	Malvaceae
Hypolimnas bolina	14.4±0.12	-	*Abelmoschus* sp.	Malvaceae
		-	*Abutilon* sp.	
		-	*Hibiscus* sp.	
Hypolimnas misippus	14.5±0.18	-	*Abutilon* sp.	Malvaceae
		-	*Hibiscus* sp.	
Junonia almana	11.4±0.30	-	*Sida rhombifolia*	Malvaceae
Junonia hierta	11.6±0.20	-	*Sida rhombifolia*	Malvaceae
Junonia iphita	10.4±0.21	-	*Sida rhombifolia*	Malvaceae
Junonia lemonias	9.8±0.12	-	*Sida rhombifolia*	Malvaceae

Cont...

Table 2. Floristic inventory associated with butterflies of crop ecosystems and proboscis length

Scientific name	Proboscis length (mm)*	Crop host plant	Weed / Tree host plant	Host family
Junonia orithya	10.4±0.12	-	*Sida rhombifolia*	Malvaceae
Melanitis leda	11.4±0.14	*Oryza sativa*	-	Poaceae
Melanitis perseus	8.2±0.24	*Oryza* sp.	-	Poaceae
Catopsila pomona	16.8±0.21	-	*Cassia fistula*	Fabaceae
		-	*Crotolaria juncea*	Fabaceae
Catopsila pyranthe	16.8±0.21	-	*Cassia fistula*	Fabaceae
		-	*Crotolaria juncea*	Fabaceae
Eurema brigittia	8.5±0.11	-	*Cassia* sp.	Fabaceae
Eurema hecabe	11.2±0.29	-	*Cassia fistula*	Fabaceae
		-	*Crotolaria juncea*	Fabaceae
Cepora nerissa	9.5±0.28	-	-	-
Colotis amata	10.7±0.23	-	*Salvadora* sp.	Salvadoraceae
Delias eucharis	15.2±0.12	-	*Sesbania bispinosa*	Fabaceae
Ixias marianne	21.4±0.36	-	-	-
Ixias pyrene	23.6±0.62	-	-	-
Leptosia nina	9.4±0.20	-	*Cleome viscosa*	Cleomaceae
Pareronia hippia	27.4±0.14	-	-	-
Pieris brassicae	25.4±0.32	Crucifers	-	Brassicaceae
Pieris canidia	25.6±0.75	Crucifers	-	Brassicaceae
Ampittia dioscorides	17.6±0.22	*Oryza sativa*	-	Poaceae
Borbo cinnara	15.8±0.21	*Oryza sativa*	-	Poaceae
Potanthus nesta	13.1±0.82	-	*Cymbopogon* sp.	Poaceae

*Mean values followed by Standard Error (SE)

Table 3. Floral morphology of nectar yielding in the survey area

Family	Nectar plant	Flower colour	Corolla type	Corolla length (mm)
Acanthaceae	*Crossandra infundibuliformis* Linn.	Orange (R)*	Tubular	25.2±0.33
	Ruellia tuberosa Linn.	Purple (B)	Tubular	33.5±0.42
Agavaceae	*Polianthes tuberosa* Linn.	White (W)	Tubular	44.6±1.17
Amarathaceae	*Gomphrena globose* Linn.	Purple (B)	Non-tubular	0.0±0.00
Anacardiaceae	*Mangifera indica* Linn.	Yellow (Y)	Non-tubular	3.5±0.03
Apocynaceae	*Nerium oleander* Linn.	Pink (R)	Non-tubular	21.5±0.27
	Catharanthus roseus Linn.	Pink (R)	Tubular	23.4±0.61
	Allamanda cathartica Linn.	Yellow (Y)	Tubular	72.4±1.23
	Tabernaemontana divaricata Linn.	White (W)	Tubular	20.8±0.59
	Pentalinon luteum Linn.	Yellow (Y)	Tubular	68.4±0.85
Asteraceae	*Tridax procumbens* Linn.	White (W)	Non-tubular	5.6±0.05
	Tagetes erecta Linn.	Orange (Y)	Non-tubular	11.4±0.34
	Cosmos sulphureus Cav.	Yellow (Y)	Non-tubular	17.5±0.21
	Centratherum punctatum Cass.	Purple (B)	Non-tubular	10.4±0.18
Bignoniaceae	*Tecoma stans* Linn.	Yellow (Y)	Tubular	25.6±0.55
	Millingtonia hortensis Linn.	White (W)	Tubular	72.2±1.48
Euphorbiaceae	*Ricinus communis* Linn.	Red (R)	Non-tubular	0.0±0.00
	Arachis hypogea Linn.	Yellow (Y)	Non-tubular	0.0±0.00
Fabaceae	*Cassia fistula* Linn.	Yellow (Y)	Non-tubular	0.0±0.00
	Calliandra sp. Benth.	Red (R)	Tubular	2.6±0.02
	Vigna radiata Linn.	Blue (B)	Non-tubular	0.0±0.00
Laminaceae	*Leucas aspera* Willd.	White (W)	Non-tubular	15.2±0.19
Polygonaceae	*Antigonon leptopus* Hook. &Arn.	Pink (R)	Non-tubular	0.0±0.00
Rubiaceae	*Ixora coccinea* Linn.	Red (R)	Tubular	28.4±0.61
Verbenaceae	*Lantana camara* Linn.	Pink (R)	Tubular	6.7±0.08

* In parentheses, Shade of the flower colour: R - Red , Y–Yellow, B - Blue , W - White


1. *Annona squamosa*
Annonaceae


2. *Polyalthia longifolia*
Annonaceae


3. *Murraya koenigii*
Rutaceae


4. *Citrus aurantiifolia*
Rutaceae


5. *Citrus limon*
Rutaceae


6. *Aristolochia bracteolate*
Aristolochiaceae


7. *Ziziphus* sp.
Rhamnaceae


8. *Amaranthus spinosus*
Amaranthaceae


9. *Ricinus communis*
Euphorbiaceae


10. *Lanatana camara*
Verbenaceae


11. *Calotropis gigantea*
Apocynaceae


12. *Nerium oleander*
Apocynaceae


13. *Mangifera indica*
Anacardiaceae


14. *Oryza sativa*
Poaceae


15. *Cymbopogon* sp.
Poaceae


16. *Salvadora* sp.
Salvadoraceae


17. *Thespesia populnea*
Malvaceae


18. *Abelmoschus* sp.
Malvaceae

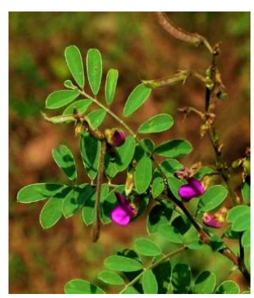

19. *Sida rhombifolia*
Malvaceae


20. *Hibiscus* sp.
Malvaceae


21. *Pongamia pinnata*
Fabaceae


22. *Vigna unguiculata*
Fabaceae


23. *Crotalatia juncea*
Fabaceae


24. *Tephrosia purpurea*
Fabaceae


25. *Sesbania bispinosa*
Fabaceae

Plate 1. Floral inventories of agricultural and horticultural ecosystem

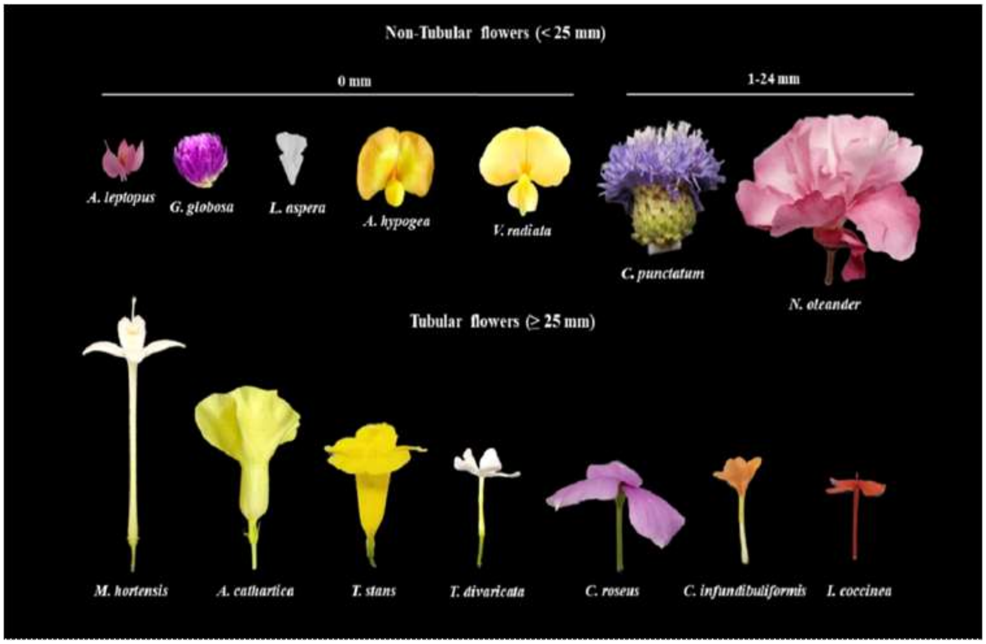


Plate 2. Nectar inventories (Tubular and Non-tubular flowers) recorded in the survey area

across the five butterfly families (Papilionidae, Lycaenidae, Nymphalidae, Pieridae, and Hesperiidae), as detailed in Table 4.

Tiple et al. (2009) demonstrated that Papilionidae had unique plant associations, particularly with Nyctaginaceae and Rubiaceae. There were also highly significant associations observed with flower shape, corolla depth, plant life form, flower abundance (mass), and flower color. Hesperiidae and Nymphalidae exhibited a preference for tubular flowers, while Lycaenidae favored non-tubular flowers. Lycaenidae showed a preference for flowers lacking corolla depth, Nymphalidae and Hesperiidae were biased towards plants with moderately deep corollas (≤10 mm), Pieridae favored flowers with deeper corollas (10–15 mm), and Papilionidae had a preference for flowers with deep or very deep corollas (10–15 mm, >15 mm). Hesperiidae and Nymphalidae also demonstrated a bias for feeding on plants with a dense massing (abundance) of flowers, whereas, in Lycaenidae, the bias was towards plants with moderate flower masses, Pieridae favoured plants with moderate and sparse flowers, and Papilionidae preferred plants with sparse flowers.

Multiple linear regression model analysis for proboscis length of butterflies with the floral characters: The multiple linear regression analysis aimed to investigate the relationship between the dependent variable and three independent variables: flower colour, corolla type, and corolla length (Table 5). The intercept, representing the estimated mean value of the dependent variable when all

Table 4. Nectar flora preference by butterfly families

Butterfly families	Flora
Papilionidae	*Polyanthes tuberosa*
	Mangifera indica
	Catharanthus roseus
	Allamanda cathartica
	Tabermontana divaricata
	Pentalinon luteum
Lycaenidae	*Gomphrena globosa*
	Tridax procumbens
	Cosmos sulphureus
	Centrathemum punctatum
	Arachis hypogea
	Vigna radiata
	Antigonon leptopus
Nymphalidae	*Crossandra infundibuliformis*
	Ruellia tuberosa
	Tagetes erecta
	Tecoma stans
	Millingtonia hortensis
	Ricinus communis
	Ixora coccinea
Pieridae	*Nerium oleander*
	Cassia fistula
	Calliandra sp.
	Leucas aspera
Hesperiidae	*Lantana camara*
	Tridax procumbens

Table 5. Multiple linear regression model analysis for proboscis length of butterflies with the floral characters

Variable	Coefficient	Standard Error	*t*	*P* value	R^2
Intercept	41.39 ^{NS}	35.51	1.17	0.45	0.692
Flower colour, X_1	3.17 ^{NS}	10.04	0.32	0.81	
Corolla type, X_2	-20.78 ^{NS}	18.65	-1.11	0.47	
Corolla length, X_3	-0.19 ^{NS}	0.37	-0.52	0.70	

independent variables are zero, is 41.39. However, the p-value associated with the intercept is 0.45, indicating that it is not statistically significant. The coefficient for flower colour (X_1) is 3.17. The associated t-statistic is 0.32, and the p-value is 0.81. Similarly, the coefficient for corolla type (X_2) is -20.78, a t-statistic of -1.11, and a p-value of 0.47. The coefficient for corolla length (X_3) is -0.19, a t-statistic of -0.52, and a p-value of 0.70. None of the coefficients are statistically significant (Fig. 2). The regression equation for the given dependent variable (Y) and for the each of the independent variables (X) can be given as

$Y = 41.39 + 3.17X_1 - 20.78X_2 - 0.19X_3$

where, Y – Dependent variable (proboscis variable)

X – Independent variable

X_1 - Flower colour

X_2 - Corolla type

X_3 - Corolla length

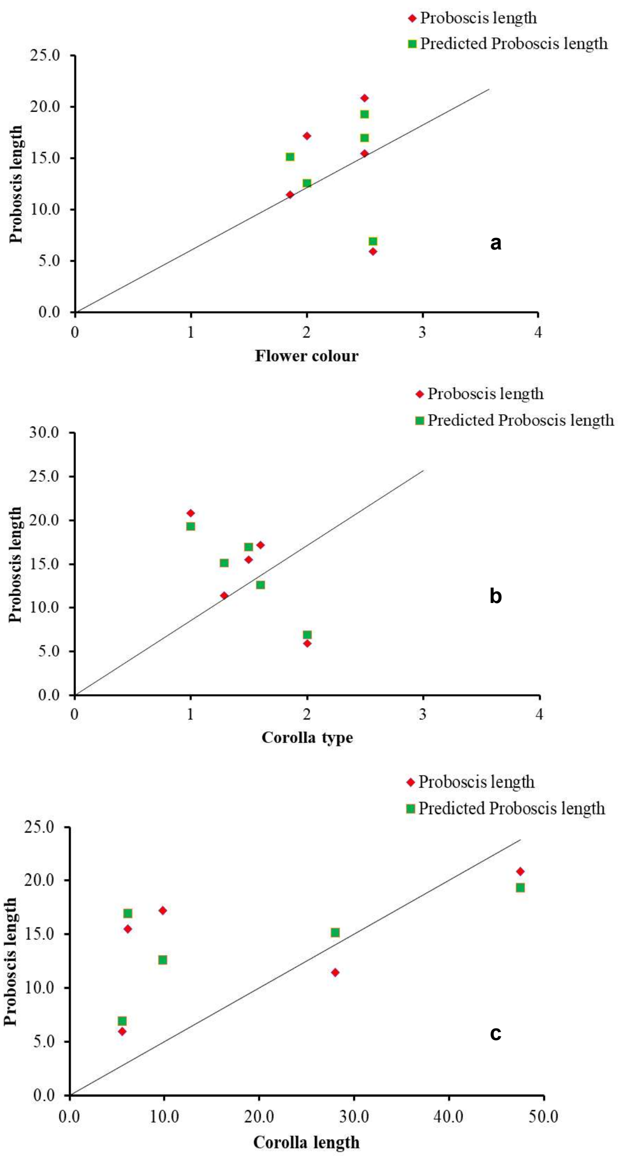


Fig. 2. Multiple linear regression model analysis for proboscis length of butterflies with the floral characters

Tiple et al. (2009) demonstrated that the exploitation of flowers by butterflies was constrained by flower corolla depth in relation to proboscis length. Butterflies with high wing load indices exhibited a bias towards nectar feeding on plants with massed flowers. Furthermore, unique associations were observed between butterflies and plants, encompassing various attributes. On the plant side, these attributes included flower shape, corolla depth, life form, flower abundance, and flower color. On the butterfly side, the associations involved proboscis length and wing load index. While the wing load index plays a significant role in explaining proboscis length, only 62% of the variability in proboscis length can be attributed to other morphological measures and indices. Additionally, this relationship is apparent in two butterfly families (Nymphalidae and Pieridae) but not in the other two families (Lycaenidae and Hesperiidae), even though there are consistent variances and comparable ranges in proboscis lengths and wing loading indices.

CONCLUSION

The butterflies exhibit distinct preferences for specific flower species, which can be attributed to various factors such as flower colour, nectar quality and morphology. The preference for specific larval host plants underlines the interconnectedness of butterflies with their habitat. Conservation efforts should thus include the preservation and restoration of these plant families to sustain butterfly populations. Despite the detailed nectar inventory, the lack of statistically significant relationships in the Multiple Linear Regression model for proboscis length suggests a complex interplay of factors influencing this crucial aspect of butterfly biology. This highlights the need for further research to understand better and address the potential threats to butterfly populations.

AUTHOR's CONTRIBUTION

Abinaya, P: Formal analysis, Writing – review & editing; Sujith Daniel Raj, S: Writing – original draft, review & editing; Sakthivel, S: Conceptualization, Writing – review & editing; Kirubakaran, T: Writing – review & editing; Kathirvelu, C: Writing – original draft, Visualization, Formal analysis, Supervision, Resources, Conceptualization.

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Predominance of Invasive Fall Armyworm (*Spodoptera frugiperda)* In Indian Crop Ecosystem

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***Abstract*:** Fall armyworm, *Spodoptera frugiperda* (J.E. Smith) is a noxious lepidopteran pest originated as a key pest of maize crop but it is also common on rice, sorghum, millets, sugarcane and is sporadically important on a vast array of accruing crops and plants, including cotton and vegetables. The introduction of this pest in the tropics is a major concern, as the favorable environment and the absence of natural enemies eventually allow it to thrive without competition. The rapid spread of *S. frugiperda* can be attributed to its sporadic and long-distance migratory behaviour. It is notorious invasive pest with high dispersal ability, broad host range, and high fecundity which makes the fall armyworm one of the most severe economic pests. In the Indian subcontinent, the first record of *S. frugiperda* was observed in 2018 from Karnataka, which later spread to Chhattisgarh, Orrisa, Gujarat, Maharashtra, Bihar, Tamil Nadu and many other states. Larva being the voracious feeder, is the most damaging stage of this pest. Control strategies include cultural practices, biological management, mechanical control, and chemical control. FAW management necessitates an integrated approach that supplements current smallholder pest management techniques. The role of native crop ecosystem adaptability on FAW needs to be explored.

Keywords: Fall armyworm, Maize, Lepidoptera, Invasive, Migratory behaviour

The Fall Armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) is an invasive and highly destructive pest of maize, is native to temperate and subtropical regions of the Western hemisphere from the United States of America to Argentina (Gebretsadik et al., 2023). Nonetheless, FAW populations have significantly increased recently throughout the Eastern Hemisphere, notably in countries like Australia, China, India, Africa, and Southeast Asia (Sun et al., 2021, Wan et al., 2021). The pest can cause damage to crops resulting in severe yield reduction and creating devastation impact (Naganna et al., 2020). FAW has a wide host range infesting primarily the maize fields along with rice and some grasses. Being a polyphagous pest, infest more than 100 hosts like sorghum and sugarcane as well as 23 horticultural crops like cabbage, beet, tomato, potato, and onion besides cotton, pasture grasses, peanut, soybean, alfalfa, and millets (Rashed 2023).

The adult moths of FAW exhibits high dispersal ability combined with a marked migratory behavior in the Americas and tend to travel up to 1500-2000 km per year in search of warmer climates, and can travel 500 km in a single season to find oviposition sites and can fly over 100 km per night (Yainna et al., 2022). Since the late 1700s, FAW outbreaks have been reported throughout the Americas (Luginbill 1928). In April 2016, FAW was first detected in the island country of São Tomé and Príncipe, followed by outbreaks recorded in Benin, Nigeria, Ghana and Togo of Western Africa in June, 2016 (Cock et al., 2017). FAW are found in the majority of sub-Saharan Africa as of October, 2017 (FAO 2017). However, populations of this pest have significantly increased in the Eastern Hemisphere in recent years. Afterwards spread across Africa through commercial aircrafts or cargo containers which later travel to Asia reaching Australia in 2019 through the dispersal of wind (Chisonga et al., 2023). In India, it was detected in 2018 from Karnataka and has now spread to several south eastern Asian countries (Nagoshi et al., 2020, Zhang et al., 2020). Subsequently, it extended to various states known for maize cultivation, including Bihar, Chhattisgarh, Gujarat, Maharashtra, Odisha, West Bengal, and numerous others (CABI 2020, Sagar et al., 2020).

In Punjab, *S. frugiperda* was initially documented in grain maize on 15th August 2019 (Rakshit et al., 2019, Cheema et al., 2021). In fodder maize, was first observed in Samrala and Kharar regions of Punjab on 30th September 2019, specifically in crops sown later in the season (Cheema et al., 2021). The presence of this invasive pest has greatly affected the means of subsistence for small and marginal farmers throughout India (Suby et al., 2020, Navik et al., 2021). The larval dispersal is a crucial adaptive characteristic of *S. frugiperda* driven by their substantial reproductive capacity, which assists in sustaining population expansion (Li et al., 2023). The swift and extensive spread of FAW, along with its considerable ability to cause significant yield losses, has garnered global attention (Qi et al., 2021). FAW could threaten the food security and livelihoods of millions of small-scale farmers in India due to its gregarious and fast feeding habits on a wide range of host plants.

Distribution

The fall armyworm is an invasive pest native to the Americas, has become a significant global threat to agriculture, particularly maize production. Since its first detection in West Africa in 2016 (Goergen et al., 2016), it has rapidly spread to nearly 40 African countries by 2018. FAW was initially reported in maize crops in India in 2018, and the University of Agricultural and Horticultural Sciences in Shivamogga, Karnataka, confirmed its existence (Ganiger et al.,2018, Sharanabasappa et al., 2018), marking the first documented occurrence of this pest in Asia. Since then, a trend of temporal extension from peninsular India to the northern, northeastern, and north-western regions has been noted (Suby et al., 2020). Confirmed outbreaks have occurred in Thailand, Bangladesh, Myanmar, China (Yee et al., 2019), Sri Lanka (Perera et al., 2019), Nepal (Bajracharya et al., 2019), Philippines (Navasero et al., 2019), Vietnam (Hang et al., 2020) and Indonesia (Trisyono et al., 2019). By 2020, *S. frugiperda* had also been reported in Oceania and the Middle East, including Australia, South Korea, Papua New Guinea, and the UAE (Ma et al., 2019, Prasanna et al., 2021, Tambo et al., 2023). This extensive geographic spread of FAW highlights the urgent need for integrated and sustainable management approaches.

FAW is a gregarious, and multivoltine pests with localized and migratory tendency of dissemination. Two distinct strains of FAW are recognized, commonly referred to as the "rice-strain" (R-strain) and "corn-strain" (C-strain) (Pashley 1988). The R-strain is found on rice, pasture, millets, and forage grasses whereas, the C-strain is observed on corn, cotton, and sorghum (Nagoshi and Meagher 2004). Until December 2018, only the rice (R) strain had been identified in India, which was found feeding on maize (Swamy et al., 2018). Subsequently, Chromule et al. (2019) reported the occurrence of the C-strain on sugarcane. Nagoshi and Meagher (2022) concluded substantial disagreements in the literature on presumptive strain differences. The pest later spread to adjoining countries including Bangladesh, Nepal, Pakistan, the Philippines, Korea, Indonesia, China, and Syria. In India, it has been reported on maize and other host crops nationwide (Sharma 2021, Chromule et al., 2019, Sharanabasappa et al., 2018, Swamy et al., 2018).

In India, FAW has been documented on a wide array of crops including maize, paddy, sugarcane, ginger, bajra, sorghum, cotton, Johnson grass, sunflower, banana, fodder grasses, and grain amaranth (Sharma 2021, Chromule et al., 2019, Sharanabasappa et al., 2018, Swamy et al., 2018, Venkateswarlu et al., 2018, Bharadwaj et al., 2020, Ragesh and Balan 2020, Maruthadurai and Ramesh 2019).

Recent Trends Illustrating the Migration Patterns of Faw

In the Indian subcontinent, *S. frugiperda* was observed in 2018 from Karnataka, which later spread to different states of India (Fig 1) *viz.,*Chhattisgarh (Deole and Paul 2018), Gujarat (Sisodiya et al., 2018), Tamil Nadu (Srikanth et al., 2018), Maharashtra (Chormule et al., 2019), Uttarakhand (Maurya et al., 2019), Orrisa (Karketta et al., 2020), Bihar (Reddy et al., 2020), Madhya Pradesh (Vishwakarma et al., 2020) Himachal Pradesh (Sharma 2021)and many other states (Fig. 2). By the end of 2018, FAW outbreaks have been discovered in several countries in Southeast Asia, including Bangladesh, Myanmar, and Thailand (Guo et al., 2018).

ECOLOGY OF FAW:

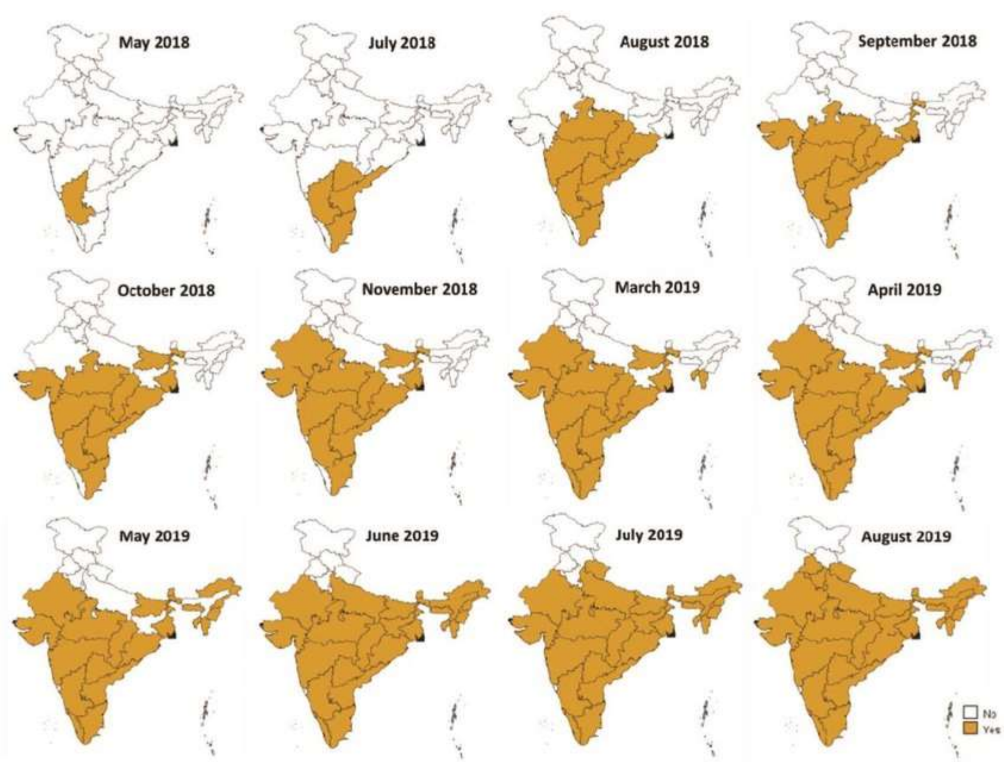
The FAW has become a significant agricultural pest in India since its detection in 2018. Its ecology is shaped by the country's tropical and subtropical climates, with warm temperatures and high humidity favoring its survival and reproduction (Ramzan et al., 2020). Seasonal dynamics are influenced by monsoon patterns, with populations peaking during planting seasons. Integrated pest management approaches, including early detection, host plant resistance, and conservation of natural enemies, are crucial for sustainable control.

The pest generally thrives in warm climates, with optimal temperatures for development ranging from 20°C to 35°C. Higher temperatures can accelerate its life cycle, leading to faster population growth. The temperature below 10°C is detrimental to its survival (Stokstad 2017). While FAW can tolerate various ranges of humidity levels, high humidity conditions favor its survival and reproduction. Dry conditions can reduce egg and larval survival rates. Adequate moisture is essential for FAW egg laying and larval development. Heavy rainfall can disperse neonate larvae and affect their movement and feeding behavior. Wind can aid FAW dispersal over long distances, facilitating its spread to new regions. Wind direction and intensity influence the movement of adult moths and larvae.

Biology and Feeding Behaviour of FAW: FAW is a lepidopteran pest, undergoes complete metamorphosis, and consists of four stages in the life cycle. It has several generations per year with a life cycle consisting of an egg stage, 6 larval instars, pupa, and an adult stage which is completed in 30 days during summer and 60 days during winter. The life cycle of the fall armyworm begins with a female moth depositing white-colored eggs on the underside or upperside of leaves (Ramzan et al., 2020), which later darken to brown just before hatching. The female moth protects the egg masses by covering them with protective scales obtained from her abdomen after oviposition. After 3-6 days, the eggs hatch, and the caterpillars emerge. The early larval stages exhibit a greenish coloration, which later transitions to orange. The larvae measure approximately 1 mm in length during the first instar and grow up to 45 mm by the sixth instar. The full-grown caterpillars may exhibit characteristic markings and spots. These identifying marks often include an inverted 'Y' mark on the head region (Nagoshi et al., 2007), and four smaller dorsal spots arranged in a trapezoidal formation on other segments. Additionally, black dots may be present in a square formation on the last segment.

Usually, only 1 or 2 caterpillars in each whorl are found as they possess cannibalistic feeding behavior where larger caterpillars consume each other to reduce competition for food. The caterpillar's excreta (frass) can also be seen in the leaf whorls after drying, they resemble sawdust. If the plant has already produced cobs, the caterpillar will burrow through the protective leaf bracts and begin feeding on the developing young kernels inside the cob. The number of larval stages, typically 6-7, depends on environmental factors and food availability. In later stages, the rate of food consumption increases, with the final stages consuming even more food than all previous stages combined. The duration of larval development also varies accordingly, at 25°C, it takes approximately 14-18 days. Orange-Brown pupal case is typical forNoctuid FAW pupa which turns darker with age (Hardke et al., 2015). Inside, the pupa, which is reddish-brown in color and measures 14 to 18 mm in length and breadth, develops into an adult (Kandel and Poudel 2020). During the day, adults hide in whorls and lay eggs on leaves, while fully grown larvae pupate in the soil at a depth of 3 to 10 cm (Ratnakala 2023). The wingspan of an adult FAW is about 3.81 cm with the upper portion of the forewing mottled dark grey and in males, a distinctive triangular white spot near the dorsal tip, or apex of the wing, while the lower portion of the forewing a light gray to brown color. Conversely, the color of the hind wing appears to light gray to white. The adult female has a relatively short life cycle of 7–21 days, with a high fecundity of 900–1000 eggs per female.

The feeding behavior of FAW larvae often results in semi-transparent patches on the leaves, commonly referred to as 'papery windows.' Particularly, they show a preference for leaf whorls in young plants, while in older plants, they tend to consume the leaves around cob silks. The larvae have the ability to spin threads, which they use to catch the wind and



Source: Suby et al., 2020

Fig. 1. Chronological order of spread of FAW through different Indian States

transport themselves to new plants. Their feeding activity is more pronounced during the night. During the early instars, FAW larvae prefer vegetative tissue, but as they mature, they increasingly target reproductive structures such as the cob and silk. Between days 6 to 14 of their lifecycle, they typically reach the leaf whorl, causing the most effective damage, resulting in ragged holes in the leaves. Damage to the leaf whorl in young plants can be particularly detrimental, potentially leading to the death of the growing point and subsequent stunting of plant growth, resulting in limited or no new leaf or cob development.

Nature of Damage and Invasiveness of FAW

Once the eggs of FAW hatch, the early instar secretes silken thread and is dispersed by the wind. The first and second instar larvae can be found on the upper surface of the leaves, where they scrape the epidermis resulting in elongated papery windows all over the leaves. When the larvae reach the third instar, they settle in the whorl and their feeding causes a series of holes and fecal matter in the unfurling leaves. As they grow, their feeding rate increases, which leads to larger holes and greater amounts of fecal matter. By the sixth instar, the larvae can defoliate the plant heavily and leave a large amount of fecal matter in the plant whorl. Older larvae may even bore into the developing internodes of the early whorl stage of maize, which can cause plant death. The larvae may also attack tassels and developing ear (Kaur et al., 2024). During their life cycle, FAW larvae devour a significant amount of foliage: 4.7, 16.3, and 77.2% for the fourth, fifth, and sixth instars, respectively. In contrast, first to third instar larvae are quite small and only consume 2% of the total foliage.

FAW emerged as one of the invasive pests species with broad host range cause significant yield losses. Major invasion mechanism involves expansion of gene families associated with detoxifying processes which makes them polyphagy (Huang et al., 2019), an increase in detoxifying metabolizing enzyme (Yu et al., 2003), mutation of toxin receptor (Xiao and Wu 2019), long distance migration, and down regulation of enzymatic expression (Jakka et al., 2016). Because of its biological traits, FAW has spread to new locations and become an invasive species.FAW infestations have the potential to result in yield reductions varying from 10% to 100%, depending on the severity of damage and the timing of infestation. Infestations occurring in the early stages, particularly during the vegetative phase, can lead to stunted plant growth, diminished leaf coverage, and decreased photosynthetic ability, ultimately leading to yield losses. In severe instances, FAW larvae can completely strip maize plants of their foliage, resulting in nearly complete crop failure. Initially, young larvae consume leaf tissue from one side, leaving the opposite epidermal layer intact. As they progress to the second or third instar, larvae start to create perforations in the leaves, feeding from the edges inward. Feeding within the corn whorl often leaves behind a distinctive row of holes in the leaves.When larvae feed nearby, their numbers typically decrease to one to two per plant due to cannibalistic behavior. Older larvae cause extensive defoliation, often leaving only the veins and stalks of corn plants or giving them a tattered, torn appearance. The early whorl stage is the least affected by damage, the mid-whorl stage moderately affected, and the late whorl stage the most affected.

Comprehensive Strategies for FAW Management

With an emphasis on remedies that can produce pest

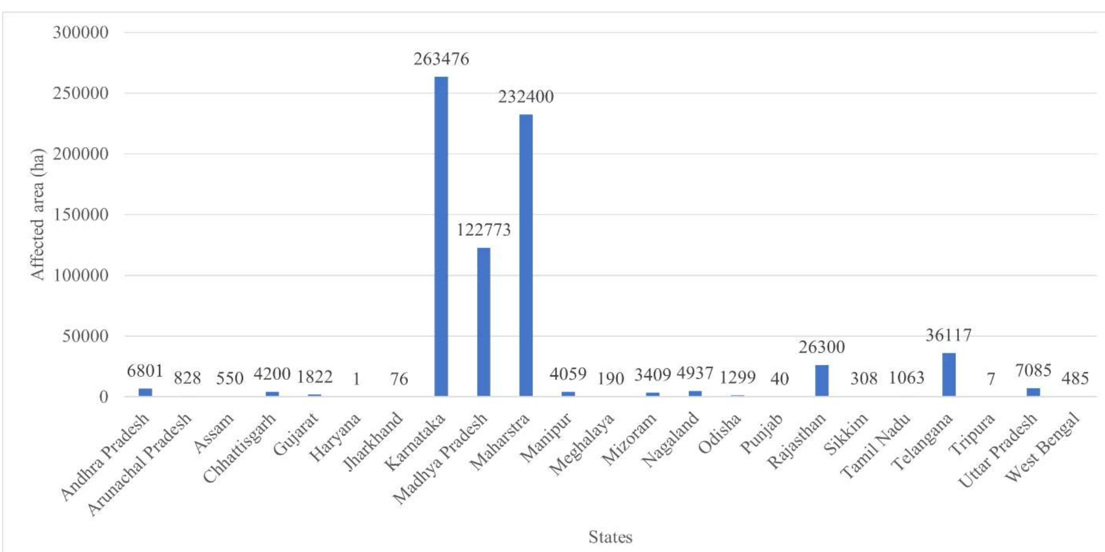


Fig. 2. Selected state-wise area affected due to fall armyworm in India (up to 2020)

control advantages across a wide array of pests and that are appropriate for a diversity of crops and cropping systems, FAW control tactics therefore need to be integrated into a broader pest management viewpoint.

Cultural management: Cultural management practices play a crucial role in controlling FAW infestations. These practices aim to disrupt the pest's life cycle and reduce its population. Some effective cultural management strategies include crop rotation, weed management, intercropping, trap cropping, and many more. To disrupt the pest's life cycle, alternate maize with crops that do not host it and avoid planting maize continuously in the same field. Early planting is advisable as it reduces susceptibility to significant damage. Mix maize with non-preferred crops or those less favored by the fall armyworm. Interplanting maize with legumes or other crops can alleviate pest pressure. Although it requires labor and additional costs, the idea of "Push-Pull" cropping (Dash et al., 2024), where intercropping maize with a pest-repellent ("push") plant (*Desmodium* spp.) surrounded by a border with pest-attractive trap ("pull") plant, like Napier grass (*Pennisetum purpureum* or *Brachiaria* spp.) has shown some promise in controlling the spread of FAW (Sagar et al., 2020).Surround the maize fields with trap crops like sorghum or millet to attract and capture adult fall armyworms, thus alleviating pressure on the main maize crop. This push–pull strategy has been shown to reduce larval density per plant by 82.7% and minimize plant damage per plot by 86.7% (Midega et al., 2018). Additionally, studies indicate that intercropping maize with *Tephrosia* and *Desmodium* can significantly suppress FAW oviposition (Harrison et al., 2019). Maintain weed-free fields to remove alternative hosts and breeding grounds for the fall armyworms, diminishing their food and shelter sources. Employ resistant maize varieties to decrease fall armyworm damage and reduce reliance on chemical measures. Prompt detection enables timely intervention and minimizes crop damage.

Mechanical management: Mechanical management techniques employ physical measures to control fall armyworm populations, aiming to directly decrease pest numbers or interfere with their life cycle. These methods include manually removing and destroying FAW eggs, larvae, and pupae from maize plants, consistent scouting to detect and eliminate pests before substantial damage occurs, utilizing pheromone traps for monitoring and trapping FAW adult populations efficiently, installing light traps to attract and capture adult moths in and around maize fields, employing physical barriers like mesh nets or row covers to shield maize crops from FAW infestations, deep plowing or tilling the soil to expose FAW pupae to natural predators and unfavorable environmental conditions, eliminating infested plant material to reduce FAW populations and halt further spread, and deploying sticky traps to ensnare adult moths and hinder mating success.

Biological control: Due to the inherently gregarious behavior of *Spodoptera frugiperda*, early identification of infestations is vital for preventing significant crop damage. It is recommended that pest management actions be initiated promptly when early signs of leaf injury are detected on seedlings or when plant whorls show substantial infestation within the first 30 days post-planting (Fernandes et al., 2012). Biological management of fall armyworm involves a multifaceted approach utilizing various natural enemies and control agents. Parasitoids like *Cotesia* spp. and *Chelonus* spp. lay eggs on fall armyworm larvae, which hatch into larvae that consume the host from within. Predators such as birds, ants, ground beetles, and spiders' prey on fall armyworm eggs and larvae, aiding in population reduction (Dash et al., 2024). Conservation of natural enemies through reduced pesticide use, habitat preservation, and diverse vegetation planting further supports population regulation of fall armyworms. These integrated strategies foster sustainable pest management while minimizing environmental impact.

Microbial control: FAW is attacked by a number of microorganisms, including entomopathogenic nematodes, viruses, and bacteria (Guo et al., 2020). *Bacillus thuringiensis* (Bt) strains produce toxins lethal to fall armyworm larvae when ingested, offering environmentally friendly control (Dash et al., 2024). Since the entomopathogenic nematode (EPN), *Heterorhabiditis bacteriophora* and the entomopathogenic fungus (EPF), *Metarhizium anisopliae* were discovered to be compatible when combined and treated together, they may be taken into consideration for FAW management in combination (Bissiwu and Pérez2016).A combination in laboratory bioassays using the commercial product Bt Dipel (Sumitomo Chemical) and the EPN, *Steinernema carpocapsae* (Viteri et al., 2018) as well as the results showed high larval mortality rates of 81.3% after 96 hr. as compared to larval mortality caused by Bt (6.7%) or *S. carpocapsae* (35%) when applied alone. Field trials in Karnataka demonstrated that the entomopathogenic fungus *Metarhizium rileyi* can induce larval mortality in *S. frugiperda*, with rates varying between 1.87% and 18.30% (Mallapur et al., 2018). In addition, *Nomuraea rileyi* was reported to infect 10–15% of larvae (Sharanabasappa et al., 2019). According to El-Sheikh (2015), *Spodoptera littoralis* nucleopolyhedrovirus (SpliNPV) has also been demonstrated to be virulent against FAW larvae in their first to third instar. It has been also observed considerable increase in larval time, decrease in pupation, larval weight, and adult emergence. Research has highlighted the effectiveness of the *Spodoptera frugiperda* Multiple Nucleopolyhedrosis Virus (SfMNPV) as a potential biocontrol agent (Komivi et al., 2019).

Chemical control: The Central Insecticide Board and Registration Committee (CIB & RC), India now recommends the pesticides, *viz.,* broflanilide 20% SC, chlorantraniliprole 50% w/w fs, isocycloseram 18.1% W/W SC (20 % w/v SC), spinetoram 11.70 % SC, emamectin benzoate 1.5% + profenofos 35% w/w WDG in order to reduce damage to maize (CIB & RC 2025). The spray technology is almost important in realizing efficacy of the chemical. Spray the crop with chlorantraniliprole 18.5 SC @ 0.4 ml per liter water or spinetoram 11.7 SC @ 0.5 ml per liter or emamectin benzoate 5 SG @ 0.4 g per liter using 120 liters of water per acre, for crops up to 20 days old. Thereafter for older crops, the amount of water used per acre needs to be increased up to 200 liters with corresponding increase in dosage of above insecticides. For effective management of this pest, direct the nozzle towards the whorl. Moreover, in order to prepare poison bait, Patil et al., (2017) described a procedure that involved mixing 5.0 kg of jaggery with 4-5 littersof water

Biotechnological approaches: In insect pest control, biotechnological interventions may improve crop resistance and tolerance. This includes a number of methods, such as protoplast fusion, RNA interference, marker-assisted selection, trait mapping, gene transformation, protoplast fusion, and the incorporation of novel genes into crops (Romeis et al., 2019, Warburton et al., 2023). To identify genes or genomic areas linked to FAW resistance, a variety of genetic techniques have been employed, such as genome-wide association mapping and quantitative trait loci (QTL) mapping (Kamweru et al., 2022). QTL mapping is a technique that finds genomic areas associated with a certain characteristic by analyzing or correlating genotypic and phenotypic data. Numerous investigations have been conducted to identify the genes causing a range of characteristics, such as resistance to disease (Jha et al., 2023), insect pest resistance (Cosme et al., 2022) and biofortification (Juliana et al., 2022). Moreover, genes that encode toxins such as *Bacillus thuringiensis* (Bt) or enhance plant defences against FAW are introduced using genetic engineering techniques (Burtet et al., 2017, Li et al., 2021). Newer biotechnological approaches to insect pest management, including gene editing (RNA interference (RNAi), gene drives, and, most recently, the CRISPR-Cas9 system (Gouda et al., 2024), have emerged as a result of insect resistance, despite the fact that transgenic Bt crops have significantly improved crop protection (Ullah et al., 2022, Li et al., 2021).

CONCLUSION

The fall armyworm is expanding quickly, encroaching on new territory owing to its remarkable dispersal ability. The food and nutritional security of the global populace has already been alerted by the FAO to the recent insect outbreak in Asia. FAW primarily targets members of the poaceae family, attacking 353 host plant species from 76 different plant families. Also regarding FAW strains like assumption on strain-specific traits are need to be explored. Implementation of an appropriate management approach is the one important factor in managing the fall armyworm. As an emergency response to tackle FAW menace, chemical control is advisable but it causes environmental deterioration. Therefore, FAW control tactics are to be integrated in a sustainable way to protect the crops.

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First Report of Invasive Nesting Whiteflies (*Paraleyrodes* spp.) Infesting Small Cardamom and Management Strategies

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Abstract: Invasion and establishment of Bondar's nesting whitefly, *Paraleyrodes bondari* Peracchi (Hemiptera: Aleyrodidae) and nesting whitefly, *Paraleyrodes minei* Iaccarino (Hemiptera: Aleyrodidae) were recorded on small cardamom for the first time in different agro-climatic zones in Kerala, Karnataka and Tamil Nadu of South India. Identities of the species were confirmed through morphological and molecular characteristics. Partial sequences of cytochrome c oxidase I gene (658 bp) for *P. bondari* (PV163890) and *P. minei* (PV163877) were submitted to GenBank, NCBI, India. The incidence of these whiteflies in different agro-climatic zones and their varietal screening in different prevailing varieties and land races of small cardamom indicated that the infestation of *P. bondari* was higher than *P. minei*. Seasonal incidence of both *P. bondari* and *P. minei* population was peaked during November to March, declined during April to May and were negligible during June to October in Cardamom Hill Reserve, Kerala. Rainy days for *P. bondari* and *P. minei* was negatively and significantly correlated with invasive whiteflies population. Field evaluation with few novel insecticides revealed that spinetoram 12% SC @ 0.45 l/ha reduced whitefly populations by > 90% in small cardamom crop.

Keywords: Cardamom, Management, Molecular analysis, Screening, Seasonal incidence, Whiteflies

Small cardamom, *Elettaria cardamomum* (L.) Maton also known as "Queen of Spices" is a high valued spice for its aromatic seeds. It is mainly grown in evergreen forests of the Western Ghats of Kerala, Karnataka and Tamil Nadu of South India and is the third most remunerative spice crop next to saffron and vanilla. The Cardamom Hill Reserve (CHR) of Idukki district of Kerala contributes 70% of the production followed by Karnataka (20%) and Tamil Nadu (10%). Nearly 60 species of insect pests have been reported in small cardamom. Among them, cardamom thrips, *Sciothrips cardamomi* (Ramk.) and shoot/panicle/capsule borer, *Conogethes* sp are major insect pests, occurring throughout the year whereas root grub, *Basilepta fulvicorne* (Jacoby) and plant parasitic nematode, *Meloidogyne* spp. are considered to be seasonal pests. Red spider mite, whitefly, scales, lace-wing bug and aphid are minor insect pests reported as emerging pests of small cardamom. Cardamom is an export orientated crop and always faces the problem of pesticide residues due to intensive cultivation with heavy application of pesticides. Whiteflies, *Dialeurodes citri, Kanakarajiella cardamomi, Aleurotuberculatus cardamomi* are reported so far in small cardamom (Gopakumar and Chandrasekar 2002). Due to climate change, intensive cultivation and indiscriminate pesticide use, several minor pests have recently resurged in cardamom plantations across the CHR, Kerala (Thiyagarajan and Ali 2016, Thiyagarajan et al., 2017). Red spider mite, cardamom whitefly, scales, lace-wing bug and aphid are minor insect pests reported as emerging pests in CHR in recent years (Thiyagarajan et al., 2019). Due to outbreak of invasive whiteflies in different agricultural and horticultural crops in India, the present studies were undertaken and focused on survey, varietal screening, seasonal incidence and management of invasive whiteflies in small cardamom crop grown in different agro zones of small cardamom tracts of Southern India.

MATERIAL AND METHODS

Survey of invasive whiteflies in small cardamom: Survey was conducted in ten places in different agro zones of small cardamom growing areas of the Western and Eastern Ghats of Kerala, Karnataka and Tamil Nadu from August, 2024 to July, 2025 at monthly interval to assess the infestation of invasive whiteflies. From Kerala, small cardamom growing districts *viz.,* Idukki, Wayanad and Palakkad were surveyed. In Idukki, a survey was conducted in different zones of CHR (A, B & C Zones) covering Puttady (Zone A), Pampadumpara (Zone B) and Pallikkunnu (Zone C), Vellimala from Wayanad district and Puliyara from Palakkad district. From Karnataka, Donigal from Hassan District and Ibnivalvadi Rural from Kodagu district were surveyed. From Tamil Nadu, Kothadipatti from Dindigul district, Kurumberbetta from The Nilgiris district and Cakkaraipatti from the Namakkal district were surveyed (Fig. 1). Ten plants of Njallani Green Gold in all locations were randomly taken from each field and number of whiteflies per leaf was recorded randomly covering three leaves each from top, middle and bottom canopy (Sathyan et al., 2018). An assessment of population level was made using the following qualitative scale i.e. Low (=less than 10 live egg spirals or adults per leaflet), Medium (=11-20 live egg spirals or adults/leaflet) and Severe (=more than 20 live egg spirals or adults/leaflet) protocol developed by Sundararaj et al. (2021). The specimens were collected in 90% ethanol and leaves containing puparium were preserved and identified at ICAR- National Bureau of Agricultural Insect Resources, Bengaluru, India. The genetic classification of invasive whiteflies was made using species confirmation by matching with the original and additional description of the respective species (Sundararaj et al., 2021). Molecular characterization of the partial mitochondrial cytochrome c oxidase I (COI) (658 bp) gene was done with adult whiteflies after morphological identification to confirm the species. Genomic DNA extraction from individual adult whiteflies were done using DNAase Qiagen kit method (Qiagen, Germany). Polymerase chain reaction amplification of the 5′ terminus of the COI gene was done following the standard protocol which involves the cocktail of reactions, using universal primers LCO 1490 5′-GGT CAA ATC ATA AAG ATA TTG G-3 and HCO 2198 5′-TAA ACT TCA GGG TGA CCA AAA AAT CA-3′ (Folmer et al., 1994). The quality of the amplicons was checked in agarose gel electrophoresis and the amplified products were sequenced by Eurofns Genomics India Pvt. Ltd., Bengaluru, Karnataka. The resulting sequence data were manually edited using BioEdit software, before subjected to BLAST analysis in the NCBI database to determine the identity of the specimens. Subsequently, validated DNA sequences, were submitted to the NCBI GenBank to obtain accession numbers.

Varietal screening for invasive whiteflies: A total of fifteen different small cardamom improved varieties and landraces were utilized for the screening for incidence of invasive whiteflies at Germplasm Conservatory, Indian Cardamom Research Institute (ICRI), Myladumpara, Idukki Dt. Kerala, India from November 2024 to April 2025. The improved varieties viz., ICRI-1, ICRI-2, ICRI-5, ICRI-6, ICRI-7, ICRI-10, TCC-9 and landraces including Njallani Green Gold, Panikkulangara-1, Panikkulangara-2, Palakkudi, PNS Vaigai, Thiruthali, Valley Green Bold and Wonder Cardamom were screened. The plot was maintained without any pesticide application. Ten cardamom plants of each improved variety and landraces were selected and tagged for observations and nine leaves per plant were taken randomly covering three leaves each from top, middle and bottom canopy for observation (Sathyan et al., 2018) and whitefly population assessment was made naturally occurred as per the protocol developed by Sundararaj et al. (2021).

Seasonal incidence of invasive whiteflies: The study was conducted at the ICRI, Myladumpara from August 2024 to July 2025 due to a sudden outbreak of invasive whiteflies in small cardamom ecosystem. The weather data such as maximum and minimum temperature, relative humidity (mean), rainfall and rainy days were obtained from the

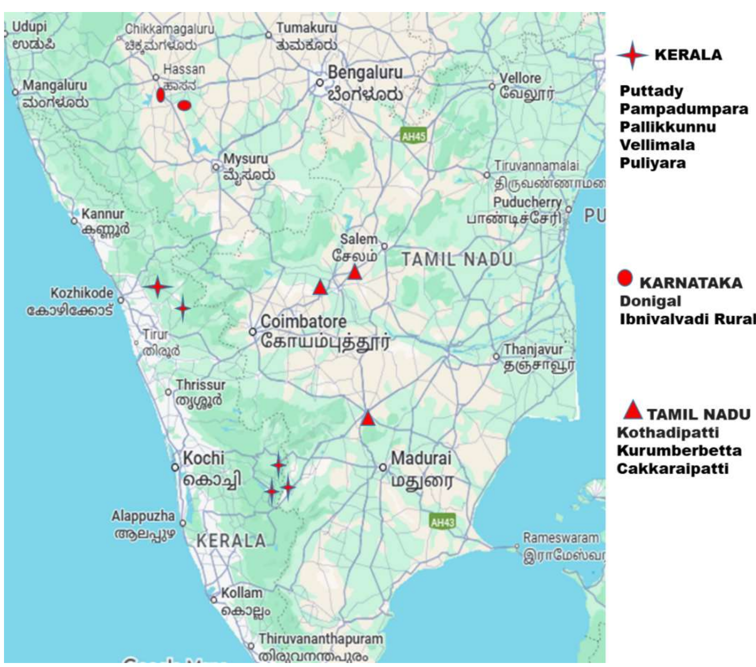

Fig. 1. Map showing locations for survey of whiteflies in small cardamom growing tracts

Meteorological Observatory at ICRI, Myladumpara and used for multiple correlation analysis. The five-year-old Njallani Green Gold cultivar plot was selected for the study and whitefly population count was taken from randomly selected fifty plants which were maintained without pesticide application at monthly intervals throughout study period. Nine leaves per plant were selected randomly each from top, middle and bottom of each plant for observation (Sathyan et al., 2018). Data on seasonal incidence of invasive whiteflies at fixed plot in an acre has been presented as mean data on a monthly basis.

Bio-efficacy of insecticides against invasive whiteflies: Field experiment was conducted at the research farm of the ICRI, Myladumpara, Kerala from November, 2024 to January, 2025 which is peak infestation in a randomized block design with eight treatments replicated three times. Small cardamom which is a perennial crop, five years old Njallani Green Gold a commonly cultivated cultivar was used and each replication had 12 plants. All standard agronomic practices were followed except pesticide applications. The insecticide treatments comprised of eight treatments in which six were new insecticide molecules viz., spirotetramat 150 % OD @ 750 ml/ha, buprofezin 25 % EC @ 1500 ml/ha, spinosad 45 % SC @ 500 ml/ha and spinetoram 12 % SC @ 450 ml/ha, one bio-pesticide (azadirachtin 1 % @ 1000 ml/ha) and CIB&RC recommended insecticides for major cardamom pests as standard check *viz.,* acephate 95 % SG @ 1000 g/ha and diafenthiuron 50 % WP @ 800 g/ha. An untreated control was simultaneously maintained during the study. Among them, the spinosad is used for organic cultivation worldwide and Spinetoram derived from fermentation product of *Saccaropolyspora spinosa.* Insecticide applications were carried out using a high volume knapsack sprayer fitted with a hollow cone nozzle, using 1000L of spray fluid per hectare. The first spraying was done when the invasive whiteflies pest population reached the maximum population, and subsequent spray was given at an interval of 28 days. The population of invasive whiteflies, *P. bondari* and *P. minei* were counted on nine leaves per plant, three each from the top, middle and bottom regions of five randomly selected plants per plot, and before, 14 and 28 days after each spray. The plants in the border rows were excluded. The percentage reduction (PR) of both invasive white flies over the untreated control was calculated as PR [(Control count - Treatment count/Control count) x 100] for each treatment following each spray. Data were analysed using randomized block design in SPSS software version 16, and means were separated using Tukey's HSD test at $p \leq 0.05$.

RESULTS AND DISCUSSION

Molecular confirmation of species identity: Morphological characterization revealed the presence of two invasive whiteflies *viz.,* Bondar's nesting whitefly, *Paraleyrodes bondari* Peracchi (Hemiptera: Aleyrodidae) and nesting whitefly, *Paraleyrodes minei* Iaccarino (Hemiptera: Aleyrodidae) on small cardamom for the first time in cardamom growing tracts of Kerala, Karnataka and Tamil Nadu. Further, their identity was confirmed through partial sequences of cytochrome c oxidase I gene for *P. bondari* (PV163890) and *P. minei* (PV163877) infesting small cardamom were submitted to GenBank, NCBI, India.

Survey of invasive whiteflies in small cardamom: The adults and its damage symptoms of both *P. bondari* and *P. minei* are represented in Figure 2. Small cardamom leaves heavily infested with both invasive whiteflies showed a cottony white appearance and it was found in the abaxial side of leaves. The population was found to be more in bottom leaves/older leaves, moderate in middle leaves and negligible in top leaves of a plant canopy. The low level of *P. bondari* adult's population was in the Karnataka region particularly Donigal, and Ibnivalvadi, and severe population was recorded in all other locations in Puttady, followed by Pampadumpara, Pallikunnu and Vellimala areas of Kerala. For *P. minei*, Kurumberbetta, Cakkaraipatti of Tamil Nadu and Ibnivalvadi and Donigal of Karnataka recorded low level of population (Fig. 3). Kothadipatti of Tamil Nadu, Puttady, Puliyara, Pampadumpara of Kerala were recorded moderate (medium) level infestation, and Pallikunnu and Vellimala of Kerala recorded severe levels of population. However, *P. bondari* population was higher than *P. minei* in all the locations of Kerala, Karnataka and Tamil Nadu.

In India, *P. bondari* incidence was first reported in coconut palms in Kerala during 2018 (Josephrajkumar et al*.,* 2019). It has been reported in Karnataka, the Andaman and Nicobar Islands (Vidya et al*.,* 2019) and Lakshadweep Islands (Selvaraj et al., 2020). *P. bondari* is polyphagous in nature, it has more than 25 susceptible host plants and is found to infest coconut, banana, guava, citrus sp. avocado, cassava, custard apple, noni and ornamental ficus (Vidya et al*.,* 2019). In India, *P. minei* was also reported in coconut in Kerala during 2018 (Mohan et al., 2019, Sujithra et al., 2019) and further reported in the Andaman and Nicobar Islands (Dubey 2019). Subsequently, this species was found to rapidly spread to different districts of Karnataka and Tamil Nadu. *Paraleyrodes minei* was found to colonize coconut, banana, guava, mango, jamun, *Ixora* sp., and *Heliconia* (Mohan et al., 2019, Sujithra et al., 2019). This host range expansion could be a mechanism to overcome the abiotic constraints and buffer the depletion of optimal resources. Since the above invasive pests were reported already many crops grown in southern states in India and they can spread from existing host to small cardamom crop and also to the entire small cardamom growing tracts of Kerala, Karnataka and Tamil Nadu which is confirmed by present findings.

Varietal screening for invasive whiteflies: Among fifteen improved varieties and landraces screened, both *P. bondari* and *P. minei* incidence were recorded in all fifteen varieties and land races with varying levels (Table 1). For *P. bondari*, severe population was observed that Panikkulangara-1 followed by Njallani green gold, TCC-9, ICRI-2, ICRI-5, ICRI-10, Panikkulangara-2 and Wonder cardamom. ICRI -1 showed moderate infestation. PNS Vaigai, Palakkudi, ICRI-6, Thiruthali, ICRI-7 and Valley green bold showed low level

Fig. 2. A. Infestation of invasive whiteflies on small cardamom leaf, B. Infestation of invasive whiteflies on small cardamom leaf (enlarged view), C. Adult of *P. minei*, D. Adult of *P. bondari*, E. Egg spirals of *P. minei*, F. Egg spirals of *P. bondari*

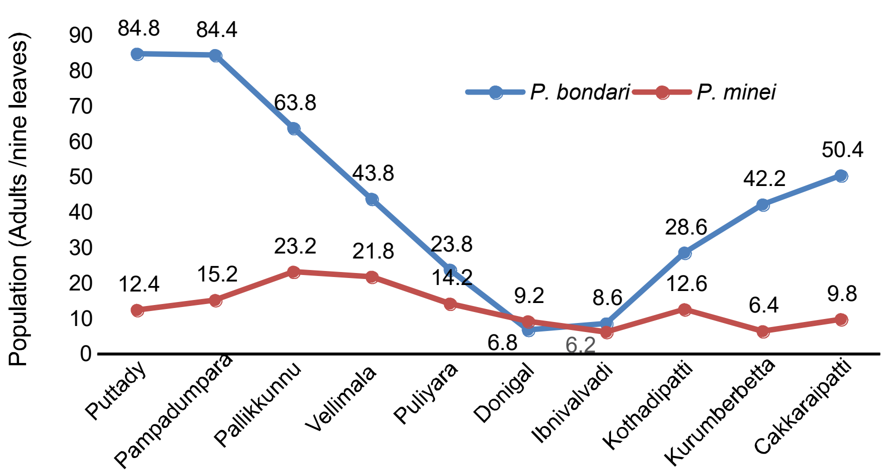

Fig. 3. Incidence of invasive whiteflies in different Indian small cardamom growing tracts

population. For *P. minei*, most of the varieties showed severe infestation were Panikkulangara-2, ICRI-5, ICRI-6, TCC-9, Njallani green gold, ICRI-10, Valley green bold and ICRI-2. Varieties, ICRI-7, ICRI-1 and Palakkudi and Wonder cardamom expressed moderate (medium) level of infestation. Varieties, PNS Vaigai, Panikulankkara-1 and Thiruthali showed low level infestation. Among the varieties and landraces screened, Panikkulangara -1 recorded highest level of *P. bondari* infestation and Panikkulangara-2 recorded highest level of *P. minei* infestation. However, PNS Vaigai and Thiruthali recorded low level infestation of both *P. bondari* and *P. minei*.

The small cardamom varieties and landraces screened against both *P. bondari* and *P. minei* were not completely free from the attack of these whiteflies. Panikkulangara-1, a landrace was recorded maximum population of *P. bondari* followed by Njallani green gold and landraces *viz.,* PNS Vaigai, Palakkudi, Thiruthali, ICRI 7 and Valley green bold had minimum population. Landrace, Panikkulangara-2 recorded maximum population of *P. minei* followed by ICRI 5 and landraces, PNS Vaigai, Panikkulangara-1 and Thiruthali. Njallani green gold, Panikkulangara-1 and ICRI-5 a commonly used variety were more susceptible to *P. bondari* and *P. minei* and whereas, landraces PNS Vaigai and Thiruthali was found be less susceptible to both *P. bondari* and *P. minei*. Nadeem et al. (2014) showed that the different cultivars screened, none of them showed complete resistance against whiteflies however, MH 3153 showed comparatively better resistance against sucking insects. Jacob et al. (2020) observed that, among 180 germplasm accessions screened, none of them were found to be highly resistant and only eight accessions were resistant to cardamom thrips. Among 100 small cardamom germplasm accessions screened only few of them slightly tolerant to cardamom thrips and shoot borer (Thiyagarajan et al., 2020). The both invasive whiteflies population were noticed in almost all the improved varieties and landraces. It might be adapting to favourable micro climate for its niche, might spread to cardamom from alternate hosts which cardamom grown under evergreen forest ecosystem.

Seasonal incidence of invasive whiteflies: Seasonal activity, simple correlation co-efficient and multiple regressions were estimated with weather parameters of appropriate months at Myladumpara for August 2024 to July 2025 (Fig. 4). During the study period, *P. bondari* incidence was first observed during August, 2024 and came to peak during November, 2024 to February 2025 and thereafter declined. In case of *P. minei* the incidence was first observed during September 2024 and peak during November, 2024 to February 2025 (13.75 - 19.60 adults/9 leaves) and thereafter declined. During June and July 2025, the population of *P. bondari* and *P. minei* was zero due to heavy rainfall and more rainy days. The minimum population of *P. bondari* was observed in August 2024 whereas the maximum population was observed during December 2024. The maximum population of *P. minei* was also observed during December 2024 and decline afterwards. Population of *P. minei* was also absent in the months of June, July and August months due to

Table 1. Screening on incidence of invasive whiteflies on improved varieties and landraces in small cardamom

Improved varieties & landraces	*P. bondari*		*P. minei*	
	Adults/ 9 leaves	Scale	Adults/ 9 leaves	Scale
ICRI -1	11.80	Medium	13.60	Medium
ICRI -2	52.40	High	21.60	High
ICRI -5	43.20	High	41.20	High
ICRI -6	4.80	Low	38.20	High
ICRI -7	8.20	Low	11.60	Medium
ICRI -10	41.60	High	22.40	High
TCC-9	52.60	High	35.80	High
Njallani green gold	71.40	High	23.20	High
Panikkulangara - 1	103.40	High	5.60	Low
Panikkulangara - 2	31.20	High	51.40	High
Palakkudi	3.60	Low	14.20	Medium
PNS Vaigai	2.20	Low	5.20	Low
Thiruthali	5.60	Low	9.20	Low
Valley green bold	9.20	Low	22.40	High
Wonder cardamom	22.40	High	16.60	Medium

heavy rainfall indicating a negative correlation between rainfall, rainy days and whitefly population. The peak population of both invasive whiteflies was found during November to March and it was declined during April & May and was negligible during June to September. The abundance of betel vine whitefly was high from November to December (Dahal et al., 2009) and the peak population of whitefly, *K. cardamomi* was noticed during February to March at five locations in small cardamom of CHR, Kerala (Sathyan et al., 2018). These findings also support the present investigation.

Maximum and minimum temperature and relative humidity weren't significantly correlated with invasive whiteflies population. Rainfall and rainy days were negatively and significantly correlated with whiteflies population. Rainy days were more significant than rainfall which shows that an increase in rainfall leads to a significant reduction in population of both *P. bondari* and *P. minei* in small cardamom. The negative correlation between rainfall and whitefly populations suggests that pest outbreaks are likely during extended dry periods. Therefore, continuous field monitoring during November to March is crucial. *P. bondari* population was found to be more in number when compared with population of *P. minei*. Coefficient of determination (R^2) value for *P. bondari* was 0.49 and R^2 value for *P. minei* was 0.48 showing 49 per cent very meager influence of all-weather factors on *P. bondari* population and 48 per cent influence of all-weather factors for *P. minei* population respectively (Table 2). The multiple regression analyses exposed that, the rainy days influenced the both *P. bondari* and *P. minei* populations by 59 per cent and 61 per cent respectively during August 2024 to July 2025. A unit decrease in rainy days increased populations by 3.4 number by *P. bondari* and 0.99 number by *P. menei* during the study period (Table 3). Vijaya Lakshmi et al. (2020) found significant negative correlation with maximum temperature and non-significant negative impact of rain fall with whitefly population in chilli. Rainfall and relative humidity had significant negative correlation with population of adults and nymphs of cotton whitefly (Balbantaray et al., 2018). Swati and Krishna (2020) reported that total rainfall had significant and negative impact on the whitefly adult and nymphal population in Bt cotton. Singh et al. (2017) observed that rainfall directly impacts on whitefly species. These results support the present investigation findings. Sathyan et al. (2018) reported positive correlation of *K. cardamomi* with the maximum temperature and sun shine hours and negative correlation with relative humidity during 2014-15 and again he found that a unit decrease in morning relative humidity, the *K. cardamomi* populations showed an increase 0.13 and 0.07 number/unit during the 2014 and 2015 respectively in small cardamom. Since, population dynamics of invasive whiteflies on *P. bondari* and *P. minei* was having limited studies in crops and these findings will be varying now a day due to sudden change of weather and climate particularly heavy rainfall with more rainy days during 2018, increase of day temperature with drought during 2024 in particular month/year in small cardamom growing tracts in India will change of outbreak and decrease of whitefly population which will support the present findings.

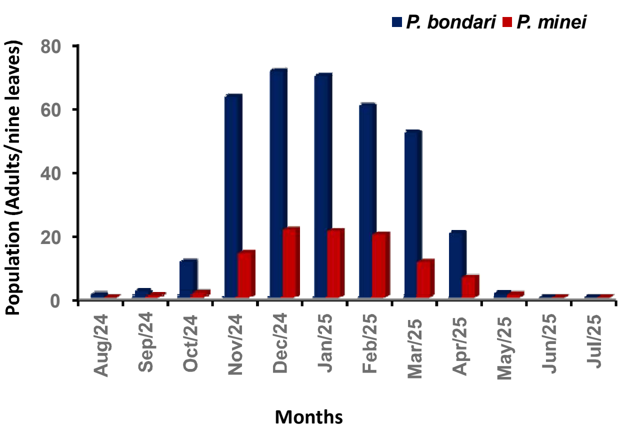

Fig. 4. Monthly variation of *P. bondari* and *P. minei* population on small cardamom from August 2024 to July 2025

Table 2. Estimated correlation co-efficient between weather parameters and incidence of invasive whiteflies in small cardamom

Weather parameters	*P. bondari*	*P. minei*
Maximum temperature	0.105 NS	0.099 NS
Minimum temperature	-0.460 NS	-0.433 NS
RH	-0.443 NS	-0.461 NS
Rainfall	-0.658*	-0.655*
Rainy days	-0.768**	-0.783**

*- Significant at 5% level, ** - Significant at 1% level, NS - Non significant

Bio-efficacy of insecticides against invasive whiteflies: Spinetoram 12 % SC reduced the *P. bondari* population

Table 3. Influence of weather parameters on invasive whiteflies in small cardamom

Pest population	Variable	Mean	Regression coefficient	Std error	t stat	Probability	Intercept	R^2 Value
P. bondari	Rainy days	11.1667	-3.422	0.902	-3.794	0.004	67.452	0.590
P. minei	Rainy days	11.1667	-0.997	0.251	-3.976	0.003	19.132	0.613

Table 4. Effect of new insecticide on *P. bondari* in small cardamom

Treatments with dosage	Number of whitefly (Adults/nine leaves)								
	PTC	1 Spray				2 Spray			
		14 DAT	PR	28 DAT	PR	14 DAT	PR	28 DAT	PR
Spirotetramat 150 % OD @ 750 ml	59.02	31.85[f]	51.82	40.66[f]	41.25	21.81[f]	69.47	24.85[f]	65.74
Buprofezin 25 % EC @ 1500 ml	59.10	21.66[d]	67.23	26.62[d]	61.54	10.95[d]	84.67	12.48[d]	82.79
Spinosad 45 % SC @ 500 ml	59.05	20.36[c]	69.20	24.81[c]	64.15	10.14[c]	85.80	12.00[c]	83.45
Spinetoram 12 % SC @ 450 ml	59.00	14.96[a]	77.37	16.73[a]	75.83	3.77[a]	94.72	4.81[a]	93.37
Acephate 95 % SG @ 1000 g	59.08	15.62[b]	76.37	17.81[b]	74.27	4.77[b]	93.32	5.11[b]	92.95
Diafenthiuron 50 % WP @ 800 g	59.04	25.22[e]	61.85	32.29[e]	53.35	21.61[e]	69.75	24.25[e]	66.57
Azadirachtion 1 % @ 1000 ml	59.06	36.59[g]	44.65	44.70[g]	35.42	29.29[g]	59.00	31.59[g]	56.45
Untreated control	59.00	66.11[h]	-	69.22[h]	-	71.44[h]	-	72.55[h]	-

PTC: Pre-Treatment Count, DAT: Days After Treatment, PR: Percent Reduction Over Control
In column, means followed by common letters are not significantly different at (P=0.05) by DMRT

Table 5. Effect of new insecticide on *P. minei* in small cardamom

Treatments with dosage	Number of whitefly (Adults/nine leaves)								
	PTC	1 Spray				2 Spray			
		14 DAT	PR	28 DAT	PR	14 DAT	PR	28 DAT	PR
Spirotetramat 150 % OD @ 750 ml	20.24	12.51[f]	49.35	18.22[f]	32.41	10.96[f]	60.21	7.81[d]	72.57
Buprofezin 25 % EC @ 1500 ml	20.20	7.85[d]	68.21	10.48[d]	61.12	4.25[d]	84.57	5.85[c]	79.45
Spinosad 45 % SC @ 500 ml	20.28	7.29[c]	70.48	9.92[c]	63.20	3.81[c]	86.17	5.00[b]	82.44
Spinetoram 12 % SC @ 450 ml	20.18	4.81[a]	80.52	7.22[a]	73.21	1.85[a]	93.28	2.44[a]	91.43
Acephate 95 % SG @ 1000 g	20.28	5.44[b]	77.97	7.59[b]	71.84	2.37[b]	91.39	2.70[a]	90.51
Diafenthiuron 50 % WP @ 800 g	20.00	11.62[e]	52.95	13.96[e]	48.21	9.44[e]	65.73	11.18[e]	60.74
Azadirachtion 1 % @ 1000 ml	20.26	16.44[g]	33.44	21.74[g]	19.36	12.25[g]	55.53	16.48[f]	42.13
Untreated Control	20.22	24.70[h]	-	26.96[h]	-	27.55[h]	-	28.48[g]	-

PTC: Pre-Treatment Count, DAT: Days After Treatment, PR: Percent Reduction Over Control
In column, means followed by common letters are not significantly different at (P=0.05) by DMRT

significantly after 14 days spray, whereas the acephate 95 % SG and spinosad 45 % SC were similar in reducing the *P. bondari* population and also in second rounds of application. The maximum reduction in *P. bondari* population over untreated control was observed after second spray for spinetoram 12 % SC followed by acephate 95 % SG and spinosad (Table 4). Spinetoram 12% SC reduced the *P. minei* population significantly after 14 days' spray followed by acephate 95% SG and spinosad 45% SC (Table 5). The maximum reduction in *P. minei* population over untreated control was observed after second spray for spinetoram 12% SC (91.43%) and the statistically spinetoram 45% SC dose of 450 ml/ha was most effective against both *P. bondari* and *P. minei*. Ambarish et al. (2017) also reported that spinetoram 10% in combination with other pesticides was effective against whitefly in cotton. Gupta et al. (2022) observed 77. 32 % reduction over control against chilli whitefly with acephate, with whereas, azadirachtin 0.15% and NSKE 5% recorded the lowest mortality of whitefly. Acephate 95% SG @ 1000 g/ha is effective for major cardamom insect pests viz., thrips and shoot borer. Thiyagarajan et al. (2025) reported spinetoram 12% SC @ 450 ml/ha also effective in reduction of these major insect pests in small cardamom.

CONCLUSIONS

This study reports the first incidence of *Paraleyrodes bondari* and *P. minei* infesting small cardamom in India. The pests exhibited seasonal peaks during November to March with rainfall and rainy days negatively influencing their abundance. Among the evaluated varieties, PNS Vaigai and Thiruthali showed relative tolerance, while Panikkulangara-1 and Njallani Green Gold were highly susceptible. Spinetoram 12% SC @ 0.45 l/ha timed at early population build-up proved most effective for field management. These findings provide baseline data for integrated pest management and future breeding programs in small cardamom ecosystems.

AUTHOR'S CONTRIBUTION

This study was conducted due to outbreak of invasive whiteflies in small cardamom growing tracts. P. Thiyagarajan involved in the varietal screening and seasonal incidence besides supervision of this work. Vyshnavi Sunil contributed the survey in different tracts and management. K. Selvaraj, G. A. Kavya Yadav contributed for morphological and molecular confirmation of whiteflies. S. Pradeep Kumar assisted for statistical analysis of data. Thania Sara Varghese, O. P. Reji Rani and A. B Rema Shree supported the interpretation of the results.

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Drone-Based Application of Pesticide Combinations for the Management of Fall Armyworm and Banded Leaf and Sheath Blight in Maize

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Abstract: The simultaneous occurrence of invasive fall armyworm (*Spodoptera frugiperda*) and banded leaf and sheath blight (BLSB, *Rhizoctonia solani*) poses significant threat to maize productivity. The study was conducted at wet land farm, S. V. Agricultural College, Tirupati, (latitude 13.615395°N and longitude 79.373317°E) during *Rabi*, 2023-24, to evaluate the efficacy of drone-based application of a combination of chlorantraniliprole 18.5 % SC and azoxystrobin 18.2 % + difenoconazole11.4 % SC against these pests. The results demonstrated that drone spraying of the insecticide-fungicide combination was highly effective in controlling FAW, achieving over 80 % reduction in larval population and 52% reduction in leaf damage. This approach also resulted in higher yields (46.8 q/ ha) with cost-benefit ratio of 1:2.24. In contrast, conventional knapsack spraying was less effective. The drone-based application minimized BLSB incidence, with negligible disease occurrence compared to untreated controls (1.13-2.13 %) with uniform distribution, improved penetration and reduced drift. The study establishes the efficiency and feasibility of UAV-based pesticide delivery for integrated pest and disease management in maize.

Keywords: Drone application, Maize, *Rhizoctonia solani, Spodoptera frugiperda*, UAV

Maize (*Zea mays* L.), is India's third most important crop after rice and wheat, providing food, feed, fodder, and industrial raw material. India ranks sixth globally in maize production (32.47 million tonnes from 9.96 million ha; 3260 kg/ha), with Andhra Pradesh leading in productivity (6066 kg/ha). However, pests and diseases such as the fall armyworm (FAW) (*Spodoptera frugiperda*), a migratory pest first reported in Africa (Goergen et al., 2016) and later in India at Shivamogga, Karnataka (Sharanabasappa et al., 2018), caused 21-53 % yield loss (Abrahams et al., 2017). Likewise, banded leaf and sheath blight (BLSB) (*Rhizoctonia solani*) leads to 11-40 % yield reduction, reaching 100 % under favourable conditions (Sharma and Saxena 2002). The simultaneous occurrence of FAW and BLSB in maize poses a serious threat to farmers, causing heavy yield losses. To manage both pests and diseases, farmers often mix pesticides in a single tank for broader control and reduced costs. However, such combinations require evaluation for bioefficacy and compatibility, as interactions may be antagonistic, additive, or synergistic (Gandini et al., 2020). Physical incompatibility between insecticide–fungicide mixtures can cause sedimentation, nozzle clogging, and uneven spray. Unmanned Aerial Vehicles (UAVs) have emerged as efficient tools in precision agriculture, offering uniform spraying, high maneuverability, and rapid field coverage. Operating at low altitudes minimizes drift compared to manned aerial spraying (Huang et al., 2009, Li et al., 2021). The rotor-induced vertical airflow improves droplet atomization, penetration, and deposition on crop surfaces and whorls, ensuring effective pesticide delivery.

Recently introduced new insecticide and fungicide combinations have been adopted by the maize farmers for managing pests and diseases, but the research studies on their compatibility and phytotoxicity effects in maize are very scanty. Therefore, evaluating their compatibility, bio-efficacy and the potential of drone-based application is essential to enhance efficiency, save time and labour. Hence, present study was undertaken to evaluate the compatibility, phytotoxicity and field efficacy of drone-based application of chlorantraniliprole and azoxystrobin + difenoconazole mixtures for the simultaneous management of FAW and BLSB in maize.

MATERIAL AND METHODS

Physical compatibility: The physical compatibility of chlorantraniliprole 18.5 % SC and fungicide, azoxystrobin 18.2 % + difenoconazole 11.4 % SC) was assessed using jar compatibility test. Observations were recorded after 30 and 60 minutes for the development of incompatible phenomenon like flakes, precipitation, gel, slurry, foams, sedimentation.

Experimental design: The field experiment was conducted at wet land farm, S. V. Agricultural College, Tirupati, (latitude 13.615395 °N and longitude 79.373317 °E), Andhra Pradesh, India during *Rabi*, 2023- 24, with Ganga Kaveri hybrid maize in randomised block design with three treatments and six replications with the plot size of 50 m × 10 m with inter- row spacing of 60 cm and 20 cm intra- row spacing. Buffer zone with 50 m × 10 m distance was maintained between the treatments.

Drone specifications: The ANGRAU-Pushpak-03 drone (Officially designated Remotely Piloted Aircraft System approved by DGCA, equipped with four anti-drift flat fan nozzles) was operated as per the SOP developed by ANGRAU at a flying speed of 4.5 m/s and a height of 1.5 m above the crop canopy, with a spray swath of 4 m, spray width of 2.8 m and a payload capacity of 12 L.

Plant protection applications were imposed at seedling stage (15-25 DAP) and tasselling stage (47-50 DAP) of maize crop (Fig. 1). The commercial formulations of insecticide (chlorantraniliprole 18.5 % SC @ 0.5 ml/l) and fungicide (azoxystrobin 18.2% + difenoconazole 11.4 % SC @1 ml/L) were pre mixed in a known quantity of water in separate vessel. The spray volume used for knapsack sprayer and drone were 500 l/ ha and 25 l/ha respectively. Before each treatment, the pesticide tank was completely cleaned to eliminate any potential incompatibilities that could have been brought over by leftover spray fluid of insecticides. The solution was well mixed before being transferred to the drone's pesticide tank, where it was blended with the remaining water to make up the required spray volume. The wind speed and temperature were recorded with digital anemometer before spraying and confirmed to be below 3 m/s and 35°C. The drone spraying of pesticides (chlorantraniliprole18.5 % SC @ 0.5 ml/l + azoxystrobin 18.2 % + difenoconazole 11.4 % SC @ 1 ml/l) was compared with conventional sprayer. Phyto toxicity studies were conducted with the test pesticides both at the recommended dose and the double the recommended dose using Knapsack and Drone sprays and the symptoms such as chlorotic leaf margins and laminae, reddish or purplish veins, wrinkled leaves, stunted growth, necrosis (death of leaf tissue), wilting and whiplashing were recorded at 1, 3, 5 and 7 days after spray.

Fig. 1. UAV, ANGRAU- PUSHPAK- 03 drone spraying on maize

Distribution of droplets on water sensitive spray cards: After spraying, water sensitive papers were collected and placed in marked envelops one by one according to treatments. Distribution analysis was performed using the 'Drop leaf' mobile app developed by Brandoli et al. (2020) by uploading images of water-sensitive papers collected from the field after spraying. The data on number of drops, mean diameter of droplet (μm), coverage area per cent, density (drops cm^{-2}), Dv 0.1 (μm), Dv 0.5 (μm) and Dv 0.9 (μm) were analyzed and tabulated.

Statistical analysis: The data were subjected to suitable transformation and analyzed using SPSS statistical package version 20 and treatment means were compared using Duncan's Multiple Range Test (DMRT) at 5% significance (P=0.05).

RESULTS AND DISCUSSION

Compatibility and phytotoxicity: The insecticide –fungicide mixture showed physical compatibility with no sedimentation, foaming, or precipitation even after 60 minutes, indicating safe spray ability without nozzle clogging. Reshma et al. (2024) also reported compatibility between chlorantraniliprole and azoxystrobin + difenoconazole, and Visalakshmi et al. (2016) observed several insecticides (chlorantraniliprole, chlorpyriphos, cartap hydrochloride, flubendiamide, profenophos) compatible with trifloxystrobin + tebuconazole and propiconazole. Compatibility among various insecticides, fungicides, and 19:19:19 N:P:K fertilizer was also documented by Anil et al.,. (2024), while Sandhya et al. (2021) confirmed similar results for lambda-cyhalothrin + chlorantraniliprole, azadirachtin, and azoxystrobin + difenoconazole or carbendazim + mancozeb. Additional jar-test studies by Matcha (2021) and Ragiman et al. (2023) further support these findings.

Phytotoxicity evaluated at double the recommended dose on maize revealed no symptoms for chlorantraniliprole + azoxystrobin + difenoconazole under both sprayers. Kandpal and Srivastava (2023) also reported non-phytotoxic and compatible mixtures involving lambda-cyhalothrin + chlorantraniliprole, flubendiamide, azadirachtin, and azoxystrobin + difenoconazole. Similarly, Ogura et al. (2023) observed no phytotoxicity with fipronil and 2,4-D.

Droplet distribution: Data on mean droplet size, droplet density, coverage area, number of drops and mean diameter were obtained from water-sensitive spray cards using the Dropleaf app. Droplet size (VMD, Dv0.5) was higher under drone spraying (829.52, 721.25, 644.56 µm) than knapsack spraying (678.15, 560.69, 345.23 µm) at the upper, middle and lower maize canopy, respectively, indicating reduced drift due to larger droplets. Droplet density decreased down the canopy, but drone spraying recorded higher droplets/cm² 82.28 (upper), 44.99 (middle) and 24.76 (lower) compared to knapsack spraying (20.23, 15.56 and 7.14 droplets/cm²), with a smaller CV, reflecting better uniformity and canopy penetration.

For drone spraying, Dv0.1 and Dv0.9 were 216.64 and 647.19 µm (upper), 232.67 and 491.18 µm (middle), and 187.87 and 569.95 µm (lower). For knapsack spraying, they were higher at the upper layer (150.22 and 789.32 µm) compared to middle (123.54 and 879.32 µm) and bottom layers (145.68 and 879.66 µm). Coverage area was highest in the upper knapsack layer (98.55%), comparable with the upper drone layer (96.65%), followed by middle knapsack (96.56%) and lower drone layers (90.49% and 90.29%). Mean droplet diameter in drone spraying was 1156.77, 813.60 and 501.74 µm (upper, middle, lower), whereas in knapsack spraying it was 1726.56, 1581.30 and 779.87 µm (Table 1, Fig. 2). These results agree with earlier UAV studies. Chen et al. (2020) reported highest droplet deposition in upper cotton canopy layers. Zhang et al. (2022) recorded uniform droplet density of 54.61/cm² in sugarcane; and Dengeru et al. (2022) observed similar patterns in red gram.**Management of fall armyworm:** Drone spraying of pesticide combinations performed better than knapsack application. After the first spray, drone plots recorded 3.44 larvae/10 plants and 40.29% leaf damage, compared to 3.43 larvae and 43.34% in knapsack spraying. After the second spray, drone spraying again showed lower larval counts and leaf damage (0.75 larvae; 37.25%) than knapsack (0.92 larvae; 49.43%). Across 3, 5, 7 and 10 days after both sprays, the most effective treatment was drone spraying of chlorantraniliprole + azoxystrobin + difenoconazole, with the lowest mean larval count (2.10/10 plants), highest larval reduction over control (84.59%), lowest mean leaf damage (37.01%), highest reduction in leaf damage (52.84%) and

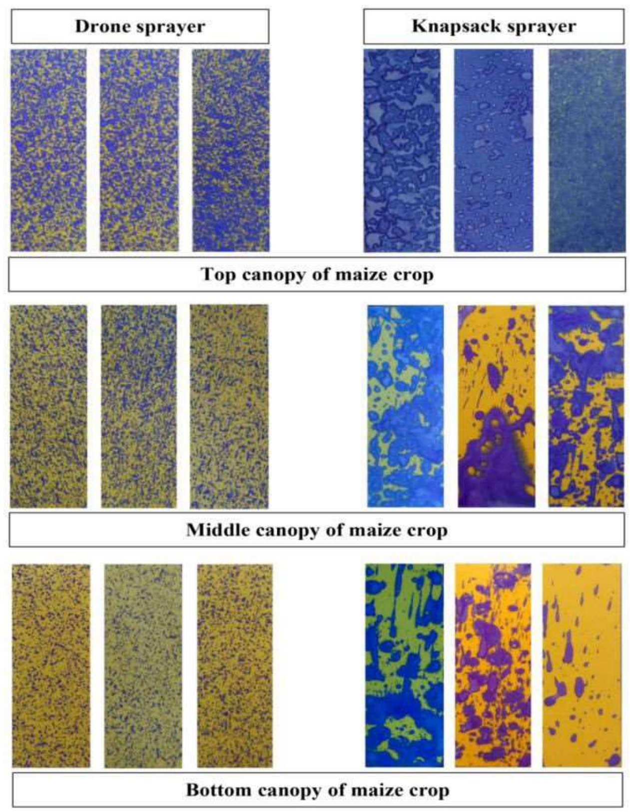

Fig. 2. Droplet deposition of pesticide on water spraying cards on top, middle and bottom canopy in maize

Table 1. Characteristics of droplet deposition, droplet density using drone spraying of pesticides on maize leaves

WSP position (Canopy of maize crop)	Droplet size			Droplet density (drops/ cm^2)	Coverage area (%)	Mean diameter (µm)
	Dv0.1 (µm)	Dv0.5 (VMD) (µm)	Dv0.9 (µm)			
Upper (Drone spray)	216.64	829.52	647.19	82.28 ^{a}	96.65 ^{a}	1156.77
Middle (Drone spray)	232.67	721.25	491.18	44.99 ^{b}	96.27 ^{a}	813.60
Bottom (Drone spray)	187.87	644.56	569.95	24.76 ^{c}	90.49 ^{b}	501.74
Upper (Knapsack spray)	150.22	678.15	789.32	20.23 ^{d}	98.55 ^{a}	1726.56
Middle (Knapsack spray)	123.54	560.69	879.54	15.65 ^{e}	96.56 ^{a}	1581.30
Bottom (Knapsack spray)	145.68	345.23	879.66	7.14 e	90.29 ^{b}	779.87

Values followed by the same letter in each column are not significantly different as per DMRT (P=0.05)
Dv0.5 - VMD (Volume Median Diameter) , Dv0.1 - 10 % droplets in volume spray which is smaller than VMD Dv0.9 - 90 % droplets in volume spray which is smaller than VMD

lowest Davis score (2.75). Knapsack spraying of the same combination was slightly inferior, recording 2.18 larvae (84.01% reduction), 39.59% leaf damage (48.39% reduction) and Davis score 2.75.

Management of BLSB: The incidence of BLSB was very much negligible in the treated maize plots (both drone spray and knapsack spray) with insecticide + fungicide combinations which were initiated at 20 days after sowing along with the incidence of FAW on maize. These prophylactic combination sprays might have reduced the BLSB incidence in treated plots whereas 1.13 to 2.13 % incidence of BLSB was recorded in the untreated control (Table 2).

Yield and economics: Drone applications of pesticide combinations resulted in higher yields than corresponding knapsack sprays. The highest yield was recorded with drone spraying of chlorantraniliprole + azoxystrobin + difenoconazole (46.86 q/ha), followed by the same combination applied with a knapsack sprayer (40.55 q/ha). Drone spraying also produced the highest additional yield over the untreated control (₹52,488/ha) compared to knapsack spraying (₹36,450/ha), with superior cost–benefit ratios of 1:2.41 and 1:1.89, respectively (Table 3). Overall, drone spraying of both insecticide + fungicide combinations outperformed knapsack application. These findings agree with earlier UAV studies. Sambaiah et al. (2022) reported better control of rice leaf folder using the "ANGRAU-Pushpak-01" UAV at 100% dose compared to backpack sprayers. Wei et al. (2020) observed improved management of aphids and FAW with UAVs. Conventional sprayers struggle due to maize canopy structure, FAW habitat, crop height and large area demands. UAV downwash improves spray penetration (Zhan et al., 2022, Wongsuk et al., 2024). UAVs also save time 25 L/ha can be sprayed in 12-13 min versus 3-4 hours with a knapsack sprayer (Sambaiah et al., 2022). Increased efficiency in time, labour and spray intensity

Table 2. Cumulative efficacy of different insecticide and fungicide combinations delivered through drone and knapsack sprayer against FAW, *S. frugiperda* and BLSB, *R. solani* in maize during *rabi,* 2023-24

Treatments	Method of spray & Spray volume	Mean No. of larvae/ 10 plants					Leaf damage (%)					Davis scale of leaf damage	BLSB disease severity (%)
		PTC	After first spray	After second spray	Mean	ROC (%)	PTC	After first spray	After second spray	Mean	ROC (%)		
Chlorantraniliprole @ 12.5 ml/ ha + Azoxystrobin + Difenoconazole @ 25 ml/ ha	Drone spray @ 25 l/ ha	12.07a	3.44[a]	0.75a	2.10a	84.59a	51.23a	40.29a	37.25ba	37.01ba	52.84ba	2.65	0.00
Chlorantraniliprole @ 250 ml/ l + Azoxystrobin + Difenoconazole @ 500 ml/ l	Knapsack sprayer @ 500 l/ ha	13.30a	3.43[b]	0.92b	2.18b	84.01b	54.52a	43.34b	49.43b	39.59b	48.39b	2.75	0.00
Untreated control	-	13.04a	13.59 [c]	13.61c	13.60c	-	79.82a	80.10c	82.24c	79.98c	-	7.10	1.33

*Means with in a column followed by the same letter do not differ significantly as per DMRT (P=0.05) PTC= Pre-Treatment Count; % ROC = Per cent Reduction Over Control; Davis scale of leaf damage: 1 - 9 scale

Table 3. Cost economics for the evaluation of insecticide + fungicide combinations delivered through drone and knapsack sprayer on maize

Treatments	Dose	Method of spray and spray volume	Grain yield (q/ ha)	Increase in yield over control (q/ ha)	Value of additional yield over control (Rs/ ha)	Avoidable yield loss (%)	Total cost of cultivation (Rs/ ha)	Gross returns (Rs/ ha)	Net profit (Rs/ ha)	C : B Ratio
Chlorantraniliprole @ 12.5 ml/ ha + Azoxystrobin + Difenoconazole @ 25 ml/ ha	0.5 ml /l+ 1 ml/l	Drone spray @ 25 l/ ha	46.86 [a]	26.56 [a]	47808	60.97 [a]	38810	84348	45538	1: 2.24
Chlorantraniliprole @ 250 ml/l + Azoxystrobin + Difenoconazole @ 500 ml/l	0.5 ml/l + 1 ml/l	Knapsack sprayer @ 500 l/ ha	40.55 [b]	20.25 [b]	36450	54.89 [b]	38710	72990	34280	1: 1.89
Untreated control	-		18.3 [c]	-	0.00	-	25000	32940	-	-

Means with in a column followed by the same letter do not differ significantly as per DMRT (P=0.05) has been reported by Shanmugam et al. (2024) and Shaw & Vimalkumar (2020), with UAVs effectively reaching maize whorls to control FAW larvae.

UAV-based spraying enhances droplet penetration and deposition in maize whorls through uniform aerial application and downward airflow, resulting in higher yield. Unlike conventional sprayers, it minimizes drift and ensures better coverage of the concealed whorl region where pests like fall armyworm reside.

CONCLUSION

The study demonstrated that drone spraying of insecticide + fungicide combinations, particularly chlorantraniliprole with azoxystrobin + difenoconazole was physically compatible, non-phytotoxic and provided superior control of FAW and BLSB in maize compared to conventional knapsack spraying. Drone application of pesticides ensured better droplet distribution, higher deposition, reduced pest incidence and increased maize yield and economic returns, highlighting UAVs as an efficient, time-saving, and effective precision tool for pesticide delivery and pest and disease management in maize.

AUTHOR'S CONTRIBUTION

The author Reshma, carried out the execution of all experiments, collected and organized the data, performed analyses and compiled the overall findings of the research. Coauthor Rajasri Mandali contributed to the conceptualization of the study and provided theoretical and academic inputs. J. Manjunath and P. Maheswara Reddy provided extensive support in drone operations and all related technical aspects throughout the study. Additionally, M. K. Jyosthna contributed significantly by assisting with the disease assessment studies, ensuring accurate observations and data collection.

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Genetic Variability of Tobacco Caterpillar *Spodoptera litura* (F.) Infesting Groundnut

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***Abstract*:** The genetic variability of *Spodoptera litura* populations in Andhra Pradesh was assessed during 2017–18 at RARS, Lam with populations collected from Guntur, Prakasam, Krishna, Vizianagaram, and Chittoor districts. DNA extracted from larvae using the HiMedia DNA kit was amplified with RAPD markers. Of the 12 primers tested, four primers (OPA-3, OPA-4, OPC-5, and OPC-9) successfully amplified all populations. Total of 33 bands were generated, showing 65.9% polymorphism. Jaccard similarity coefficients ranged from 0.61–1.00. The lowest similarity was observed between the Guntur and Vizianagaram populations and between Chittoor and Vizianagaram populations. The highest similarity was between Prakasam and Vizianagaram, and between Krishna and Chittoor populations.

***Keywords*:** *Spodoptera litura,* Genetic variability*,* Polymorphism, Jaccard similarity coefficients

Tobacco caterpillar, *Spodoptera litura* Fabricus (Lepidoptera: Noctuidae) has become an economic important pest of tobacco, cotton, rice, maize, soybean and groundnut over the years. And caused economic crop losses from 25.8 to 100 per cent depending on the stage of the crop and its intensity in the field (Natikar and Balikai 2015). Synthetic pyrethroids were introduced in 1982 for the management of tobacco caterpillar on cotton in Andhra Pradesh in response to rising control failures due to insecticide resistance (Rao et al., 2007). By the late 1980s, the pest had become widely regarded as uncontrollable by farmers and research–extension personnel, Mehrotra (1997) reported that *S . litura* had already developed multiple resistance, particularly to pyrethroids. Subsequent studies further established widespread resistance to several insecticide groups. Armes et al. (1997) documented resistance cypermethrin, fenvalerate, endosulfan, quinalphos, monocrotophos, and methomyl. Kranthi et al. (2002) also reported high resistance levels during 1997–98 to commonly used insecticides such as chlorpyrifos in *S. litura* populations from Warangal, Medak and Amaravathi. More recently, resistance to novel insecticides including abamectin, emamectin benzoate, fipronil, indoxacarb, spinosad, and chlorantraniliprole has been reported in several countries (Ahmad et al., 2008, Shad et al., 2010, Shad et al., 2012, Su et al., 2012, Tong et al., 2013).

Further, the issue involved is whether all *S. litura* populations across Andhra Pradesh exhibit high insecticide resistance or whether resistance is localized remains unclear. Genetic variability among geographically distinct populations often contributes to differences in insecticide resistance potential. Understanding such variability is essential for designing effective surveillance programs and location-specific IPM strategies. Variations in genetic structure and the molecular characterization of a pest population in space and time, the gene flow among sub populations are incredibly accountable for the rate of resistance evolution (Fuentes-Contreras et al., 2004). Therefore, molecular markers have been extensively used to evaluate genetic similarity and estimate gene flow among insect populations. The Random Amplification of Polymorphic DNA (RAPD) method described by Williams et al. (1990) produces PCR products by annealing to homologous target sites randomly distributed the template DNA. Thus, RAPD markers are traditionally used to investigate genetic similarity and population structure as described for many different insect species (Zhang et al., 2005). Using RAPD and later Amplified Fragment Length Polymorphisms (AFLP) protocols, different populations of *Spodoptera frugiperda* (Smith) have been successfully genetically characterized (Martinelli et al., 2006). Considering the importance of *S. litura* as a major polyphagous pest, understanding its genetic diversity across major crop-growing regions is crucial for anticipating resistance evolution and designing location specific sustainable pest management strategies.

MATERIAL AND METHODS

Genetic variability of *Spodoptera litura* in Andhra Pradesh was conducted during 2017-18 at RARS, Lam

DNA extraction: Larvae of *S. litura* were collected from groundnut fields in six different districts of Andhra Pradesh *viz*., Vizianagaram 18.10649, 83.14903, Krishna 16.22853, 81.07406, Guntur 15.90732, 80.50671, Prakasam 15.7891, 79.664762, Kurnool 15.593205, 77.570829 and Chittoor 13.694836, 79.589327 (Fig. 1). The larval population was collected in sterile plastic vials poured with 70 percent ethanol and brought to the Entomology Laboratory, Regional Agricultural Research Station, Lam, and stored at -20 ^{O}C until DNA extraction. The DNA extraction was done using Himedia kit. *S. litura* collected from six districts of Andhra Pradesh were weighed (not more than 30 mg) and grounded using mortar and pestle in liquid nitrogen to a fine powder. The tissue powder was transferred to a clean capped 2.0 ml microcentrifuge tube. The DNA was quantified using a Nanodrop spectrophotometer at 260nm. Twelve random primers (Operon technology) *viz.,* OPA-1, OPA-2, OPA-3, OPA-4, OPA-5, OPA-9, OPA-11, OPA-13, OPA-20, OPC-2, OPC-5, and OPC-9 were screened. Four primers with high polymorphism, *i.e*., OPA-3, OPA-4, OPC-5, and OPC-9 were used for generating polymorphism among the *S. litura* populations. The experiment was repeated thrice, and the results were reproducible.

PCR amplification was performed using random primers in the Eppendorf master cycle. The PCR conditions were optimized in the concentration of template DNA from 50 ng to 100 ng in a reaction volume of 25 µl. A reaction volume of 25 µl and 100 ng of DNA gave a maximum number of reproducible bands and thus was considered ideal and used subsequently in the analysis.

Agarose gel electrophoresis: Amplified products were separated on 1.5 per cent agarose gel stained with ethidium bromide (0.5µg/ml of gel). Agarose gel 1.5 percent (w/v) was prepared by dissolving 1.5 g of agarose in 100 ml of 1x TBE buffer. The gel was allowed to cool for some time, and then two µl of ethidium bromide (10 mg/ml) was added. 3µl of loading dye was added to 25 µl of PCR product and mixed well before loading into wells (Appendix). Electrophoresis was conducted at 100 volts for 2 hours, and the gel was photographed under U.V. light using gel doc system (Alpha Innotech, USA). The PCR Amplification conditions were: initial denaturation at 94^{0}C for 5 minutes, 40 cycles of Denaturation at 94°C for 1 minute, Annealing at 38°C for 1-minute Elongation at 72°C for 2 minutes each and Final elongation at 72°C for 7 minutes.

Similarity coefficient: Jaccard's similarity coefficient was calculated by using the data matrix. The Similarity coefficient (Jaccard, 1908) index was deduced using the following formula.

Similarity coefficient = a/n

Where,

a = Number of matching bands for each pair of comparisons

n = Total number of bands observed in two samples.

$$\text{Percent polymorphism} = \frac{\text{Total no. of polymorphic bands}}{\text{Total no. of bands}} \times 100$$

The similarity coefficients were subjected to the Unweighted Pair-Group Method of Arithmetic averages (UPGMA) cluster analysis for grouping the genotypes based on their overall similarities using NTSYspc-2.02i software (Rohlf 1998)

Statistical analysis: Data entry was done in a binary matrix where all observed bands were listed-assigning character states '1' for those where the bands were reproducible and '0' for those where the bands were absent in the RAPD pattern for each genotype.

RESULTS AND DISCUSSION

RAPD profiling for different populations of *S. litura:* Of the 12 primers evaluated, four primers consistently amplified DNA from all six *S. litura* populations. These primers

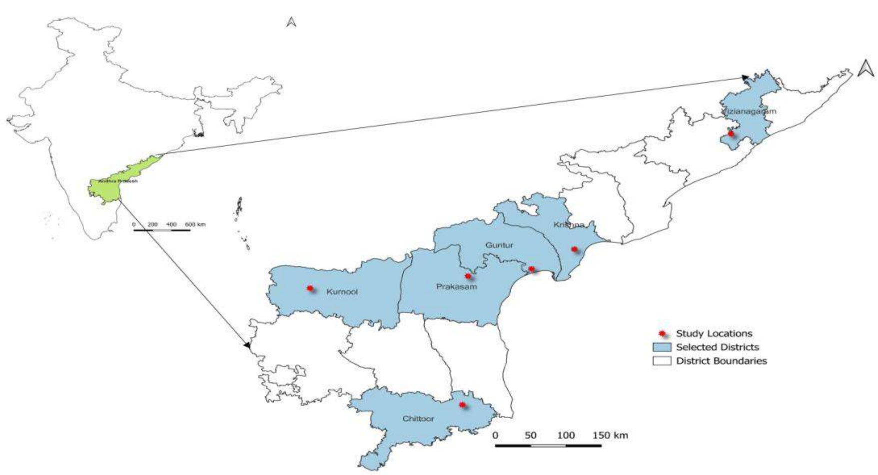

Fig 1. Map showing study area with GPS locations

produced 33 total bands, of which 65.9% were polymorphic (Fig. 2). OPA-3 produced nine bands that were 66.6% polymorphic, and the band size ranged between 250-2000 bp. OPA-4 had given eight polymorphic bands that varied from 300-3000 bp. OPC-5 generated nine polymorphic bands that ranged between 300-3000bp with 77.7% polymorphism. OPC-9 produced seven polymorphic bands of 200-5000 bp band size with 57.1% polymorphism (Table 1).

Jaccard similarity coefficients: The Jaccard similarity coefficients among the six *S. litura* populations varied between 0.61 to 1.00. The lowest similarity of 0.61 was observed between Guntur and Vizianagaram, Chittoor and Vizianagaram populations, while the highest similarity was noticed between the populations of Prakasam and Vizianagaram, Krishna and Chittoor at 0.85 (Table 2).

Dendrogram Analysis for the different populations of *S. litura*: UPGMA cluster analysis grouped the six *S. litura* populations of Andhra Pradesh into two major clusters (Fig. 3). Of the two main clusters, four populations formed one big cluster, and two remained as another small cluster. The Vizianagaram population formed a close cluster with Prakasam, sharing 85% similarity. The second major cluster comprised the Krishna and Chittoor populations, which also

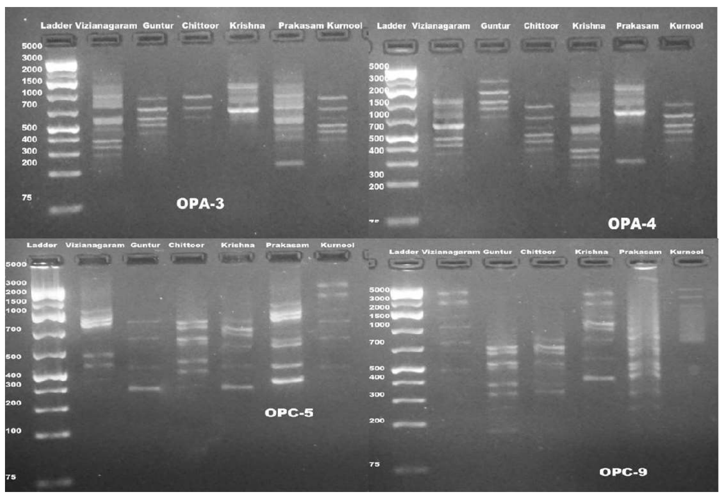

Fig. 2. RAPD profiling for different populations of *S. litura* with OPA-3, OPA-4, OPC-5, and OPC-9 primers

Table 1. Percent polymorphism in *S. litura*

Primer	Sequence	Total no. of bands	Polymorphic bands	Polymorphism (%)	Band size (bp)
OPA-3	5'AGTCAGCCAC3'	9	6	66.6	250-2000
OPA-4	5'AATCGGGCTG3'	8	5	62.5	300-3000
OPC-5	5'GATGACCGCC3'	9	7	77.7	300-3000
OPC-9	5'CTCACCGTCC3'	7	4	57.1	200-5000
Total		33	22	65.9	

Table 2. Jaccard similarity coefficients between different populations of S. *litura*

	Vizianagaram	Guntur	Chitturu	Krishna	Prakasam	Kurnool
Vizianagaram	1					
Guntur	0.61	1				
Chitturu	0.61	0.76	1			
Krishna	0.64	0.79	0.85	1		
Prakasam	0.85	0.64	0.64	0.67	1	
Kurnool	0.69	0.73	0.73	0.76	0.67	1

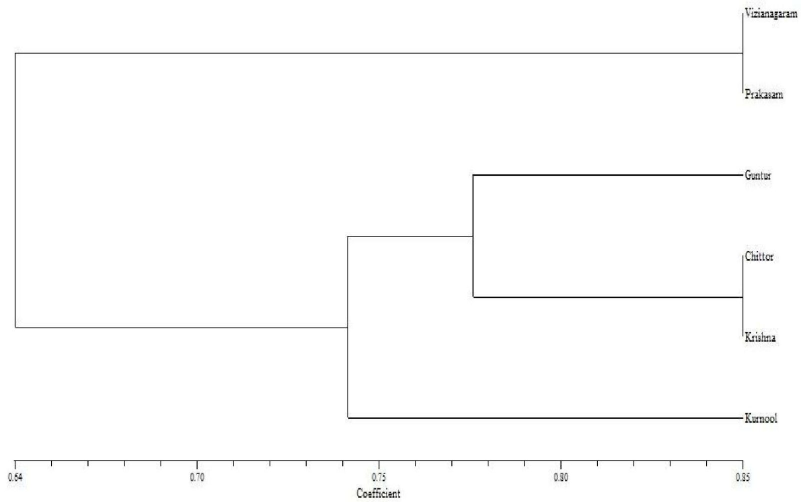

Fig. 3. Dendrogram for different populations of *S. litura*

exhibited 85% similarity and together showed 78% similarity with the Guntur population. Among all populations, Kurnool was the most genetically distinct, displaying 74% dissimilarity from the Guntur–Chittoor–Krishna group.

The present studies are in accordance with Barman (2019) indicating pronounced genetic variability among *S. litura* populations in the Kumaon region, noting that the strain collected from the plains showed only 32 per cent similarity with strains from the mid-hills, valley, and Tarai regions, indicating substantial genetic divergence. Such variability suggests that new biotypes with enhanced insecticide resistance may emerge from this diverse gene pool. Similarly, Gandhi and Patil (2017) reported considerable variation among seven *S. litura* populations from soybean fields, with genetic similarity ranging from 46 to 100 per cent. Hyderabad and Indore populations shared complete similarity, while Pune and Parbhani recorded 90 per cent similarity, populations from Adilabad, Hyderabad, and Indore showed 83 per cent similarity, and Dharwad and Belagavi exhibited 72 per cent similarity. The lowest similarity (46%) was observed between the Dharwad and Parbhani populations, Janarthanan et al. (2002) also assessed genetic variability in six ecotypes of *S. litura* using RAPD markers. Of the 40 random primers screened, only three (OPA-1, OPA-5, and OPM-1) produced clear and distinguishable banding patterns. Their analysis showed that the Chengalpattu and Chennai populations were genetically closer to each other, whereas the Coimbatore population was more distant from the remaining ecotypes. Similarly, Bharathiraja et al. (2013) reported high genetic variability among *S. litura* populations collected from ten locations across Tamil Nadu, with RAPD polymorphism ranging from 90–100%, indicating strong genetic differentiation. Gandhi and Patil (2017) observed high similarity (90%) between Pune and Parbhani *S. litura* populations, while the lowest similarity (46%) was recorded between Dharwad and Parbhani populations. Bharathiraja et al. (2013) demonstrated the highest polymorphism of 90 to 100% in RAPD analysis, confirm the presence of strong genetic polymorphism among geographically distinct *S. litura* populations collected from different castor fields in South India. The observed genetic variability in the present study indicates substantial genetic structuring among *S. litura* populations in Andhra Pradesh. Geographical and chronological factors might have influenced the presence of prevailing diversity among the populations. Such variability can facilitate the emergence of new biotypes with different insecticide resistance potentials, emphasizing the need for region-specific IPM strategies.

CONCLUSION

The substantial genetic variability among *S. litura* populations collected from different agro-ecological regions, reflecting the dynamic nature of this polyphagous pest. UPGMA clustering clearly separated the populations into distinct groups, indicating region-specific genetic structuring and possible adaptation to local host plants and environmental conditions. These results emphasize the need for region-specific management strategies and continuous monitoring of population structure to design effective, sustainable pest management programs.

AUTHOR'S CONTRIBUTION

Conceptualization and experiment design: Dr. GMV Prasada Rao, Trial execution and data collection: Ms. Annie Diana Grace, Data curation, statistical analysis and draft preparation: G. Annie Diana Grace, Dr. GMV Prasada Rao.

Dr. PV Krishnayya, Dr. V. Manoj Kumar. And Dr V. Srinivasa Rao Final draft revision and approval: G. , Annie Diana Dr. GMV Prasada Rao. Dr. PV Krishnayya, Dr. V. Manoj Kumar. And Dr V. Srinivasa Rao. The authors declare no competing interest exists.

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