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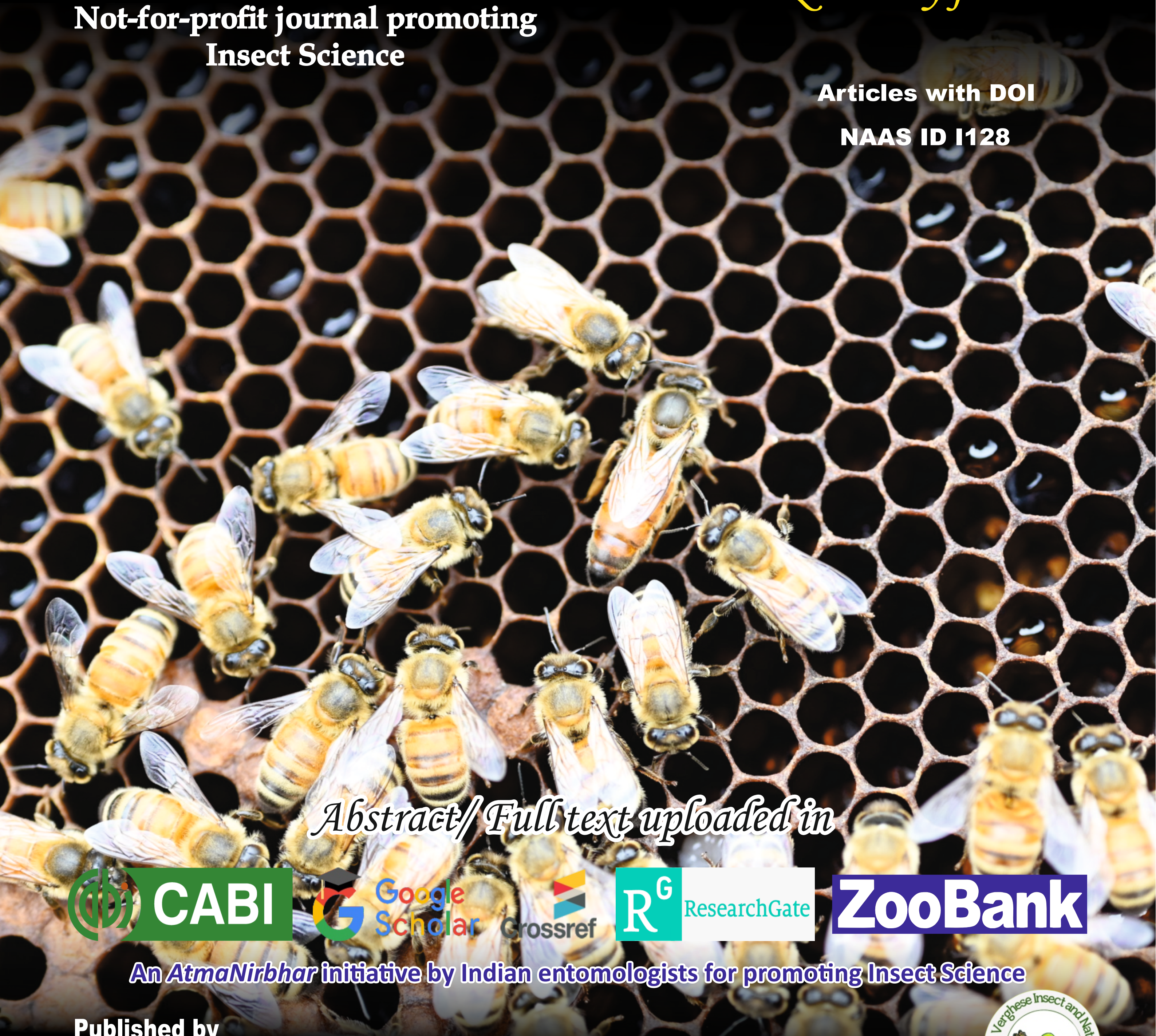
Insect Environment

Quarterly journal

Not-for-profit journal promoting Insect Science



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Cover Page:** ***Apis mellifera **colony**

Photo credit: Dr. M. A. Rashmi

Insect Environment

(Quarterly journal to popularize insect study and conservation)

ISSN 0975-1963

The first issue of Insect Environment was published in 1996. The sole objective of Insect Environment is to popularize insect study through popular, semi-technical and technical research notes, extension notes for managing insect pests, photographs, short blogs and essays on all aspects of insects. The journal is published quarterly, in March, June, September, and December.

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Short popular insect notes, review essays, new records, profiles, tributes, and views are acceptable. There are no page charges; each article should preferably not exceed 500 words. Authors can refer to back volumes available on the website for writing style. Good photographs are encouraged. A special insect photo gallery "Insect Lens" is to encourage professional and amateur photographs on insects. These will be published in the quarterly *Insect Environment.*

The blogs are for quick dissemination of insect "news". These will be uploaded within a week of submission and will be on the website. Blogs should be about hundred words with one photograph, in simple English

This journal is unique in that it encourages articles from students to amateurs to professionals! It is hosted in CABI (as full text) and ZooBank, Indian Abstracts, Research Gate, Google Scholar etc. ensuring global coverage. Scientific articles are assigned DOI.

Mail your papers/notes/queries/photos related to *Insect Environment* to *einsectenvironment@gmail.com*

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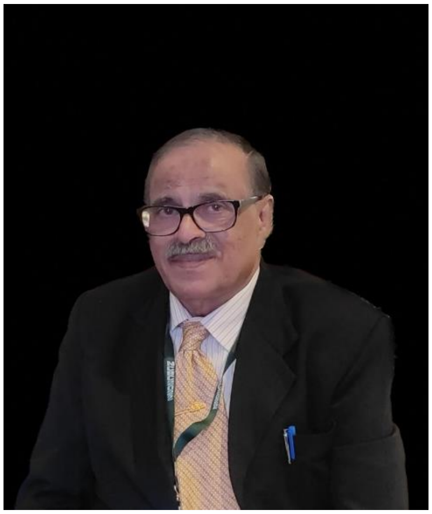
Editorial

Chandrayaan 3

Climate change demand accelerated expeditions

Plant Health Clinic-second anniversary



Surely the eye-catching achievement of the last quarter is Chandryaan-3. The Vikram lander and the Pragyan rover on south pole of the moon, is indeed a proud moment for scientists of Indian Space Research Organization (ISRO) and for the rest of us too, including life scientists! This is an excellent demonstration of integration of sciences and institutions and backed by very supportive government and an enthusiastic Nation. Insect Environment is proud of all our space team.

In our context it was a Drosophilidae fly that was first sent to space by USA on a V-2 rocket on 20 February, 1947. Records are there for ants carried to International Space Stations. In future Entomologist here can certainly plan experiments with insects in collaboration with ISRO.

Maui- one of the Hawaiian Islands was hit by wildfires mainly the beautiful town of Lahaina causing immeasurable damage. I have had the privilege of visiting Maui, three times, and its people are mostly friendly Polynesians with best of modernity, whale-watching, crystal clean beaches and sea, all go to make Maui a great destination (but costly!!). Add to Maui, wildfires in the American continent, crazy floods in China, blasting temperatures in Europe and hottest August this year, makes climate changes seem like a dreadful monster. Then the Moroccan earthquake and Libyan flood make it more of *climate shock* than change! The context again, how does insects survive or perish in these ordeals needs intensive studies. Again, needless to emphasise that insect expeditions and collections need acceleration in disaster sensitive areas, before we lose out on species!

Our plant health clinic, Shree Nidhi Agrochemicals completed two years of service to farmers. Shreenidhi Agro Chemicals Startup under the aegis of Rashvee International Phytosanitary Research and Services, a super state-of-the-art clinic, came into being on 5th September 2021. The highlights are: It is set in the heart of horticulture farms (in Vijayapura, close to Bangalore Airport) catering to > 20,000 farmers in Bangalore Urban/Rural, Devanahalli, Dodaballapura, Chikaballapura, Shidalghatta, Bagepalli, Gudibande, Gauribidanur, Chintamani, Kolar, Hoskote all in Karnataka), Chittoor, Madanapalli (Andhra Pradesh), Krishnagiri, Vellore, (Tamil Nadu) etc. Farmers get the benefit of expert (all postgraduate agriculture- no quacks) discussion, diagnosis and dispensation of all the required inputs under a single window; seed to plant health to marketing services.

In the last two years, we had more than 56,000 farmer visits! Some of our pomegranate, tomato, chrysanthemum and mango growers have become *crorepatis*! In the last two years, we conducted more than 1000 field visits. Our advisory services are free!

Some of our features are:

- Well-connected; farmers reach the clinic in less than one-hour, Daily visits average 80 farmers. Functions from 8am to 8pm all 365 days.
- Our laboratory is well equipped with microscopes, laminar air flow, environment chambers, olfactometer, autoclave etc.,
- We are closely connected with ICAR-IIHR, ICAR-NBAIR and several agricultural universities.
- We are accredited by the Directorate of Plant Protection Quarantine and Storage, as phytosanitary service providers (PSSP) for exporters.
- Rashvee IPRS is recognized by the Department for Promotion of Industry and Internal Trade, Ministry of Commerce & Industry, Government of India and supported by the Biotechnology Industry Research Assistance Council (BIRAC), Department of Biotechnology (DBT).
- A big thanks to our 8000+ loyal farmers.

Insect Environment and its blogs are integral part of this Clinic,

The issue has an array of diverse interesting articles and I leave the reading pleasure to you without a curtain raising suspense!

True to our fellow-feeling, we offer our tributes in the issue, through two obituaries tor Dr. Jim Thomas and Dr. Pawar Vinayak Motiram. We also carry in this issue a special poster on ICAR-National Bureau of Agricultural Insect Resources, on their celebration of the 30th Foundation Day on 19th October 2023. We have two more posters on the announcement of BIPA International Journal of Biological Agriculture and BIOAGRI – 2023 Conference and Expo. Do read, share and respond.

As we move to the last quarter, we request authors to hurry through their articles and photographs. As climate change is buzzing be safe from floods, fire and heat/cold wave….!

Abraham Verghese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Research articles

DOI: 10.55278/ITAM3183

First report of invasive fall armyworm *Spodoptera frugiperda* (J.E. Smith) in the province of Davao del Norte, Philippines and its damage to the corn crop

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Fall armyworm, *Spodoptera frugiperda* (J.E. Smith) also called FAW, is a highly polyphagous insect pest native to the Americas particularly in Florida and Texas (Prasanna *et al.,* 2021). It is regarded as one of the most destructive pests of many economically important cereals such as rice, corn and sorghum. It also feeds on other major crops such as soybean, cotton, and banana. The pest was reported to attack nearly 353 species under 76 families of plants with high preference on grasses (Montezano *et al*., 2018).

Spodoptera frugiperda is a strong flier that can travel approximately 100 km per night. Its invasion outside of its native origin commenced in Africa in 2016 (Georgen *et al*., 2016), and then rapidly dispersed across Sub-Saharan Africa (Early *et al*., 2018). After two years of invasion in Africa, the polyphagous pest entered Asia in 2018 through India (Sharanabasappa *et al*., 2018). In 2019, *S. frugiperda* invaded several countries in Asia such as Indonesia, Vietnam, China, Korea, Taiwan (FAO, 2020), and the Philippines (Navasero *et al*., 2019).

In Philippines, *S. frugiperda* was initially reported in northern Philippines particularly in Piat, Cagayan, Central Luzon by Navasero *et al*. (2019) through the collection of suspected larvae feeding on corn plants. In 2021, after its formal detection in Piat, Cagayan, the pest was reportedly attacking young rice seedlings in Gonzaga, Cagayan (Valdez *et al.,* 2023). Meanwhile, larvae of FAW were collected in 2020 in some areas in Southern Philippines (Mindanao) particularly in the Province of North Cotabato (Agravante *et al*., 2022). This report confirms the presence of *S. frugiperda* in the Province of Davao del Norte, Philippines.

Following the complaints of worm attacks by corn farmers in the Municipality of Carmen, Province of Davao del Norte, Philippines (7.3682° N, 125.6861° E), a field survey was conducted on April 10, 2023. At the time of the field visit, there were two stages of corn in the field *viz*., the seedling stage and the vegetative stage. The site where the survey was conducted was surrounded by banana plants with some farmers' houses within 20-30 m from the corn field.

As a standard protocol, the field observations were made by establishing five inspection points in a "W" pattern within the field. At each established point, ten corn plants were carefully examined in succession. The infestation of FAW was confirmed by the indicators such as; (1) presence of fresh excreta in leaf funnels, (2) white dots on leaves at seedling stage due to scrape feeding by early instar larvae, (3) irregular cuts on leaves at vegetative stage due to the intensive feeding of the late instars, and (4) presence of FAW larvae in the heart of the plants (Day *et al.*, 2019). The severity of the damage was determined by the 1-5 rating scale (Kuate *et al.*, 2019). The degree of infestation was determined as the proportion of infested plants to the total number of plants sampled and expressed as percentage.

There were no *S. frugiperda* eggs collected during the field survey. The larvae were identified using the known morphological characters. The late instar larvae collected were yellowish green to light brown (Figure 1a). The inverted "Y" shape ecdysial line was positive on the light to dark brown colored head (Figure 1b). The presence of four black spots (pinacula) on the first 7 terga, arranged in a trapezoidal form in every segment, was consistently observed in all collected specimens (Figure 1c). The distinct clear dark spots arranged in a square form on the 8th segment of the body were also observed (Figure 1d).

Damage symptoms due to the larval feeding were highly apparent in the field regardless of plant stages. Irregular white marks, scrapped surfaces, and small pin holes were observed on the leaves of corn at seedling stage (13 days after sowing) because of the feeding activity by the early instars of *S. frugiperda* (Figure 1e-g). Damage to whorls in this stage was not too severe with a rating of 2.9±0.32 (Table 1). The feeding activity of the late larval instars was clear in corn at the vegetative stage and can be observed as medium to large irregular shaped holes and window panes on the fully expanded corn leaves (Figure 1h and 2i). Whorls were severely damaged with a rating of 3.8±0.63 (Table 1). Medium-sized borings on the side of the developing leaves as signs of larval entry (Figure 1j) were almost consistent on damaged plants. Damage in the stalks and stems were rarely observed. The feeding activity of the late larval instars was further confirmed by the presence of fresh yellowish green to brown excreta in the whorls or around the feeding location. Percentage infestation was recorded to be at 40±22.28 and 66±11.40 percent at seedling and vegetative stage, respectively (Table 1). The feeding damage on corn plants was highly attributed to *S. frugiperda* activities because there were no other species of armyworms found with different morphology that co-infest in the field.

Spodoptera frugiperda is a highly and well-known polyphagous insect pest originally from western hemisphere but now becoming invasive in the eastern hemisphere (Prasanna *et al*., 2021). This polyphagous pest is confirmed through a survey in the Municipality of Carmen, Davao del Norte, Philippines. All the distinguishing morphological characters of *S. frugiperda* were invariably observed in all collected samples. These characteristics were consistent with that of *S. frugiperda* observed in the province of Cagayan, Central Luzon, Philippines reported by Navasero *et al*. (2019). Molecular analysis shows that this pest involves two sympatric and morphologically indistinguishable 'C-strain' and 'R-strain' (Nagoshi *et al.*, 2021). These strains were reported to differ in terms of mating, host preference and response to insecticides including the Bt toxins. Although the strain of *S. frugiperda* found in corn fields of Cagayan, Philippines reportedly belonged to the 'R-strain' (Caoili *et al*., 2019 as cited by Navasero and Navasero, 2020), a recent report by Valdez et al. (2023) showed that both the 'R-strain' and 'C-strain' of *S. frugiperda* almost had an equal proportion among the collected samples in rice seedlings. Therefore, it is imperative to confirm the populations present in the other parts of the country including in Southern Philippines where this survey was conducted. This would further explain its behavioral patterns, host preferences, and potential adaptation to different environmental conditions.

Damage of *S. frugiperda* larvae in the current survey was more apparently severe at the vegetative stage than in the seedling stage of the corn. Damage rating scores at the seedling stage were lower than the vegetative stage. Damage was visible in the fully expanded leaves and in whorls. Entry holes were also noted in the field which was the result of an intensive feeding by the late larval instars. The fresh excreta of the late larval instars were visible and could be seen as sawdust-like structures on the upper portion of the leaves. The percent infestation recorded in the present survey is relatively higher than what Navasero *et al*. (2019) found in the Province of Cagayan which recorded 30% infestation in corn. This variation could be attributed to differences in corn varieties planted wherein almost 90% of corn grown in Northern Philippines were Bt corn. To really determine the extent of the problem and damage caused by the pest in the Philippines, comprehensive monitoring and systematic surveillance of *S. frugiperda* infestation should be carried out. This would lead to early detection, intervention, and would avoid further *S. frugiperda* outbreaks in the country.

From its first detection in Africa in 2016, it only took three years before it successfully invaded the Philippines in 2019. The strong migratory ability of *S. frugiperda* was believed to be a big factor in its rapid dispersion in the invaded countries. International trade of agricultural products from contaminated countries was also one of the possible means of *S. frugiperda* spread from west to east (Wang *et al*., 2020). Its pattern of invasion in the Philippines however is still largely unknown until this date. Even the relationships between the Northern Philippines (Luzon) and Southern Philippines (Mindanao) *S. frugiperda* populations also remain in question. Moreover, no information details whether these populations entered the Philippines via a single genetically related invasion or whether they were driven by multiple independent introductions. Rane *et al.* (2023) recently found using molecular evidence that *S. frugiperda* invasion in Asia is driven by complex, multiple, and independent introductions. With this, it is likely that there are two or more genetically unrelated *S. frugiperda* invasions that may have occurred in the Philippines. The population of *S. frugiperda* in Northern Philippines (Navasero *et al*., 2019) might be sourced from Taiwan and China by the help of the northeast monsoon winds within the months of November to March. Meanwhile, the population detected in the Southern Philippines (Agravante *et al.*, 2022 and this report) probably came from Indonesia and Malaysia aided by the southwest monsoon winds during July to September every year. To confirm this presumption, molecular-assisted studies should be further intensified in order to address information gaps as to the invasion history, demography and genetic relationships of *S. frugiperda* in the Philippines.

The invasion of *S. frugiperda* in the Philippines definitely threatens the food security of the country. The impact of this invasive pest in the Philippines are limited currently to corn, and in some extent, to rice. However, it is important to take into consideration the polyphagous nature of *S. frugiperda* and its capacity for rapid migration. Other economically important host plants such as sorghum, soybean, cotton and sugarcane are now facing a considerable risk from this pest. It is expected that both the small-and large-scale farmers in the country will be affected by *S. frugiperda* in the coming years. Common strategy used by farmers to control pests on their farms even before was to utilize chemical insecticides. But literature from the invaded countries suggests that careful usage of chemical pesticides should be strictly observed in managing *S. frugiperda.* This is because the pest can immediately develop insecticide resistance even to the Bt toxin incorporated in transgenic crops such as the Bt corn (Huang, 2021). It is therefore imperative that integrated actions should immediately be taken to mitigate the impacts of this pest to the agricultural sector of the Philippines.

Table 1. Percentage infestation and damage severity of *S. frugiperda* on the surveyed corn field in the Municipality of Carmen, Davao del Norte, Philippines.

Crop Stage	Degree of Damage	% Infestation
Seedling	2.9 ± 0.32	40 ± 12.27
Vegetative	3.8 ± 0.63	66 ± 11.40

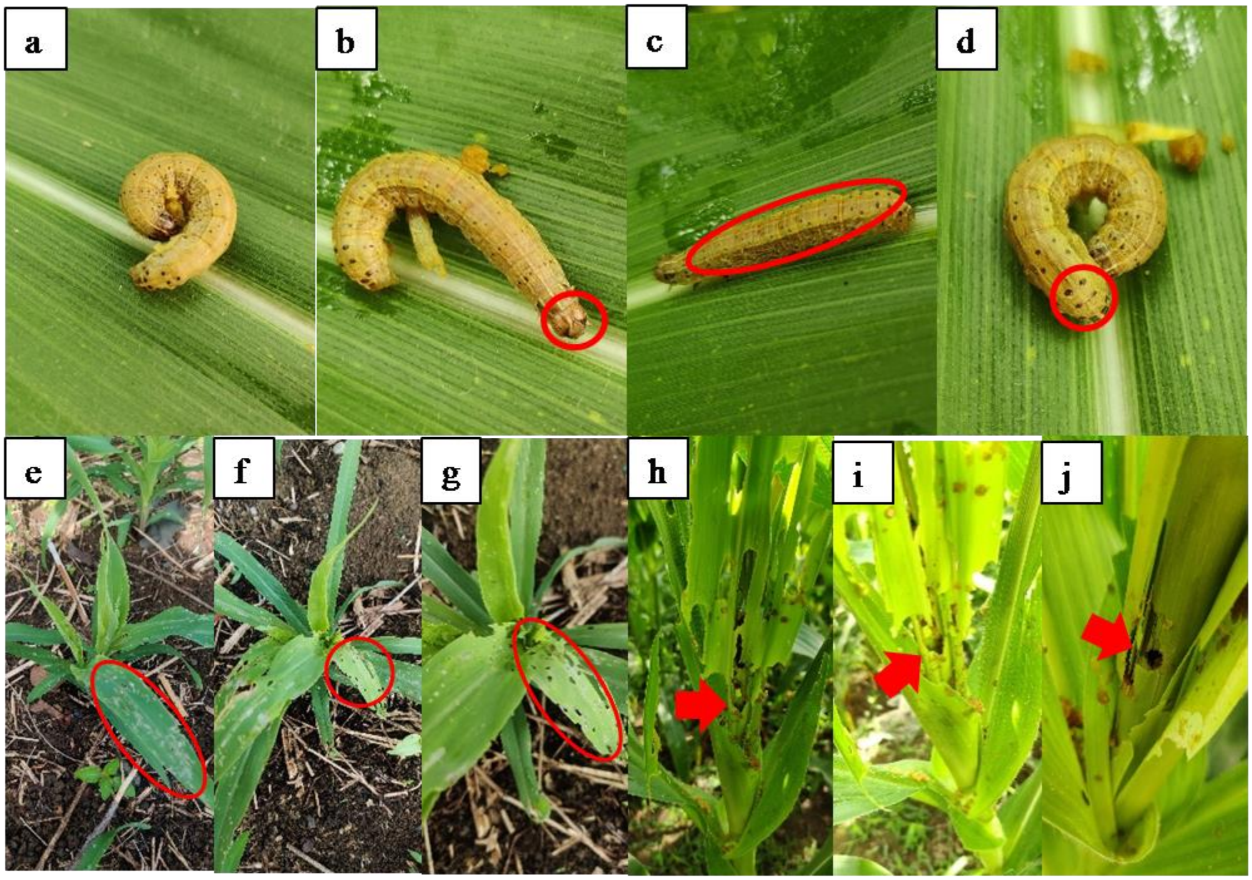

Fig. 1 Distinguishing morphological characteristics of *S. frugiperda* larvae and its characteristic damage to corn in the surveyed corn field.

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Emergence behavior of an uncommon Pentatomid, *Codophila maculicollis* on thistle (*Echinops* sp.)

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Recent times have witnessed emergence behaviour in several species of Pentatomidae. *Udonga montana* (Distant) swarming on forest plants in Shivamogga district (Sharanabasappa *et al.*, 2018) and *Catacanthus incarnatus* (Drury) on *Pavetta indica* L. (Salini, 2006) are two such examples. The emergence behaviour of these species usually depends on the availability of host plants in concurrence with suitable climatic conditions. Sometimes, quite a few rare bugs mass multiply on their specific host plants, which also becomes an opportunity to collect them in large numbers for taxonomic research, diversity, and documentation studies. Examples are *Phricodus hystrix* (Germar) on *Ocimum* spp. (Salini *et al.,* 2021); *Brchycerocoris petrii* Salini and Roca-Cusachs on *Vitex trifolia* L. (Salini & Roca-Cusachs, 2021).

During a survey conducted in Kailasagiri area of Chintamani, (13° 24' 6.52" N78° 03' 16.13" E) Karnataka, it led to the finding of an uncommon Pentatomid bug, *Codophila maculicollis* (Dallas, 1851) in large numbers, on a wild plant, thistle (*Echinops* sp.). This species was recorded for the first time from Karnataka by Salini and Viraktamath, 2015. Carapezza (1997) reported this species on *Echinops spinosus* L. from northern India. *C. maculicollis* is a dazzling, medium sized species belonging to Carpocorini of Pentatomidae and is the sole representative of the genus *Codophila* Mulsant & Rey from India.The adult bugs (Fig. 2 a) are black dorsally with pale white or ochraceous longitudinal stripes particularly on head, pronotum and scutellum. Antennae, legs and labium are black. Ventral side (Fig. 2 b) is pale white with small, round and sparse black spots usually arranged as equidistant to each other in five longitudinal rows.

Both adults and nymphs were found feeding on the host plant, *Echinops* sp. (Asterales: Asteraceae) (Fig. 1). They were collected and killed using ethyl acetate, pinned, preserved and deposited in the National Insect Museum (NIM) collections of ICAR-NBAIR, Bangalore. Images of the adult bugs feeding on *Echinops* sp. were captured using DSLR camera, Canon EOS 77D with macro lens 100 mm. The images of habitus and dissected genitalia parts were captured using DFC 420 camera mounted on Leica M205A Stereomicroscope. Adult male and female were dissected under Leica S8 APO sterozoom microscope.

Adults are 13.5 to 16.0 mm long, head subtriangular with apex rounded, slightly shorter than width of head including compound eyes. Mandibular plates straight and as long as clypeus. Antennae five segmented with segment I not exceeding apex of head. Pronotum with humeri rounded. Scutellum is subtraingular, slightly longer than breadth between basal angles and the apex is rounded. Connexivum is ampliate and well exposed. Thoracic sternites are provided with narrow, median longitudinal carina. External scent efferent system (Fig. 2c) with peritreme is modified into short, peritremal spout. Labium reaching posterior margin of second visible abdominal sternite. Abdominal sternites are smooth with basal abdominal sternite devoid of a spine or tubercle.

Male genitalia with genital capsule (Fig. 2 d-f; Fig. 3 a) nearly subquadrate, dorsal rim (dr) of genital capsule widely and shallowly concave between caudal lobes where as ventral rim (vr) medially deeply concave and infolding of ventral rim with narrow, median U-notch. Ventral rim laterally with one tuft of hairs (ts) near to each caudal lobes (cl). one short tooth is present inner to each caudal lobes. Paramere (Fig. 3 d, e) with well developed crown (cr), which is concave or scooped out ventromedially. Phallus with phallotheca (pt) moderately sclerotized and nearly subtraingular in shape. A pair of conjunctival process (cp), broad and wings-like in inflated form, apically slightly sclerotized and notched at apex (Fig. 3 b, c). Aedeagus sclerotized, tubular, partially coiled basally and apically goose-neck like.

Female genitalia with terminalia (Fig. 3 f) and spermatheca. Valvifers viii (vlf viii) of terminalia are roughly subtriangular; valvifers ix (vlf ix) narrow, transverse, roughly quadrangular plate; laterotergite ix (lt ix) finger-like and laterotergite viii (lt viii) is roughly triangulate with smooth caudal margin. Spermathecal pump with proximal flange well developed and distal flange merged with apical receptacle. The apical receptacle (ar) (Fig. 3 g) is orbicular without ductules.

C. maculicollis, a Pentatomid species, depict the behaviour of mass multiplication on specific host plants, which is by now known in several species of Petatomidae. Though any host switching mechanism has not been noticed so far, this documentation helps to know the multiplication behavior of this species.

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Fig. 1. Adults and nymphs of *Codophila maculicollis* congregating on Thistle (*Echinops* sp.)

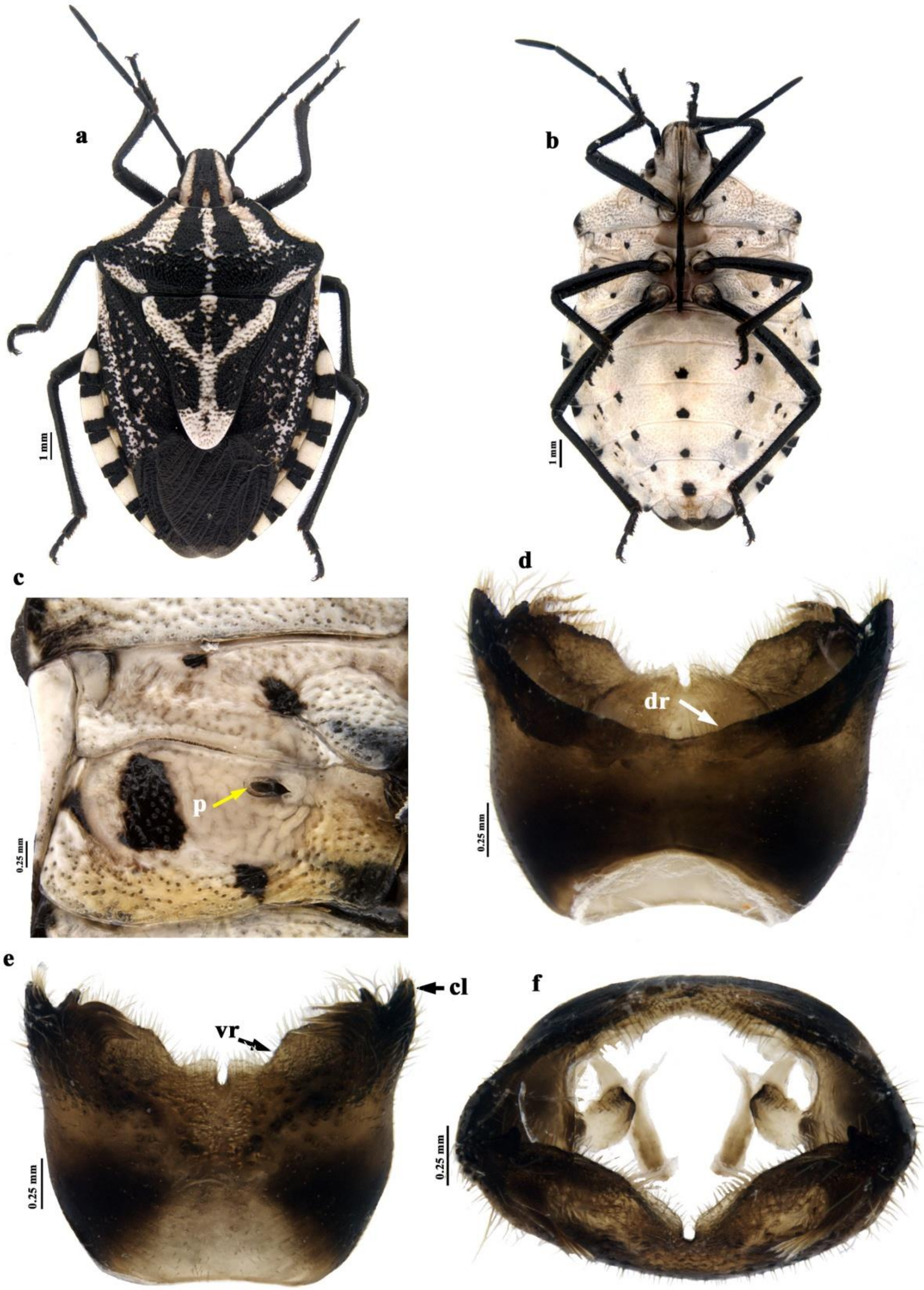

Fig. 2. Habitus, extrnal scent efferent system and male genitalia of *Codophila maculicollis.* a, habitus (dorsal); b, habitus (ventral); c, external scent efferent system; d, genital capsule (dorsal); e, genital capsule (ventral); f, genital capsule (caudal). Abbreviations: cl- caudal lobes; dr- dorsal rim of genital capsule; p-peritreme; vr-ventral rim of genital capsule

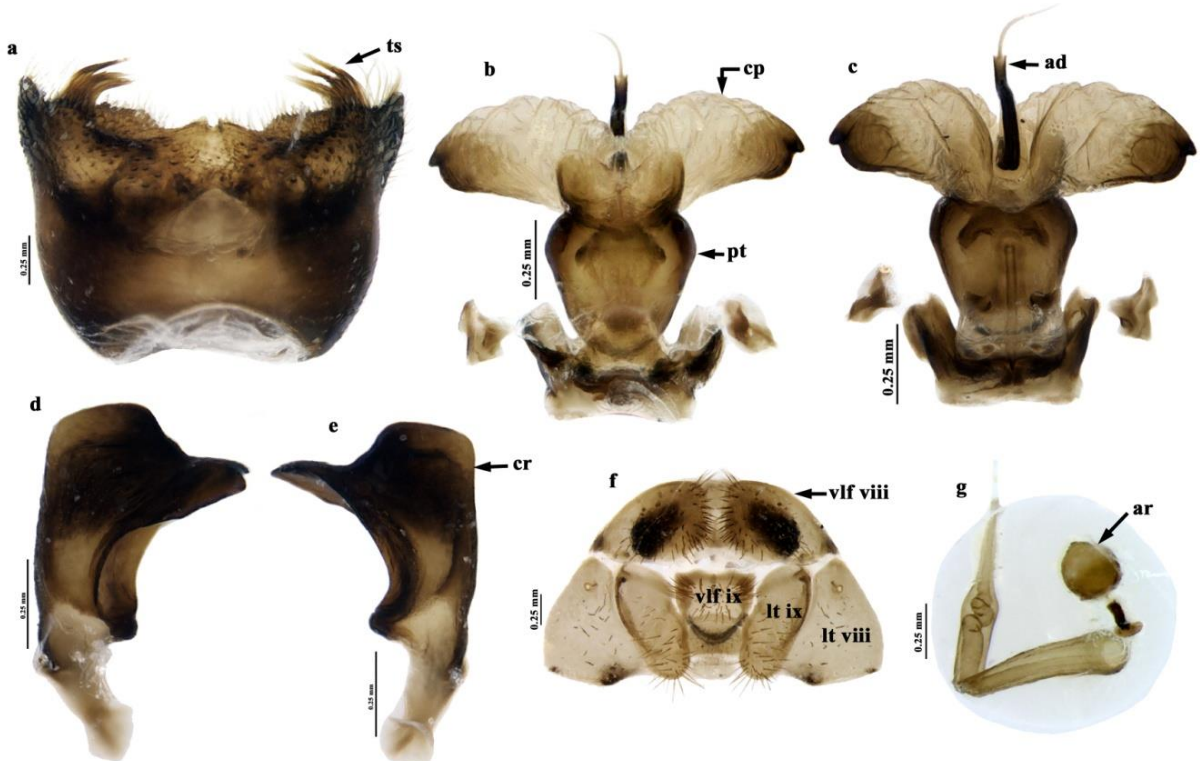

Fig. 3. Male and female genitalia of *Codophila maculicollis*. a, genital capsule (ventral-tilted view); b, phallus (dorsal); c, phallus (ventral); d and e, parameres (different views); f, terminalia; g, spermatheca. Abbreviations: ad- aedeagus; ar- apical receptacle; cp-conjunctival process; cr- crown; lt viii- laterotergite viii; lt ix- laterotergite ix; pt- phallotheca; ts- tuft of setae; vlf viii- valvifers viii; vlf ix- valvifers ix

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Some interesting records on invasive fall armyworm, *Spodoptera frugiperda* (J.E. smith) (Lepidopetera: Noctuiidae) on rice (*Oryza sativa*) from Kerala

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Abstract

Alien invasive pest, fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) was introduced into India in 2018 and had turned out to be a serious pest to agriculture due to its polyphagous nature. Currently in Kerala FAW populations were found feeding primarily on maize crop in addition to banana. In this communication, we are providing some details on FAW larvae feeding/infestation in rice in the state of Kerala. Besides, a brief note on the nature of damage caused by this pest is also given.

Key words: Fall armyworm, *Spodoptera frugiperda*, invasive pest, rice, Kerala

Introduction

The fall armyworm *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), a notorious noctuid invasive pest of maize and more than 350 host plants (Montezano *et al.*, 2018) was recorded from India severely damaging maize crop during 2018 from Karnataka state, South India (Ganiger *et al.*,2018, Sharanabasappa *et al.*, 2018). FAW is native to the tropical region of the western hemisphere from the United States to Argentina and is also reported as the most important pest of corn in Brazil causing annual economic losses of millions of dollars in crop losses (Shylesha *et al.*,2018 ; Ganiger *et al.*, 2018). After its introduction to India during May, 2018, the pest has rapidly spread to more than 90% of maize-growing areas of diverse agro-ecologies of the country within a span of 16 months and is threatening cereal cultivation in India (Suby *et al*., 2020).

FAW has been reported from peninsular Indian states of Karnataka, Tamil Nadu, Andhra Pradesh and Telengana as a pest that prefers crops belonging to Poaceae family and other field crops like cowpea, groundnut, potato, soybean and cotton (Venkateswarlu *et al.*, 2018). The conspicuous absence of reports on this pest from Kerala lead to concerted FAW targeted surveillances, culminating in the first report on FAW as an invasive pest in banana from India especially in the state of Kerala (Gavas and Sanju, 2020) and their spread throughout maize grown areas in the state. These findings lead to the possibility of existence of races/strains of FAW in India (Verghese, 2021).

Report of rice as a host of FAW in India by Kalleshwaraswamy *et al.* (2019) led to renewed search for FAW strains attacking rice crop in Kerala, especially in the hilly district of Wayanad, due to its close proximity to Karnataka state along with the record of banana race by Gavas and Sanju (2020).

Materials and Methods

Surveys for detecting the occurrence of FAW on crops other than maize were undertaken regularly during 2020-21 with the help of progressive farmers, pest survelliance unit of CIPMC, Ernakulam and officials of Department of Agriculture, Wayanad. Severe attack of hitherto unseen caterpillars on rice was brought to the notice of the authors. Field visits were promptly conducted and damage symptoms and associated larvae that caused it were documented.

The populations of caterpillars infesting rice were collected from Ellumannam of Edavaka Panchayat (Mananthavadi Block, Wayanad District; Lat 11°47 '0.3768" N; Long 75°57' 26.28" E, 742 MSL, 02.ix.2021. *coll*. Gavas Ragesh & Tom Cherian). They were brought to the entomology laboratory at Banana Research Station, Kannara, Thrissur, Kerala for rearing and studies on both morphological and molecular characterization as well as for presence of natural parasitisation. A few collected larval specimens were preserved in 70% ethanol, and few were kept for rearing.

The larvae in various instars collected were identified as *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera, Noctuidae) using Ganiger *et al.* (2018) and Venkateswarlu *et al.* (2018). The caterpillars had a prominent white inverted "Y" mark on the head and with distinct four black spots on the dorsum of 8th abdominal segment that are arranged in a square (Fig. 1).

Results and Discussion

Numerous caterpillars of *S. frugiperda* were observed feeding on 36 days old rice seedlings of variety named "*Thondi*", a land race preferred by the locals and ethnic Kurichyar tribals of Wayanad, Kerala and extensively grown in the area. The ready to transplant seedlings were raised in a nursery area of approximately one acre and the fields were bordered by banana/plantains (cv. Nendran). For assessing the FAW population and damages, eight grids of 1m^2 dimensions were selected. Observations on number of

FAW larvae/grid, number of parasitized larvae/grid, nature of damage/ feeding symptoms were taken.

Damage symptoms: Earlier instar larvae were seen feeding mostly the tip of young leaves (Fig. 2), whereas bigger larvae defoliated mature leaves (Fig. 3). It is curious to note that the late instar caterpillars were mostly seen feeding the outer whorls of leaves whereas young caterpillars preferred inner whorls of young leaves. The larvae were seen feeding on the leaves, by cutting from the margin and feeding inwards or feeding the whole leaf tips leaving characteristic pattern on the leaves (Fig.4). Presence of large numbers of dead larvae parasitized by entomopathogenic fungus (EPF) *Metarhizium riley*, could be documented and were collected for further isolation and characterization. The mummified FAW larvae were fully covered by white mycelia of the fungus (Figs. 5 and 6).

FAW population assessment: The FAW populations in rice were monitored on fortnightly intervals and the larvae were found with restricted presence only in a localized area in the field. The larval density in the infested patches was 2-8 numbers of larvae/ m^2 grid and 1-3 EPF infected mummified larvae/m^2 grids were recorded. Eighty percent of the FAW larvae collected were of 3rdinstar stage and above. Further, extensive field search was carried out for egg masses, pupae and adults in infested rice fields, but did not yield any results. The infested field was monitored at fortnightly interval and it was observed that the larval density reached zero at the maturity stage of the crop.

In India rice, wheat and maize are the three most important cereal crops both in terms of area and production. Polyphagous fall armyworm with their remarkable dispersal ability and preference for warmer temperature (Suby *et al*., 2020) has made them a serious threat to global food security. At global level rice has been already reported as a staple food plant of FAW. Montezano *et al*., (2018) in their exhaustive compilation of host plants of *Spodoptera frugiperda* in the Americas mention more than six references on rice as a preferred host of FAW. FAW populations are known to consist of two strains, *viz.* 'C'-strain (corn strain) which feeds predominantly on maize, sorghum and cotton, and 'R'-strain (rice strain) which prefers rice and turf grass (Suby *et al*., 2020). Molecular genetic diversity studies suggest that the FAW population in India belongs to the 'R' strain based on polymorphisms in the *Cytochrome oxidase subunit I* gene (*COI*) (Suby *et al*., 2020). Comparisons of genetic markers revealed that fall armyworm from Myanmar and southern China are closely related to those from Africa and India, suggesting a common origin for these geographically distant populations (Nagoshi *et al*., 2020). Hence such molecular similarities pose a question whether the subpopulations are most likely to be a threat to rice and millet crops in Asia.

While reporting FAW as pest of rice in India for the first time, Kalleshwaraswamy *et al*. (2019) did DNA Barcoding using mitochondrial *Cytochrome oxidase subunit I*, which revealed that FAW on rice belonged to "R" strain. They also opined that they were not clear whether the FAW was preferring rice as a host plant. Similarly in our study, the presence of larvae of different instars causing defoliation and prevalence of their characteristic feeding symptoms in a very limited area point out that, rice may be a transitional host in the absence of its most preferred host maize. Inundated field conditions of rice ecosystem may have not facilitated the pupation of larvae. However, larvae pupated in the potted plants in the laboratory (Figs. 7 & 8). Further, the infestation was naturally controlled by the natural occurrence of EPF and insectivorous birds such as black drongo (*Dicrurus macrocercus*), egrets (*Bubulcus ibis)* etc., which are commonly found in the rice ecosystem in Kerala, which was confirmed by further surveys during 2022.

In Kerala, presence of FAW populations feeding on maize and banana (Gavas and Sanju, 2020) raises the possibilities of development of either races or strains of *Spodoptera frugiperda* as opined by Verghese (2021). Further morphological, molecular and host preferential studies can only clear this enigma. If proven as a separate strain, the FAW populations feeding on banana may be named as 'B'-strain (banana strain). Further intensive surveys can shed more light into their life cycle and possible emergence as a threat to Kerala's agriculture.

Conclusions

There is a high possibility that *S. frugiperda* in future can replace or suppress the existing defoliators recorded in the rice ecosystems viz. *Spodoptera mauritiana*, *Pelopidas methias*, *Melanitinis leda ismene* etc. by niche competition, if it gets established. Their innate capacity to lay high number of eggs and its polyphagous nature may help them to emerge as a serious pest problem in Kerala. Promoting eco-friendly management options like mass release of *Trichogramma pretiosum*, a known egg parasitoid of FAW; exploiting the potentials of FAW strains of *Metarhizium riley;* use of pheromone/light traps to collect the adult moths etc. coupled with use of green labelled plant protection molecules will be a game changer in the management of this invasive pest in Kerala.

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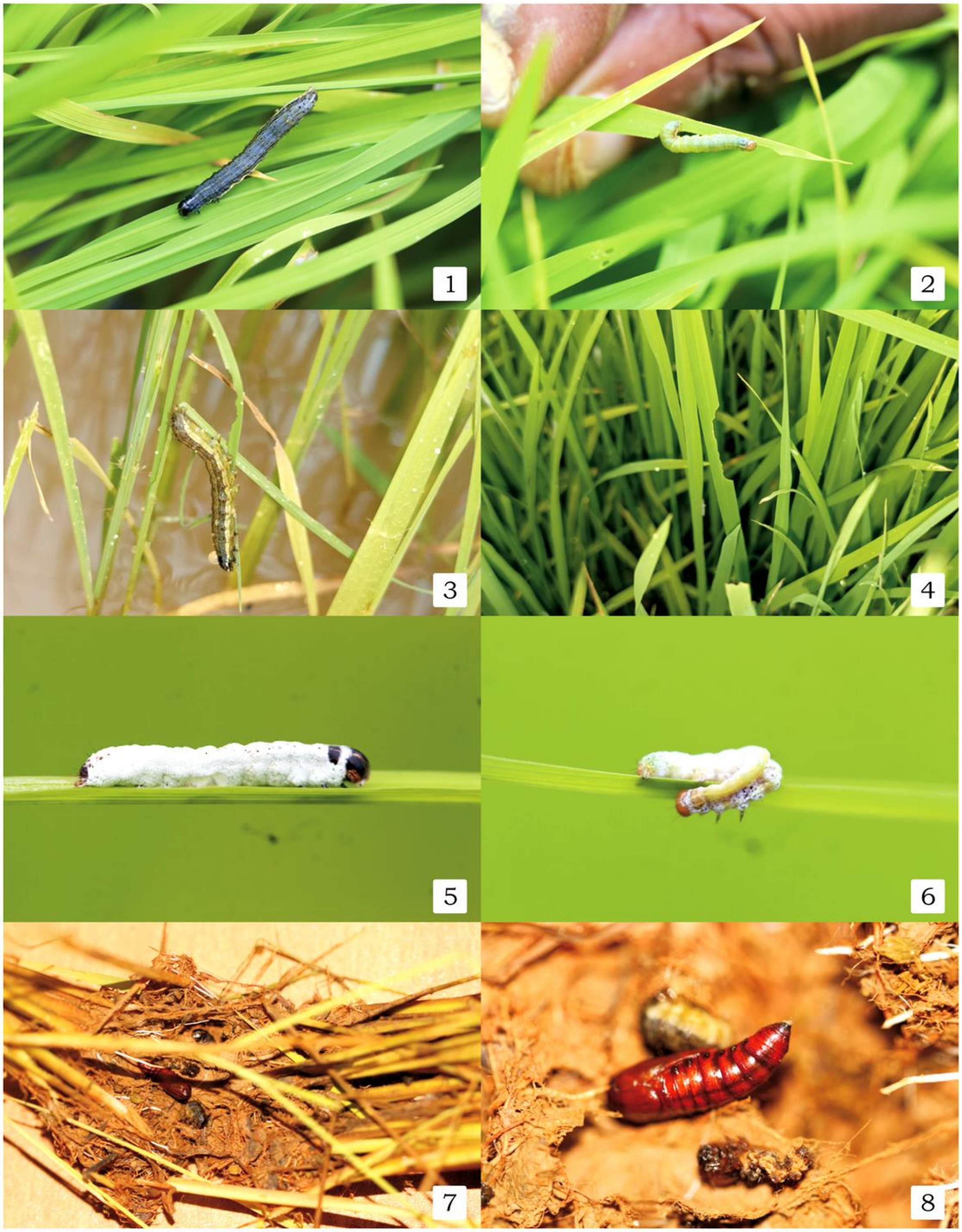

Fig. 1-8. ***Spodoptera frugiperda*: 1. FAW on rice; 2. Second instar feeding on rice; 3. Fifth instar defoliating rice; 4. Damage symptoms on leaves; 5-6. *Metarhizium riley* infected FAW larvae in the field; 7. Pre-puape and pupae among the rice seedling clumps; 8. Pupae.**

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Separation aggression: A captive study on two Indian ant species, *Camponotus compressus* (Fabricius 1787) and *Tetraponera rufonigra* (Jerdon 1851) (Hymenoptera: Formicidae)

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Abstract

We studied the aggression reaction of two Indian ant species, *Camponotus compressus* and *Tetraponera rufonigra*, using both the species either as a resident and/or intruders to each other and to conspecifics in the ant box to observe whether or not they were showing the reaction towards conspecific and interspecific in the captivity at different time points of isolation from the parental colony. The study revealed a strong and positive correlation between the degree of aggression and the duration of remaining in isolation from the parental colony. A shorter aggression time was recorded during the short period of separation but with more time of isolation, the aggression time increased to a great extent. With time, the ants in the formicarium lost the original body odour, which caused the conspecific to become distant, and aggression followed. Conspecifics of non-parental colonies also exhibited aggression reaction in both the ant species under study, therefore, it can be stated that aggression could not only be due to the body odour dilution, rather there could be an additional factor. The gradual increase in the ambient temperature might play a role. During the change in season from winter to summer the ambient temperature was increasing and the ants were getting active and became more aggressive. We observed a differential aggression in the interspecific reaction and this may be due to the different genetic compositions between them.

Keywords: *Camponotus*, *Tetraponera*, Ants

Introduction

Ants can distinguish colony members from non-members (Hickling and Brown, 2000; Jones et al., 2004; Quinet et al., 2005; Hölldobler and Wilson, 2009) and they show aggression towards individuals other than nestmates (Fernando and d'Ettorre, 2008). Nestmate recognition is an essential feature to preserve group cohesion and ants can maintain the stability of the colony through the efficient nestmate recognition system (d'Ettorre and Lenoir, 2010; Sturgis and Gordon, 2012). It has been noted that the recognition system can be a result of genetically imprinted behaviour or environmentally derived cues (Lacy and Sherman, 1983; Crozier and Pamilo, 1996). Behavioural assays in the form of aggression tests have been extensively used to study the mechanisms underlying nestmate recognition (Carlin and Hölldobler, 1986). The level of aggression has been usually measured by displays related to aggression. Studies have shown the effect of temperature on foraging behaviour (Chambers, 2011; Jayatilaka *et al*., 2011) but as far as our knowledge goes, not many studies have so far been made on the association between the increase in ambient temperature and aggression in ants. Most of the recent research on aggression in ants has been done either in a natural population or in a colony maintained in the laboratory.

Our present study aimed to investigate the extent of conspecific and interspecific aggressions in isolation of two Indian ant species, *Camponotus compressus* (a soil-inhabiting ant), and *Tetraponera rufonigra* (an arboreal ant) in captivity without usual colony nestmates. In the present study, our research questions were as follows-

1) Was there any relation between the duration of aggression, and the number of days of isolation from the original parental colony in both the ant species in captivity?

2) Did the conspecifics from different colonies show aggression in captivity?

3) Did the ambient temperature influence the aggression reaction in captivity?

Materials and Methods

Both the ant species under study are found almost in all habitats throughout West Bengal, India. After procurement from the natural habitats, the ants were kept in rectangular shaped transparent Perspex-sheet made formicarium (ant box) (26 cm x 20 cm x 13 cm) with an opening of 2.6 cm diameter, at the centre of the top lid, guarded by nylon mesh through which air could pass but ant could not. The base of the formicarium was covered with soil (collected from the site of ant collection) up to ~5.0 cm high from the floor and guava leaves (*C. compressus*) or pieces of hollow wood (*T. rufonigra*) were placed in the formicaria along with watch glasses to keep water-soaked and honey-soaked cotton wools (Figs. 1A, 1B and 2A).

A. Small isolated captive workers of *C. compressus* and *T. rufonigra* in formicaria

Fifty workers of *C. compressus* of three different sizes were collected from a natural colony in a local garden (Lake District Housing Complex, Kolkata-700054, India in January and were brought to the laboratory to keep in the formicarium. The collected ants represented the captive workers that lacked eggs, larvae etc. Similarly, thirty ants of *T. rufonigra* were collected from the Chinsura area of the district of Hooghly, WB, India. The captive individuals were kept in the laboratory for two to three days for acclimatization. The temperature was recorded every day during the entire study period. Light and dark regimens (12h:12h) were maintained in the laboratory. There were three formicaria each for two groups of ants. After acclimatisation, for experimental purposes, ants of the comparing species were collected from the natural colonies and introduced into the formicaria as 'intruder' ants. For *C. compressus*, each formicarium contained 15-20 ants, and for *T. rufonigra* there were 9-12 ants in each formicarium.

B. Scaling of aggression behaviour

Based on the aggressive reaction the level of aggression was categorised into the following classes as reported by Carlin and Hölldobler (1986) with slight modifications.

‘0’ - Indifference, did not pay attention.

‘1’ -Touch, antennation, antennal boxing

‘2’ - Retreat, escape

‘3’ - Chase, mandible opening reflex (MOR)

‘4’ - Biting, gaster flex

‘5’ - Biting, drag-hold down

The ‘0’, ‘1’ and ‘2’ could be classified as submissive behaviour though in many cases antennal boxing led to full-blown aggressive attack, while categories ‘3’, ‘4’ and ‘5’, on the other hand, could be considered as aggressive behaviour.

***C. Conspecific* aggression**

The intruder ants were collected from the same parental colony and different (non-parental) colonies. There was a minimum gap of one week after the initial procurement of ants from the parental colony and subsequently, the intruders were collected and released into the formicaria in the laboratory every week, where some residents were inside. This method was also performed in the case of *T. rufonigra.* Two protocols were employed in the present study for both ant species.

1. At the start of the experiment (in the first week), the worker was collected from the same colony from where the initial procurement was made, and the ant was referred to as the OL (original locality).
2. In the second protocol, the intruder was collected from the colony of a different locality and that ant was referred to as DL (different locality).

a) For *C. compressus,* the intruder for the DL was collected from the Bidhannagar College Campus, Salt Lake, Kolkata 70064, WB, India, which is about 3.5 km away from the OL site and,

b) For *T. rufonigra*, the intruder for the DL was collected from Lake District Housing Complex, Kolkata 700054, WB, India, which is about 55.0 km away from the site of resident ant collection.

Every week, one collected ant as an intruder was introduced into the three formicaria each for both the species of resident ants in the laboratory. An individual ant from one colony (treated as an intruder, either from OL or DL) was gently picked up, marked on the abdomen with a poster colour for identification, and dropped into the formicarium containing the resident ants. This was done every week for up to nine weeks from January to March for both species. The aggression reaction (resident vs OL) and (resident vs DL) was performed weekly in three separate formicaria with at least one-hour intervals.

For each experiment, the response time, the number of attacking ants, the type of response, and the duration of the fight were recorded. The response time was calculated from the time the intruder was put into the residents' formicaria to the appearance of the first sign of response. The total duration was calculated from the first sign of response till the end of the interaction, *i.e.*, either the ant(s) died or one of the either ran away. The aggression time was calculated by subtracting the response time from the total time.

D. Interspecific aggression

One species was introduced into the formicarium of another species that lived as a resident. In one trial, *C. compressus* was resident and *T. rufonigra* was an intruder, and *vice versa* in the next trial. For this experiment, one individual ant of one resident group (either *C. compressus* or *T. rufonigra*) was introduced as an intruder into the formicaria having residents of either *T. rufonigra* or *C. compressus*. This experiment was carried out for six weeks altogether and was repeated five to eight times. Parameters like response time, number of ants responding, types of behaviour, etc. were noted.

Statistical Analyses

To test whether the increment in mean aggression time (MAT) along with the increment in the week interval in conspecific and interspecific aggression reaction was significant or not we used a one-way ANOVA test. The Pearson Correlation and Coefficient analysis was performed to find out any significant association between two factors like the time point (week) elapsed and the MAT increased.

Results

a) Conspecific Aggression

The resident *C. compressus* showed aggression towards the OL-intruder conspecific following the first week of separation with a mean aggression time (MAT) of 29.52 ± 10.38 (Mean ± SD) seconds (Fig. 3). The intruder was approached by a few residents, and antennal tapping and physical contact were noticed. The MAT increased with time intervals. The intruder experienced intermittent MOR (Fig. 2B and 2C) and the first sign of attack was seen after eight weeks of observation. The highest MAT was recorded in the 8th week (359.28 ± 76.28 seconds). Figure 3 shows that up to week No.

5, the MAT was found almost uniform with slight variation but 7th week onward, it started rising steadily and a significant and positive correlation was noted (*r* = +0.89).

The DL *C. compressus* showed a gradual rise in the MAT but not like that of OL (Fig. 4). The residents were found chasing the intruder conspecific and from the 4th week onward, most of the intruders (~70%) were found dead after being attacked (Fig. 2E). Interestingly, during the attack, only one or two residents were taking an active part. In this case, too, we found a positive and significant correlation (*r* = +0.953). In the one-way ANOVA, we obtained an F statistic of 107.67 and 104.07 respectively for OL and DL in the case of *C. compressus* (P<0.01). The analyses indicated that the MAT at each time point was significantly different from one another for both OL and DL

For *T. rufonigra*, concerning the conspecific aggression (OL), the MAT was more as compared to that of *C. compressus*, because they hardly came out of their hideouts in the formicarium. It was only we observed interaction when the intruder came near the opening of the makeshift wooden log-nest of residents. The conspecific aggression took place over a long time, ranging from 10 to 15 minutes up to more than an hour. For the first two weeks, they showed slight antennation and escape reaction but did not amount to full-blown aggression. From the 3rd week onward, an increase in the MAT was noted with both the ants displaying MOR, and gaster flexion with which they stung each other repeatedly. The highest MAT (3694.78 ± 900.36 seconds) was noted in 7th week and the lowest value (169.14 ± 44.31 seconds), in the 1st week of isolation (Fig. 5). Usually, the number of residents reacting to the intruder was three, and even then, direct conflict was always one-on-one. The mortality rate of intruder individuals was quite high (death occurred almost every time) except for the times when there was no response since residents did not come out of the nest (Fig. 2D). The MAT in DL (Fig. 6) showed an almost similar trend except for the magnitude of aggression. The highest MAT recorded in DL was 3596.50 ± 885.04 seconds in the 7th week (similar to that of OL), and the lowest in the first week (284.80 ± 141.38 seconds). The ants of OL and DL both showed a moderate and significant positive correlation between the two factors under consideration, (***r*** = +0.77 and +0.61 for OL and DL respectively). We found significant F (40.73 for OL and 20.83 for DL). In the case of the one-way ANOVA test, the MAT in OL and DL of *T. rufonigra* were significantly different at different week intervals for OL and DL.

When the MAT values of OL and DL of *C. compressus* were compared using the one-way ANOVA, we obtained a significant F statistic (15.40) but the OL and DL comparison in *T. rufonigra* did not show any significance. Further, the MAT of OL between the two ant species showed a significant F statistic.

b) Interspecific aggression

When *C. compressus* was resident and *T. rufonigra* was intruder, the MAT remained almost similar in all week intervals (Fig. 7), and both the F statistic and ***r*** showed insignificance (F= 0.67 and -0.19 respectively). In the reverse experiment (*T. rufonigra* resident and *C. compressus* invader), we recorded a very small MAT in earlier time points, 6.55 ± 3.17 and 7.73 ± 4.31 seconds in 1st and 2nd week respectively, and the rest of the weeks showed slightly higher values (Fig. 8). The mortality rate of the invader was high and it increased steadily in the subsequent weeks (both due to dreadful war or due to injury following the war). One-way ANOVA showed a significant F statistic (15.21) when tested between MAT and week intervals and the Pearson correlation coefficient showed a positive and insignificant value (r = +0.38). The interaction between resident *T. rufonigra* and intruder *C. compressus* took place for a very brief period, and always one on one basis but sometimes other ants gathered around and some ran in a frenzy. Resident *T. rufonigra* did not participate in the aggressive response more than once i.e., after one episode of biting and stinging the intruder, the resident retreated and never returned to fight with the intruder again. The intruder *C. compressus* was seen to wither for some time and die. The intruder was almost always killed in those bouts. In none of the cases, *T. rufonigra* was seen to die rather they ran in the opposite direction on the first encounter with the *C. compressus* after it performed antennal boxing, but when it returned, the full aggressive response followed.

Discussion

Our study indicates that the isolated ants in captivity showed aggressive responses toward their conspecifics from the same parental colony and also from the non-parental colony despite the captive resident individuals lacking queen, egg, larva, pupa, etc. It implied the fact that aggression is an inherent behavioural feature which also remains fully active under stressed conditions. For parental conspecifics, the more the time of isolation among nest-mates, the higher the aggression, especially for *C. compressus*. From this behaviour, it is revealed that with the increase in the time interval, the ants of the original parental group gradually become aliens to the isolated nestmates. They show a similar aggression response that has been observed between conspecific non-nestmates. It can be said that the isolation from the parental colony gradually makes them non-nestmates as indicated by the aggressive behaviour in the experimental groups of both the ant species under observation. The cause behind the aggressive responses in ants of the OL and DL was found not to be similar. The body odour dilution is the primary reason in the case of the captive members of the OL group. In addition, the increased ambient temperature during the entire experimental period may also play some role. But in the case of the DL group, the conspecifics were unrelated, and this is the major cause of their aggression in addition to the captivity and the increased ambient temperature. Resident *T. rufonigra* showed aggression both toward the conspecifics of OL and DL but the duration of aggression is much higher than that of *C. compression.* The interspecific aggression between resident *C. compressus* and introduced *T. rufonigra* and *vice versa* indicates altogether a different aggression response. Unlike that of conspecific aggression, the reaction time in interspecific aggression either almost remains the same all through the experimental schedule or shows slight variations.

It is a very well-known fact that animals always defend their colony from enemies or intruders and the animals like ants also do a similar thing instinctively, and for this behaviour, aggression is an important component (Frizzi *et al*., 2015). In the present study, on the day of isolation, the body odour of the intruders was the same as that of the resident counterparts, but we noted an increased MAT in both ant species under observation with the week elapsed. The conspecific from the non-parental colony (DL) had no issue with body odour dilution but such a group also exhibited a similar pattern of aggressive response as recorded in ants from the parental colony (OL). The body odour of all members of an ant colony has been maintained (Crozier and Dix, 1979; Vander Meer and Morel, 1998; Boulay *et al*., 2000) and the unique body odour of all colony members of a particular colony has generally maintained the integrity of the colony (d'Ettorre and Lenoir, 2010; Sturgis and Gordon, 2012). The ants have the power of strong chemical sensation, and they can easily discriminate nestmate from non-nestmate (Janni *et al*., 2014). As our ants gradually lost the body odour in the OL group, the MAT increased gradually because those two factors like aggression and body odour are inversely correlated. The direct correlation between MAT and weeks of isolation from the parental colony concerning aggression could not be applied to the ants of the non-parental colony.

Ants are ectothermic and thermophilic creatures (Bishop *et al*., 2017) and the temperature has an enormous effect on ant biology. The increase in MAT along with the increase in weeks of isolation may not only be due to the duration of isolation from the parental colony alone (as found in OL), the environmental factor in this connection such as ambient temperature, may play a crucial role (Parr and Bishop, 2022). As per the present study, the ambient temperature along with body odour and captivity stress played a significant role in increasing the aggression. The experimental thermal stimulation was shown to have a direct correlation with aggression like MOR in ants (Desmedt *et al*., 2017). In one of our previous observations with *Polyrhachis lacteipennis,* we recorded fewer ants outside the makeshift nest in the formicarium during the winter days of the experiment as compared with a large number of ants during summer days (Karmakar *et al*., 2012). In the present investigation with two different ant species, we too observed a similar response towards the ambient temperature in the captive ants in the formicarium. Our present findings states that this particular response could be genetically hard-wired i.e., the change in habitat, and absence of fellow members in formicarium did not at all affect this type of behavioural feature (aggression) in ants.

The duration of MAT was found less in *C. compressus*, and the shorter MAT can be considered the species ability to quickly overcome the stress developed due to the captivity. Further, besides the media caste, the major caste of *C. compressus* took charge of aggression because the particular caste is specially equipped with mouthparts for aggression, and the function of bowing down to the enemy was quickly done. On the contrary, the longer MAT in *T. rufonigra* can be correlated with the lack of specialised caste in them and all the morphologically similar workers perform the duty to defend the colony. Moreover, the species are of wild type and they could not manage the stressful captive conditions inside the formicarium and subsequently, the higher stressful condition increased the MAT greatly. A single ant colony can have genetic diversity that can be associated with aggression and foraging (Saar *et al*., 2018) and in the present study, the differential aggression response in two Indian ant species can be correlated with the difference in their genetic makeups concerning aggression reactions.

Conclusions

Isolation alone may not increase the aggression reaction in ants under investigation rather captivity in this regard may play a crucial role in addition to the change in the ambient temperature because both groups OL and DL were less active during the early experimental days (winter days) but the MAT was gradually increasing as the ambient temperature was rising. In the end, it could be commented that ants like *C. compressus* and *T. rufonigra* efficiently defend their natural colonies and in captivity too the same aggressive behaviour was displayed. This study warrants further observation with a view to testing the effect of a long time of isolation. Seasonal changes may have an influence on the aggression reaction in captive conditions. A future study could be designed to test the aggression in the formicarium in one-on-one conditions to come out with a logical explanation about the cause of aggression.

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Declaration

Authors' contribution: BC: Field collection, rearing of specimens, observation and collection of data SC: Data analysis, manuscript preparation RK: Designing of the study and experimental setup, observation and collection of data, manuscript preparation.

Competing interests: All the contributing authors declare that they have no conflict of interest.

Availability of data and materials: The raw data are available with the corresponding author. It is available upon request.

Consent of publication: All authors have consented to the publication of this article.

Ethical approval consent to participate: Not applicable.

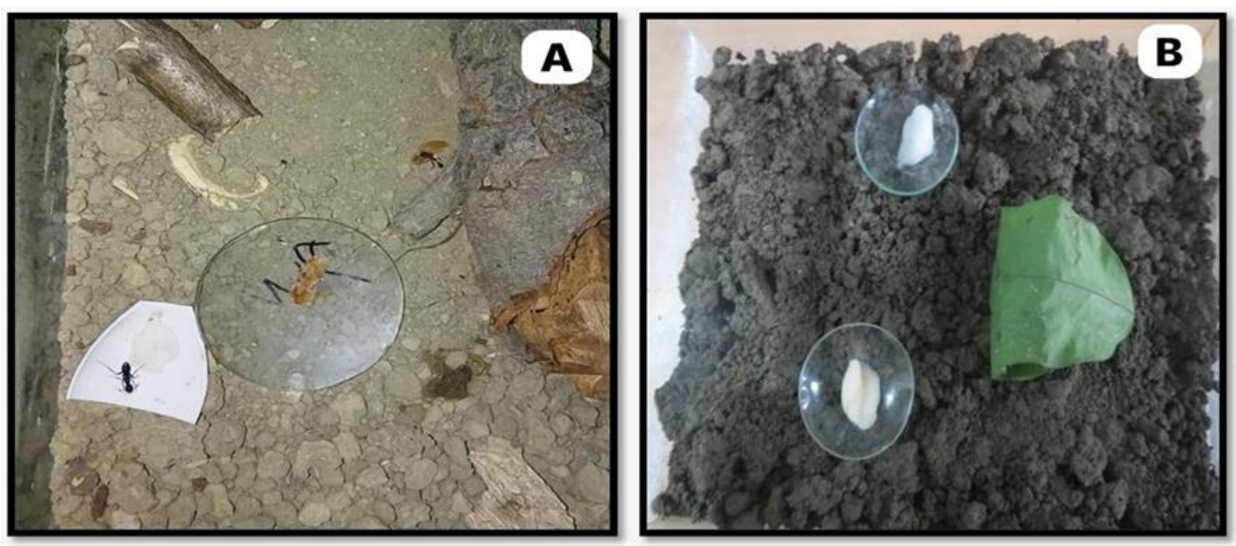

Fig. 1: Experimental setup inside the formicarium. On the left, is the formicarium of resident *T. rufonigra* ants (A) and on the right is the formicarium of resident *C. compressus* ants (B).

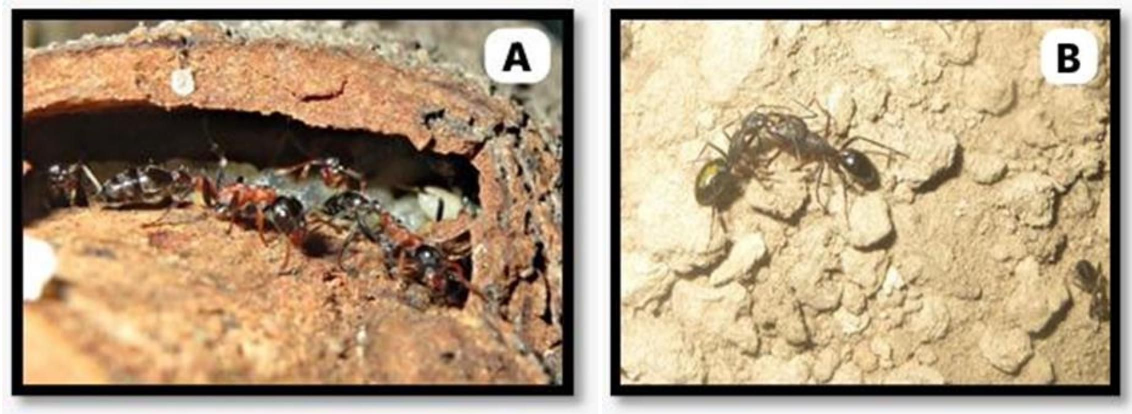

Fig. 2A: A makeshift nest in a wooden log of resident *T. rufonigra* inside a formicarium

Fig. 2B: Intraspecific aggression inside formicarium between intruder (yellow marked) and resident *C. compressus.*

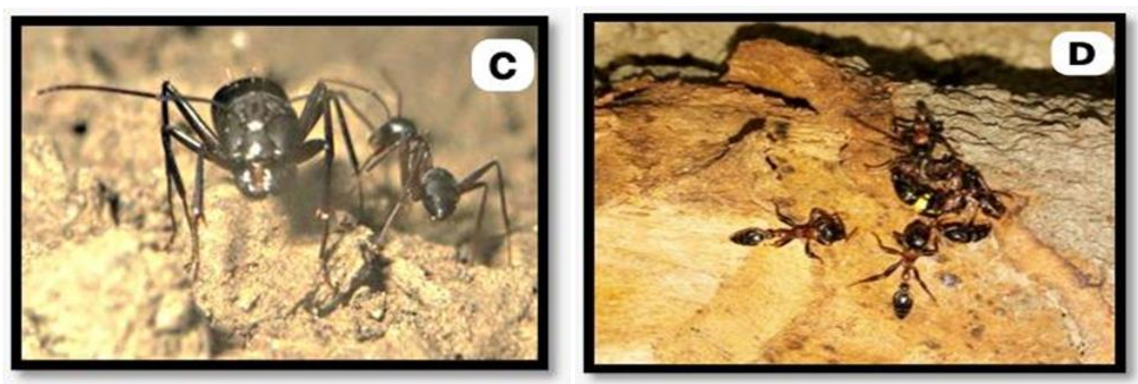

Fig. 2C: Mandible Opening Reflex (MOR) in intraspecific aggression in *C.compressus*)

Fig. 2D: Intraspecific aggression between conspecifics of *T. rufonigra* of different localities. The yellow marked is the intruder *T. rufonigra.*

Fig. 2 E: Interspecific aggression can be seen between resident *C. compressus* and intruder *T. rufonigra* inside the formicarium.

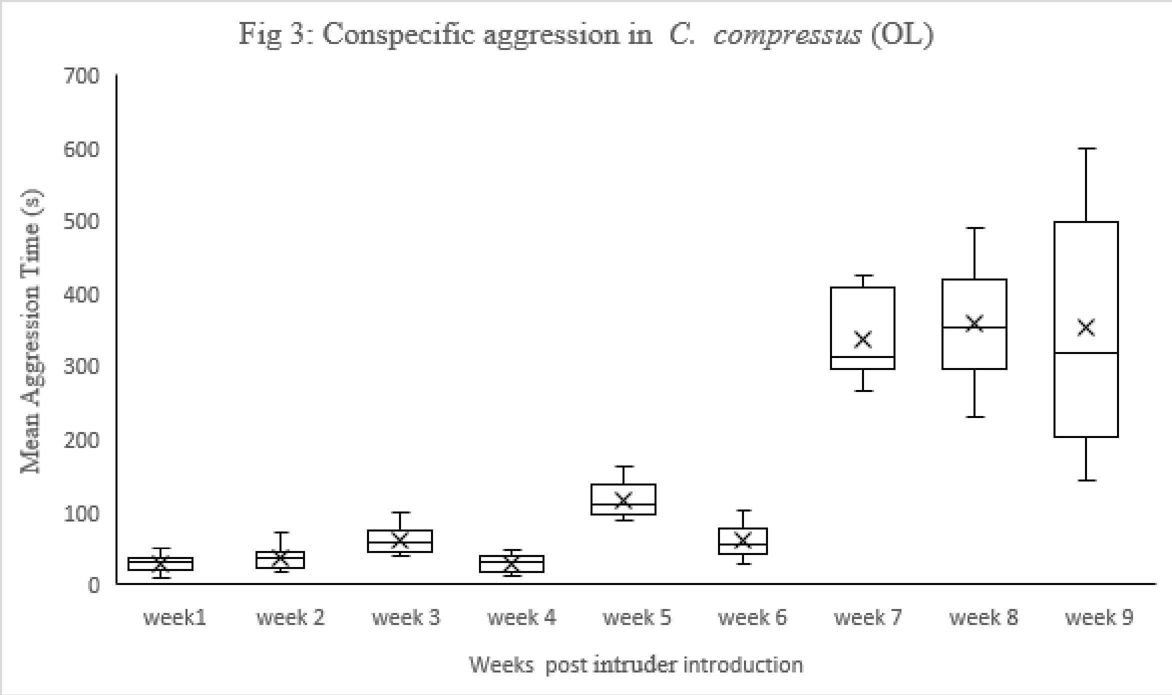

Fig. 3: Conspecific aggression in *C. Compressus* (OL)

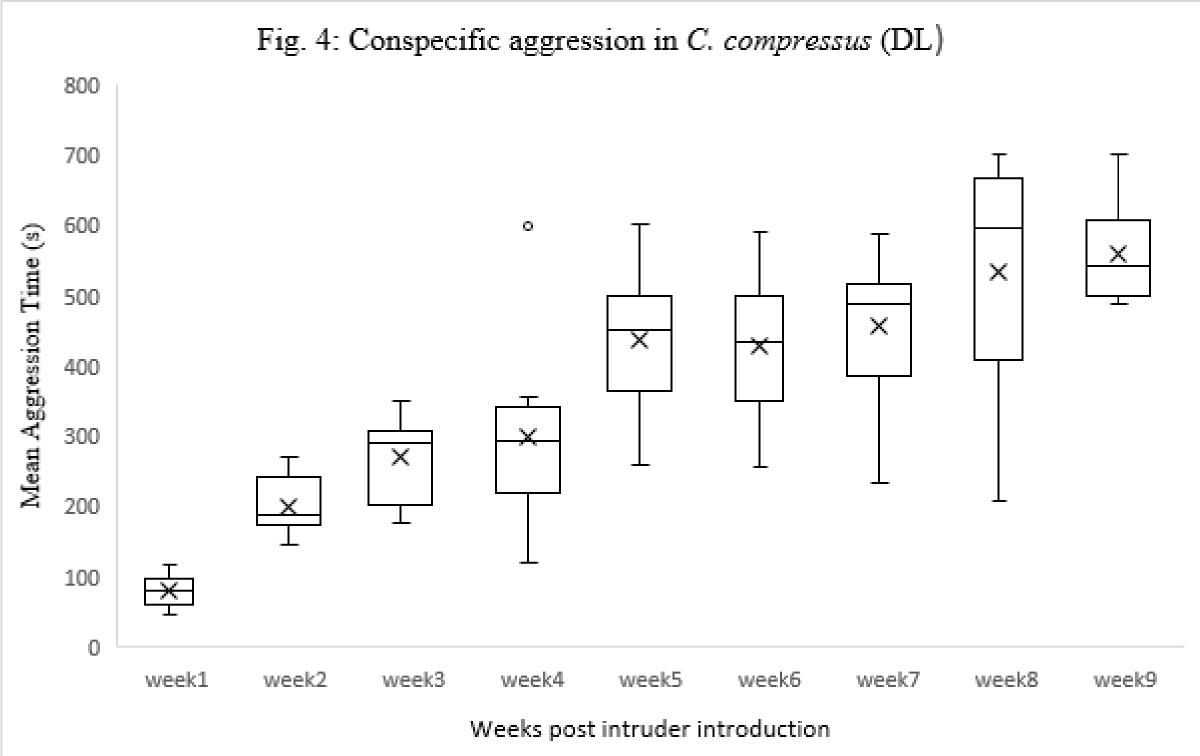

Fig. 4: Conspecific aggression in *C. Compressus* (DL)

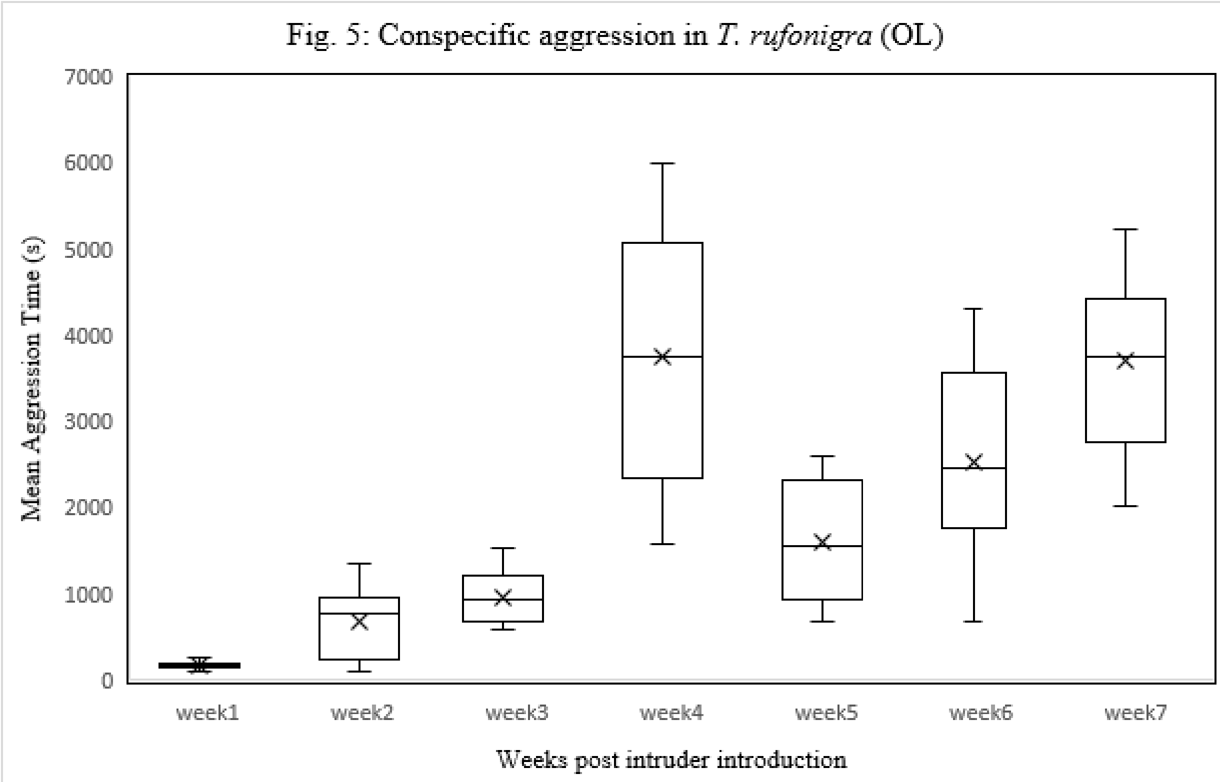

Fig. 5: Conspecific aggression in *T. rufonigra* (OL)

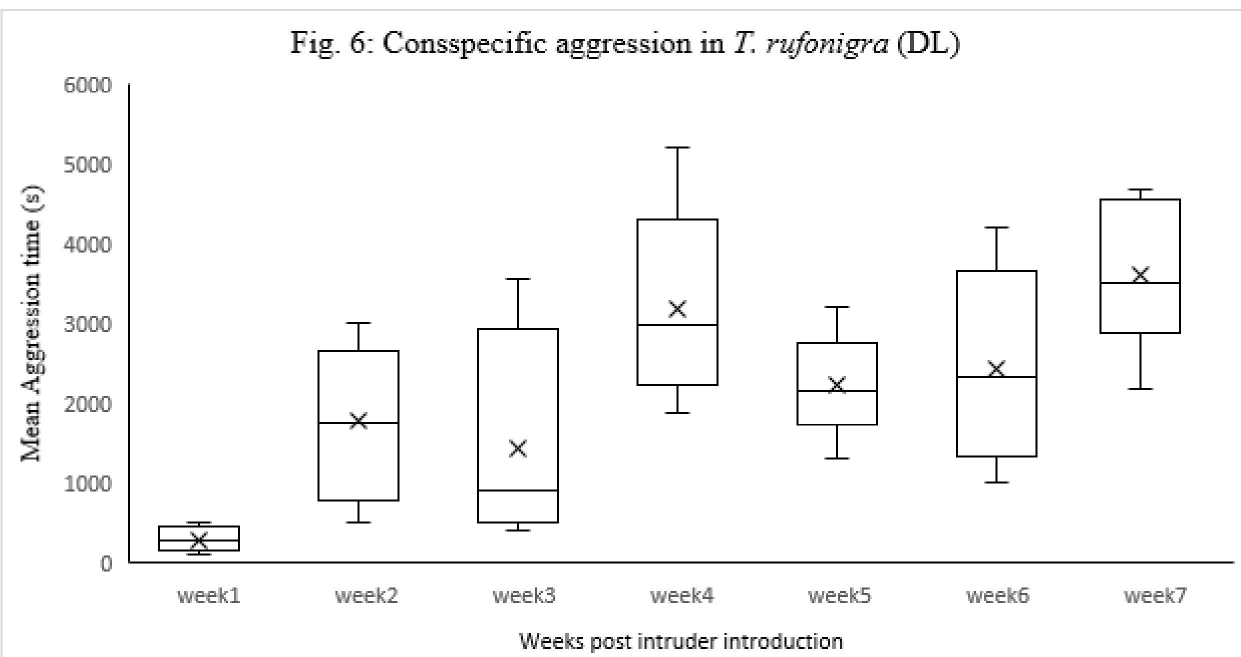

Fig. 6: Conspecific aggression in *T. rufonigra* (DL)

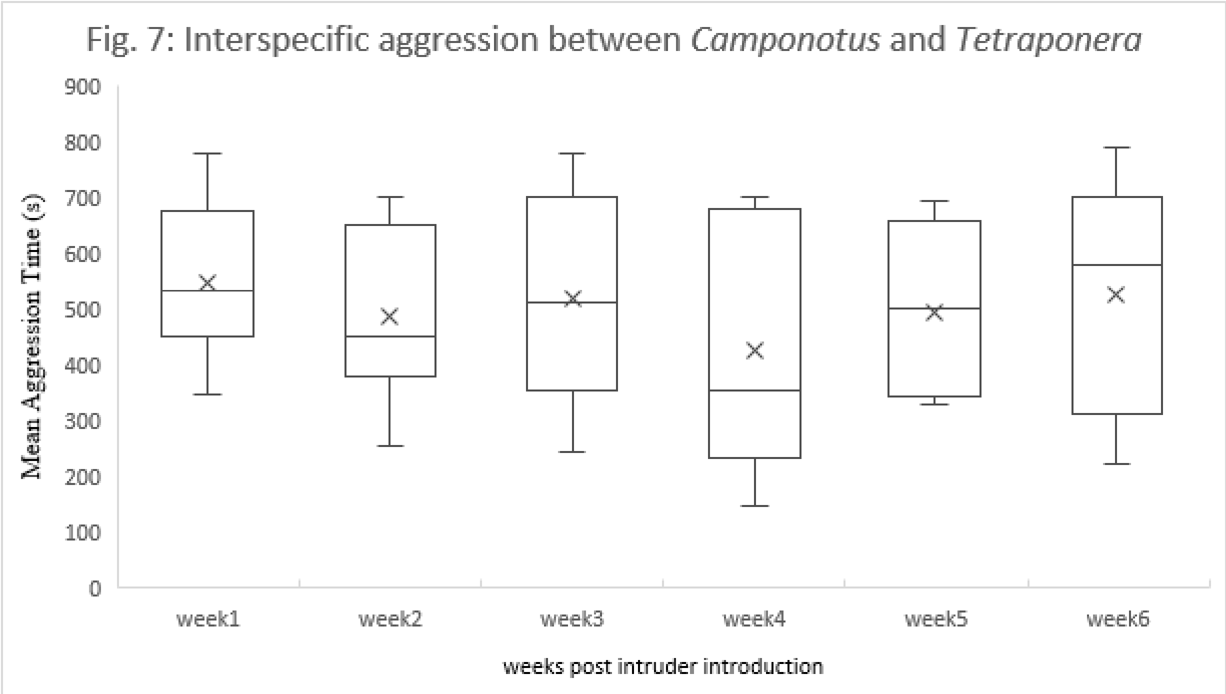

Fig. 7: Interspecific aggression between *Camponotus* and *Tetraponera*

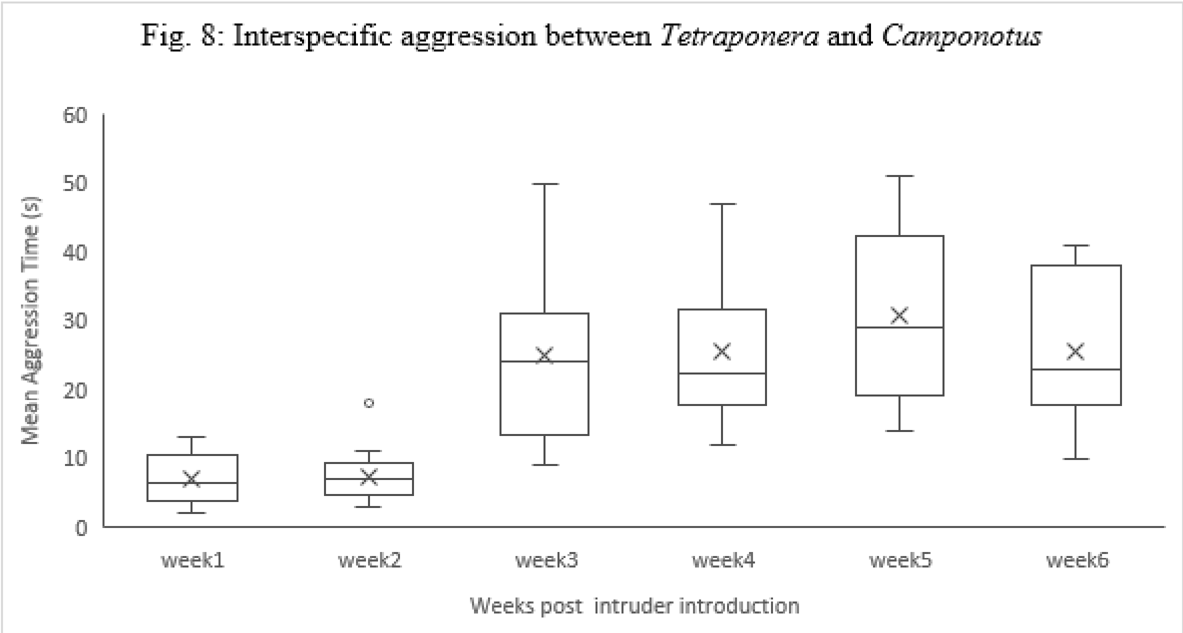

Fig. 8: Interspecific aggression between *Tetraponera* and *Camponotus*

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Review articles

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Unravelling the wonders of endosymbionts in insect sex determination: principle and prospects

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Abstract

Insects, the most diverse group of animals on Earth, exhibit a bewildering array of reproductive strategies. Among their many fascinating characteristics, the mechanisms governing sex determination have long captivated researchers. In the vast and diverse world of insects, the determination of an individual's sex is a fascinating phenomenon. While the mechanisms of sex determination can vary greatly across different species, recent research has shed light on the significant role of endosymbionts in this process. This article explores the intriguing relationship between endosymbionts and sex determination in insects, highlighting recent findings and their implications. By examining recent scientific findings, we aim to shed light on the mechanisms by which endosymbionts shape the sex ratios of insect populations.

Keywords: Endosymbionts**,** *Wolbachia*, *Spiroplasma*, sex determination, insects

Introduction

Endosymbionts are organisms that live inside the cells or body of another organism (the host) in a mutually beneficial relationship and this association is known as endosymbiosis. The most well-known example of endosymbiosis is the mitochondria and chloroplasts found in eukaryotic cells. According to the endosymbiotic theory, these organelles were once free-living prokaryotic organisms that were engulfed by a eukaryotic cell, but over time, formed a symbiotic relationship (Archibald, 2015).

Insects can harbor a wide array of endosymbionts, including bacteria, viruses, and other microorganisms. Over the years, researchers have discovered that certain endosymbionts profoundly influence the sex determination of their insect hosts. These microscopic organisms that live inside the insect's body have emerged as key players in shaping the sex ratios of various insect populations. Associated bacterial symbionts of insects are often involved in their host's ecological fitness and development. Feldhaar, (2011) therefore suggested that the holobiont (the host along with the associated symbionts), should be regarded as a unit of selection. A wide range of microbiota has been reported from insects, which can be broadly categorized into: the intracellular (housed in specialized bacteriocytes) and the extracellular endosymbionts; the latter is associated with the gut lumen or endocoel.

The association of endosymbionts could either be obligatory or facultative (Rosenblueth *et al.,* 2018); or parasitic or mutualistic (Wernegreen, 2002). Extreme specialization due to long co-evolutionary processes has rendered intracellular endosymbionts unculturable; only extracellular endosymbionts are generally culturable. Technological advances in molecular phylogenetic characterization allow the exploration of these uncultured bacteria. These endosymbionts of insects live in special cells of the host called bacteriocytes forming a structure like an organ (bacteriome) in the insect's body cavity. The transmission of these endosymbionts associated with bacteriocytes is vertical *i*.e. from mother to offspring but the possibility of horizontal transfer is also there. Both the partners in this case live in obligate association with each other. Bacteria require the host and cannot be cultured in-vitro outside the host body whereas for the normal growth and reproduction of the host, bacterial endosymbiont is required. *Wolbachia* is one such type of endosymbiont found in insects, crustaceans, filarial nematodes, and mites that cannot be cultured in-vitro and requires a living host.

Wolbachia

Wolbachia is perhaps the most extensively studied endosymbiont due to its remarkable influence on insect sex determination. Taxonomically *Wolbachia* is a gram-negative bacterium belonging to class, α-proteobacteria, order Rickettsiales. They have the ability of manipulating host reproduction leading to a change in the sex of the insect causing sex ratio distortion and affecting the insect. It was reported that *Wolbachia* infection is present in several invertebrates; about 66% of insects are infected with this endosymbiont (Hilgenboecker *et al.,* 2008). Different types of reproductive alterations are exerted by *Wolbachia pipientis* (Werren *et al.,* 2008). The reproductive manipulations include parthenogenesis, cytoplasmic incompatibility (CI), feminization, and male-killing. Insects and different terrestrial arthropods having *Wolbachia* and *Candidatus* infection have been reported with cytoplasmic incompatibility (CI). Lady beetles, butterflies, fruit flies, and other insects have been reported with male-killing having *Wolbachia, Rickettsia, and Spiroplasma* as endosymbionts and also as causal agents (Boutzei and Miller, 2003). Narita *et al.,* (2007) showed that *Wolbachia* feminizing effect is active throughout the larval development, in the butterfly *Eurema hecabe.* The above instances of feminization involve the conversion of chromosomal males into females by the presence of *Wolbachia*.

Cytoplasmic incompatibility (CI), wherein infected males can only successfully reproduce with infected females, gives the bacterium a reproductive advantage. Male-killing, as the name suggests, selectively eliminates male offspring, thereby increasing the proportion of females within a population. Parthenogenesis enables females to produce offspring without fertilization, further altering sex ratios.

It is reported in *Drosophila melanogaster,* that *Wolbachia* interferes with the juvenile hormone (JH) pathway. Zheng *et al* (2011) reported a nearly ten-fold increase in the JH-26 transcription in the testes of later larval stages of *D. melanogaster* infected with *Wolbachia.* In males, the JH expression peaks at the second instar stage and declines during subsequent prepupal and pupal stages. This manipulation often results in biased sex ratios, ultimately benefiting the reproductive success of the bacterium.

Spiroplasma

Spiroplasma is another endosymbiotic bacterium that has been found to impact sex determination in certain insects (Verhulst *et al.,* 2023). This bacterium exhibits unique strategies, including male-killing and male-biased sex ratios, to influence host reproduction (Arai *et al*., 2023). These bacteria can disrupt normal sexual development, leading to male-killing or male bias in the progeny of infected individuals, by selectively eliminating males from the population, *Spiroplasma* can influence the sex ratio and potentially increase the overall reproductive success of infected females.

Male-killing occurs when *Spiroplasma* selectively eliminates male offspring during embryonic development. This skewed sex ratio favours females and can lead to significant changes in population dynamics. In some instances, *Spiroplasma* induces the production of a male-killing factor (MKF), which targets male embryos specifically. The presence of MKF interferes with hormone signaling, disrupting normal sexual development and resulting in male mortality.

The precise mechanisms by which *Spiroplasma* manipulates sex determination are not yet fully understood. However, studies suggest that *Spiroplasma* interferes with hormonal pathways, particularly the juvenile hormone (JH). JH plays a vital role in determining the developmental trajectory of insects, including their sex differentiation. By disrupting JH signaling, *Spiroplasma* can distort the delicate balance between male and female offspring, favouring females.

The intricacies of other endosymbionts

The *Wolbachia* and *Spiroplasma* have been the focus of extensive research on endosymbiont-mediated sex determination. Apart from these, there are other endosymbionts known to influence the sex determination of their insect hosts. For instance, *Arsenophonus*, a bacterial endosymbiont, has been found to induce male-killing in a butterfly species, resulting in female-biased populations. Similarly, *Cardinium*, another endosymbiotic bacterium, has been associated with various reproductive alterations, including male-killing, feminization, and cytoplasmic incompatibility.

The influence of endosymbionts on sex determination extends beyond bacteria. For example, the microsporidian parasite, *Nosema* has been shown to induce feminization in its host, a crustacean called the amphipod. Additionally, the parasitic wasp *Nasonia* exhibits an intriguing system of haplodiploidy, where males develop from unfertilized eggs and females from fertilized eggs. *Wolbachia*, found in some *Nasonia* species, can manipulate this system, leading to male-killing and biasing sex ratios.

Implications and Future Directions

Although significant progress has been made in unraveling the mechanisms of endosymbiont-mediated sex determination, many questions remain unanswered. Researchers are still exploring the diversity of endosymbionts involved in sex determination and their interactions with host genetics and physiology. Understanding the precise molecular mechanisms through which endosymbionts manipulate host sex determination pathways is a crucial area of future investigation.

Additionally, the ecological and evolutionary consequences of endosymbiont-induced sex ratios require further exploration. How do sex ratio imbalances influence population dynamics, genetic diversity, and species interactions in natural communities? Answer to these questions will provide valuable insights into the broader ecological implications of endosymbiont-mediated sex determination in insects.

Conclusions

The discoveries surrounding endosymbiont-mediated sex determination in insects have revolutionized our understanding of reproductive biology and symbiotic relationships. *Wolbachia* and *Spiroplasma*, in particular, have been found to exert significant control over sex ratios through mechanisms such as cytoplasmic incompatibility, feminization, male-killing, and parthenogenesis. Understanding the intricate ways in which endosymbionts shape sex determination pathways provides valuable insights into the biology of insects and opens up new avenues for ecological research and pest management strategies. As research continues, uncovering the intricacies of endosymbiont-mediated sex determination will undoubtedly deepen our knowledge of insect biology and provide innovative solutions for addressing pest-related challenges.

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SPLAT: A green technology for insect pest management

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Abstract

Semiochemicals are naturally occurring, species-specific molecules exploited for inter and intra specific communication between insect and its environment. In pest management these semiochemicals are used mainly to modulate the behaviour of target insect pest, wherein development of resistance in insect pests is almost absent. In the recent past, sex pheromones have been employed for pest management through a novel technique, Specialized Pheromone and Lure Application Technology (SPLAT). It is a technology that lowers reproduction by preventing mating, attracting and killing the target insect, and repelling it. The wax-based product SPLAT disrupts mating due to prolonged release of pheromones over a time period of two weeks to six months.

Keywords: Semiochemicals. pheromone, SPLAT, mating disruption, pesticide

Innovative technologies have long drawn inspiration from nature, and one exciting field of research is the use of specialized pheromones and lure application technology (SPLAT) (Mafra-Neto *et al.*,2014). SPLAT dollops constantly release large quantities of pheromone, unlike females. It is a patented base matrix composition of biologically inert elements utilized to regulate the release of semiochemicals and/or odours, either with or without pesticides (Mafra-Neto *et al.*,2013). A sustained-release pheromone found in the wax-based SPLAT product prevents insect pests from reproducing by interfering with their mating process. These developments have transformed approaches to pest control, enhanced agricultural techniques, and aided in attempts to conserve natural enemies and environment. On the other side, the deployment of delta sticky traps (8-10 traps/acre) and sleeve traps (8-10 traps/acre) in mass trapping and mating disruption techniques are expensive and ineffective (Sreenivas *et al.*, 2021). The simulation of synthetic female pheromone emission continuously will render males perplexed and unable to locate the female for mating in natural conditions (Mafra-Neto *et al.*,2013). This product is an effective IPM tool that may be used to combat a variety of economically significant pests including many insect orders *viz*., Lepidoptera, Coleoptera and Diptera. SPLAT is a ground-breaking solution that streamlines the field distribution of semiochemicals and attractants, automating the dispensing of these substances. SPLAT works with any labile and/or volatile substance, optimizing and modulating the release of odors over time and is revolutionizing the field of crop protection.

Mechanism of SPLAT

SPLAT is a proprietary base matrix formulation of biologically inert materials used to control the release of semiochemicals and/or odors with or without pesticide. The aqueous component of the SPLAT® emulsion gives the product its liquid character, allowing it to flow. The non-aqueous component of the emulsion is the controlled-release device. It comprises of active ingredients (e.g., semiochemical compounds or pesticides) and additives that will protect these and fine-tune their release rates from the dispenser. Upon application, the aqueous component of SPLAT® evaporates from the dispenser within 3 hours, leaving the rainfast, non-aqueous component firmly affixed to the substrate, where it will release the active ingredients until all available molecules are dispensed. The longevity of the dispenser depends on the manner in which the particular SPLAT® formulation was created, its composition, how it was applied, as well as the environmental conditions to which it is exposed following application. SPLAT® products are typically formulated to release semiochemicals for 2 weeks to 6 months (Mafra-Neto *et al*., 2013).

Application and available formulations

The SPLAT formulation can be applied in many ways. A wide variety of manual and mechanical applicators can be used to apply SPLAT®. The most basic SPLAT® applicator can be a stick, spatula, or knife. More advanced manual applicators include syringes, grease guns and caulking guns. SPLAT® formulations have been developed to release a variety of compounds, including sex pheromones, kairomones, attractants, repellents, phagostimulants, and insecticides. Several SPLAT® products are developed for mating disruption, attract & kill and as repellent.

Case studies on SPLAT

Till date many studies have been done on the efficacy of SPLAT over traditional pheromone technology. In 2021, Sreenivas and co-workers revealed in their research that SPLAT-PBW applied to control *Pectinophora gossypiella* at 500 g/acre was found to be optimum, with minimum rosette flower (8.23%), green boll damage (7.36%), locule damage (8.41%), and higher yield (33.59 q/ha) as compared to farmers' practice which yielded 22.33 q/ha even after 5-6 rounds of insecticide spray.

A unique emulsified wax dispenser (SPLAT- OFM) of pheromone mating disruption of the Oriental fruit moth, *Grapholita molesta* (Busck), in the apple environment was examined (Stelinski *et al*., 2007). The results of this approximately 17-week trial, which involved releasing tethered virgin females throughout the season, revealed that mating was not seen in SPLAT-OFM treated blocks, but it was on average 27% in control blocks.

Gypsy moth mating was disrupted by SPLAT® GM, according to Onufrieva *et al*. (2010). In plots treated with SPLAT® GM at doses ranging from 15 to 75 g of active ingredient (a.i.) per ha, female gypsy moth mating success was reduced by >99% and male moth captures in pheromone-baited traps by >90%. According to dose-response studies done in 2008, SPLAT® GM given at a dosage of 7.5 g a.i. per ha was just as effective as a dosage of 15 g a.i. per ha.

In Taiwan, under greenhouse and outdoor circumstances, Hsu *et al*. (2010) investigated the male annihilation method employing SPLAT-MAT-Spinosad METM on Oriental fruit flies. It was investigated how many male *Bactrocera dorsalis* perished in greenhouse and outdoor circumstances. They showed that at 24 and 48 h grading intervals, SPLAT-MAT-Spinosad METM outperformed naled + ME. Fruit fly mortality percentage was substantially higher in the SPLAT-MAT-Spinosad METM therapy than in the naled + ME treatment.

The first SPLAT® ACP Repel prototype was tested in the field on an 18-year-old sweet orange tree that was highly infected with Asian citrus psyllids, *Diaphorina citri.* A non-treated control was put up against SPLAT® ACP Repel, which was administered at a rate of 50 g per tree. Three weeks after treatment, the population of Asian citrus psyllids was decreased to 50% (Mafra-Neto *et al*., 2014).

While working on male *Anomala orientalis*, Rodriguez-Saona*et al*. (2010) observed that the beetles responded to plastic dispensers and SPLAT-OrB dollops placed at least 60 metres from the source. However, after the first 3–4 weeks, both emission rates and attractiveness rapidly decreased. This study definitely confirms that a key mechanism is the competitive attraction of males and shows the viability of employing SPLAT-OrB as an alternative to hand-applied plastic dispensers for oriental beetle mating disruption.

Advantages of SPLAT over traditional pheromone dispensers

SPLAT formulation offers many advantages over traditional dispensing technologies:

- **Various approaches for application**: SPLAT boosts productivity by automating the application of pheromone dispensing sites and offers a wide range of viscosities and application techniques (e.g., applicator sprays, aerial applicator sprays, caulking gun type tubes, etc.).

- **Simple Applications for Both Large-Scale and Small-Scale Operations**: This highly flexible product's amorphous and flowable characteristics make it simple to switch from small-scale manual applications to large-scale mechanical ones.
- **Variable Strategies with the same active ingredient level**: A fixed quantity of this material can be applied differently depending on the pest population pressure.
- **Rain fast formulation**: Once cured, SPLAT will not wash off from vegetation.
- **Complete seasonal protection**: SPLAT can remain effective in managing pest populations up to six-month duration.
- **Combines with feeding stimulants and kairomones**: SPLAT can be mixed with a variety of feeding stimulants or attractants including liquids, solids and oils to enhance attraction or stimulate feeding (Source: https://ipmsymposium.org/2006/posters/004.pdf).

Conclusions and future aspects

SPLAT® stands out from other commercial semiochemical dispensers in that it offers a matrix that can distribute a wide range of chemicals and be used with nearly countless manual and mechanical processes. No matter the semiochemical, crop, or plot size, SPLAT® may be used in any pest control programme based on semiochemistry. Locally and internationally, SPLAT® attract-and-kill formulations, mating disruption and repellent formulations have been developed for economically important agricultural and forestry insect pests. Non-chemical approaches of insect pest management in field crops and horticultural crops will significantly benefit in reducing the load of chemical pesticides and cost of protection thereby increasing the health of environment and profitability of farming community.

Table 1: Different products of SPLAT® available in market

SPLAT® for mating disruption	
SPLAT® MAT CL	Melon fruit fly, *Bactrocera cucurbitae*
SPLAT® MAT TML	Mediterranean fruit fly, *Ceratitis capitata*
HOOK® TUTA	Tomato pin worm, *Tuta absoluta*
SPLAT® SWD	Pomace fruit fly, *Drosophila suzukii*
SPLAT® for attract and kill	
SPLAT®YSB	Paddy yellow stem borer, *Scirpophaga incertulus*
SPLAT® Cydia	Codling moth, *Cydia pomonella*
SPLAT® OFM,	Oriental fruit moth,*Grapholita molesta*
SPLAT® GM	Gypsy moth, *Lymantria dispar*
SPLAT® Tuta	Tomato pin worm, *Tuta absoluta*
SPLAT® EC	Carob moth, *Ectomyelois ceratoniae*
SPLAT® OrB	Oriental Beetle, *Anomala orientalis*
SPLAT® PBW	Cotton pink bollworm, *Pectinophora gossypiella*
SPLAT® CLM	Citrus leaf miner, *Phyllocnistis citrella*
SPLAT® as repellent	
SPLAT® VERB	Mountain pine beetle, *Dendroctonus sponderosae*
Hook™ RPW	Coconut Red Palm Weevil, *Rhynchophorus ferrugineus*

(Source: Mafra-Neto *et al*., 2014 and Pawar *et al.,* 2022)

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A brief review on integrated pest management of pink bollworm, *Pectinophora gossypiella* (Saunders) in cotton

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Abstract

An outline of integrated approaches to managing the pink bollworm (*Pectinophora gossypiella*) within cotton crops is presented. The pink bollworm poses a notable menace to cotton production, necessitating a comprehensive strategy for its effective control. This assessment delves into the fusion of varied techniques for pest management, encompassing cultural, biological, and chemical methodologies, all aimed at mitigating the harm caused by the pink bollworm in an environmentally sound manner. Cultural practices like altering crop types, initiating early planting, and eliminating affected plant remains, disrupt the life cycle of the pest. Biological agents, such as *Trichogramma* wasps and natural predators, act as inherent checks on population expansion. The judicious application of insecticides, guided by monitoring methods, brings the integrated plan to fruition. The amalgamation emphasizes the importance of a holistic standpoint in curtailing the use of pesticides while upholding effective pest control. The triumphant execution of this approach necessitates the training of farmers, the dispersion of advanced technology, and collaboration among all stakeholders. The different studies underscore the viability of IPM as a sustainable and holistic strategy to manage pink bollworm infestations in cotton, ensuring enhanced yield and ecological equilibrium.

Keywords: Pheromone trap, mass trapping, mating disruption, biological control and pesticides

Introduction

Bt cotton, also known as *Bacillus thuringiensis* cotton, represents a pivotal advancement in agricultural biotechnology. This genetically modified crop has demonstrated its desirability by addressing critical challenges in cotton farming. By incorporating genes from the Bt bacterium, it has granted cotton plants the ability to fend off destructive insect pests, notably the cotton bollworm. This pest resistance not only reduces the need for chemical pesticides but also significantly boosts cotton yields, leading to improved livelihoods for farmers. However, its desirability is also accompanied by ongoing debates about its long-term ecological impact and the need for responsible and sustainable farming practices. Overall, Bt cotton remains a prominent example of how science can enhance agricultural productivity while calling for a balanced approach to address its associated concerns. Bt cotton remains a viable and widely cultivated crop in many regions globally. Its pest-resistant traits have helped reduce insect-related losses and lower pesticide use, contributing to increased yields and profitability for cotton farmers. However, its long-term viability depends on responsible management practices, including resistance management and sustainable farming approaches, to address evolving challenges and ensure continued effectiveness.

The economic impact of the pink bollworm (*Pectinophora gossypiella*) is a significant concern for cotton-producing nations worldwide, notably India, China, USA, and Pakistan. Yield reduction statistics illustrate its widespread influence: 61 per cent in the USA (Schwartz, 1983), 20.2 per cent in India (Agarwal and Katiyar, 1979), 17-26 per cent in China (Luo et al., 1986), and 20-30 per cent in Pakistan (Mallah *et al*., 2000). To address this, various strategies have been proposed by researchers, including insecticide applications (Toscano *et al*., 1974; Haynes *et al*., 1986), pheromones (Huber *et al*., 1979; Haynes *et al*., 1986), gossyplure (Henneberry and Clayton, 1982; Henneberry *et al*., 1981), parasitoids, host-searching kairomones (Chiri and Legner, 1983), short season cotton (Chu *et al*., 1996), and integrated approaches (Henneberry and Naranjo, 1998). However, a pivotal advancement has been the introduction of transgenic Bt cotton, engineered with Cry1Ac and Cry2Ab toxins. This innovation has emerged as a crucial, cost-effective solution, not only combatting the pink bollworm (PBW) but also addressing a complex of lepidopteran pests that jeopardize the cotton crop. However, applying Bt proteins externally through spray or other meansis generally not recommended for several reasons: effectiveness (Exogenous application of Bt proteins may not be as effective as the built-in expression in Bt cotton plants. Bt cotton is engineered to produce the Bt toxin continuously, providing ongoing protection, whereas external applications may need to be reapplied frequently), Environmental impact (Indiscriminate application of Bt proteins can have unintended consequences, harming non-target insects and disrupting natural ecosystems) and Risk management (The use of Bt proteins in an exogenous manner can also increase the risk of resistance development in target pest populations if not managed properly).

In India, the adoption of Bt cotton variants harbouring the Mon 15985 (BG-II) event and expressing Cry1Ac and Cry2Ab toxins resulted in effective control of bollworms, leading to a substantial reduction in the application of bollworm-targeted pesticides. This achievement played a pivotal role in propelling India as a prominent global cotton producer. Notably, from 2000-01 (9.52 million bales) to 2018-19 (28.71 million bales), cotton production surged, accompanied by an increase in yield from 1.90 quintals/ha to 3.66 quintals/ha. This triumph also spurred an expansion in cotton cultivation area, expanding from 8.53 million hectares to 12.66 million hectares over the same span. Nonetheless, instances of bollworm survival within genetically modified (GM) cotton fields have been reported by various researchers, including Carriere *et al.* (2015) and Ranjith *et al.* (2010), indicating potential challenges to the efficacy of Bt toxins. India witnessed its first documented case of Bt technology breakdown in 2009, as pink bollworm (*Pectinophora gossypiella*) survived on BG-II cotton varieties. By 2015, extensive pink bollworm infestations afflicted regions in Gujarat, Andhra Pradesh, Maharashtra, and parts of Karnataka. In Maharashtra, a significant cotton-producing state, pink bollworm damage ranged from 40% to 95% (Fand *et al.*, 2019). The emergence of resistance to Cry1Ac and Cry2Ab toxins in the pink bollworm population was scientifically substantiated through research conducted by the Central Institute for Cotton Research (CICR) in Nagpur, India (Naik *et al.*, 2018).

The sustainability of Bt transgenic traits combating bollworm species in Indian cotton cultivation is currently facing challenges. The occurrence of pink bollworm survival in BG-II cotton fields in Gujarat, India, marked a shift from the Cry2Ab toxin resistance in pink bollworms being purely academic knowledge. Substantial losses were incurred due to pink bollworm infestations in Bt cotton during 2013 and 2014 (Kranthi, 2015). The documented resistance of pink bollworms to Cry1Ac toxins (Ojha, 2014) and Cry1Ac+Cry2Ab toxins (Naik *et al.*, 2018) underscores the necessity of integrating alternative management strategies alongside GMO seed technology. Pink bollworm's nature as an internal-feeding insect, coupled with its less exposed life stages, hinders the efficacy of biocontrol or chemical approaches, prompting the adoption of integrated pest management (IPM) strategies (Henneberry and Naranjo, 1998). Consequently, this study evaluates selective tools for pink bollworm management, aiming to formulate a versatile IPM framework.

Significant research has been dedicated in investigating the influence of cultural practices on pink bollworm survival, unveiling their substantial role in reducing overwintering populations. A study conducted by Adkisson *et al*. (1960) reported an over 80 percent decrease in moth emergence from fields subjected to shredding and ploughing. During the diapause period, larvae usually inhabit immature cotton bolls, debris, and soil (Bariola, 1984). To curtail the overwintering population, a practical strategy involves the removal of immature cotton bolls toward the season's end (Kittock *et al.*, 1973). Numerous cultural control techniques, such as timely sowing (Variya *et al.*, 2023), narrowing sowing windows (Henneberry *et al.*, 1982), crop termination (Watson, 1978), stalk shredding, disking, ploughing, and winter irrigation, have shown their efficacy in causing significant mortality among diapausing larvae in bolls, debris, and soil (Watson, 1980). Nevertheless, adjustments in sowing practices (Javaid, 1995; Ingole *et al*., 2019) and crop termination dates remain contingent on specific geographical contexts (Javaid, 1995; Watson *et al*., 1978; Khakwani *et al*., 2022).

In various global regions, extensive research has been conducted to address pink bollworm management through a range of tools and technologies centred around pheromones, including mass trapping (Agenor Mafra Neto and Mohamed Habib, 1996) and mating disruption (Lykouressis *et al*., 2005). Therefore, there is a need to assess the effectiveness of employing pheromone traps in integrated pest management (IPM) strategies for pink bollworm (Table 1). Nonetheless, while mating disruption techniques have also demonstrated promising outcomes in pest management, their application has been hindered by unavailability. In contrast, the integration of pheromone traps has been observed as a safe approach for preserving natural enemies within the arthropod ecosystem (Udikeri *et al*., 2022). Notably, in Egypt, the most substantial reduction in PBW infestations was observed in mass-trapped fields, followed by fields with released parasitoids (Darwish *et al*., 2017), whereas insecticide applications correlated with higher infestation rates. Similarly, a decrease in seasonal green boll infestation percentages was observed in both parasitoid release and mass-trapping plots compared to plots treated with insecticides (Darwish *et al*., 2017; El-Bassouiny *et al*., 2021).

Exploring biocontrol alternatives, various egg parasitoids including *Trichogrammatoidea bactrae* (Naik *et al*., 2019), *T. evanescens* (El-Hafez *et al*., 2007; Abd El-Hafez, 2004), *Trichogramma embryophagum*, *Trichogramma brassicae* (Abd El-Hafez, 2004), *T.* sp. *nearguamensis* (Sekhon and Varma, 1983), as well as egg-larval parasitoids like *Chelonus* sp. (Sekhon and Varma, 1983) and *Chelonus* sp. nr. *curvimaculatus* (Hentz *et al*., 1998), and larval parasitoids such as *Apanteles angaleti*, *Bracon greeni*, *Camptothlipsis* sp., *Rogas* sp., *Elasmus johnstoni*, *Goniozus* sp., and *Scambus lineipes* (Sekhon and Varma, 1983) have been documented. Notably, among these, egg parasitoids, particularly *T. bactrae*, have emerged as a dependable choice due to their target specificity, cost-effectiveness (Almeida, 1996), ease of mass production (Jalali, 2016), and notable reduction in pink bollworm populations in field conditions (as outlined in Table 2). Successful pink bollworm management has even been achieved by synergizing *Trichogramma* with chemical control approaches (Sarwar, 2017; Shree *et al*., 2023), indicating their potential integration into the existing Integrated Pest Management (IPM) strategies to combat pink bollworm infestations.

Similarly, entomopathogenic fungi demonstrated effectiveness in causing mortality across various developmental stages of *P. gossypiella* and *B. bassiana* exhibited greater toxicity induction compared to M. anisopliae (Omar *et al*., 2021) under laboratory bioassay studies. Compatibility studies also showed the highest mortality rates when combining *V. lecanii*, *M. anisopliae* and *B. bassiana* with A. indica extract. However, *B. bassiana* showing superior mycosis and sporulation on PBW larvae under controlled condition (Farooq *et al*., 2020). There is a significant need for further research to assess the field efficacy of entomopathogens and determine the appropriate dosage levels.

Another essential facet within the framework of IPM is the utilization of chemical pesticides. While chemicals constitute a significant strategy within cotton IPM, the market's availability of insecticides tailored specifically to target PBW remains limited. Despite this, farmers often employ chemicals without sufficient understanding of their efficacy or the biological traits of the pest. Profenophos effectiveness, particularly in PBW management, has been previously underscored (as seen in Table 3), owing largely to its ovicidal and larvicidal properties. Conversely, pyrethroids are recognized for their swift knockdown and adulticidal effects on PBW (Gopalaswamy *et al*., 2000). A judicious approach is required for employing selective insecticides (excluding pyrethroids) during the later stages of crop growth to avert aphid resurgence. Synthetic pyrethroids like Cypermethrin 25 EC and Deltamethrin 2.8 EC exhibited higher efficacy, as highlighted by various researchers (Dandale *et al*., 2001, Prasad *et al*., 2007, Varia *et al*., 2020). The application of chemical pesticides is recommended when trap catches exceed 8 per day for three consecutive days or when 10% rosette flowers or 10% damaged green bolls are observed (Narayanamma *et al*., 2022).

Hence, a holistic approach that encompasses the various facets of IPM is imperative for the effective management of PBW. In alignment with this perspective, numerous researchers have evaluated the individual components of IPM, seeking to seamlessly integrate them into practical IPM applications. Even the validation of the developed IPM module (as outlined in Table 4) for pink bollworm management (Variya *et al*., 2023, Rajashekhar *et al*., 2022, Udikeri *et al*., 2022) has yielded optimal outcomes. These integrated approaches have demonstrated superior performance in PBW management, showcasing reduced occurrences of rosette flowers, larval infestations, green boll damage, and locule damage, while also resulting in higher yields and greater net returns in IPM-based cultivated fields, as compared to conventional farmer practices (Patil *et al*., 2011; Jahnavi *et al*., 2019; Rajashekhar *et al*., 2022).

Summarily, the IPM-PBW module should encompass the subsequent strategies to achieve efficient pest management.

- Optimal sowing time (varies by location)
- Implement field sanitation, clearing old stalks, and eliminating unopened and partly opened bolls
- Select verified Bt cotton seeds for sowing
- Avoid storing infested or stained cotton
- Deploy pheromone traps for mass trapping of pink bollworm (>20 traps/ha) at 45 Days after Sowing (DAS)
- Commence monitoring from 45 DAS using pheromone traps at a rate of 5/ha
- An Economic Threshold Level (ETL) is reached at 8 moth captures per pheromone trap for three consecutive days; if surpassed, targeted ovicidal and larvicidal insecticides can be applied as needed.
- Release the egg parasitoid *T. bactrae* during flowering and boll formation (release quantity and dosage vary with pest severity, location, and climate)
- 10% green boll and flower damage serves as the ETL; if exceeded, application of insecticides like Neem-based formulation @ 1500 ppm, Lambda-cyhalothrin 2.5 EC, Deltamethrin 2.8 EC, and Chlorpyriphos 20 EC is recommended (usage based on need and rotation among different insecticide groups)
- Carry out timely crop termination (varies with location)

Conclusion

In conclusion, implementing integrated pest management (IPM) for pink bollworm in cotton offers sustainable pest control through a multifaceted approach. By integrating natural enemies and careful insecticide use, farmers can reduce pink bollworm populations while maintaining ecosystem balance. Cultural tactics like early planting and trap crops further disrupt the pest's lifecycle. IPM's economic benefits include reduced reliance on costly chemicals and increased yields, improving farmer livelihoods while minimizing environmental impact. Successful IPM hinges on ongoing monitoring, timely decisions, and farmer education. Collaboration among stakeholders is vital to fully realize IPM's potential in countering pink bollworm and securing cotton production's future. In essence, IPM aligns pest management with sustainability, offering a holistic solution that safeguards crops, the environment, and farming communities' prosperity.

Table 1. Evaluation of pheromone trap for PBW management in cotton

Sl. No.	Pheromone trap type	Rosette flower (%)		Green boll damage (%)		Yield (q/ha)		Author
		Treated	Control	Treated	Control	Treated	Control	
Mass trap								
1	Sleeve traps (Phero-sensor SP) @20/ha	-	-	12.05	28.11	16.68	14.55	Udikeri *et al*., 2022
2	Sleeve traps @ 35/ha	-	-	23.8	10.8	21.98	17.13	Patil *et al*., 2008
3	Sleeve traps @ 60/ha	11.64	20.71	15.52	25.98	30.78	19.52	Suthar *et al.*, 2019
Mating disruption								
1	SPLAT-PBW 500 g/acre	8.23	Higher than treated	7.36	Higher than treated	33.59	22.33	Sreenivas *et al*., 2021
2	SPLAT-PBW @ 1250 g/acre	3.88	17.32	3.67	22.57	50.00	23.85	Sreenivas *et al*., 2019
3	SPLAT @ 400 g/ha	1.90	20.43	1.33	14.99	30.89	20.81	Jethva *et al*., 2018
4	PB-rope L @ 80/acre	-	-	5.88	12.47	24.95	22.45	Radhika and Reddy, 2006

Table 2. Evaluation of natural enemy for PBW management in cotton

Sl. No.	Natural enemy	Rosette flower (%)		Green boll damage (%)		Larval incidence Per boll		Yield (q/ha)		Author
		Treated	Control	Treated	Control	Treated	Control	Treated	Control	
1	*T. bactrae* (3 release b/w 50-90 days after sowing at 2.5 la/ha	3.15	14.25	9.30	13.10	-	-	17.81	16.46	Udikeri *et al*., 2022
2	*T. bactrae* (12 sequential releases of *T. bactrae* from the flowering stage onwards	1.7	2.7	-	-	1.5	3.5	27.73	Less than treated	Kumara *et al*., 2022

Table 3. Bio efficacy of insecticides against PBW in cotton

Sl. No.	Insecticide	Green boll damage (%)		Larval incidence Per boll		Yield (q/ha)		Author
		Treated	Control	Treated	Control	Treated	Control	
1	Profenophos 50 EC	5.40	14.35	2.97/ 50 bolls	8.65/ 50 bolls	17.73	10.93	Udikeri *et al.*, 2022
2	Thiodicarb 70 SP	4.46	16.00	3.96/ 20 bolls	23.41/ 20 bolls	18.37	9.53	Patil *et al.*, 2009
3	Profenophos 50 EC	26.48	34.39	-	-	-	-	Hnialum *et al.*, 2023

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Ambrosia beetle: An emerging pest of arecanut palm

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Introduction

Arecanut (*Areca catechu* L.) is commonly known as betel nut palm and is an important commercial crop in most South Asian countries (Thube *et al.* 2018). In India, it is mainly grown in coastal, plain and hilly regions of states such as Karnataka, Kerala, Tamil Nadu, West Bengal and Assam. India is the largest producer of arecanut worldwide, producing 15.65 lakh metric tonnes from an area of 7.8 lakh hectares (Anon, 2022). The yield potential of arecanut is greatly influenced by both biotic and abiotic factors such as cultural operations, nutrients, pest and diseases, soil type and weather parameters. Among them, the incidence of pest and diseases pose a serious threat and are major limiting factors on arecanut production. The important insect pests include white grub, inflorescence caterpillar, pentatomid and spindle bug (Mohan *et al.* 2022). However, occurrence of new insect pests in the plantation-based ecosystem often correlated with climate change (Madhu *et al.* 2023). Recently, a new beetle pest, commonly known as 'Ambrosia beetle' is becoming a serious threat on areca palms and is causing significant damage under favourable conditions.

Two species of ambrosia beetle, *viz.*, *Xylosandrus crassiusculus* (Motschulsky, 1866) and *Euplatypus parallelus* (Fabricius) (Coleoptera: Curculionidae: Platypodinae) infest areca palms and they are more prevalent in poorly managed orchards. Presently, they are distributed worldwide and are known to cause damage to more than 200 species of trees belonging to 60 families (EPPO, 2021). However, these beetles are commonly noticed in forest trees, fruit orchards and other perennial crops. In India, these also called as pin hole borers and were first reported in Kerala and Karnataka on arecanut palms recently (Sreekumar *et al.* 2018: Thube *et al.* 2018). The adult beetles make small galleries and inoculate them with mutualistic fungi (*Ambosiella xylebori* and *A. roeperi)*, which serve as a food source for the developing broods. They maintain a close association with a specific fungi group known as Ambrosia, which resides in a specialized pocket of a glandular tissue called 'Mycangia' (Gebhardt *et* *al.* 2005). Hence, these borers are referred to as Ambrosia beetles.

Association with fungi

These beetles are fungivorous and live mutualistically with species-specific fungi. After finding a suitable tree, adult beetles excavate a tunnel and inoculate the spore of the fungal symbiont. Further, continuous burrowing of the beetle by chewing internal tissue allows rapid multiplication of fungus. The fungus is benefited from the nitrogenous waste of the insect as a source of nutrition and the larvae of beetle are exclusively mycetophagous. In addition, it also provides nourishment for adult beetles (Harrington, 2005). Further, the fungus may weaken the plant tissue for several days and thus facilitates further excavation of tunnel by the larvae. However, subsequent succession of other non-specific fungi may hasten the decaying of palms. With this mutualistic relationship, these beetles expand their host range under changing climatic conditions (Thube *et al.* 2022).

Nature of symptoms and damage on arecanut

Generally, these beetles attack stressed woody host plants and are found more frequently on thin-barked surfaces. However, in recent times, this pest has been found infesting healthy palms, which includes stem and nuts. Upon infestation on younger palms, oozing of a yellowish-brown resinous exudation from infested stems can be noticed. In addition, small or pinhead size holes can be seen after removal of the resinous exudation and the severely infested nuts may fall prematurely. Whereas, in older/stressed/ diseased palms, a typical extrusion of fine wood powder outside can be seen at the entrance (Fig 2). Sometimes, foliage wilting, canopy dieback, branch and trunk necrosis can also be seen after penetration of beetle towards plant tissues and settlement of symbiotic fungus. They are most active from March to April; however, activity can be seen throughout the year at a lower level. Furthermore, the polyphagous nature and dispersal capabilities of these tiny species, combined with their great efficiency in locating and colonizing stressed plants make it difficult to control *X. crassiusculus* and *E. parallelus* under its invaded range (Gugliuzzo *et al.,* 2021).

Management

It is practically difficult to control this pest using chemical measures once they enter the tunnel. Therefore, the timing of preventive insecticide application is crucial to protect palms from damage by this pest.

1. If infested, remove the resinous exudation/sawdust frass and swabbing the infested stem with Chlorpyriphos 20EC@ 5ml/litre. Further, apply wet soil over the swabbed stem to improve treatment efficiency.

2. Heavily infested palms should be cut and destroyed to prevent subsequent succession on healthy palms.

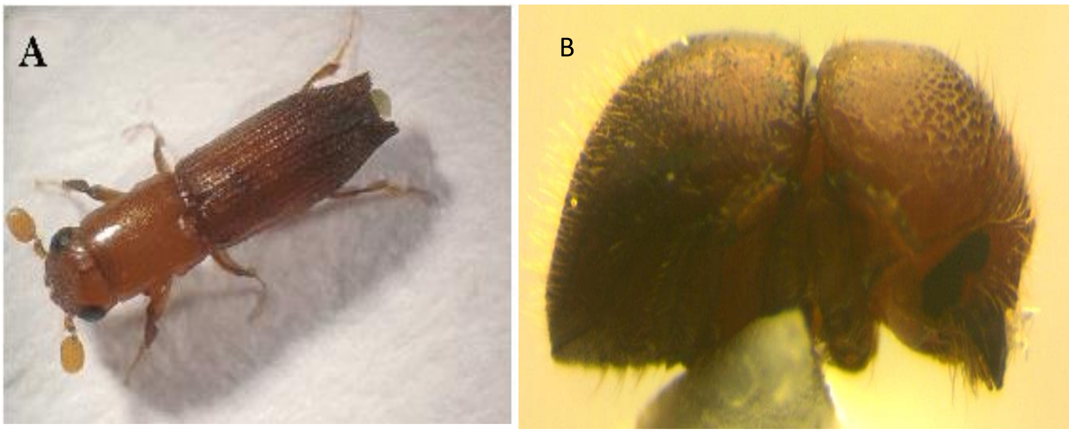

Fig. 1. Ambrosia beetle, *Euplatypus parallelus* (A) and *Xylosandrus crassiusculus* (B)

Fig. 2. Symptoms of Ambrosia beetle on nuts and stem. Presence of typical frass noodle on infested nuts (A & B). Multiple entrance holes and dark staining of exocarp(C). Bored holes on kernel (D). Extrusion of fine wood powder outside the entrance on stem

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Short notes

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First report of the leaf beetle, *Madurasia undulatovittata* Motschulsky, (Coleoptera: Chrysomelidae: Galerucinae: Galerucini) on green gram from middle Gujarat, India

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Pulses or food legumes are nutritionally balanced food to the people of India and many other countries throughout the world (Nene, 2006). The major pulse crops are green gram, black gram, chickpea, pigeon pea, cowpea, faba bean, grass pea, lablab bean, lentil, moth bean and pea (Swaminathan *et al*., 2012). Among the different pulses, green gram is one of the important short-duration crop and is cultivated in the *Kharif* and summer as well. Green gram/mung bean, *Vigna radiata* (L.) Wilczek [Synonyms: *Phaseolus radiatus* L. (1753), *Phaseolus aureus* Roxb. (1832)], is native to India and Central Asia (Swaminathan *et al*., 2012). The insect-pest spectra that infest green gram include more than 40 species (Haripriya and Jeyarani, 2019). The annual yield loss due the insect-pests is estimated to be 30 per cent in mung bean and urd bean. On an average, 2.5 to 3.0 million tonnes of pulses are lost annually due to insect-pest problems (Rabindra *et al.*, 2004).Thrips (*Megalurothrips distalis* Karny), jassids (*Empoasca kerri* Pruthi) whiteflies (*Bemisia tabaci* Gennadius), gram pod borer (*Helicoverpa armigera* Hubner) and spotted pod borer (*Maruca vitrata* Fabricius) are major insect-pest causing considerable yield loss in green gram (Singh *et al.*, 2016; Mahalakshmi *et al.*, 2018).

The present study was conducted to know the activity of different insect-pests of green gram during *Kharif,* 2021 at Agricultural Research Station, Anand Agricultural University, Derol, Gujarat. During the survey, a new coleopteran pest was found infesting leaves of green gram. It was collected from the field and brought to the laboratory for further investigation. The collected beetle was released on the green gram leaves under laboratory conditions for confirmation of damage by the beetle. After close evaluation under the microscope, a newer one was found and sent for identification. For this purpose, the adults were collected and then kept in 70 per cent alcohol filled in a glass vial. These were sent to Dr. K. D. Prathapan, Kerala Agricultural University, Vellayani (India). It was identified as *Madurasia undulatovittata* Motschulsky.

The adult leaf beetle, *M. undulatovittata*, is small, pale brown in colour and measures 2.0–3.0 mm in length, 1.0–1.3 mm in width and it is 2.0–2.3 times longer than wide (Prathapan, 2016) (Fig. 1). The head is dark brown to pale brown, often darker than pronotum. Pronotum is more or less pale brown, generally paler than the head. Background color of elytron is paler than pronotum. Adults of *M. undulatovittata* feed on foliage and make small circular holes on the entire leaf surface of green gram (Fig. 2). The affected plants were visible from a long distance due to the numerous tiny shot holes and scraping of chlorophyll over the entire leaves. At dusk and early morning, the beetles eat the crops and adults hide in cracks and crevices of the soil during the daytime. Infestation of this pest starts from the seedling of green gram *i.e.,* 2nd week of August to 4th week of September. A heavy infestation was observed before flowering stage. In the past, this pest was not reported on green gram from Gujarat, making this the first report. It is also observed on gum guar, *Cyamopsis tetragonoloba*.

The *M. undulatovittata* is widely distributed in Africa (Sudan); Asia (Bangladesh, India [Andhra Pradesh, Bihar, Gujarat, Haryana, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Meghalaya, New Delhi, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh, Uttarakhand, West Bengal], Nepal, Sri Lanka, Yemen). Recently revised genus *Madurasia* Jacoby (Coleoptera: Chrysomelidae) and the species *Madurasia obscurella* Jacoby are synonymized with *M. undulatovittata* Motschulsky (Coleoptera: Chrysomelidae) Prathapan (2016). Adults lay eggs singly on soil near the root zone of the crop (Oza *et al.*, 1996). Larvae feed on the root hairs and on root nodules whereas adult beetles feed on leaves, buds and leaves and also on the buds and flowers of pigeon pea (Gupta and Singh, 1981; Gowda *et al.,* 2006 and Prathapan, 2016). During the rainy season, this pest has been noticed in *Vigna* spp., *Glycine* spp., *Phaseolus* spp., *Cajanus cajan* and as a vector of bean southern mosaic virus (Reddy and Verma, 1986; Swaminathan *et al.,* 2012). It may cause up to 10-20 per cent losses during pod and seed development stages in soybean (Babu, 2017). Swaminathan *et al*. (2012) reported up to 20-60 per cent losses in green gram due to *M. undulatovittata*. Grubs feed on root nodules and make holes by entering inside the root nodules causing 25 to 60 per cent losses in mungbean and urdbean (Sharma *et al.*, 2012). Babu (2017) also reported the infestation of soybean which correlated with high temperatures and prevailed after continuous dry spell in the zone during the 37th Standard week (2nd week of September). According to Srivastava and Singh (1976), *M. undulatovittata* infestation during the early stage of the crop may lead to serious damage to the soybean crop as reported that the growth of the plants is retarded due to severe foliage damage in young plants. The available literature on this pest indicated that there was no report of this pest on the green gram in

Gujarat. Therefore, this is the first report of *M. undulatovittata* as a pest of green gram in Gujarat.

Fig. 1: Overview of adult of the leaf beetle, *Madurasia undulatovittata* Motschulsky

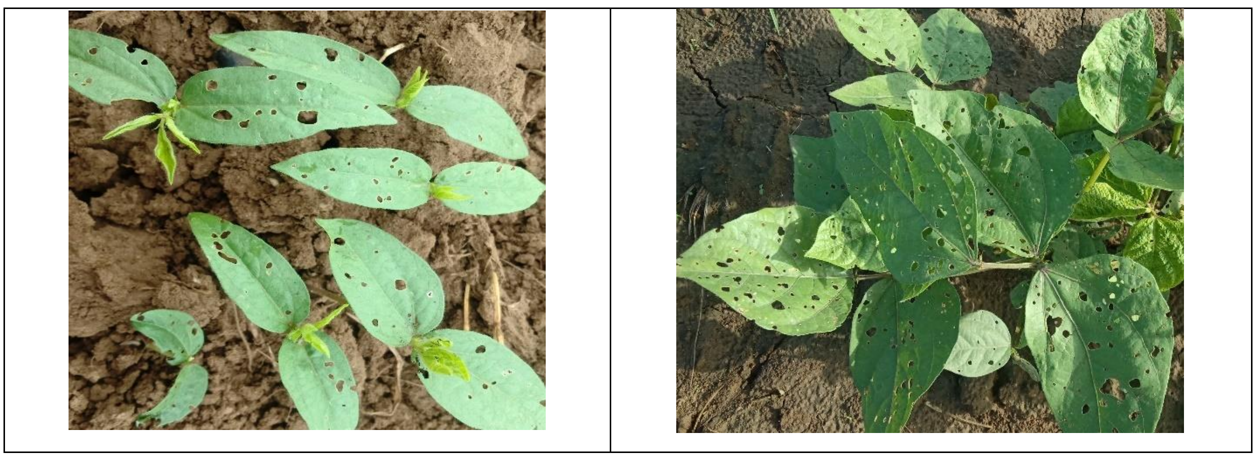

Fig. 2: Damage symptoms by adult of *Madurasia undulatovittata* Motschulsky

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Pollination of *Moringa oleifera* (Moringaceae) by *Amegilla zonata* (Linnaeus, 1758)

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Moringa oleifera commonly known as drumstick or moringa is a vegetable native to India. Cultivation of drumstick in India is prominent in the southern states of India like Tamil Nadu, Karnataka, Kerala, and Andhra Pradesh (Srinivasan *et al*., 2021). Moringa flowers are zygomorphic and gullet type, that open from early morning to most part of the day. *Xylocopa* spp and *Amegilla* carry pollen on their heads/thorax to bring about nototribic pollination (Jyothi *et al* 1990). 27 pollinator species in a moringa orchard in Tamil Nādu, comprising Hymenopteran, Dipteran and Lepidopteran was recorded by Soumya *et al*., 2018 of which most abundant was *Apis cerana* indica followed by *Amegilla zonata* and *Apis dorsata.*

We observed a dozen drumstick tress (*M. oleifera*) in the backyards of urban Bengaluru city during July 2023.The only insect visiting flowers was *Amegilla zonata*. About 1-2 visited the flowering trees in first two weeks of July by end July and early August pods set. Unlike *Apis* bees, *Amegilla* are rapid visitors, spend less time on a flower and seem to fly from one flower to another in a streakish disorderly manner; nevertheless they seem to have contributed to the pollination and pod setting. Earlier we had reported *Xylocopa* foraging on Moringa (Verghese, 2022)

Moringa trees tucked within urban environs do not seem to have the luxury of an array of pollinators. However, flower visitors have been recorded not making any meaningful contact with stamens on stigma except for *Xylocopa* and *Amegilla* whose body washings showed pollen grains (Jyothi *et al* 1990) We also noticed purple-rumped sunbirds (*Nectarinia asiatica*) probing these flowers in the morning hours. They are also said to bring about pollination (Ali, 1988 Handbook of birds of India, Bombay Natural History Society).

Fig 1. ***Amegilla zonata on Moringa oleifera flowers***

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Non-nest associated congregation in drones of *Meliponines*

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The eusocial stingless bees are the most abundant bees on earth and are limited to tropical and subtropical areas. Generally, eusocial insects are quoted for their mysterious behaviors, and stingless bees are not exceptional. Like honey bees, stingless bees also have a well-defined caste system. A stingless bee colony consists of three members, *i.e.,* queen, drone, and worker. Each caste in the colony exhibits different behaviours both inside and outside the nest. The picture shown here completely deals with drones' behavior. The only sole function of the drone is to impregnate the young queen. For that, it exhibits a behaviour called 'drone congregation'. The drones form nest associated, and non-nest associated drone congregation. Nest associated drone congregation occurs at the nest's entrance containing gynes (virgin queen), where the drones hover from dawn to dusk with intermittent short periods of rest.

Fig 1 shows 'non-nest associated drone congregation' activity near the nest congregation area. The present study was conducted near the Division of Basic Sciences, in ICAR-Indian Institute of Horticultural Research, Bengaluru, Karnataka (13.1348° N Latitude and 77.4960° E Longitude) during May 2023. The drones hovered around the canopy of nearby trees, and they formed clusters on twigs called sleeping threads (Figure 1). In the present observation, it was 15 m from the nest in a wall. There was no association of these bees with their nest, and, no excitement was found at the nest entrance in seven days of observation. All the males in the sleeping threads were motionless and showed no interest in the nest. When disturbed, the entire group immediately took off and disappeared from that twig and again congregated in another undisturbed twig. The time of commencement and time of cessation of the drone's activity is erratic. This typical non-nest associated drone congregation at sites distant from the maternal nests of the drones, where drones usually compete for mating, signifies the importance of males in stingless bees.

Fig. 1 Sleeping threads of stingless bees

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First report on the tropical fire ant, *Solonopsis geminate* (Fabricius) as flower damaging pest of moringa (*Moringa oleifera* Lam.) cultivated near the Western Ghats of Dindigul, Tamil Nadu

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Moringa (*Moringa oleifera* Lam.) is an important vegetable crop belonging to the family Moringaceae. It is distributed throughout the world, and majorly cultivated in India, Africa, Sri Lanka, Mexico, Malaysia and the Philippines. India is the largest producer of moringa pods in the world with a production of 2.2 million tonnes from a 43,600-hectare area. Tamil Nadu is one of the leading moringa pod-producing states in India occupying 13,062 hectares of cultivable land (Jyothi, 2018). The Karur, Theni, Madurai, Dindigul and Coimbatore districts of Tamil Nadu are leading in the production of both annual and perennial moringa types. The pod production in perennial moringa is majorly affected by various biotic and abiotic factors. Insect pests are the major drawback in moringa pod production. The perennial moringa types are comparatively vulnerable to insect pests. Irrespective of their pest status in the earlier reports, more than 70 insect pest species were recorded on moringa associated with leaves, flowers, pods, stem and root of moringa in India which includes 13 species of borers or internal feeders, 16 species of defoliators, 22 species of sap-feeding or sucking pests and 21 species of weevils/beetles/bark-eating pests (Kotikal and Math, 2016).

Solenopsis geminata (Fabricius) (Hymenoptera: Formicidae) commonly known as tropical fire ants are widely distributed worldwide. It infests more than twenty crops including brinjal, bhendi, sorghum, tomato, citrus, avocados, coffee, cocoa, corn, tobacco and soybean. Infestation occurs at various stages of the crops including the seedling stage, flowers, fruits and stems (Sasinathan, 2018; Nalini and Sasinathan, 2019; CABI, 2022).

We studied the insect pest incidence in perennial moringa cultivated near western ghats and during the study we observed the incidence of *S. geminata* on moringa buds and flowers in the moringa orchard located in Vattaparai village, Dindigul district of Tamil Nadu (Latitude:10.3385827, Longitude: 77.8887517). There are no earlier records of tropical fire ants as a pest damaging the moringa flowers. We observed twenty inflorescences in randomly selected five trees (Variety: Karumbu) which were not sprayed with plant protectant chemicals to record the ant incidence. The observations were taken both in the summer and kharif seasons of moringa during 2021. However, the incidence occurred only in the summer season and ant incidence was cleared in the trees which were sprayed with chemicals. The tropical fire ants heavily fed on the inner portion of the flowers including stamen and carpel and they bore into unopened flowers and fed the inner portion before the opening of the flowers. The inflorescence heavily infested with ants failed to produce moringa pods. However, the ant infestation was negligible in the fields sprayed with pesticides.

Hence, we planned further research to record the seasonal incidence and the influence of weather factors on tropical fire ants in moringa and to assess the damage potential of red ants on moringa flowers. Such findings will be helpful if tropical fire ants become a significant threat to moringa production.

Fig 1. Ants infesting unopened flower buds

Fig 2. Ants infesting opened flowers

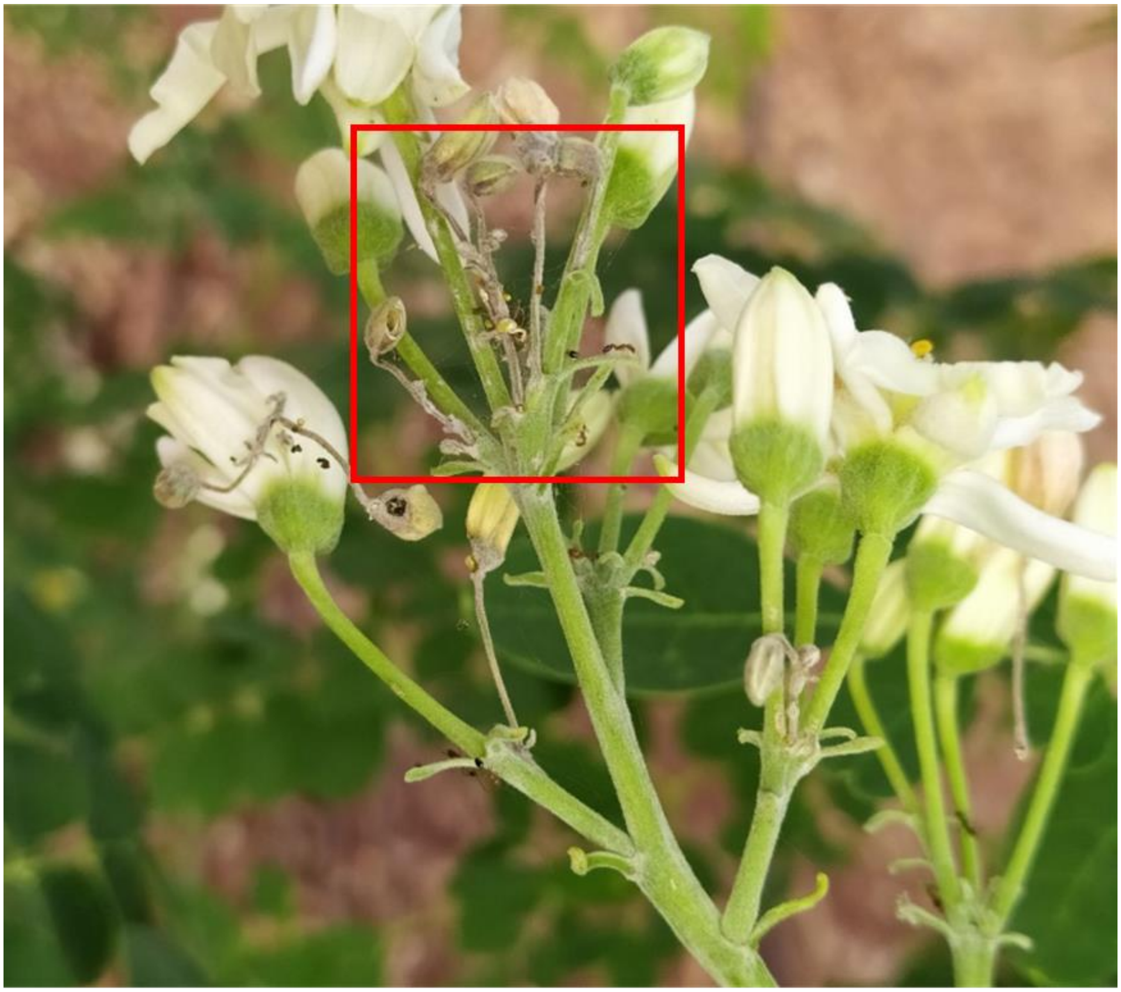

Fig. 3. Drying of bud/flowers after ant infestation

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A note on the immune system and defence mechanism in honey bees

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Honey bees belong to the family Apidae of the order Hymenoptera among which, eusocial bees belong to the subfamily Apinae and Meliponinae. Honeybees are the most important pollinators of agricultural and horticultural crops. However, due to environmental stress, they exhibit a high annual colony loss in the US (Brutscher *et al*., 2016; Kulhanek *et al*., 2017) and over-wintering colony losses in Europe (Hung *et al*., 2018). In order to overcome the harmful effects of parasites and pathogens, bees have evolved both individual and group defence strategies.

Defence mechanism in honey bees

Social insects have evolved both individual and group strategies to combat disease. Grooming, nest hygiene, and other behavioral traits found in social insects can reduce the impacts of pathogenic bacteria, fungi, and parasitic mites.

Social immune defence

Social immunity is defined as any defense against parasites and pathogens that evolved and is maintained due to the benefits derived by group members (Meunier, 2015).

1. Polyandry and genetic diversity

Multiple mating of the queen is referred to as polyandry. The queen typically mates with 5 to 35 males. It results in colonies with high levels of genetic diversity. Colonies with increased levels of genetic diversity exhibit increased fitness and productivity (Mattila and Seeley, 2007), increased foraging efficiency (Eckholm *et al*., 2011), healthier gut microbial communities (Mattila *et al*., 2012), and better survival in commercial beekeeping (Tarpy *et al*., 2013).

2. Task allocation

Task allocation promotes task efficiency and prevents the spread of pathogens and parasites within colonies. The tasks assigned to bees are largely guided by bee age, known as temporal polyethism.

3. Use of antimicrobial compounds

3.1. Use of self-produced compounds

Venom peptides on the honey bee cuticle have antimicrobial properties (Moreau, 2013) and may have a direct effect against pathogens as has been shown in some ant species (Tragust *et al.*, 2013)

3.2. Collection and use of plant-based defensive compounds

Honey bees forage for plant resins, mix them with varying amounts of wax and incorporate them into their nest architecture as propolis. The propolis may function as an initial barrier against pests.

4. Grooming

Grooming is generally a first line of defence against invading microorganisms. Grooming at the individual level can effectively eliminate the mites at the colony level. Social immunization (Konrad *et al.,* 2012) and trans-generational immune priming, (Lopez *et al.,*2014) also prevent pathogen infection.

5. Hygienic behaviour

Hygienic behaviour is the detection and removal of infected brood (Evans and Spivak, 2010). It is assessed using the freeze-killed brood assay, where a section of brood is frozen, and the removal of these dead pupae after 24 hours is determined. Varroa Sensitive Hygiene (VSH) is a trait that has been under selection as part of a breeding program (Danka *et al.*, 2016).

6. Highly induced colony responses: social fever and absconding

Honey bees increase the brood nest temperature slightly to inhibit the development of chalkbrood symptoms in infected larvae (Starks *et al.,* 2000). Colony-level infection can cause honey bees to leave the nest behind and restart in a new, disease-free hive. Some other behavioral defense approaches are stinging and biting, guarding, fanning, shimmering behavior, bee balling, and protective body covering (Nouvian *et al.*, 2016).

Individual immune defence

Insect innate immunity constitutes evolutionarily conserved defense strategies that provide immediate responses against invading pathogens. It consists of the three levels of resistance: physical barriers as the first line of defense, cell-mediated immunity, and cell-free humoral immunity. A complex network of intracellular signaling pathways like Toll, Imd, JNK, AND JAK-STAT Pathway (Evans *et al.,*2006) leads to the activation of a variety of humoral factors.

Conclusions

Immunity and defense are an evolutionary process and have developed over a long period of time. It occurs at two levels *i.e.,* social level and individual level. Social defence is more pronounced in comparison to individual defence. Maintaining good colony strength helps in fighting different stresses at the colony level. Selecting a colony with high social or individual level defence can be exploited in a bee breeding program.

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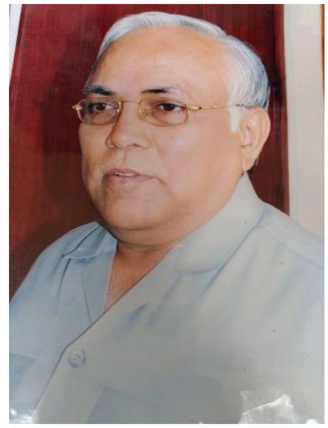
MS Accepted on 10th September 2023

Obituary

Dr. Pawar Vinayak Motiram



Born on 23rd August 1947 in the village of Pimpalgaon, Malegaon taluk in the Nashik District, India, Dr. Pawar began his schooling there. He acquired his agricultural education from the College of Agriculture, Pune and subsequently at the Indian Agricultural Research Institute, New Delhi. Being a merit student throughout, Dr. Pawar obtained a Ph.D. degree in 1974 and did his post-doctoral studies at the Institute of Virology, Oxford, U.K. from 1979-80 where he also learned French. He was proficient in English, Marathi, Hindi, French and Sanskrit.

Dr. Pawar started his career as Assistant Professor of Entomology at Mahatma Phule Krishi Vidyapeeth, Rahuri. He was also an Entomologist (Pulses), Professor of Entomology, and Senior Insect Toxicologist, at the Pesticide Research Centre in Marathwada Agricultural University, Parbinani. Later he rose to the post of Professor and Head, Department of Entomology, and also held posts such as Associate Dean, Post Graduate Institute, Associate Dean & Principal, Director of Extension Education and Dean, Faculty of Agriculture and Director of Instructions, Mahatma Phule Krishi Vidyapeeth, Rahuri. He was also the Vice-Chancellor of Marathwada Agricultural University, Parbhani. Dr. Pawar was recipient of prestigious awards such as the Young Scientist Medal, Hexamar Award, ICAR/IARI Fellowships, Commonwealth Fellowship, and several merit certificates.

During his stay in the UK, he visited several well-known laboratories and harnessed linkages. Devoted to his profession, he was an active member of various professional societies across India and abroad. He has extensively visited various countries like the United Kingdom, Italy, the Philippines, and Thailand. His contributions to various branches of entomology such as biology, ecology, and control of crop pests including life-tables of important pests, biological control especially microbial control, bio-efficacy, and residues of newer pesticides etc. have been acknowledged not only by the scientific community but also appreciated by the farmers. Dr. Pawar developed four commercial microbial pesticides namely Heliokill, Ajay, Splocide, and Magic. To bring honour to the academy, Dr. Pawar has performed several prestigious assignments such as Visiting Professor, Guest Teacher, University Professor on selection panels, scientific panels on education and entomology, quinquennial review team, research and scientific committees, etc. As an under-graduate and post-graduate teacher, Dr. Pawar taught several important courses and guided 11 Ph.D. and 19 M.Sc. students both at Marathwada Agricultural University, Parbhani, and Mahatma Phule Agricultural University, Rahuri in the fields of Economic Entomology, Toxicology, Biological Control and Insect Pathology.

He authored more than 125 research papers, and 45 popular articles in English and Marathi and co-authored "Handbook of Pesticides" for the benefit of students, teachers, and research workers. He generated funds grossing over Rs. 2.5 crores for research from ICAR, Department of Biotechnology (DBT), and R & D centres of several pesticide firms. He was also a Principal Investigator for the following biocontrol projects:

1.Biological Control of Key Pests of Pulses, Oil Seeds and Important Cash Crops.

2.Development, Production and Demonstration of Biological Control Agents.

3. Establishment of Insect Cell lines.

4. Women Entrepreneurship Programme on Practical Training in Biological Control

Receiving award from Smt. Indira Gandhi, late Prime Minister of India

Dr. Pawar at his office….

Tribute by Dr. S S Nakat

Principal Scientist and Professor, Biological Control

[Dr. Pawar was a friend and a great supporter of Insect Environment. I last saw him in Pune in 2016 when we met over an informal dinner at a hotel. Dr. Nakat was also present. Our respectful tributes….. Abraham Verghese]

Obituary to a beloved Professor

Remembering Prof. Dr. Jim Thomas

It was with great sadness that we learned of the demise of Dr. Jim Thomas, retired Professor of Agricultural Entomology, who passed away on 24th July, 2023. He was an extremely popular professor in Kerala Agricultural University that it wasn't easy for all those who knew him, to come to terms with this great loss.

Prof. Jim Thomas completed his B.Sc. (Ag.) degree programme from College of Agriculture, Vellayani, Trivandrum in 1977. Soon after, he joined as Junior Agricultural Officer in Cashew Development Scheme at Thalassery, Kannur district, Kerala He started his career in Kerala Agricultural University as a Junior Instructor (re-designated as Junior Assistant Professor) at Horticultural Research Station, Ambalawayal in 1978. While in service, he joined M.Sc. (Ag) in the Department of Agricultural Entomology, College of Agriculture, Vellayani. He completed his Masters' research programme on the 'Effects of levels of pesticides on the control of paddy pests ad water pollution' under the guidance of Dr. N. Mohandas, Professor and Head of the Department. He was then posted as Assistant Professor at Rice Research Station, Moncompu in the year 1982. During his tenure, he contributed immensely to rice pest management and was acclaimed as rice entomologist in the state of Kerala. In 1984, he joined for Ph. D. programme at IARI, where he worked under the guidance of Late Dr. K. G. Phadke on the topic 'Effectiveness of chlorpyriphos and quinalphos in the management of the aphid, *Lipaphis erysimi* in rape seed crop'. After completion of his doctoral degree programme in 1988, he was posted at College of Agriculture, Vellanikkara (formerly, College of Horticulture) in the Department of Agricultural Entomology. He became Associate Professor in 1988 and Professor in 1998.

In the Department, he was actively involved in teaching, research and extension activities. He offered courses like Insect Ecology, Insect Toxicology and Integrated Pest Management, regularly for Under Graduate and Post Graduate students. He served as research guide to two Ph. D and six Masters' students in the Department. His students remember him as a great teacher, who always instilled enthusiasm in them. With the treasure of knowledge, he had, he never would confine his lectures within the boundaries of syllabus. Even as a strict academician, he was a loving, approachable and compassionate teacher to his students.

He was a farm scientist in the true sense that many of his research projects involved experimental trials in farmers' fields. When the ICAR UK DFID project on 'Integrated management of fruit flies in India' was implemented during 2002 - 2005, he was one of the Principal Investigators of the project in Kerala Agricultural University. His contributions in developing an effective strategy for fruit fly management in fruit and vegetable crops in the state are remarkable. He was instrumental in popularising fruit fly traps in Kerala. He also contributed immensely to the management of coconut perianth mite, through area wide, farmer participatory management programmes, when the pest created havoc in the state.

He maintained a very good rapport with farming community in the state and was always available on their call. He was the first person to be consulted by extension officials in the state in situations of alarming pest problems in farmers' fields. Though a proponent of Integrated Pest Management, he never was hesitant to admit that 'insecticide usage in crop fields is not an ecological sin'.

Dr. Jim Thomas at his office

He shared a very close relationship with all his peers and was affectionately called as 'Jim bhai'. It is therefore, not surprising that he enjoyed a wide circle of friends, across institutions and profession. He also maintained good relationship with his junior faculty members, and always motivated them. During his tenure as Head of the Department, he spearheaded many developmental activities in the Department, and contributed much towards its progress. He also served the University in various administrative roles in capacities like Associate Director of Research and the Associate Dean of the College of Co-operation, Banking and Management. He retired from KAU service on superannuation in April, 2016. Even after retirement, he was actively involved in teaching, extension and many socially committed activities. He served as a faculty at Vananvarayar Institute of Agriculture at Pollachi for a brief period, where he headed the Department of Entomology. He was one of the resource persons of the Energy Conservation Society in the state that works towards energy conservation and environmental protection. He was the chairman of JACKTEN foundation, formed for promotion of jack cultivation in the state.

Prof. Jim Thomas is survived by his wife Smt. Susan Koshi (retired Professor, Sacred Heart College, Chalakkudy), sons Deepak and Vivek, daughters in law Anshita and Rita and grandchildren Sihika and Yohan. Prof. Jim Thomas will be remembered as a passionate teacher, a successful researcher, a farmer friendly extension personnel, and above all, a great human being.

Dr. Haseena Bhaskar
Professor (Agricultural Entomology)
College of Agriculture, Vellanikkara
Kerala Agricultural University

[I have known Jim Thomas from 2001 when he joined me as a co-worker in fruit fly program under ICAR-DFID (UK). Dr Thomas along with Dr. T. Jiji developed excellent IPM from fruit fly for fruits and cucurbits which is still being practiced. In fact, the para pheromone technology developed by our team and published in 2005 is still being manufactured by Kerala Agriculture University and are being given to the farmers. Insect Environment pays homage to the departed sole – Abraham Verghese]

INSECT LENS

Hoverfly, Phytomia incisa (Syrphidae: Diptera)* (*ID courtesy: Dr Georg Goergen, IITA)

Hoverfly is widely distributed around the world. It is a bumblebee mimic possessing clear black-yellow color pattern and can be easily recognized by the sturdy body with thick hairs. The adults can be found flying around the flowers of Theaceae and Ericacea and plays an important role of pollinator.

Author: *Dr. Sevgan Subramanian*

Location: *Baringo, Kenya*

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Lesser cucurbit fly, Dacus ciliatus (Tephritidae: Diptera)

D. ciliatus is a polyphagous fruit fly that damages cucurbitaceous crop. This species mostly occurs in high population densities in cultivated melons and to a lesser degree in wild cucurbits and causes serious damage to crops in India.

Author: *Dr. Sevgan Subramanian*

Location: *ICIPE, Kasarani, Nairobi, Kenya*

Email: *ssubramania@icipe.org*

Trophic interactions (Plant: Parthenium, Predator: Crab Spider, Thomisus sp. most likely T. citrinellus, Prey: Syrphid fly, Eristalinus quinquelineatus Fab. (Syrphidae: Diptera)

These crab spiders are capable of changing colours according to the habitat they occur. The decision process that goes behind the choice of colour by these spiders seems intriguing. Whether they try to merge with the background or do they try to project themselves as a flower in situations which might not be attractive to their prey? In these situations, the crab spider is very cautious not to leave the prey and it weighs its options carefully. It either decides to leave the prey and run for safety or it takes its chances with the intruder (myself). But it seems that it decided to take its chances and gave me ample opportunity to take this photograph.

Author: *Dr. Sevgan Subramanian*

Location: *ICIPE, Kasarani, Nairobi, Kenya (June 2023)*

Email: *ssubramania@icipe.org*

Eurybrachys tomentosa (Eurybrachidae: Hemiptera)

A common planthopper found on Sandal and Calotropis gigantea in South India. On sandal, the early instar nymphs and adults suck the sap from tender green shoots. This species is also responsible for stag-headedness prevalent in sandal forests.

Author: *Dr. Nagaraj, D.N Project Head (Entomologist) Ento Proteins Pvt., Ltd., Mangalore*

Location: *Bengaluru*

Email: *nasoteya@yahoo.co.in*

Wing polyphenism & vivipary in sow-thistle aphids, Uroleucon sp. (Aphididae, Hemiptera)

Recently when I was in the ICIPE farm with my insect photography walk, I observed a sow-thistle (Sonchus sp: Asteraceae), heavily infested with the sow-thistle Aphids, Uroleucon sp. (Aphididae: Hemiptera).

My attention was drawn to one of the moulting aphids, which was transforming to an alate form. Alate forms are formed when aphid senses overcrowding, unfavourable environment that aid in their wide dispersal, unlike the wingless forms that largely multiply in the same plant. After taking the photograph, when I looked at it in detail, I observed that I had actually captured two key biological processes of aphids in one frame.

The second process was vivipary. Observe the female, just before the moulting aphid and you will realise that it is giving live birth to a young aphid nymph.

Author: *Dr Sevgan Subramanian*

Location: *ICIPE, Nairobi, Kenya (June 2023)*

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Cotton Grasshopper, Cyrtacantha tartarica (Acrididae: Orthoptera)

Cyrtacanthacris tatarica is a species of bird grasshopper. It is found in the Afrotropic and Indomalaya region.

Author: *Dr. Nareah Talari*

Location: *Vadlamudi, Guntur, Andhra Pradesh*

Email: *drtn_ahs@vignan.ac.in*

Larvae of queen butterfly, Danaus gilippus (Nymphalidae: Lepidoptera)

Larvae feed on plants of Apocynaceae (milkweeds and dogbanes) and adults feed mainly on nectar from these flowers. Unpalatability to avian predators is a feature of this butterfly; however, its level is highly variable. Unpalatability is correlated with the level of cardenolides obtained through the larval diet.

Author: *Dr. Nareah Talari*

Location: *Vadlamudi, Guntur, Andhra Pradesh*

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Green lynx spider, Peucetia viridans Hentz (Oxyopidae: Araneae)

Lynx spiders are hunters specialized for living on plants. This species does not use a web to capture its prey. It pounces on its prey in a cat-like manner, which is the reason for the name lynx. They are active during the day.

Author: *Dr. Nagaraj, D.N Project Head (Entomologist) Ento. Proteins Pvt. Ltd., Mangalore*

Location: *In mulberry ecosystem near Srivilliputhur, Tamil Nadu, India*

Email: *nasoteya@yahoo.co.in*

The leaf twisting weevil, Apoderus tranquebaricus (Attelabidae: Coleoptera)

A. tranquebaricus is a minor pest of mango. When trees are affected, their leaves begin to twist from the tip, making them look twisted. This twisting happens because of the adult weevil. The weevil cuts and shapes the mango leaves making them roll up neatly like thimbles. These rolled leaves stay connected to the main leaves. Inside these rolled leaves, grub feeds on the leaf tissue. Manual removal of damaged leaves is best practice to manage this pest.

Author: *Dr. Nagaraj, D.N Project Head (Entomologist) Ento. Proteins Pvt. Ltd., Mangalore*

Location: *Bengaluru*

Email: *nasoteya@yahoo.co.in*

African Caper, Belenois aurota (Pieridae: Lepidoptera)

Belenois aurota is a small to medium-sized butterfly found in South Asia and Africa. In Africa, it is also known as the brown-veined white and is well known during summer and autumn when large numbers migrate north-east. Food plants of the larvae include Capparis zeylanica. In Africa, the host plants are almost exclusively from the family Capparaceae and in particular the genera Boscia, Maerua and Capparis.

Author: *Dr. Sevgan Subramanian*

Location: *ICIPE, Kasarani, Nairobi, Kenya*

Email: *ssubramania@icipe.org*

Larva of fruit piercing moth, Eudocima phalonia (Erebidae: Lepidoptera)

Larval hosts are primarily species of Menispermaceae and Erythrina (Fabaceae). When threatened, larva curls its head exposing the eye-spots, and at the same time lifting its tail. Depending on its orientation, you may even see a face with a wry mouth where the true legs are held against the second abdominal segment.

Author: *Dr. Pasupathy*

Location: *Nilgiris Biosphere area, Tamil Nadu, India*

Oleander hawkmoth, Daphnis nerii L., (Sphingidae: Lepidoptera)

Camouflage, also called cryptic coloration, it is a defence tactic that insects use to hide their outward show, usually to blend in with their surroundings. Organisms use camouflage to mask their location, identity, and movement. This allows prey to avoid predators and for predators to sneak up on prey.

Author: *Dr. Gaurang K Rudani*

Location*: Bidi Tobacco Research Station, Anand Agricultural University, Anand (22.57° N, 72.93° E, 30 MSL)*

Red Pierrot, Talicada* sp. *(Lycaenidae)

This Red Pierrot was captured with my iphone. Succulents attract these butterflies. The larvae mines on leaves of succulents.

Author: *Dr. Abraham Verghese*

Location: *Bengaluru*

Email: *abraham.avergis@gmail.com*

Silkworm, Bombyx mori, (Bombycidae)

*The male silk moth uses it's antennae to detect pheromones released from nearby female**.***

Author: *Prathika, R*

***Location**: Bengaluru*

Email: *prathiprathika08@gmail.com*

EXTENSION

OUTREACH BY RASHVEE-IPRS AND AVIAN TRUST

Visit to Vedic Hivery, an apiary maintained by Agri graduates on the foot hills of Nandi hills, near Bangalore city.

Profitable guava orchard: Regular consultation with quality inputs from experts

IE team with Dr. Jemla Naik D., Professor & Head and Dr. Shivanna, B, Professor, Department of Entomology, University of Agricultural Sciences, Bangalore

Attended 38th Annual Conference of the International Society of Chemical Ecology which was held in Bangalore between 23–27 July 2023

Survey on fruit fly trap usage and guidance on fruit fly management to gherkin growers and exporters, Tumkur, Karnataka

Participated in the awareness cum training programme on glyphosate usage organized by Regional Central Integrated Pest Management Centre, DPPQS Bengaluru, Karnataka

With Regional Head (Southern Region), *Reeba* Abraham, Agricultural and Processed Food Products Export Development Authority, Bengaluru

Spreading awareness to farmers on usage of commercial biopesticides

Crossandra field visit

Discussing with woman farmer- ridge gourd field

Pomegranate orchard: Regular consultation with our plant health clinic experts

***Spodoptera frugiperda* surveillance -maize field visit**

Progressive pomegranate farmers-our clients

Collaborating with Natura Crop Care for training farmers

Our successful horticulture farmers made profit in crores during July -August 2023

Tomato- Nagaraj Gowda, Kadehalli, Kolar Dist. Pomegranate- Manjunath Gowda, Vijayapura Devanahalli Dist.

Our plant health clinic, Shree Nidhi Agrochemicals completed two years of service to farmers

Startup incubated with ICAR-Indian Institute of Horticultural Research

With the office bearers of Association for advancement of pest management in horticultural ecosystem

Demonstration of THAVEE gel (one of our products) in management of mealy bug borer and shot hole borer

Bird scaring by beating drums in pomegranate fields


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