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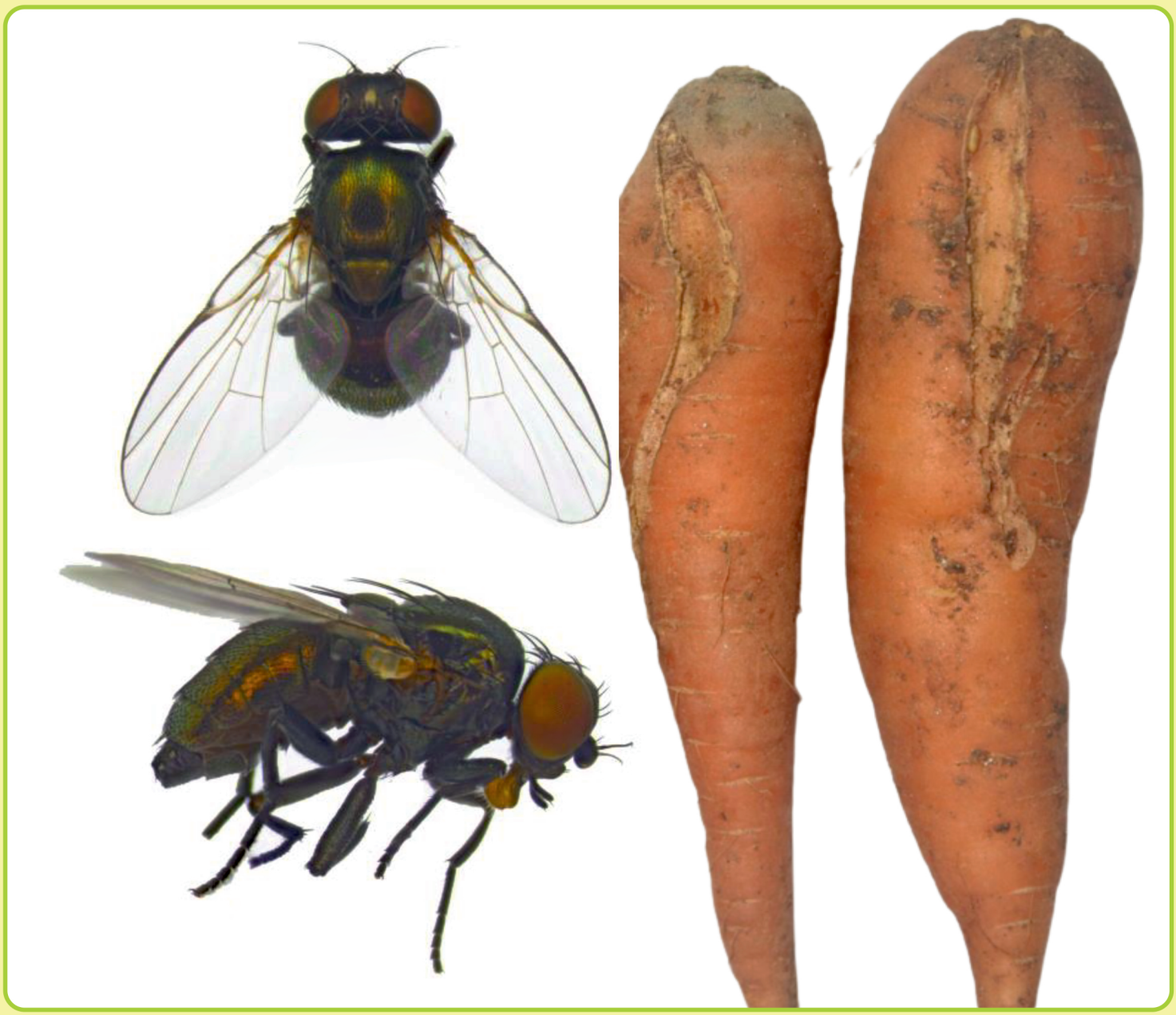

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COVER PHOTOS : *Melanagromyza* sp. - A new pest on carrot

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REVIEW ARTICLE

Tree injection method to manage coconut pests with special reference to blackheaded caterpillar, *Opisina arenosella* and mite, *Aceria guerreronis* - A Review

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ABSTRACT: The injection of exogenous materials into plant system for pest management is being followed since early years of twentieth century. Numerous studies on the tree injection have been done to explore the possibility of injecting chemicals into trees. Root feeding, stem or trunk injection have received significant results of nutrient and pest or disease management across the world. Owing to the practical difficulties in foliar application of pesticides in tall trees like coconut, tree injection became an alternative mode of pesticide delivery to target site. Although tree injections have some limitations, they also have some specific advantages over other methods of management such as minimized use of water and chemicals, reduction in the labour cost, effective management of target pests and environmental safety as non-target organisms can be protected from the effect of pesticides. Serious efforts are needed to standardizing of the technologies of administration for various chemicals under diverse environmental conditions to make it easy and ultimate for specify host plant / nutrient condition which cannot be properly addressed by other methods.

Keywords: Coconut palm, tree injection, pest management, black headed caterpillar, coconut mite

INTRODUCTION

The injection of various exogenous materials into plants have been implemented as early in the middle of the twentieth century (Perry *et al.,* 1991) and expanded in the 1970s. Early literatures show that supply of water to young transplanted trees through the cut end of the root was successful, thus suggested the possibility of injecting chemicals into trees (Cott, 1897). During 1910, tree injection with specific chemical, potassium ferrocyanide was reported for the control of insect pests (Sanford, 1914; Shattuck, 1915). A review on 'Methods of Tree Injection' by May (1941) created interest for injection studies on plants. Gravitational method of liquid injection was reported to control the red palm weevil of coconut (Davis *et al*., 1954). Later the method of trunk injection with systemic insecticides has become an important practice against various insect pests that are difficult to control (Ginting and Desmier, 1987). During that period numerous studies on the tree injection have been done by North American researchers (Ferry and Gomez, 2013). A´cimovi´c *et al*. (2016) examined injection port damage and wound closure in apple trees. Similarly, Dalakouras *et al*. (2018) inspected the movement of hairpin and small-interfering RNAs in apple and grape trees. Uptake and translocation of antibiotics into the tree system was explored by Killiny *et al.* (2019). Berger and Laurent (2019) focuses on modern injection technologies and factors affecting the efficacy of chemicals. Leigh *et al*., (2022) reviewed the concepts of trunk injection method, physiological principles and concerns associated with the injection method.

Considering the tree architecture of coconut, the palms have been exploited for pesticide administration through injection for management of different insect pests. Coconut palm, *Cocos nucifera* L. which belongs to family Arecaceae has been variously described as "console of the east", "the tree of heaven", the 'Kalpavriksha' because of its great versatility demonstrated for many domestic, commercial and industrial uses of its different parts like leaves, fruits, stem and roots. In India, coconut is grown under varied soil and climatic conditions in 17 States and 3 Union Territories. The decrease in yields of coconut has been attributed to a number of factors consisting of biotic and abiotic factors. Among the biotic factors, the insect pests and mites are very important. Amongst foliage pests, coconut black headed caterpillar, *Opisina arenosella* Walker (Lepidoptera: Oecophoridae) is one of the major and serious pests of coconut palm in India, Srilanka, Bangladesh and Myanmar. The pest during its larval stage causes serious damage to the leaves of the palm. In case of severe infestation, several hundreds or thousands of larvae could be observed on a single palm and affected palm often take several years to recover completely (Ramkumar, 2002).

Coconut eriophyid mite, *Aceria guerreronis* (Keifer) is another important and introduced pest of coconut palm. At the end of the 1990s it was reported for the first time from Sri Lanka and southern India (Fernando *et al*., 2002) causing considerable damage to coconut. The coconut eriophyid mites feed and breed beneath the perianths (floral bracts) of coconut fruits causing damage to the epidermal meristematic tissues. The severity of its damage on nuts may result in deep fissures on pericarp, distortion of the fruit, reduction in fruit size and weight, and a decline in copra yield (Julia and Mariau, 1979; Hall *et al.,* 1980). Higher damage caused by these mites leads to premature nut drop or extreme reduction nuts size which are difficult to dehusk and yield losses ranges from 10 to 70 per cent (Moore *et al*., 1989) while reduction in nut size led to 25 per cent yield loss of copra (Gopal and Gupta, 2001). Several studies have been undertaken for the management of these pests through use of conventional pesticides, biopesticides, natural enemies and palm injection. Injection as a delivery method has received significant results in managing these pests on coconut palm. However, the complete knowledge of injection methods on different aspects have been lacking. Therefore, we reviewed the tree injection methods and pesticides used on different trees and coconut palm.

TREE INJECTION METHOD

Injection hole

Injection of chemical materials requires the drilling hole ranging from of 2 mm to 9.5 mm. The injection devices are high pressure devices whose pressure ranges up to 100 psi or more (Leigh *et al*., 2022) or 207 kPa to 450 kPa (Berger and Laurent, 2019). High pressure injection uses 7.15 mm or larger diameter plastic plugs as injection ports which inserted into the tree after drilling of a hole. Low pressure injection allows the plug-free injection of materials and occurs at relatively low pressures (<60 psi) by manual squeezing or with spring-loaded syringe system. The rate of liquid uptake associated with higher pressure is faster than lower pressure devices. However, the different tree injection methods explored the different types of the injection tools with a range of injection hole.

Pesticide transportation in tree system

Understanding of the transportation of pesticides to be administered in the tree system has important significance for the injection method. The movement of chemical in the tree system varies mainly on environmental conditions and physiological attributes of the tree. Generally, metabolically activeness and high vapor pressure deficit have a positive effect on the movement of chemical materials into the tree (Hunt *et al.,* 1974). Anatomical features of the plants *viz.,* size and arrangement of xylem vessels, tracheids and vessel parenchyma cells determine the path, patterns of compound uptake and distribution and efficiency of the chemical substances in the trees as well as wound response and compartmentalization (Martínez-Vilalta *et a*l., 2012; Cartenì *et al*., 2018). The radial movement of chemicals may occur via active transport of parenchyma cells and diffusion through cell walls (Kuroda *et al*., 2021).

Various studies have been taken into consideration to understand the transportation of the chemicals in the tree systems. Shivashankar (1999) studied the procedure for chemical translocating in the tree system after treatment through injection. In the study the movement of the insecticide soluneem (neem-based bio-pesticide) in the internal tissues of coconut trunk was understood. A mixture of methylene blue (3 g) and soluneem (1500 ppm) was dissolved in 20 ml of mineral water and was administered by syringe method in coconut palms on trunk and after 24 hours of placing syringes, the palms were cut to record the movement of the dye. They found that methylene blue dye mixed with soluneem was traced in the xylem vessel up to a height of 6.3 m within 24 hours and revealed that chemical translocate into the tree via xylem vessels. Similarly, the translocation speed and distribution of thiamethoxam solution in date palms was studied by Samarrie and Abula (2011) and showed that thiamethoxam when injected, moved at a rate of 2.8 meters per hours in date palm trunk. In another study, Harrell (2006) studied that green ash trees (*Fraxinus pennsylvanica*) when injected with imidacloprid to control emerald ash borer (*Agrilus planipennis*) was found in sap, leaves, xylem and cambial zone tissues up to 90 days after treatment. He also found the higher concentrations of imidacloprid in xylem and cambial zone tissue of trees. Similarly, Mota-Sánchez *et al*. (2009) injected green ash (*Fraxinus pennsylvanica*) and white ash (*Fraxinus americana*) trees with 25 µCi of ^{14}C-imidacloprid plus non-labelled imidacloprid against emerald ash borer, *Agrilus planipennis*. The results of their studies showed that imidacloprid translocation occurs primarily in xylem. They also observed that extremely high concentrations of imidacloprid were observed in the stained regions of the trunk cross-sections and in leaf tissues and lower amount in roots. In their experiment emerald ash borer, *A. planipennis* was controlled in both green and white ash trees.

Adnan *et al*. (2006) reported translocation and movement of some systemic and non-systemic insecticides *viz.,* dimethoate + phenthoate, primiphos-methyl, chlorpyrifos-ethyl + dimethoate, chlorpyrifos-

methyl and lambda-cyhalothrin in date palm trees. Their results revealed that these pesticides distributed through the date palm trunk and detected in pith at above the injection pore on 10, 20, 30 and 100 days post injection in the same and the opposite sides of injection pore. They concluded that distribution of the pesticides in trunk sap facilitated by existence of large vascular bundles tubes over whole trunk of date palm. Moreover, the pesticides can also be reached the plant sap either by root up take, penetration through leaves and stem or directly by injection into trunk. However, interestingly in one study, Sharma (2018), reported that pesticides translocation and distributions in plant tissues were influenced by the pesticide's physical properties such as solubility partitioning and polarity as well as the appropriate application position which affect trunk injection methods efficiency. He assumed that abiotic factors *viz., w*ater soluble potential of active ingredients, water soluble potential of non-active ingredients components and other environmental variables like humidity, temperature, rainfall etc. as well as biotic factors *viz.,* the anatomic point of injection site on the coconut palm and age of the coconut palm may influence the transport of the chemical into the tree. He observed the solubility potential of formulation of monocrotophos and cartap hydrochloride have the highest absorption in coconut palm. As monocrotophos has the highest solubility (100% soluble in water, Tomlin, 1994) followed by cartap hydrochloride (20 mg/ml; Hartley and Kidd, 1997). The non-active-ingredients components of these insecticides had the lowest impact on the solubility of formulation and therefore monocrotophos and cartap hydrochloride had highest absorption even at highest concentrations whereas, other insecticides studied had lower absorption potential in the decreasing order as follows; acetamiprid > emamectin benzoate > clothianidin > spinosad > imidacloprid > thiacloprid. Though the insecticides formulation such as acetamiprid and emamectin benzoate had a relatively better solubility of active ingredient, the presence of the non-active-ingredients components may find to interfere with the absorptions. He also made comparison that, when the polarity of non-active ingredients of the insecticide formulation is hydrophobic a complex and stable emulsion is formed upon diluting with water. Though these emulsions are stable at lower concentration, at higher concentration the non-active ingredients of the emulsion form fine aggregates and a suspension is often formed. A suspension naturally will have fine insoluble particulate matter and such matters are tend to sediment on long duration static storage and form a thin film on the bottom of the cavity. The coconut palm/frond has a very unique stem anatomy with xylem and phloem confined to vascular bundles scattered throughout the central cylinder of the stem/ frond.

In most species, these bundles are concentrated near the periphery of the stem and interspersed within a matrix of thin-walled undifferentiated parenchyma cells. Palm stem xylem, phloem and even parenchyma cells remain alive for the life of the palm, which can be hundreds of years in some species (Tomlinson and Huggett, 2012). In the centre of the stem, the number of vascular bundles per unit cross sectional area is quite low but in the cortex region this increases rapidly. In cortex region (about 75 to 100 mm), the vascular bundles are very congested and separated by only very narrow bands of ground parenchyma tissue (Richolson and Swarup, 1977). Below the cortex region the vascular bundles are embedded in ground tissue. Upon making an incision of size (0.3 × 2 cm) on the basal region of coconut palm stem and (0.3 × 1.5 cm) on the frond and base of the of coconut palm (Sharma, 2018); the vascular bundles include xylem, phloem, parenchyma tissues and thick-walled sclerenchyma fibres are directly exposed in the incision. When the syringe loaded with the appropriately diluted insecticide formulation is plugged into the incision, a very unique micro environment is created in which the diluted insecticide formulation is directly fed into the vascular bundles. In coconut palm, though the vascular bundles are unified with different types of tissues, it is believed that a major portion of the insecticide solution is taken by the xylem vessels. In addition, differences in the site of injection can affect the rate of uptake and distribution (Tanis *et al*., 2012). The dye in a root injection moved to the xylem vessels of the current year's growth (Holmes, 1982) whereas dyes injected into the lower trunk of the trees moved radially throughout the entire root tissue, while in the stem the dye was confined to the most recent growth (Tattar and Tattar, 1999). However, further studies on the possibility of the entry of the insecticide formulation on other types of vascular tissue, uptake and distribution of chemicals as a function of the injection location on the tree are required for individual crop species.

Tree injection for disease management

Early studies on trunk injection were reviewed by Roach (1939). Applications of liquids through roots and stems in combination with syringes, tubing systems and specially designed devices were explored in many countries during the 19th and beginning of the 20th century (Roach, 1939). However, more research aspects on tree injection took place with the devastating spread of Dutch elm disease in the 1960s (Perry *et al*., 1991). The onset of Dutch elm disease in the United States led to a renewed interest in tree injection. Richard and Susan

(1997) conducted studies to determine the curative and efficacy of avermectins in controlling plant parasitic nematodes, *Meleidogyne javanica* and *Radopholus similis* when injected into the pseudo stem of banana (*Musa acuminate*). The results of the study indicated that avermectins injection of 250 and 500 µg a.i./plant were effective in reducing nematode infection up to 28 to 56 days after imposing treatments. Similarly, nematicidal solutions *viz.,* carbofuran, oxamyl, phenamiphos, sulfocarb and di-bromo-chloro-propane (DBCP) were used against the nematode, *Pratylenchus vulnus* through pressurized injection technique by Viglierchio *et al*., (1977). They observed significant reduction in *P. penetrans* incidence on apples and walnuts. The fungicides *viz.,* dimethomorph, fosetyl-al, iprovalicarb and metalaxyl were applied as stem injection in field-grown grapevines and obtained the desired protective effect against downy mildew (*Plasmopora viticola*) (Duker and Kubiak, 2009). Similarly, fungicides namely, triazoles (myclobutanil, penconazol and tebuconazole) were used for the control of powdery mildew by means of stem injection and found effective in managing the disease (Duker and Kubiak, 2011). In a field study, the fungicides namely; propiconazole, phosphites and penthiopyrad were injected against apple scab, *Venturia inaequalis* on apple trees (Vanwoerkom *et al.,* 2014). But they observed limited effectiveness of these fungicides in the management of apple scab. However, similar trunk injection of fungicide phosphorous acid was performed on mature apple trees to manage apple scab, *V. inaequalis* and resulted in lower incidence of apple scab compared with untreated trees (Coslor, 2017).

Tree injection for insect pest management

In 1970s, several systemic insecticides were used via trunk injection for the management of insect pests. These insecticides studied were *viz.,* monocrotophos, dichrotophos, acephate, phorate and methamidophos (Wood *et al*., 1974). Similarly, application of 6 ml of 60 per cent monocrotophos per palm via stem injection was given highest mortality of the coconut caterpillar, *Brassolis sophorae* (Rai, 1973). Similarly, the insecticides *viz.,* monocrotophos, methamidophos and acephate were effective in controlling the leaf miners on angsana plant, psyllid and buprestid on pongamia plant at doses of 6 ml (3.30 g a.i.), 6 ml (2.90 g a.i.) and 6 g (4.50 g a.i.) per tree respectively, when administered through trunk injection at three points at midway, between the first crown and on the ground using 20 ml Chem-Jet syringes (Jusoh, 1998). In a sequence, the green ash (*Fraxinus pennsylvanica*) street trees were injected on the trunk with emamectin benzoate at rates of 0.10 to 0.60 g a.i. per 2.54 cm diameter at different locations in Michigan, United states and the result showed that a single trunk injection of emamect in benzoate at the rate of 0.1, 0.2 and 0.4 g a.i. gave 100 per cent control of emerald ash borer larvae in 98 of 99 treated trees for a long time up to 2-3 years (Smitley *et al*., 2010). Hasber (2012) conducted field trial to evaluate trunk injection technique using systemic insecticides *viz.,* methamidophos and monocrotophos to control bagworm, *Metisa plana* in oil palm. He used a plastic syringe containing 10 ml solution per palm each methamidophos (5 g a.i.) and monocrotophos (6 g a.i.) formulations to inject chemicals into the hole. The results of study showed that both methamidophos and monocrotophos were highly effective in reducing the population of bagworms up to 94 to 97 per cent after 3 days of treatment in all injected plants. Similarly, in a study by Huang *et al*., (2016) the Sweet olive trees (*Osmanthus fragrans)* were injected using a no-pressure injection system to control the nettle caterpillar, *Latoia lepida* and found that 4% imidacloprid + carbosulfan and 21 % abamectin + imidacloprid + omethoate were completely absorbed in 14 days with lower mortality of *L. lepida* while 10 % emamectin benzoate + clothianidin and 2.5 % emamectin benzoate were reported to absorbed in 30 days but achieved the higher larval mortality of the nettle caterpillar in the canopy.

A field trial was determined using two systemic insecticides imidacloprid 200 SL and thiamethoxam 240 SC to manage Arabian Rhinoceros Beetle (*Oryctes agamemnon arabicus)* in date palms by three methods *viz.,* direct spray, trunk injection and drenching and the results showed that trunk injection method was more effective as compared to other methods tested (Khalaf and Alrubeai, 2016). Coslor (2017) tested the insecticides *viz.,* emamectin benzoate, imidacloprid, dinotefuran, spinosad, chlorantraniliprole and abamectin via trunk injection against pests of apple trees. He indicated that tested neonicotinoids reduced *Empoasca fabae* while emamectin benzoate, chlorantraniliprole and abamectin resulted in moderate to high mortality along with reduced feeding by *Choristoneura rosaceana* and spinosad was found with lower absorption and least effective. In field trials, Sharma (2018) and Sharma *et al.* (2020) reported that the different insecticide solutions when injected to fronds and base of the coconut palms managed *O. arenosella* effectively (figs. 1 and 2) Furthermore, the insecticides also reduced the pupation, pupal weight, adult and parasitoid emergence of *O. arenosella*.

Tree injection for the management of *O. arenosella* and *A. guerreronis*

Root feeding

The difficulties in spraying taller palms and harmful

Fig.1 Syringe method of insecticide application at base of coconut palm (Image; 1- Excavating soil around the coconut base, 2- Removing the bark at cortex region to drill a hole, 3- Drilling, 4- A fresh hole made by hand drill, 5- Sealing wax on end (tip) of syringe, 6- Measuring injection volume, 7- Placement of syringe into drilled hole and 8- Syringe covered with polyethene cover (Sharma, 2018).

effects of spray application on natural enemies lead to administering chemicals through root feeding and stem injection. The first report on root feeding method was attempted by Ganeswara *et al*., (1980) using systemic insecticide monocrotophos against *O. arenosella* in coconut palms. Subsequently, the root feeding method was followed by Pushpalatha (1986). A smooth slant cut was made to the root, with a sharp knife, and then the cut end was inserted into the glass tube contained the monocrotophos solution in such a way that the tip of the root contacted with the bottom of the tube and monocrotophos at the rate of 9 ml and 18 ml through the root feeding for the coconut palms below 10 years and above 10 years, respectively was found effective against *O. arenosella*. Similarly, neem-based biopesticide was also tried for the management of coconut black headed caterpillar using root feeding method palms (Srinivasa *et al*., 1994).

Similarly, root feeding with triazophos 20 ml per palm was found effective in reducing *A. guerreronis* population (Mohansundaram *et al*., 1999). Subsequently, use of eco-friendly formulation such as TNAU Agrobiocide 30 ml per palm also recorded the reduction in *A. guerreronis* population of 65-100 per cent over untreated control using root feeding (Kannaiyan *et al*., 2000). The comparison between the two methods was made by Dey *et al*., (2001) who reported that application of fenazaquin 10 EC administered through roots at 10 ml per palm and spraying the same chemical at 200 to 250 ml/litre of water reduced *A. guerreronis* population by 83 and 92 per cent respectively. Similarly, root feeding of fenpyroximate 5 EC at 10 ml per palm reduced *A. guerreronis* population by 90.24 per cent whereas spraying palm with same chemical at 1.0 ml/litre of water found reduce mite population by 80 per cent (Dey and Somchoudhary, 2001). Sujatha *et al*., (2004a) evaluated different chemicals *viz.,* monocrotophos, fenobucarb, fipronil at 20 ml + 20 ml water respectively, fenazaquin at 1 ml + 10 ml water and acetamiprid at 0.5 + 10 ml water through root feeding against *A. guerreronis* in coconut palms. The results revealed that monocrotophos was most effective with 89 per cent decrease in mite population followed by fenazaquin with 78 per cent reduction. Subsequently Sujatha *et al*., (2004b) found that fenpyroximate (10 ml + 10 ml 1 % urea solution) via root feeding was most effective compared to monocrotophos (10 ml + 10 ml 1 % urea solution), triazophos (20 ml + 20 ml water) and dicofol (15 ml + 15 ml 1 % urea solution). The study using different chemicals namely, abamectin 1.8 EC (2.5, 5.0 and 7.5 ml), profenofos 50 EC (10, 15 and 20 ml) and monocrotophos 36 SL (15 ml) applied through roots as aqueous solutions against *A. guerreronis* indicated abamectin 7.5 ml + 7.5 ml water and abamectin 5 ml + 5 ml water resulted in moderate reductions (58.84 and 51.44 %) of mite population (Shanmugam and Kunchithapatham, 2012).

Stem injection

Nadarajan and Channabasavanna (1981) used stem injection method against *O. arenosella* using monocrotophos at 3.5 ml and 7.0 ml, below 5 years old and more than 5 years old, respectively. They found that both the dosages were effective in reducing larval population. Moreover, they reported that monocrotophos persisted up to 90 days after administration. Similarly, Kanagaratnam and Pinto (1985) worked on stem injection method in coconut palm. The drill hole (15 cm deep) was made using an auger at an angle of 45 degree on the trunk at a height of one metre from the ground level and monocrotophos injected at 5 ml and 10 ml per palm of undiluted 60 per cent water soluble concentrate. After the treatment of 36 to 85 days, no live *O. arenosella* larvae and pupae were recorded from the infested palm. Similar, finding was observed with undiluted monocrotophos 60 WSC when administered through stem injection (Rao *et al*., 1981) and 5-10 ml quantity of chemical was sufficient to kill the larvae of *O. arenosella.* An eco-friendly bio-pesticide, soluneem (water-soluble neem formulation) containing 3000 ppm of azadiractin was injected using syringes to manage *O. arenosella.* The significant reduction in the larval population, adult emergence and malformation in the emerged adults were recorded in soluneem treated trees. Soluneem was effective up to 120 days with no phytotoxic symptoms to the treated palms (Shivashankar *et al*., 2000). Sharma *et al*., (2020) conducted a field study at farmer's field in Halebudanuru village in Mandya district in Karnataka, India during 2017-2018 using the frond injection method. This novel approach of insecticide administration into the coconut palm was applied using the imidacloprid 17.8% SL, acetamiprid 20% SP, clothianidin 50% WG, thiacloprid 21.7% SC, emamectin benzoate 5% SG, spinosad 45% SC, cartap hydrochloride 50% SP and with check monocrotophos 36% SL against *Opisina arenosella*. Cartap hydrochloride 50% SP and monocrotophos 36% SL caused 100 per cent larval mortality and all other treatments also gave significant mortality over control. Frond injection in coconut was done first time in India and it was found easy, quicker and accurate method for observing the absorption and efficacy of insecticides and also not caused any secondary infection and damage to the frond tissues. Periodic application of monocrotophos using stem injection was found effective to manage the coconut eriophyid mite (Julia and Mariau,1979). In the Caribbean region, vamidothion, an organophosphate was used as stem injection but was not effective in reducing coconut

Fig. 2. Frond injection of pesticides on coconut (1-4 Making holes; 5-9 administering pesticides)

eriophyid mite (Moore and Alexander, 1987; Moore *et al*., 1989). In Sri Lanka, trunk injection of monocrotophos was recommended to control *A. guerreronis* population. Although control was effective initially for about 2 months (Fernando *et al*., 2002). However, in a study, on absorption of pesticides formulation into coconut palm using syringe method of pesticides application, Sharma *et al*., (2019) showed that the acaro-insecticides *viz.,* spiromesifen 22.9 % SC, abamectin 1.9 % EC, fipronil 5 % SG and buprofezin 25 % SC found to have very low solubility threshold and were not effective in complete absorption by coconut fronds. They concluded that though the acaro-insecticides having acaricidal activity but may not be used against coconut eriophyid mite. This study, therefore, suggest that desire solubility level of different chemical formulations and their absorption should be considered for effectiveness.

Tree injection for nutrient management

In an earlier study, injection method was employed in delivering nutrients in trees of lemon to cure chlorosis through directly injection of ferrous sulphate solution into the plant system by Lipman and Gordon (1925). Similarly, the injection of iron salts into holes bored on the stem proved effective in overcoming chlorosis of grape vines, peach and apple trees (Wann, 1929). In 'Red Delicious' apple trees (*Malus domestica*) iron deficiency was cured either by ferrous sulphate ($FeSO_4 \cdot 7H_2O$) or ferric citrate ($FeC_6H_5O_7 \cdot H_2O$) at rates of 100 ml of 1 % solution per year of tree age through pressure injection (Danny *et al*., 2008). Mahmoud (2009) also showed that mango and grapevine plants can be fertilized by trunk injection through xylem. He also suggested that growth of mango trees was 20-25 % higher in injected trees than soil fertilized trees. Similarly, in grapevine fruits the yield was increased by 32-49 % higher as compared to fruit harvested from the plants given soil fertilization. Felipe *et al*., (2013) also showed that application of fertilizers at 0.9 m insertion height through stem injection in banana plants was found better than soil application.

LIMITATIONS AND ADVANTAGES OF TREE INJECTION

Pesticides administration through injection methods have some of the limitations such as chemical toxicity, mechanical injury and secondary infections to the tree. Earlier studies showed that administration of chemicals *viz.,* copper sulphate, boric acid, ferrous sulphate, manganese sulphate and zinc sulphate using trunk injection were resulted in oozing out of liquids from the trunk and induced deleterious effects in coconut palms (Davis *et al*., 1954). The major drawback to the trunk injection method on coconut palm include drilling of a 3-6 mm diameter hole approximately 75 mm deep on the trunk above the ground level (injection site) led to results in bleeding of sap from the injected site. Since coconut palms produce no secondary trunk growth, these holes remain indefinitely resulting in dark stains and these sites serve for secondary infections by pathogens (Mccoy, 1977). A few limitations were studied regarding trunk injection by Richard (1977) in control of Dutch elm disease management. He found that chemical moves upward from points of incision on stems and losses its strength as dosage decreases and often ineffective at higher canopy of the tree. Sometimes under the most advantageous circumstances, the chemical is not uniformly distributed in whole tree and some branches receive little or no chemical at all. In addition, chemical may lead to phytotoxicity to foliage or internal tissue of trunk. The wound reacting at the chemical tissue may interfere with normal translocation of food and water. The wounds of the injection site enhance the probability of secondary infections by parasitic fungi and bacteria. The wounded cell tissues are not replaced and the cells peripheral to the injured zone react to create barriers, isolating the healthy area from the outside and this process is called "compartmentalization" in trees (Shigo, 1972) and "sealing" in palms (Shigo, 1994). Tree injections have some limitation but also have many of the significant advantages over other delivery method such as minimized use of water and chemicals, reduction in the labour cost and environmental safety as non-target organisms can be protected from the effect of pesticides etc.

CONCLUSION AND PERSPECTIVES

Tree injection methods are useful for taller plants and also manage persistent and notorious pests where the other methods of pest management have less importance. Injection method has also received significant results in nutrient and disease management. However, the transportation of pesticides to be administered in the tree system via injection method need to be focused under the further research studies. The complete knowledge about the chemicals and their transportation into the different trees should also be assessed. The recommendation should be assessed for the pests, nutrient and disease management sing the trunk injection method for effective and suitable pesticides. Furthermore, strategies should be planned to minimize chemical toxicity, mechanical injury and secondary infections to the tree using injection methods. More focused efforts are required to standardization of methods of injection of different chemicals under various environmental conditions.

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Modifying oviposition behaviour of the Oriental fruit fly, *Bactrocera dorsalis* (Hendel) to obtain uniform G_0 stage eggs for microinjection

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ABSTRACT: The CRISPR/Cas9 technology has opened up newer avenues in insect pest management like precision guided sterile insect technique (pgSIT) which achieves a highly specific mutation in the target genes such as spermatogenesis, sex determination related genes etc. In this regard, validating the loss-of-function of the target gene/s is a prerequisite before the final application. This is easily achieved through DNA-free editing by embryonic delivery of the cognate ribo nucleo protein complex (RNP) into G_0 stage eggs. Obtaining uniform G_0 stage eggs is necessary to offset the microinjection injury and have high heritability of the genomic edits. We to optimized a method to obtain intact eggs of Oriental fruit fly, *Bactrocera dorsalis* (Hendel) without injury for microinjection by modifying the oviposition behaviour of the gravid female of *B. dorsalis* to retrieve intact eggs and to obtain large number of G_0 eggs for genome editing. This paper describes a method to obtain required number of eggs for such studies. Out of two egg laying methods, the one with a small container with water covered with parafilm and topped with a thin banana pulp slice provided intact eggs. Maximum oviposition was observed between 20-60 days after eclosion. By the present finding we can obtain sufficient eggs for microinjection at 15-minute interval.

Keywords: G_0 phased embryo, egg laying, gene editing, oviposition parameters, Tephritidae

INTRODUCTION

Bactrocera dorsalis (Hendel) is a destructive polyphagous pest of horticultural crops with a wide host range which includes commercially cultivated crops like Mango, Guava, Custard apple and papaya (Clarke *et al*., 2005; Liquido *et al*., 2017). Infestation by this fly can hamper domestic and export market as it is a notorious quarantine pest resulting in substantial economic losses (Alvarez *et al*., 2016; Ndlela *et al*., 2022). Though different control modules are employed to combat fruit fly infestation most of the options have some disadvantages related to efficiency, time-consuming, mammalian hazard and residual effects. This necessitates the new interventions for effective pest management. Modern advancements in the area of pest management and genetic biological control methods such as the precision guided Sterile Insect Technique (pgSIT) and CRISPR-Cas9 mediated gene drive (Kandul *et al*., 2019; Buchman *et al*., 2018) are making the steady inroads and are emerging as a sound alternatives strategy in managing the insect pests. Despite its potentiality, pest control using CRISPR-Cas9 face numerous challenges including, harvesting numerous undamaged eggs within a narrow time (G0 stage) after egg laying. In *Pyrrhocoris apterus* bug, more mutants were obtained when germ line transformation was carried 12 h after egg laying than eggs injected within 2 h of laying (Kotwica-Rolinska *et al.,* 2019). In lepidopterans, the critical stage lapses after 4 h from egg deposition (Zhang and Reed, 2017). In, sand fly the time window for conducting microinjection was between 1.3 h to 3 h and this time window is even very less for mosquitoes. Generally, the G_0 stage for dipteran insect is less than 2 h so it is very crucial to get sufficient number of viable embryos within this timeframe (Campos and Hartenstein, 1985). Thus, it is essential to decipher information on fecundity and oviposition behaviour of gravid *B. dorsalis* females which are governed by several factors including multiple mating (Shelly, 2000), age of the female fly (Huang and Chi, 2014; Jaleel *et al*., 2018; Choi *et al*., 2020) and host substrate available for oviposition (Huang and Chi, 2014; Kalia and Yadav, 2005). In the present investigation we have carried out a detailed study of the egg laying behaviour of *B. dorsalis* flies, in order to achieve enhanced and scheduled egg laying for laboratory studies. The following parameters,

Table 1. Oviposition frequency of gravid females in different time intervals

Time interval (Minute)	Total	*Mean ± SD
15'	47	4.70 ± 4.32
30'	108	10.80 ± 7.89
45'	61	6.10 ± 6.93
60'	75	7.50 ± 6.50

**Note: ***Mean of five individuals

with regards to oviposition behaviour, have been examined (i) Laboratory host preference (to identify the best host which can elicit enhanced ovipositional response), (iii) Daily egg laying pattern (to decipher the correct age group of the flies for oviposition), (iv) period of time and oviposition response (to schedule timing for oviposition) and (v) Egg laying behaviour in time intervals (to plan number of flies required to harvest desirable number of eggs).

MATERIALS AND METHODS

Insect colony maintenance

Adult flies of *B. dorsalis* were recovered from the infested mango fruits collected from Fruit orchards of Indian Institute of Horticultural Research, Bangalore. Since mango is a seasonal fruit, in order to maintain fly population for extended study period, ripe banana fruit (cv Ney Poovan, commonly called as 'Yelakki') was used. The adults were enclosed in a wooden cage of size 30 x 30 x 30 cm. The cage had a wooden framework fitted with mesh on all sides except for the wooden floor and a glass cover on top for observation and illumination (Figure 1). Yeast extract, sugar and water were provided inside the cage for adult development and survival. Flies were housed in these cages for the entire length of the study. All the experiments were conducted under standard laboratory conditions (temperature: 28°C ± 3°C; RH: 70 ± 10%).

Laboratory host preference

These experiments were performed to identify the most suitable elicitor for egg laying. The following elicitors were tested for oviposition preference by the flies: Banana pulp slice, Banana peel, Guava skin (colour break stage) and Guava skin (ripe, yellow colour). The above-mentioned testing materials were placed on 0.5% agar plates and placed in a cylindrical plastic box [14 cm (height) X 11 cm (diameter)] containing gravid females, for oviposition (no choice experiment) (Figure 2). The agar plates were collected after 1 hour of exposure to the gravid flies. The eggs oviposited on agar plates were counted. The most efficient elicitor was identified by comparing the number of eggs oviposited per hour, beginning with equal number of flies. As Banana and Guava are available throughout the year, only these two fruits were tested as an elicitor for oviposition by female.

Oviposition experiment and egg collection method

The aim of this experiment was to disentangle the effect of oviposition source to assure more egg deposition which can render quality egg collection. In the first experiment (Method A) 0.5% agar was brought to boil with distilled water and poured into small plastic cups and allowed to solidify. In the second experiment (Method B) expanded wax Paraflim was spread over a plastic cup containing sterile water (Figure 3). A thin slice of banana (cultivar Yelakki) of thickness approximately 2-5 mm was placed over the solidified gel/expanded paraflim sheet to elicit oviposition response. The eggs were collected using a brush after distorting the agar gel in method A. Eggs in oviposition cups in method B were harvested by empting the oviposition cup onto a clean cloth and subsequently collected using a brush. Further the quality/viability of eggs collected were assessed. The collected eggs from each method were placed individually in small plastic wells containing mashed banana mixed with preservatives Methyl Paraben (0.1%) and sodium benzoate (0.1%) (Figure 4). The set up was kept in a container floored with water-soaked cotton to avoid moisture loss in mashed banana and to facilitate eclosion. The number of eggs hatched was noted after 24hrs till the fourth day. Mortality at egg stage, were documented and data were subjected to student's t test.

Daily egg laying pattern

These experiments were performed to understand the variability in egg laying during the female lifespan, in order to determine the best age group of the flies for

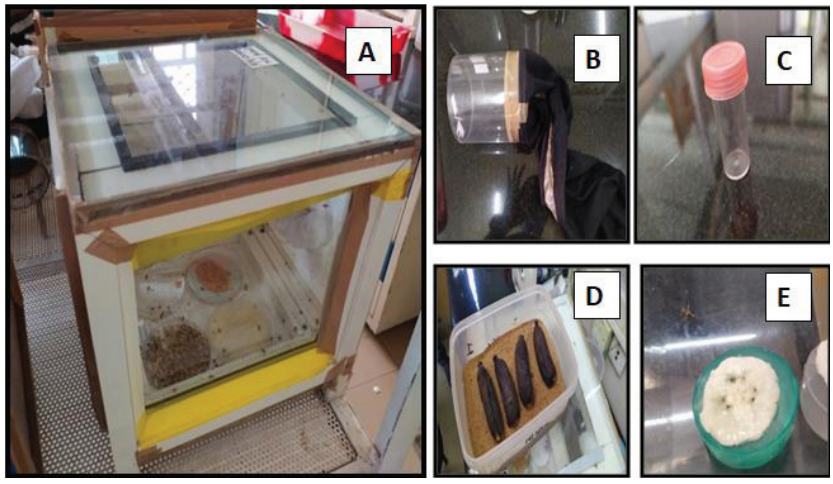

Figure 1. The rearing of fruit fly- a) wooden rearing cage b) Cylindrical box (14 cm height X 11 cm diameter) c) cylindrical cap d) pupation box e) Oviposition cup

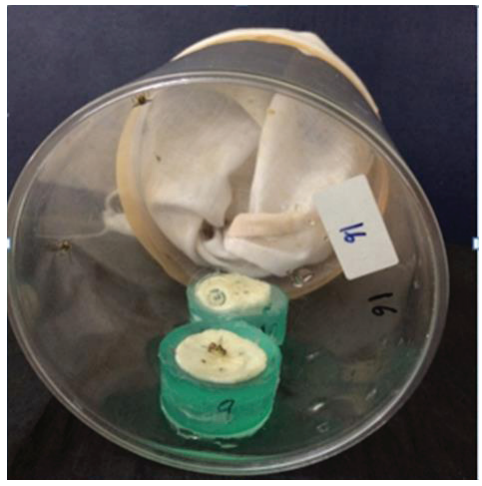

Figure 2. Oviposition substrate provided to the gravid females

maximum egg collection. Flies reared on banana in the laboratory were used for these experiments. After emergence from the pupa, the adults are sexed and paired immediately (1 female and 2 males) in individual cylindrical plastic boxes [14 cm (height) X 11 cm (diameter)]. Yeast extract, sugar and water were provided in the boxes, along with an oviposition source (a slice of banana placed on solidified agar). This oviposition source was replaced at 24h intervals until the female was spentor dead. The number of eggs laid was documented at 24h intervals.

Determination of number of gravid females required for optimal egg harvest

The goal of this experiment was to determine the number of flies per cage to obtain more eggs per fly in a given time. As a prerequisite, the flies reared in banana were maintained in different cages according to their age. Five treatments, with varying number of female flies (1,2,3,4,5) between age group 20-35 days old were released into a plastic container of size 14 cm (h) x 11 cm (r) and provided with oviposition source (Method B). For each treatment, females were selected randomly among the individuals in the same cage. The observations were made three times in a day *viz.,* 1st h- morning (0800 -1000), 2nd h- afternoon (1100- 1300) and 3rd h- evening (1600-1800). Oviposition source were removed after each hour and replaced with fresh oviposition cups until three successive hours. The total number of eggs laid in each oviposition sources were counted. The number of eggs laid per female in each treatment was determined by dividing the total number of eggs laid by the number of females present. The data were subjected to Analysis of variance followed by post hoc test. All the experiments were conducted in laboratory where temperature is 28°C ± 3°C with relative humidity of 70%.

Period of time and oviposition response

These experiments were performed to find the most suitable time of the day to elicit oviposition. Three time points in a day were chosen- Morning (08:00 -10:00), Afternoon (12:00- 02:00) and Evening (04:00 – 06:00). Total of 15 replicates were performed for each period of the day (each replicate consisted of two boxes, one with a single gravid fly and another with 5 gravid flies). Each box was provided with an oviposition cup (0.5% solidified agar with a slice of banana on top). The cups were removed after two hours of exposure and the number of eggs on the oviposition cups was counted. The experiments were conducted in a well-ventilated room on a sunny day.

Oviposition time intervals

G_0 egg stage, *i.e.* intervention within a few minutes of the egg laying in dipterans, is crucial for a successful germline transformation. Experiment was planned to know the number of eggs that can be oviposited to the oviposition source during 15 minutes of exposure period. For this experiment five gravid females aged between 25-40 days were caged in a box and provided with an oviposition cup at time zero, this oviposition cup was removed after 15 minutes of exposure and replaced for the next 15 minutes by fresh oviposition cups. Oviposition cups were removed in this manner for every 15 minutes for 4 times (1h). The total number of eggs laid over the period of every 15 minutes was counted.

RESULTS

Laboratory host preference

Under laboratory conditions banana pulp (45.8 ± 15.75 eggs) was the most preferred host for oviposition followed by banana peel (16.8 ± 10.28), Guava skin (green, colour break stage) (12.6 ± 6.5) and Guava skin (Ripe, yellow colour) (4.2 ± 5.14) (Figure 5). The difference between the treatments were statistically significant (Kruskal wallis test: H =13.07, p=0.004) clearly exhibiting the preference.

Oviposition experiment and egg collection method

In method (A) the average number of eggs produced per female was 26.2 ± 11.20 where as in method (B) the average egg produce per female was 24.4 ± 9.15. There was no statistically significant difference in egg laying among method (A) and Method (B) t(16)=0.5528, p=0.5881, n1=10, n2=10. However, the survival percentage of eggs harvested from the two oviposition methods were 58% and 74% in method A and method B respectively (Figure 6). Clearly the survival of eggs collected from method B oviposition experiment was more and was statistically significant (U=25377, Z=3.066, P=0.0002 n1=210 and n2=288).

Daily egg laying pattern

A total of 18 female flies were observed from the day of emergence till mortality. In plastic containers flies were released in the ratio of one female to two males and were provided with water food and oviposition source. The earliest egg laying was observed on 11th day from emergence and the last batch of eggs were deposited by flies as old as sixty days. The average egg laying in the first twenty days was 2.67 ± 5.13. In the subsequent twenty days it was 19.94 ± 5.013 eggs per female and final twenty days the average egg production per female was 21.79 ± 8.94. The average egg laying per day per gravid female during its life span was 15.2 ± 11.98 in banana (Fig. 7).

Determination of number of gravid females required and period of time for optimal egg harvest

During the first hour of oviposition (Introduction of oviposition source to 1 hour) the mean number of eggs collected per box was 82.4, 28.4, 59.6, 65.8, and 85.8 corresponding to treatments T1 to T5 respectively. For the first hour of oviposition ANOVA test confirms the variability in the egg laying pattern by gravid females in different treatments F (4, 20) = 4.291, P= 0.01114). Similarly, during the second hour the mean egg laying

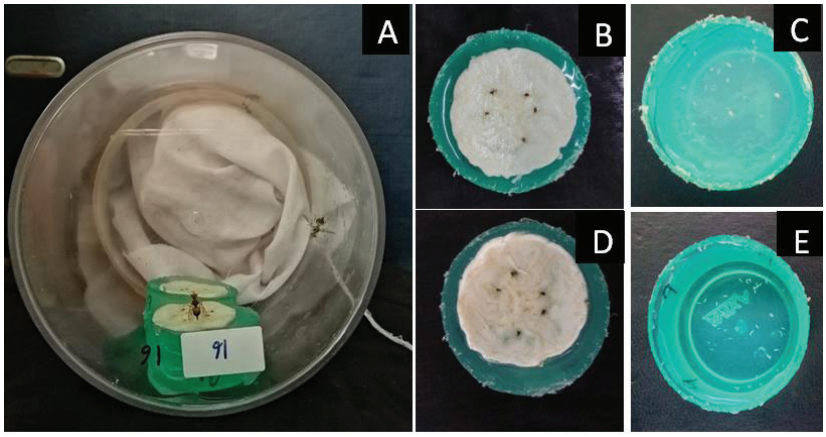

Figure 3. A. Oviposition cage with five gravid females and two oviposition cups **B**. Oviposition cup with 0.5% agar and topped with slice of banana (Method A); **C**. Eggs laid in oviposition cup (Method A) **D**. Oviposition cup with water covered with parafilm and topped with slice of banana (Method B) **E**. Eggs laid in oviposition cup

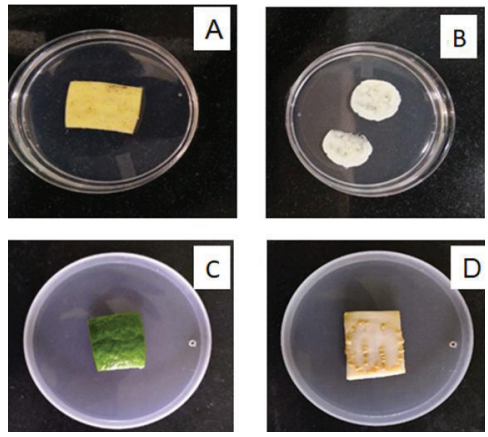

Figure 4. Substrate preference in *Bactrocera dorsalis* under laboratory conditions, **A**. Banana peels **B.** Banana pulp **C.** Guava green **D.** Guava yellow.

was 8.61, 29, 37.5, 43.5, and 60.3. During the third hour the mean egg laying was 25.8, 40, 40.6, 72.2 and 36.8 for the treatments T1 to T5 respectively (Figure 8). The ANOVA result was F (4, 20) =2.331, p=0.0911 and F (4,20) =2.585, p=0.0683 respectively for the second and third hour. The mean number of eggs laid per gravid fly in different treatments from T1 to T5 was 4.68, 4.87, 9.18, 8.3 and 5.74 respectively. In treatment T1 and T2 only 20-46% of flies responded by ovipositing in the oviposition source. In the treatments T3 to T5, 62-100% of flies responded by ovipositing during the three consecutive observation hours. The flies were also tested for their oviposition response following exposure to the oviposition source in three different time windows, during the day.

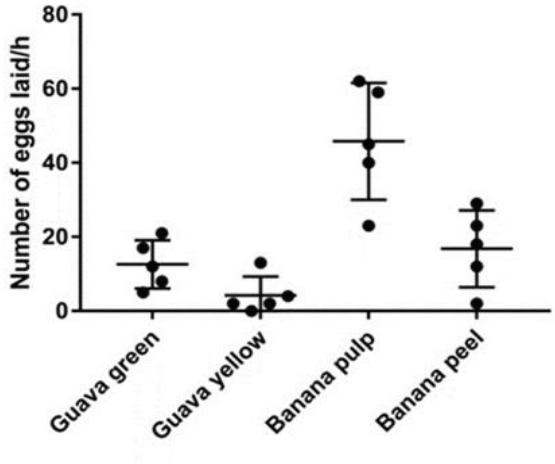

Figure 5. Host preference by B. Dorsalis: guava green, guava yellow, banana pulp, banana pulp (Kruskal wallis test: H =13.07, p=0.004)

Period of time and oviposition response

In the boxes with a single gravid female, 13.6%, 20.0% and 53.3% of the flies responded by ovipositing during the morning, afternoon, and evening hours, respectively. In boxes with five gravid females, 86.6%, 73.3% and 93.3% of the oviposition cups had eggs during morning, afternoon, and evening hours, respectively (Fig. 9). Hence, when single flies were caged, during the two hours of exposure, only half or less than half of the population responded by ovipositing and the oviposition response was greater during the evening hours. However, when a group of gravid females was housed together, the oviposition response of the flies was greater than that which was seen when the flies were housed singly. At any given time, the oviposition response was more than 70% when the flies were housed together.

Oviposition in time intervals

Oviposition in first 15 (15') minute was 47 eggs likewise 108 eggs were laid in next 15 (30') minutes interval, 61 eggs in next 15 (45') minutes interval and 75 in next 15 (60') minutes interval. The observation was

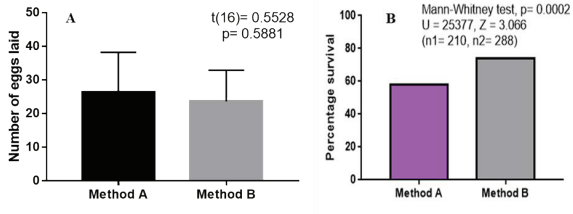

Figure 6. Effectiveness of two different methods in harvesting the eggs. **A** Average number of eggs laid by a gravid female in two different oviposition sources. **B** Survival of eggs after collection from two different oviposition cups.

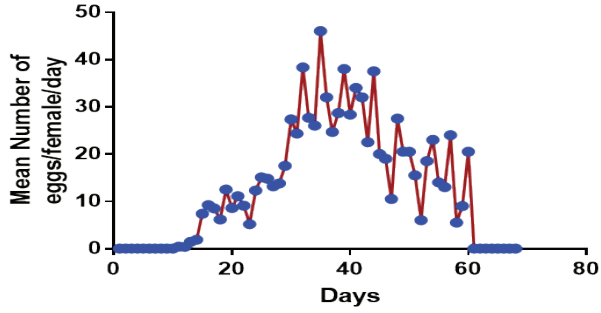

Figure 7. Oviposition pattern in *Bactrocera dorsalis* during their life span (n=18).

done within 1h. The results obtained were signifying that enough numbers of eggs were available for germline transformation at each 15-minute interval to get viable numbers of G_0 phased embryo or eggs. In corroboration to G_0 stage of embryo Wu *et al*., (2018) explained that there was more than 90 per cent mutation, when the Cas9 and sgRNA injected at G_0 phased embryos (Table 1)**.**

DISCUSSION

Bactrocera dorsalis is highly polyphagous in nature and has been recorded on about 478 different host plants (Clarke *et al*., 2005; Liquido *et al*., 2017). Selection of an appropriate host is a very critical decision for the fly as this behaviour should ensure proper egg hatching and facilitate larval development (Joseph *et al*., 2009). This host selection may be mediated by olfactory cues (Jayanthi *et al*., 2014) or by visual stimuli like the colour, size, shape of the fruit (Pinero *et al*., 2017). This host selection may be mediated by olfactory cues (Jayanthi *et al*., 2014) or by visual stimuli like the colour, size, shape of the fruit (Pinero *et al*., 2017). Thus, to harvest the required amount of eggs for the germline transformation through CRISPR – Cas9 the oviposition eliciting substrate becomes crucial.

From the present study we found that banana pulp is a most preferred substrate among the different substrate that were tested. But for experimentation purposes, recovery of the oviposited eggs from the infested whole fruits is difficult and any such attempt may damage the eggs while handling. Hence, a proper egg collection device carrying the food source or oviposition elicitor is necessary for collecting eggs quickly, without damaging them. Previously, agar gel has been used as an egg collection medium in different species such as *Drosophila melanogaster* (Lihoreau *et al*., 2016) and *Anastrepha obliqua* (Fontellas - Brandalha and Zucoloto, 2004). However, in these examples the food material was added into the agar medium prior to solidification. In our current work in order to collect eggs from the

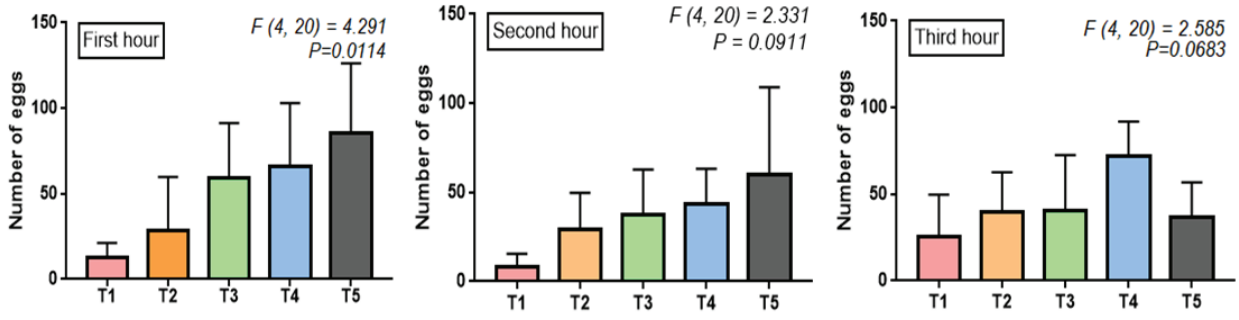

Figure 8. Egg laying in different treatments during three consecutive hours. The total number of eggs laid in 10 boxes for each treatment is plotted with its standard deviation (T1 – One female + One oviposition source; T2 – Two female + one oviposition source; T3 – three female + Two oviposition source; T4 – Four female + one oviposition source; T5 – Five female + One oviposition source).

oviposition cups/sources different methods are followed based on the object of the study. The fast collection was facilitated using method B. Collection from method A involves disruption of agar gel and picking eggs individually which involves more handling error, proportion of eggs prone to damage is high resulting in significantly high egg mortality and subsequently is time consuming. Hence, method B will be advantageous and will aid in our proposition. In nature, flies thrust their ovipositor through the skin of the fruit and deposit their eggs inside the fruit. Replicating this through a slice of banana which is less than 2mm thick allows the flies to insert the ovipositor through the slice and lay the eggs on the parafilm, rather than deep into the agar medium (method A). This enables the easy harvesting of the eggs from the parafilm surface as it is not required to dig the eggs from pulp, a process which can easily damage the eggs and render them unfit for further processes such as microinjection.

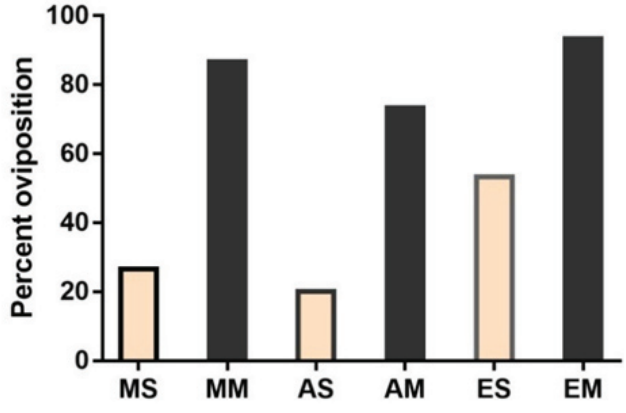

Figure 9. Period of time and egg laying behaviour in the corresponding period (First alphabet: M – Morning, A –Afternoon, E – Evening; Second alphabet: S – Single female, M – multiple female).

Further we have found that maximum egg deposition period was in the age group 20 – 40 days old which account for about 50.51% of the total egg produced during the life span of the fly. Similarly in the study conducted by Xu *et al*., 2012 maximum egg production was observed in the first eight days of egg laying when the first 27 days of egg laying period was considered. Nevertheless ovary maturation and egg development depends on the nutritional status of the flies Pelisse *et al*., 2011.Also when a group of gravid females were housed together the oviposition was accelerated, this shows the plausibility of the effect of conspecifics on the oviposition response. Similarly, Xu *et al*., (2012) found that that when the number of gravid females increased per given enclosure, the fecundity was found to decrease after a critical number of flies. The objective was to get a greater number of eggs; it was evident from our findings that five female flies per box were sufficient.

The present study results show that Yelakki banana is a good elicitor for timely collection of eggs at will, which is economical and available throughout the year. Egg collection for genetic manipulation experiments would require a minimum of around 50 gravid females, in the age group of 20-40 days old, to be housed together for oviposition. A time period of 15 min is enough to collect sufficiently large number of eggs, following which eggs can be collected repeatedly from the same set of flies, if required. In the cage housing the flies, at-least two oviposition sources should be placed, to avoid crowding and facilitate efficient oviposition by the flies.

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Information and communication technology (ICT) based e-Pest surveillance for assessment of population dynamics of sucking pests on Orange in Maharashtra, India

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ABSTRACT: Continuous and systematic pest surveillance can prevent epidemic situations of any pest by detecting damage before a higher pest population is firmly established. This study generated valuable data on the population dynamics of sucking pests of orange over the seasonal months from 2012 to 2022 with the aid of applied information and communication technology tools. The majority of the pests under current study showed their seasonal activity throughout the monitoring period. July to December months were the peak periods of infestation by majority of orange pests. The study on the seasonal incidence revealed *Diaphorina citrii* and *Dialeurodes citri* having their peak infestation in the month of September and October. November and December were the congenial months for extensive infestation by *Brevipalpus phoenicis*. The population dynamics of *Aleurocanthus woglumi* showed their peak incidence in the month of August and October whereas *Scirtothrips citri* were most abundant in August, September and March. The data so generated in this study would help in the forecast of the pests and helpful in devising an effective IPM strategy for their management.

Keywords: wide-area pest surveillance, ICT, seasonal incidence, forecast, pest management

INTRODUCTION

Citrus (L.) is one of the world's most economically important fruit crops, belonging to the Rutaceae subfamily Aurantioideae. It is found throughout the world's tropical and subtropical climates and is thought to have originated in Southeast Asia, specifically northeast India, the Malayan archipelago, China, Japan, and Australia (Moore, 2001). Citrus (*Citrus* spp.) fruits are among the most important fruits grown in over 52 different countries. Brazil and China are the largest producers followed by US, India and Mexico (FAO, 2020). *Citrus tangerina* (Orange, tangerine or santra), *Citrus sinensis* (sweet orange or Mosambi) and *Citrus limon* (lemon) are the most important citrus fruits grown in India. The citrus orchards encounter high prevalence of pests in India. Around 250 species of insects and mites have been reported to infest different citrus varieties in India (Wadhi and Batra, 1964). Major citrus pests include citrus psylla, blackflies, whiteflies, thrips, leaf miners, scales, bark eating caterpillars, fruit-sucking moths, fruit flies, mites etc. (Ahuja and Chattopadhyay, 2015).

Citrus Psylla, *Diaphorina citrii*, Citrus blackfly, *Aleurocanthus woglumi* and Citrus whitefly, *Dialeurodes citri* suck the sap from newly developed leaves, delicate shoots, and flowers, curling their edges and causing dieback and defoliation (Lima *et al.,* 2018). Citrus thrips, *Scirtothrips citri* and mites, *Brevipalpus phoenicis* are known to cause rind disorder and lowers the market value (Kaur *et al.,* 2020). Information regarding the population dynamics of each pest in a specific ecological niche should be taken into account for designing of an eco-friendly pest management programme. Site-specific research is even more crucial because it is well known that weather variability has a substantial impact on the dynamics of pest populations. That is the reason why this current study was carried out to investigate the population dynamics of sucking pests of orange pests in which we compiled a list of sucking pests that are affecting orange trees in Maharashtra based on study carried out from 2012 to 2022. This is a step toward examining the abundance of sucking pest fauna in orange as well as their seasonal occurrence in order to develop effective mitigation strategies against these pests and thereby enhance the citrus fruit production.

MATERIALS AND METHODS

Operational Plan of Pest Surveillance

The investigation was carried out during the crop-growing seasons from 2012 to 2022. The pest surveillance programme was implemented in the four districts of

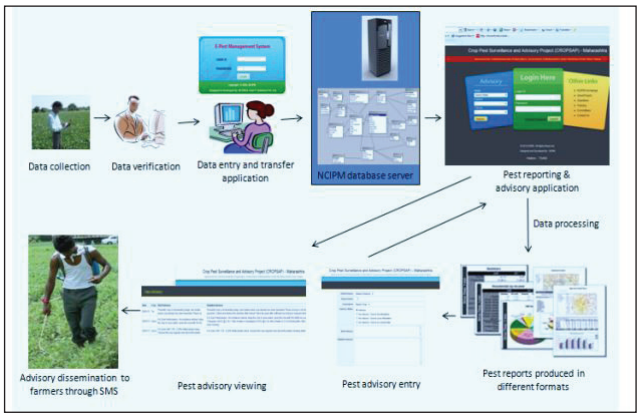

Fig. 2. Structure of ICT-based pest surveillance

Maharashtra, namely Akola, Amaravati, Buldhana, Nagpur, Vardha and Washim (Fig. 1) and it was made possible through the use of information technology, which aided in the development of an e- pest surveillance programme by recording pest activity data with the assistance of scouts and pest monitors employed by the Department of Horticulture, Govt. of Maharashtra.

Selection of orchards and trees

Two fixed orchards were chosen by a scout and in each orchard, 4 trees were examined by picking one tree from each direction viz., East (E), South(S), West (W) and North (N). The orchard with at least one acre was selected for observation in a fixed survey (Ahuja and Chattopadhyay, 2015).

ICT based pest surveillance

A three-tier architecture-based system was developed consisting of three functional components viz., a mobile app for data collection, a central database and a web-based pest reporting and advisory application. The structure and arrangement of components of the system is shown in Fig. 2. This system was developed in consideration of the challenges of pest surveillance and internet connectivity in remote areas of the state. The pest scouts were trained to capture pest observations from farmers' fields through mobile app. The app had the inbuilt ability to automatically sync the gathered

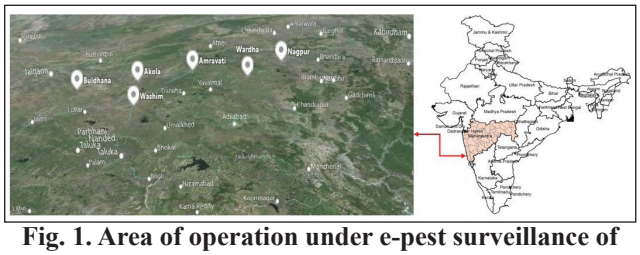

Fig. 1. Area of operation under e-pest surveillance of Orange in the state of Maharashtra, India

data to the central database maintained at the National Research Centre for Integrated pest management, New Delhi as and when the device entered an area with an internet connection. Data formats were devised for pest surveillance in consultation with crop experts to record pest observations from the fields. Location details of the field and insect pests information were major components of these data formats which were incorporated in the mobile app. Each field was assigned a unique ID and its geo-spatial coordinates were also recorded by the mobile app while capturing pest information from the field. SQL 2012, ASP.net, Android Studio and XML technologies were used to create the system (Ahuja and Chattopadhyay 2015).

Method of observations in monitoring

Weekly observations of the number of citrus psylla (nymphs and adults) per 10 cm shoot were recorded on four selected shoots per tree in each selected orchard. Similarly, number of whiteflies and blackflies (both nymphs and adults) per 10 leaves per tree were recorded weekly, whereas the total number of leaves observed are 40 per orchard while in recording the observations of the thrips population, one terminal branch was selected and each selected branch was tapped and the number of thrips fallen were recorded. A total of 4 branches were tapped from each tree and there was a total of 16 branches from an orchard are observed for documenting the data. For monitoring the mite population, the total number of infested leaves/fruits per 20 leaves/fruits per tree was examined and recorded where the total number of observed leaves/fruit is 80 per orchard (Ahuja and Chattopadhyay, 2015).

Statistical analysis

Statistical analysis was done by using the seasonal incidence data of sucking pests in orange obtained during the study period from 2012 to 2022. The data generated was subjected to analysis of variance (ANOVA) and the statistical procedures were performed using the R programme. Figures for the percentage of total infestation and mean seasonal abundance were graphically drawn using Google Colab by exploring the Matplotlib library of the Python program.

RESULTS AND DISCUSSION

Trends in Seasonal incidence of citrus psylla: The results revealed a significant difference with September having the highest infestation of psylla (19.17 psylla per tree) followed by October (12.71 psylla). The August month had 9.01 psylla per tree while the November had 9.45 psylla per tree. There were no significant differences

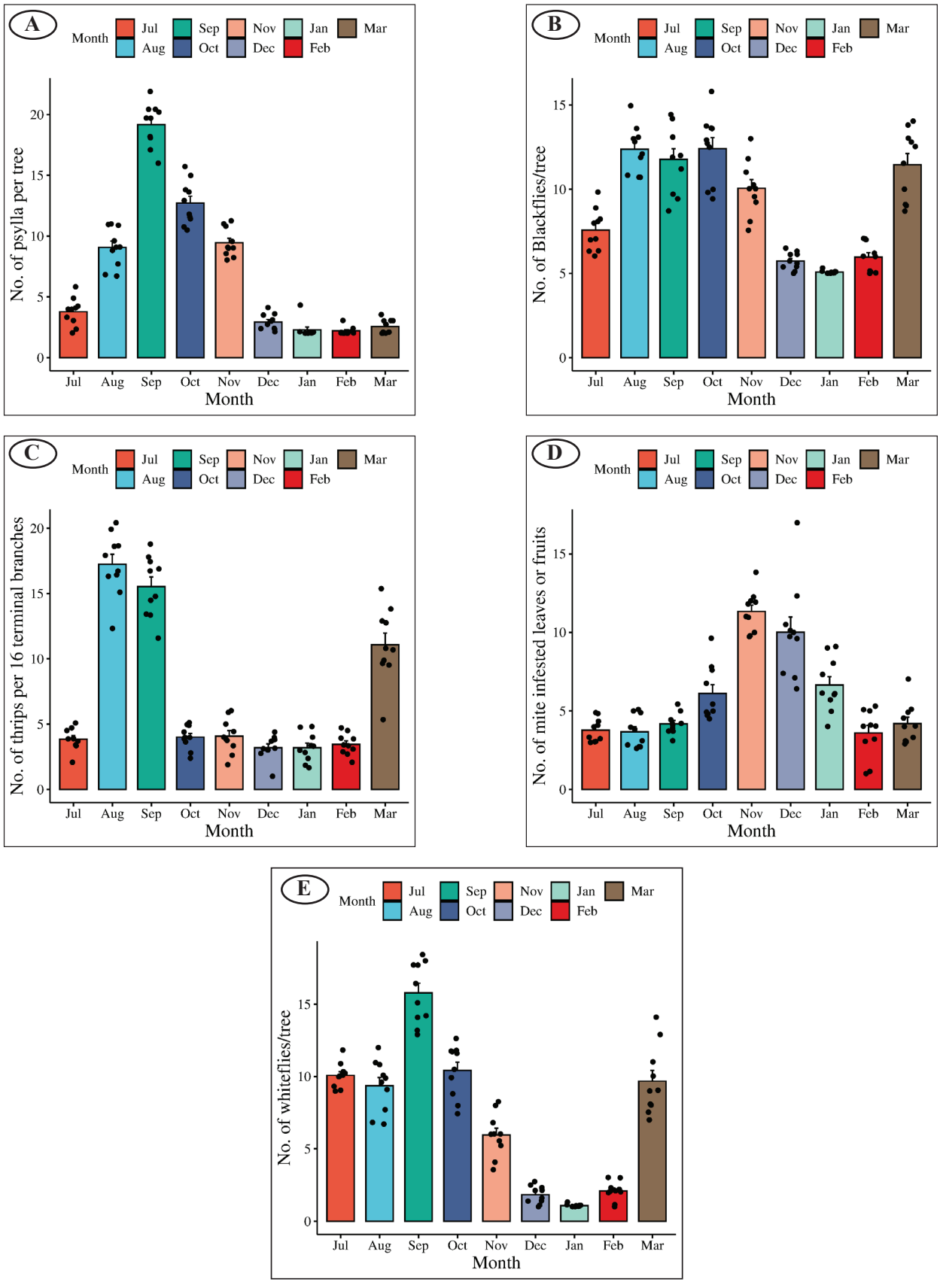

Fig. 3. Seasonal incidence of sucking pests in the studied Orange orchards from 2012 to 2022. (A) Psylla, (B) Blackfly, (C) Thrips, (D) Mites, (E) Whiteflies

Table 1. Trends in Seasonal incidence of insect pests in a particular month of orange growing seasons of the years from 2012 to 2022 in the state of Maharashtra, India

Month	Psylla	Blackfly	Thrips	Mites	Whiteflies
July	3.775 d	7.575 c	3.848 c	3.775 d	10.075 b
August	9.071 c	12.37 a	17.24 a	3.671 d	9.371 b
September	19.17 a	11.77 ab	15.52 b	4.176 cd	15.776 a
October	12.71 b	12.41 a	4.000 c	6.116 bc	10.416 b
November	9.457 c	10.05 b	4.078 c	11.33 a	5.957 c
December	2.933 d	5.733 cd	3.192 c	10.01 a	1.833 d
January	2.282 d	5.082 d	3.194 c	6.642 b	1.082 d
February	2.204 d	5.964 d	3.448 c	3.594 d	2.084 d
March	2.559 d	11.45 ab	11.07 b	4.195 cd	9.675 b

Note: Means in the same row followed by the same letters are not significantly different (P > 0.05) using the Shapiro-Wilk normality test

in other months of the study years (Fig. 3A and Table 1). Our results are consistent with previous reports where psylla peaked in September at 8.1 per 5 cm branch and then dropped to 0.1 per 5 cm branch in February. Psylla populations were higher during the rainy season and lower during the post-rainy and winter seasons (Krishna Kumar *et al.,* 2021). Furthermore, oranges have been shown to have their highest populations between September and November (Chatterjee *et al.,* 2000) while in orange the population peaked in September and November and then began to decline in December and January (Sahu and Mandal, 1997).

Trends in Seasonal incidence of citrus blackfly: The blackflies were observed with seasonal activity started in July and lasting until October with its activity peaking again in March. October had the highest infestation (12.41 blackflies per tree) followed by August (12.37 blackflies). In September, there were 11.77 blackflies per tree and in March, there were 11.45 blackflies per tree. There were no significant differences found in other months of the study years (Fig. 3B and Table 1). Our results were consistent with previous reports where infestations peaked in August and then declined in September. In addition, the population increased in October and decreased in November (Krishna Kumar *et al.,* 2021). Blackfly numbers increased rapidly between July and September along with relative humidity and precipitation (Chatterjee *et al.,* 2000) while peak populations of blackflies occurred in June, July and October (Poovizhiraja *et al.,* 2019).

Trends in Seasonal incidence of citrus thrips: The results revealed a significant difference between the thrips and the highest infestation observed in August (17.24 thrips per 16 terminal branches) followed by September (15.52 thrips) and March (11.07 thrips). There were no significant differences found in other months of the study years (Fig. 3C and Table 1). Several previous studies obtained the same results with activity noted in the first week of March and continuing through the last week of May. The population shows an increasing trend with increasing temperature (Kaur *et al.,* 2020) and constant peaks have been observed between March and April (Sharma *et al.,* 2007).

Trends in Seasonal incidence of citrus mite: The incidence data of citrus mite revealed that November had the highest infestation (11.33 mite-infested leaves and fruits per 20 leaves or fruit) followed by December (10.01). No significant infestation was detected during the remaining months of the study years (Fig. 3D and Table 1). The current results agreed with those of Kaur *et al.* (2020) who reported that citrus mite emergence started from May but peak infestations were recorded in November and December. Bhullar *et al.* (2015) documented the prevalence of citrus mite from November to February.

Trends in Seasonal incidence of citrus whiteflies: The data showed that whitefly activity started in July (10.07 whiteflies per tree) and continued to increase in August (9.3 whiteflies) but the highest infestation was recorded in September (15.77/tree) followed by October (10.41/tree). Infestation decreased in winter and increased sharply again in March (9.6/tree) (Fig. 3E and Table 1). Similarly, whiteflies showed their high percentage frequency in September (23.8%), followed by October (15.7%) and again in March (14.6%) (Fig. 4E). Similar past carried-out investigations showed two peaks, first in March-April and then again in September-October (Kumar *et al.* 2001). Citrus whiteflies were more

prevalent in the first week of January, second week of March and October (Lekurwale *et al.,* 2017).

In conclusion, It is crucial to have a thorough understanding of the population dynamics and damage potential of sucking pests of orange in order to develop appropriate management techniques. Although similar studies have been conducted earlier, this is the first of its kind including continuous pest monitoring from 2012 to 2022. The present findings on population dynamics have far-reaching implications for pest management in orange orchards.

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Bio-intensive integrated management of fruit piercing moths in Citrus

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ABSTRACT: Fruit piercing moths, *Eudocima* spp. and *Acanthodelta janata* L. affect both quality and quantity of the citrus fruits. Field studies were carried out during 2020 and 2021 to evaluate IPM modules against fruit piercing moths. Mean fruit damage was significantly low in trees covered with nets, followed by treatment with Horticulture Mineral Oils (Arbofine HMO, HP HMO and MAK HMO) followed by PAU Homemade Neem extract and PAU Homemade Dharek extract. Use of Poison bait traps @ 20 traps/acre also resulted in less fruit damage when compared to control. The average fruit yield was higher (36.7q/acre & 38.1q/acre) in netted trees followed by spraying of HMO's (35.6q/acre & 38.q/acre) during 2020 and 2021. Cumulative effects of applying all IPM components resulted in benefit-cost ratio of 9:1. These recommended IPM tools can be adopted by farmers as they are easily available, effective and economical.

Keywords: Citrus, fruit-piercing moths, IPM, Horticulture mineral oil, submontaneous zone

INTRODUCTION

Citrus is grown commercially throughout the India and comes third after mango and banana. In India, the estimated area under citrus is 973 thousand ha with an annual production of 15 million MT (Statista, 2022). In Punjab, citrus fruits are occupying an area of 50.195 thousand hectares with production of 1223027 metric tonnes (Thind, 2021). The area under citrus is declining especially under Kinnow mandarin inspite of prolific bearer with excellent fruit quality. This could be due to lower market price and secondly, the production is bogged down by different biotic and abiotic stresses. Among biotic stress, insect pest are important factors. Citrus fruits are attacked by various insect pests from time to time, which not only cause damage to fruits but also act as vector of many diseases, thus leading to huge economic losses to farmers in Punjab. There have been reports of about 250 species of insect pests in India which infest citrus. In Punjab, only 34 insect and mite species are active (Singh *et al.,* 2021; Singh *et al.,* 2020; Sharma *et al.,* 2011). Among these, fruit-piercing moths (FPMs), *Eudocima materna* (Linnaeus), *Eudocima fullonia* (Clerck), *Acanthodelta janata* (Linnaeus) and other species are among the potentially serious pests of citrus and occurs all over the country causing medium to high level of infestation (Singh *et al*., 2020; Singh *et al.,* 2021).

Fruit piercing moths are serious pests of different fruit crops throughout tropical and subtropical belt from Africa through Southeast Asia and Australia to the Pacific Islands (Leong and Kueh, 2011). These moths are reported on citrus, carambola, guava, mango, papaya, banana, fig, kiwifruit etc. About 86 species of fruit piercing moths are reported from Thailand. The most important species is *Eudocima phalonia* (L.) (Lepidoptera: Noctuidae), a species widely distributed in Africa, the Indian Islands, Asia, Australasia and the Pacific Islands (Leong and Kueh, 2011). These pests are sporadic in nature but can cause serious damage to ripe and ripening citrus fruits particularly in sub-mountainous zones of District Hoshiarpur, Punjab, India (Singh *et al.,* 2016). During 2004 to 2021, about 10 to 90 per cent fruit damage have been observed in Citrus (Kinnow, Daisy, sweet oranges, grapefruits and W. Murcott) orchards in the *Kandi* belt of District Hoshiarpur, Punjab, India. The damage by FPM *Eudocima* species alone sums up to 40% to 100% of the production on pomegranate, citrus in southern and northern India thus causing heavy loss to farmers (Singh *et al.,* 2012).

Unlike the other lepidopteron pests where larval stages are harmful, in fruit sucking moths adults are destructive due to their feeding habit on matured fruits. The larvae of these insects prefer to feed on the leaves of unrelated trees, shrubs and weeds often located well away from the adult feeding places, mostly belonging to the family Menispermaceae (Ramkumar *et al*., 2010). Larvae of *E.*

materna feed on leaves of creeper, *Tinospora cardifolia* (Giloe) (Fig. 1A) whereas larvae of *A. janata* feed on leaves of castor (*Ricinus communis*) (Fig. 1B).

Upon emergence, the adult moth swarm in large numbers from the adjoining areas/bushes/weeds, during September-October, towards the odour released by the ripening fruits, particularly fallen fruits. Adult moths suck the juice from ripe fruits (Fig. 1C and 1D), piercing the fruits with their strongly sclerotized proboscis with sharp spines, with which they macerate the pulp and suck the juice (Robinson *et al*., 2012). A circular pinhole like spot appears at the feeding site (Fig. 1H). Later on, the area around the damaged portion turns yellowish-brown (Fig. 1E, 1F, 1G). As many as 1-16 holes have been recorded on a single fruit of Kinnow mandarin (Singh *et al.,* 2012). As a result, the area around the holes becomes soft which results in fungal and bacterial infection. On squeezing such fruits, jet of fermented juice comes out from each hole. Furthermore, secondary invasions by micro-organisms spread into damaged tissues causing rot and premature fruit fall (Magar, 2012). Their peak activity period is recorded from September-October on Citrus in northern India.

The damage caused by fruit piercing moths in the *Kandi* belt of district Hoshiarpur, Punjab over the years ranged from 20 to 90 per cent. During a normal year, damage to fruit crops caused by this moth are less than 30 per cent, but the species can be highly destructive, up to 100%, when outbreak occurs as reported by Leroy *et al.,* (2021). Singh *et al.* (2012) also reported that the damage caused by fruit piercing moths, *Eudocima* spp. in citrus orchards in Punjab ranged from 15-100% depending on severity of infestation. With increasing incidence of fruit piercing moths, there is need to adopt IPM model for management of this pest and to get better fruit yield.

These moths are very difficult to control as their egg, larval and pupa stages are in/on the weeds/creepers and thus they escape from any management practices. Adult moths cause damage to fruits after sunset and return to adjoining area after a few hours of feeding (Chaudhari, 2020). Practically, no stage of these moths is available in the orchards for control. Farmers bear heavy losses due to severe fruit drop and also spray applications are leading to a heavy increase in their expenditure. Furthermore, application of insecticides at ripening stage is not desirable. Eco friendly management tactics can be applied as an alternative to the use of insecticides as they have been shown to be effective for pest management (Leroy *et al.,* 2021). To overcome these hurdles in control of fruit piercing moths, the present study was taken up to explore the feasibility of IPM module devised for eco-friendly management of fruit piercing moths in citrus including cultural practices, HMOs, botanicals, poison bait traps, netting and light traps.

MATERIALS AND METHODS

***Location*:** Studies were conducted at the village Gardhiwala, District Hoshiarpur, Punjab (India) (31.7325°N, 75.7506°E) during 2020 and 2021 in Citrus orchard (variety Daisy Tangerine) during August to November.

Treatments: IPM module consisting of netting of entire row of trees, application of PAU Homemade Neem extract and PAU Homemade Dharek extract @ 12 ml/l water, spray of three horticulture mineral oils (HMOs) viz., HP HMO, Arbofine HMO and MAK HMO @ 12.5 ml/l water, Poison bait traps @ 20 per acre was imposed in citrus orchard during the 1st week of August with the initiation of colour break stage of fruits; destruction of wild weeds and creepers, especially *Tinospora cardifolia* (*Giloe*) and castor (*rind*) in and around the orchards; disposal of fallen fruits as they attract the moths; creating smoke in the orchards after sunset; burning *Mashals* in the orchards after sunset and manual collection and killing of moths attracted towards the *Mashals;* fixing of lights traps to attract the moths; For each treatment 20 trees per row were selected representing 3 replications and in control, 20 trees were kept unsprayed.

Preparation of Light Traps

100 W bulb was installed on a five litre plastic container and 200 ml burned diesel oil was placed at the bottom of container. 200 meter electric wire was used to fix 20 traps.

Preparation of Poison Bait Traps

Malathion 0.05% @ 10 ml + Citrus fruit juice 100 ml + jaggery 100 g in 900 ml water were mixed to make final volume 1 litre.

Preparation of PAU Homemade Neem extract:

PAU Homemade Neem Extract was prepared by boiling 4.0 kg terminal parts of the shoots of neem trees including leaves, green branches and fruits in 10 L of water for 30 minutes. This material was then filtered through muslin cloth to get the desired plant extracts and used for spraying as per doses recommended in the treatments.

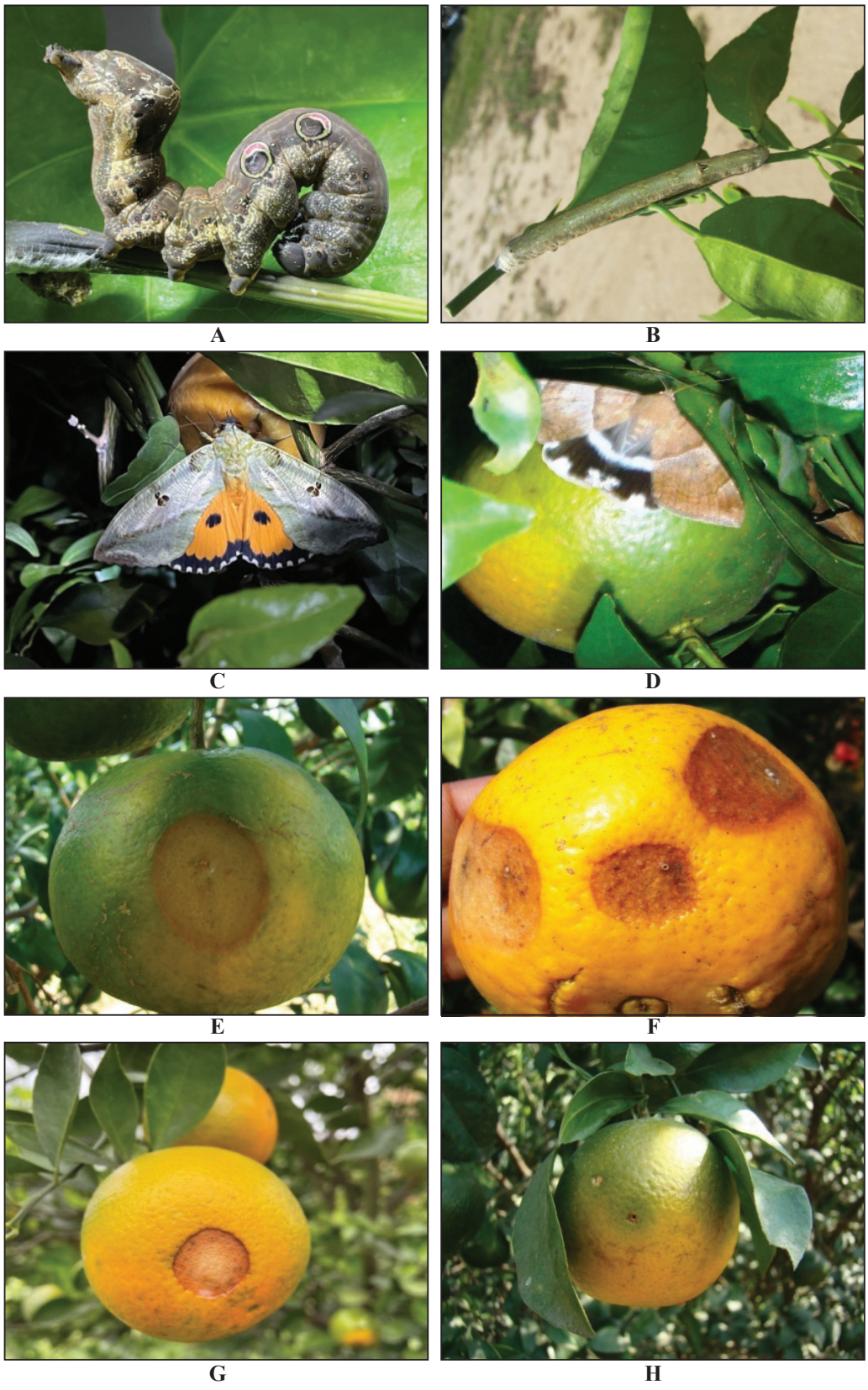

Fig 1. A. Larva of *Eudocima materna on* Giloe leaf; B. Larva of *Acanthodelta janata*; B. Adult of *Eudocima materna* on Kinnow fruit; D. Adult of *Acanthodelta janata* on Kinnow fruit; E. Damage on Kinnow fruit; F. Damage on Kinnow fruit; G. Damage on Daisy fruit; H. Hole on Kinnow fruit

Table 1. Evaluation of treatments against fruit sucking moths on Citrus Cv. Daisy at Village Garhdiwala, district Hoshiarpur during 2020

Treatment	Damaged fruits* (%)							
	Sep. 9	Sep. 16	Sep. 23	Sep. 30	Oct 7	Oct 14	Oct 22	Mean
Netting of trees **(Entire row of 20 trees)**	31.0 (33.9)	32.5 (34.6)	33.0 (35.4)	34.0 (35.6)	36.0 (37.0)	37.5 (37.6)	41.0 (39.9)	35.0 (36.4)
PAU Homemade Neem Extract @ 12 ml/l	40.0 (38.9)	41.6 (40.2)	43.2 (41.3)	45.0 (41.9)	46.5 (42.9)	48.0 (44.2)	50.0 (45.7)	44.9 (41.9)
PAU Homemade Dharek Extract @ 12 ml/l	40.0 (38.9)	41.0 (39.9)	44.0 (41.2)	46.7 (42.9)	48.1 (44.2)	50.5 (45.8)	52.0 (45.9)	46.0 (42.6)
Arbofine HMO @ 12.5 ml/l	32.0 (34.6)	33.0 (35.4)	35.5 (36.8)	36.0 (37.0)	38.5 (38.6)	39.0 (38.8)	40.0 (38.9)	36.3 (37.2)
HP HMO @ 12.5 ml/l	35.0 (36.4)	35.5 (36.8)	37.0 (37.4)	38.0 (38.4)	38.0 (38.4)	40.0 (38.9)	43.0 (41.2)	38.1 (38.4)
MAK HMO @ 12.5 ml/l	35.0 (36.4)	36.0 (37.0)	37.2 (37.4)	38.0 (38.4)	40.0 (38.9)	41.0 (39.9)	41.5 (40.1)	38.4 (38.9)
Poison Bait traps @ 20 traps/ acre	46.0 (42.6)	47.0 (43.4)	49.8 (45.4)	52.0 (45.9)	52.5 (45.9)	53.0 (46.8)	55.0 (48.3)	50.8 (45.8)
Control	73.0 (64.7)	80.0 (67.5)	84.3 (69.1)	85.0 (69.6)	86.4 (70.1)	88.0 (70.9)	90.0 (71.9)	83.8 (69.2)
CD (p=0.05)	**(8.4)**	**(6.9)**	**(6.1)**	**(5.8)**	**(5.5)**	**(5.1)**	**(4.6)**	**(5.9)**

*Figures in parentheses are the means of arc sine transformations; Mean of 20 trees

Preparation of PAU Homemade Dharek extract

PAU Homemade Dharek Extract was prepared by boiling 4.0 kg of green branches, leaves and fruits of dharek tree were boiled in 10 liters of water for 30 minutes. Filter the material through muslin cloth and use the filtrate as spray.

Observation

Observations on damaged fruits (%) due to fruit piercing moths before and after the treatments were recorded at weekly intervals. Yield data of each treatment and control orchards were also recorded.

Data collection and analysis

The data thus collected were subjected to statistical analysis using analysis of variance (ANOVA) of Statistical Package for Social Science (SPSS) to know the significance of differences in per cent damage among treatments for their efficacies. The data on per cent fruit damage were transformed into arc sine root transformation in a Randomized Block Design before statistical analysis (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

The effect of different treatments on the fruit damage by fruit piercing moths during 2020 and 2021 are presented in Table 1 and Table 2. The results revealed that all the treatments were significantly effective in reducing fruit damage as compared to control.

During 2020, fruit damage was recorded lowest (35.0% damaged fruits) in the rows covered with nets, thereby protected 65 per cent of fruits (Table 1). The next best treatment was application of horticulture mineral oils (HMOs) with Arbofine HMO protecting the fruits with only 36.3% fruit damage while HP HMO and MAK HMO managed the fruits from fruit sucking moths with 38.1% and 38.4 % fruit damage, respectively. Furthermore, there were 44.90 and 46.04 percent damaged fruits recorded in PAU homemade Neem extract and PAU homemade Dharek extract treatments, respectively. Placing of poisonous baits recorded significantly higher fruit damage (50.7%) followed by control with 83.8 % fruit damage as compared to other treatments.

During 2021, there was a significant decrease ($P \leq 0.05$) in the percent fruit damage caused by fruit piercing moths in treatment with netting of trees as evident from

Table 2. Evaluation of treatments against fruit sucking moths on Citrus Cv. Daisy at Village Garhdiwala, district Hoshiarpur during 2021

Treatments	Damaged fruits* (%)							
	Sep. 7	**Sep. 15**	**Sep. 22**	**Sep. 30**	**Oct 5**	**Oct 12**	**Oct 21**	**Mean**
Netting of trees **(Entire row of 20 trees)**	30.0 (33.3)	32.0 (34.6)	32.5 (34.6)	33.0 (35.4)	33.0 (35.4)	34.0 (35.6)	37.5 (37.6)	33.1 (35.4)
PAU Homemade Neem Extract @ 12 ml/l	38.0 (38.4)	40.5 (39.9)	41.0 (39.9)	43.2 (41.3)	44.3 (41.3)	45.0 (41.9)	45.5 (42.9)	42.5 (40.9)
PAU Homemade Dharek Extract @ 12 ml/l	41.0 (39.9)	42.0 (40.5)	42.5 (40.9)	45.5 (42.9)	46.5 (42.9)	47.0 (43.4)	47.0 (43.4)	44.5 (41.5)
Arbofine HMO @ 12.5 ml/l	32.0 (34.6)	33.0 (35.4)	33.5 (35.6)	34.0 (35.6)	34.0 (35.6)	35.5 (36.8)	36.0 (37.0)	34.0 (35.6)
HP HMO @ 12.5 ml/l	34.5 (36.2)	35.0 (36.4)	35.0 (36.4)	36.0 (37.0)	38.0 (38.4)	39.5 (39.2)	41.0 (39.9)	37.0 (37.4)
MAK HMO @ 12.5 ml/l	36.0 (37.0)	38.0 (38.7)	38.5 (38.6)	39.0 (38.9)	40.0 (38.9)	40.0 (38.9)	42.0 (40.5)	39.1 (38.9)
Poison Bait traps @ 20 traps/ acre	48.0 (44.2)	50.5 (45.8)	50.5 (45.8)	53.0 (46.8)	53.5 (46.9)	55.0 (48.3)	56.5 (48.5)	52.4 (45.9)
Control	75.0 (61.3)	78.0 (63.8)	80.5 (66.3)	83.0 (66.3)	84.0 (68.7)	84.5 (69.4)	88.0 (70.9)	81.9 (66.7)
CD (p=0.05)	**(3.6)**	**(4.4)**	**(5.3)**	**(6.3)**	**(5.9)**	**(5.9)**	**(5.2)**	(6.5)

*Figures in parentheses are the means of arc sine √percentage transformations; Mean of 20 trees/ row

the results (33.1% damaged fruits) (Table 2). However, there was no significant difference in the percent fruit damage between HMO's treatment that ranged from 34.0-39.1 per cent followed by PAU homemade Neem extract (42.5%) and PAU homemade Dharek extract (44.5%). Up to 52.4 per cent damaged fruits were recorded in poison bait traps treatment while in control trees; damage was as high as 81.86 per cent.

The data on fruit yield showed that the fruit yield in all the treatments was significantly higher than the untreated control (Table 3). However, the highest fruit yield of daisy fruit (36.7 q/acre and 38.1q/acre) was realized in treatment with netting of trees which was at par with management of fruit piercing moths with spraying of Arbofine HMO (35.6q/acre and 38.0) during 2020 and 2021 respectively. It was followed by treatment of spraying HP HMO (34.3q/acre and 34.7q/acre) and MAK HMO (34.2q/acre and 33.3q/acre) followed by treatment with spraying of PAU homemade neem extract (27.1q/acre and 30.8q/acre) and PAU homemade dharek extract (26.6q/acre and 27.2q/acre) during 2020 and 2021. The lowest yield 8.7 q/acre and 8.9 q/acre was registered in untreated control plots, indicating immense damage potential of fruit piercing moths on daisy fruit during 2020 and 2021.

These studies are in line with findings of Bhumannavar and Viraktamath (2012) who reported that nylon nets of 1cm mesh extended on each orchard line or by tree remains a possible alternative for short term for the management of fruit piercing moths in pomegranate orchards in the south India and orange in the central India. It could help to protect crops from other pests too (birds, fruit bats or fruit flies). This method was great success in Australia and in American Samoa against *E. materna* and a number of secondary fruit-piercing pest moths in Japan. While protective nets have some advantages for small areas or isolated trees they require a considerable investment even if they can be used for several years.

Present results are in confirmation with the earlier studies, who reported that the fruit and non-fruit based baiting techniques were screened for trapping the fruit sucking moths *E. materna* in the guava field but this technique alone was not so successful (Kamala Jayanthi *et al*., 2009; Mallikarjun *et al.,* 2019). In a nocturnal lepidopteran like the FPMs, olfaction is one of the major means to locate food (Doreen, 2011). In the present study, the olfactory preferences of FPMs towards baits in the citrus orchard to lure them away from the main crop were studied thus lowering fruit damage. Repelling an insect is the recognition of an unpleasant or repulsive

molecule causing insect to move away from the host. The use of neem and dharek extracts was effective in reducing fruit damage by repelling these moths away from main host and these results are also confirmed by study of Kamala Jayanthi *et al.,* (2010) who studied the effect of neem oil (*Melia azedarach*, Meliaceae) on guava and pomegranate fruits which was able to repel moths such as *E. materna*. Horticulture mineral oil provide significant decrease in fruit damage as was observed in Malaysia where Horticulture mineral oils (at 0.35%) were sprayed weekly until the fruits were ripe and a decrease in the damages (ranging fruit damage from 4-21%) caused by *E. phalonia* as compared to control with more than 40% fruit damage was recorded in orange orchards (Leong and Kueh, 2011).

Observations of Robinson *et al*. (2012) are in conformation with our results where it was stressed to keep the light traps on from before dark until midnight because moths are not easily disturbed once feeding. Of the light sources that attract nocturnal insects, those that emit relatively large amounts of UV radiation (blue fluorescent lights, black lights, and mercury lamps) exert the strongest attraction (Cowan and Gries, 2009). Setting of light traps along with poison baiting with malathion 50 EC @ 10 ml + 100 g jaggery + 100 ml mandarin juice + 900 ml of water (two bottles containing poison bait/25-30 trees) will attract the adults of fruit sucking moths. Similarly, foliar application of neem oil @ 1 per cent or malathion 50 EC @2 ml at 10-15 days interval during fruit maturity till harvest provided good control of fruit piercing moths on Citrus (Singh *et al.,* 2016). Foliar application of NSKE 5 per cent or fish oil rosin soap 2 per cent or karanj oil 1 per cent or azadirachtin 1500 ppm and neem oil 1 per cent spray on trees at fruit maturity was effective against *Eudocima* spp. depicted in above studies (Singh *et al*., 2016).

The use of smoke in the pomegranate orchard after sunset as it repels the moths of *Eudocima* spp. and appears to be quite effective as it was also reported by (Balikai *et al.,* 2009) but the method is constrained by climatic conditions (wind, rain), which can sometimes seriously reduce its efficiency. In addition, it is effective for only one night and must therefore be repeated every night during the fruiting season and moths return to orchards as soon as the smoke dissipates. But it can be used in integral part with other methods of management of fruit piercing moths. Sherlin *et al.,* (2022) also reported similar results with use of IPM module i.e poison bait trap, light traps, smoke, removal of weeds etc. for management of *Eudocima* spp. in fruits.

Economic impact: In this study, the economic impact of different treatments was worked out by calculating total cost of treatment, total yield, gross returns, net income and net benefit of IPM module over control plot. Cost of treatments and B:C ratios are given in table 3. Netting of trees resulted in benefit of Rs. 5820.50, Neem and Dharek resulted in Rs. 7,057.75 and Rs 6335, respectively over control. HMOs also gave more returns such as Arbofine HMO: Rs. 9,369.50, HP HMO: Rs. 8,580 and MAK HMO: Rs. 8,326.80 over control. Similarly, poison bait traps gave benefit of Rs. 6,012 over control per row of 20 trees. Overall, with total expenditure of applying IPM module was Rs. 5704.63, benefit of Rs. 51, 501 was achieved. Although netting of trees is an expensive treatment but this treatment has proved to be very effective in preventing fruit piercing moth damage. Also, this will be very useful for small orchards and kitchen gardens.

On basis of findings of present study, following IPM module is proposed for management of fruit piercing moths

- Clean cultivation i.e. removal and destruction of weed hosts such as *Tinospora cardifolia* (*Giloe*) and castor (*rind*) in and around the orchards, as weed hosts act as oviposition substrate, resting place for adult moths and their larvae.
- Disposal of fallen fruits as they attract the moths.
- The moths are active during dusk so create smoke in the orchards after sunset as it deters the fruit sucking moths from orchards
- Cover the entire row of citrus trees with net of mesh size 1.2 mm from last week of August to avoid damage to fruits
- Spray PAU Homemade Neem extract and PAU Homemade Dharek extract @ 12 ml/ litre water at 7 days interval or spray horticulture mineral oils (HMOs) (HP HMO or Arbofine HMO or MAK HMO) @ 12.5 ml/litre water at 10 days interval starting from last week of August.
- Fix poison bait traps (Malathion 0.05% @ 10 ml + citrus juice 100 ml + jaggery 100 g + 900 ml water) in the orchards @20 traps/acre during 1st week of August with the initiation of colour break stage.
- Burning of *Mashals* in the orchards after sunset and manual collection and killing of moths attracted towards the *Mashals*
- Fix Homemade Light Traps using 100 W bulbs @ 20 traps/ acre during last week of August.

Table 3. Yield of Daisy fruits at Village Garhdiwala, district Hoshiarpur during 2020 and 2021

Treatment	2020		2021			
	No. of fruits per tree	Yield per acre (q)	No. of fruits per tree	Yield per acre (q)	Cost of treatment	B:C ratio
Netting of trees **(Entire row of 20 trees)**	98.8	36.7	102.0	38.1	4200	1.39
PAU Homemade Neem Extract @ 12 ml/l	72.9	27.1	83.7	30.8		
PAU Homemade Dharek Extract @ 12 ml/l	71.5	26.6	73.0	27.2	437.5	
Arbofine HMO @ 12.5 ml/l	95.7	35.6	101.7	38.0	406.25	21
HP HMO @ 12.5 ml/l	92.1	34.3	93.0	34.7	396.88	21
MAK HMO @ 12.5 ml/l	91.8	34.2	89.4	33.3	50.0	20
Poison Bait traps @ 20 traps/ acre	70.0	26.1	70.7	26.2	214.0	120
Control	23.4	8.7	24.0	8.9		
CD 5%	**2.52**	**1.55**	**0.51**	**0.12**		

Number of tree per acre= 200, average fruit weight = 186 g, average number of fruits per tree= 150

CONCLUSION

With increasing concern/risk of use of insecticides for management of fruit piercing moths in citrus, there is need to develop IPM module of pest control. Therefore, it could be concluded from above study that IPM module consisting of netting of trees followed by spraying of HMO's (Arbofine, HP HMO, MAK HMO) @ 12.5 ml/ l water at 10 days interval starting from last week of August or spraying of PAU Homemade Neem extract and PAU Homemade Dharek extract @ 12 ml/ l water at 7 days interval followed by fixing of poison bait traps in the orchards @ 20 traps/acre during 1st week of August was significant effective and economic, could be used for the management of fruit piercing moths in citrus. Besides this, various physical and mechanical control methods such as use of light traps (20 traps/acre), destruction of weeds and removal of damaged fruits from the orchards, use of smoke and mashals during dusk will also result in the tremendous reduction in fruit damage in citrus. These recommended IPM tools should be adopted by farmers because they are easily available, least cost and with maximum return. Pesticide residue free citrus fruits will be harvested which will increase the chances of export from Punjab, India.

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Development and survival of different generations of *Bemisia tabaci* (Gennadius) on brinjal under north Indian conditions

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ABSTRACT: Annual life cycle of *Bemisia tabaci* was studied under screen house conditions at Punjab Agricultural University, Ludhiana, Punjab during 2019-20. The results revealed that *B. tabaci* completed 13 overlapping generations on brinjal in a year. The mean incubation period ranged between 3.60-23.70 days and egg hatchability varied from 80.18 to 95.0 per cent during different generations. The nymphal stage prolonged during winter months and mean duration of nymphal stage varied from 14.83 to 47.22 days during different months. The survival of nymphs ranged from 52.78 to 76.30 per cent, being higher during spring, rainy seasons and lower during summer, winter months. Total development period (egg to adult emergence) of *B. tabaci* varied from 19.38 to 65.30 days during different months. The mean generation survival ranged between 45.0 to 69.2 per cent and it was higher during spring and rainy season, whereas lower in summer and winter season generations. The multiple regression analysis revealed that different weather parameters contributed 37.0 to 63.0 per cent (R^2) variations in survival of different generations of *B. tabaci* on brinjal. This study is the first report on annual life cycle of *B. tabaci* on brinjal under north Indian conditions.

Keywords: *Bemisia tabaci*, brinjal, development period, generations, life cycle, whitefly

INTRODUCTION

Whiteflies are one of the most important pests, which cause severe damage to vegetable, horticultural, agricultural, and ornamental plants worldwide. However, among 1500 reported species of whiteflies, *Bemisia tabaci* (Gennadius), is a destructive polyphagous insect pest, which exhibits a wider host range (over 1000 species) (AbdRabou and Simmons, 2010). This pest causes heavy losses in some plant families such as cucurbitaceae, solanaceae and fabaceae, particularly in tropical and subtropical regions of the world (Martin and Mound, 2007) . *Bemisia tabaci* causes substantial damage and economic losses to susceptible crops through phloem feeding and induction of sooty moulds that reduce photosynthesis (Oliviera *et al.,* 2001). Besides this, *B. tabaci* is able to transmit more than 350 species of plant pathogenic viruses including Begomovirus, Carlavirus, Crinivirus, Ipomovirus, and Torradovirus (Jones, 2003). In favourable environment with warm climatic conditions, whiteflies maintain a high rate of reproduction for the whole year (CABI, 2017) and have the capacity to achieve exceptionally high population size within few generations.

Bemisia tabaci was first reported as a pest of tobacco in 1889 from Greece and named tobacco whitefly, *Aleyrodes tabaci* Gennadius. But, in India, *B. tabaci* was first time reported in 1905 on cotton crops (Misra and Lambda, 1929) and it became a serious pest of cotton in the late 1920s and early 1930s in northern India (Hussain and Trehan, 1933). Recently, an outbreak of *B. tabaci* during 2015 resulted in huge loss to the cotton growers in northern India. In Punjab, 60% of the cotton crop was damaged, leading to reduction in lint yield from 574 kg ha^{-1} in 2014-15 to 197 kg ha^{-1} in 2015-16 (Dhillon and Sidhu, 2016). The potential crop losses by *B. tabaci* are exacerbated by its high reproductive rate, dispersal ability and lack of a diapause stage, which resulted in buildup of pest population throughout the year by shifting to different host plants during different seasons (Lin *et al.*, 2007).So, the appraisal of alternate host plants and their importance in pest build up, survival can be fundamental to manage the polyphagous pest on its main hosts (Tabashnik *et al*., 1991).

Under Punjab conditions, *B. tabaci* is not limited to cotton plants, but it can remain active throughout the year due to the continuous availability of alternative host plants. Moreover, agricultural practices have changed due to fragmentation of farms and sowing of different crops in fields adjoining to cotton is now common. Brinjal is an important host plant of *B. tabaci* which is cultivated throughout the year in Punjab, in an area of 5.47 thousand hectares (Anonymous, 2022). Being cultivated round the year, brinjal played an important role in population build up and carryover of *Bemisia tabaci* under north Indian conditions (Kedar *et al*., 2018). But information

pertaining to number of generations completed by *B. tabaci* on brinjal was lacking. Accurate information on biological parameters on specific host plant is required for implementing sustainable management practices, which facilitate the present study to determine the development and survival of different generations of *B. tabaci* on brinjal in a year under Punjab conditions.

MATERIALS AND METHODS

Studies were conducted during 2019 and 2020 in the screen house conditions at Punjab Agricultural University, Ludhiana (Punjab) India. The geographical location of Punjab Agricultural University, Ludhiana has the reference to 75° 80' 45" East longitude and 30° 90' 10" North latitude. To study number of generations of *B. tabaci* on brinjal, the experiment was conducted round the year under screen house conditions. The seedlings of brinjal were transplanted in earthen pots and these pots were kept under screen house. The experiment was started at 15 days after planting, when crop recovered from transplanting shock and started new growth. A pair of whitefly adult was released in a cup cage on undersurface of the fully developed leaf of 15 plants. After 24 h, the adults were removed and leaves were examined for eggs. For this purpose, the leaf portion inside each clip cage was marked with non toxic marker and observed by using stereo zoom binocular microscope. Those leaves which contain eggs were tagged at petiole region and five eggs on each infested leaf were retained for taking observations and remaining were removed with the help of a fine brush. Cup cage were again attached to selected leaves to avoid further infestation of whitefly or other insects. The time period between laying of eggs and appearance of the crawler were taken as incubation period. The observations on incubation period, nymphal and survival of different stages were recorded after 24 hours. Whenever, the first adult emerged in a generation, the next generation of whitefly was initiated by releasing the pair of whitefly adults from stock culture assuming two days pre oviposition period. The next generation was reared on new brinjal plants and development period and survival of eggs and nymphs were recorded. The data was analyzed using mean and standard errors.

RESULTS AND DISCUSSION

When reared round the year, whitefly completed 13 overlapping generations on brinjal from February 2019 to March 2020 (Table 1). Ten overlapping generations were recorded between February 2019 to mid October 2019, whereas, the development of *B. tabaci* during winter months was slower and it completed two generations between November 2019 and March 2020. No published work on annual life cycle of *B. tabaci* on brinjal was observed in literature. However, earlier reports also demonstrated that *B. tabaci* can complete 11 to 15 generations a year under favourable conditions in the laboratory (Avidov, 1956). Our results are in conformity with findings of Aneja (2000), who reported 11 generations of *B. tabaci* during cotton growing season (April to October) in Punjab, India.

Egg: The incubation period varied during different generations and it was influenced by the prevailing weather during different months of the year. The egg stage lasted for longer period in winter generations, being maximum (23.70±0.35days) in generation completed during January 23-March 11, 2020 followed by November 19-January 21 (17.90±0.29 days). The incubation period was shortest (3.60 ± 0.09 days) during August 14-September 2, which was statistically at par with all other generations except four generations during, February 16-March 20, March 22-April 18, November 19-January 21 and January 23-March 11. The egg survival in term of hatchability was recorded and data showed that hatchability ranged between 80.18 to 95.0 per cent during different generations. The hatchability was highest (95.0 %) in whitefly generation during October 22 - November 17, which was at par with generations completed during February 16 - March 20 , April 20-May 1, August 14-September 2 and September 4-September 24. The egg survival was minimum (80.18) in generation during June 8-June 29, being on par with generation completed during May 13-June 6, July 1-21, July 23-August 12, September 26–October 20, November 19-January 21, January 23-March 11 (Table 1).

Nymph: The observations on total nymphal development period (first instar to adult emergence) revealed that nymphal stage prolonged during winter months and temperature has pronounced effect on development of nymphs. The mean development period of nymphs varied from 14.83 to 47.22 days during different generations. It was shortest in generation during April 20-May 11, which was statistically on par with generation during May 13-June 6, June 8-June 29, August 14-September 2 and September 4- September 24. The mean nymphal period of *B. tabaci* generations during winter *i.e* November 19-January 21 (47.22±0.40 days) and January 23-March 11(27.12±0.34 days) was significantly higher and they differ significantly from each other as well as other generations. The nymphs experienced higher mortality than eggs as depicted from the data presented in Table 1. Mean nymphal survival varied from 52.78 to 76.30 per cent as compared to 80.18 - 95.0 per cent egg survival. The nymphal survival was maximum during, July 1-July 21, which was on par with *B. tabaci* generation during February 16-March 20

Table 1. Development and survival of different generations of whitefly, *B. tabaci* on brinjal under screen house conditions at Ludhiana, 2019-20

Generation	Period	Eggs			Nymphs			Total development period			#GT (Days)
		Incubation period (days)		Hatchability (%)	Duration (days)		Survival (%)	Duration (days)		Survival (%)	
		Mean± SE	Range		Mean± SE	Range		Mean± SE	Range		
*I	February 16 – March 20, 2019	16.89±0.23	16-19	93.33	17.48±0.18	16-18	74.20	34.17±0.33	32-38	69.20	32.0
II	March 22 – April 18	9.00±0.15	8-10	87.67	18.00±0.14	17-19	62.60	27.13±0.18	26-29	55.05	26.0
III	April 20– May 11	5.33±0.16	4-6	90.85	14.83±0.23	13-17	53.20	20.18±0.19	20-23	47.50	20.0
IV	May 13 – June 6	5.20±0.14	4-6	82.50	16.56±0.14	15-19	54.50	21.76±0.21	20-25	45.60	21.0
V	June 8– June 29	5.44±0.13	5-7	80.18	16.39±0.16	15-17	57.30	21.83±0.21	20-24	45.70	20.0
VI	July 1– July 21	3.90±0.13	3-5	86.50	17.33±0.13	16-19	67.70	21.23±0.18	19-24	58.50	19.0
VII	July 23– August 12	4.00±0.15	3-6	85.00	17.00±0.24	16-18	76.40	20.06±0.23	19-24	65.00	19.0
VIII	August 14 – September 2	3.60±0.09	4-5	90.83	15.78±0.24	14-18	66.10	19.38±0.21	18-23	60.00	18.0
IX	September 4– September 24	3.88±0.12	4-6	89.33	15.88±0.15	15-18	67.00	20.75±0.19	19-24	59.85	19.0
X	September 26– October 20	4.67±0.09	4-5	85.00	18.25±0.13	17-19	73.60	22.88±0.18	21-24	62.56	21.0
XI	October 22– November 17	4.90±0.13	4-6	95.00	19.75±0.20	18-21	68.30	24.75±0.22	23-27	65.00	23.0
XII	November 19– January 21, 2020	17.90±0.29	17-20	85.00	47.22±0.40	43-51	52.78	65.30±0.48	60-71	45.00	63.0
XIII	January 23– March 11	23.70±0.35	20-27	84.00	27.12±0.34	24-31	55.68	50.82±0.37	46-58	47.50	47.0
	CD (p=0.05)	1.85	-	7.04	1.74	-	6.75	1.53	-	6.39	

*assuming two days pre oviposition period; #minimum generation time

(74.20 %) and September 26-October 20 (73.60 %). The minimum nymphal survival corresponded to November 19-January 21, which was on par with the survival during April 20-May 11 (53.20 %), May 13-June 6 (54.50 %), June 8-June 29 (57.30 %) and January 23-March 11(55.68 %) generations.

Total development period: Total development period i.e. egg to adult emergence of *B. tabaci* varied between 18 and 71 days during different generations on brinjal. It was longer during winter months, being maximum (65.30±0.48 days) during November 19 - January 21, followed by January 23-March 11 (50.82±0.37 days). The shortest development period was recorded in generation completed during August 14-September 2 (19.38±0.21 days) which was statistically on par with July 23-August 12 (20.06±0.23 days), September 4-September 24 (20.75±0.19 days), and April 20-May 11 (20.18±0.19 days) generation. *B. tabaci* experienced varied level of mortality during different generations and total generation survival ranged between 45.00 and 69.20 per cent. The highest survival during February 16-March 20, was statistically on par with survival of the generation completed during July 23-August 12 and October 22 -November 11 (65.0 % each). The minimum survival of 45.0 per cent was recorded in generation occurred during November 19-January 21, which was on par with generation during January 23-March 11 (47.50 %) and three generations during mid April to June (45.60-47.50 %) (Table 1).

Effect of different abiotic factors on development of *B. tabaci* on brinjal: The data pertaining to correlations between major abiotic factors and developmental stages of *B. tabaci* are presented in Table 2. Significant negative correlations were registered (r = -0.83 to -0.89) between egg development period of *B. tabaci* and temperatures, whereas the correlation between egg survival and temperatures were non-significant. The relative humidity (RH) showed positive effects on egg survival (hatchability), but correlations were not significant. The data revealed that temperatures exhibited significant negative correlation with nymphal duration (r = 0.71 to 0.82) as well as total development period (r = 0.83 to 0.87) of *B. tabaci* during different generations. The relative humidity (RH) exhibited non-significant relationship with both nymphal period and total development period. However, relative humidity during evening exhibited positive influence on nymphal survival (r = 0.48) and total generation survival (r = 0.51). The multiple regression equations between development period of eggs, nymphs of *B. tabaci* as dependent variable (Y) and different meteorological parameters as independent variables are also presented in Table 2. The regression analysis revealed that different weather parameters together accounted for 0.84–0.87 (R^2) fluctuations in the development period of *B. tabaci* on brinjal. Similarly,

Table 2. Multiple regression analysis of different developmental stages of *B. tabaci* and meteorological parameters

	Correlation coefficient						Regression equation	R^2
	T max	T min	T avg	RH morning	RH evening	RH average		
Eggs development period	-0.83*	-0.88*	-0.89*	0.49	0.01	0.25	Y = 82.54- 1.58 Tmax + 0.15Tmin -0.19 RHmax -0.21 RHavg	0.87
Eggs survival	-0.23	-0.17	-0.21	0.44	0.12	0.30	Y = 56.75- 0.14 Tmax + 0.26 Tmin + 0.52 RHmax -0.31 RHavg	0.37
Nymphal development period	-0.82*	-0.71*	-0.79*	0.39	0.35	0.39	Y = 171.03- 5.22 Tmax + 3.41 Tmin + 0.23 RHmax -1.16 RHavg	0.85
Nymphal survival	-0.02	-0.19	0.08	0.54	0.48*	0.50	Y = -71.82+ 3.69 Tmax – 2.51 Tmin + 0.03 RHmax +1.07 RHavg	0.63
Total development period	-0.86*	-0.83*	-0.87*	0.45	0.22	0.35	Y = 199.72-4.38 Tmax +1.47 Tmin - 0.60 RHmax -0.26 RHavg.	0.84
Generation survival	-0.13	0.09	-0.12	0.55	0.51*	0.56	Y = -55.35+2.15Tmax – 1.05 TMin+0.56 RHmax+0.33 RHavg	0.54

Tavg: average temperature (°C); Tmax: maximum temperature (°C); Tmin: minimum temperature (°C); RHavg: average relative humidity (%); RHmin: evening relative humidity (%); RHmax: morning relative humidity (%);

the different weather parameters contributed 0.37–0.63 (R^2) variations in survival of different generations of *B. tabaci* on brinjal (Table 2).

Hence it can be concluded that *B. tabaci* completed 13 overlapped generations on brinjal in a year under Punjab conditions. The development of immature stages of *B. tabaci* was slower during winter month and total development period may prolonged up to 71 days as compared to 18 to 24 days during summer and rainy season. The overall generation survival was less than 50 per cent during summer and winter months. So, development of whitefly assorted with temperature variations during different months under Ludhiana conditions. The results were in agreement with earlier reports on variations in development time of immature stages of *B. tabaci* under different temperature regimes. The negative correlation between temperature and development period of *B. tabaci* were in accordance to Nava-Camberos *et al.* (2001) who observed that total development time of *B. tabaci* (egg to adult) at temperature range of 20-32°C varied between 16.3-37.9 days on cotton and generation survival ranged between 37.3-64.4 per cent at different temperatures. Bonato *et al.* (2007) reported that development time of *B. tabaci* was 20 days at 30°C and it prolonged to 56 days at 17°C on tomato. Similarly, Aregbesola *et al.* (2020) also reported that development time of whitefly, *B. tabaci* on cassava decreased from 59.3 days at 16°C temperature to 16.3 days at moderate temperature of 28°C. *tabaci* on cassava decreased from 59.3 days at 16°C temperature to 16.3 days at moderate temperature of 28°C.

The positive relationship between relative humidity and survival of immature stages of *B. tabaci* also got support from previous reports. Anjali *et al.* (2012) reported that infestation of *B. tabaci* exhibited significant positive correlation with relative humidity. Mathur *et al.* (2012) also observed that *B. tabaci* population on brinjal showed positive correlation with mean relative humidity, while significant negative correlation was recorded with temperature. Shera *et al.* (2013) also reported that correlation of *B. tabaci* was significantly positive with evening relative humidity. Kataria *et al.* (2017) reported that hot and humid climate favour the whitefly development and pest population showed positive correlation with relative humidity. Later, Khanday *et al.* (2019) found that *B. tabaci* population was favored by minimum temperature and morning relative humidity. The positive correlation between relative humidity and *B. tabaci* population on brinjal was also reported by Lal *et al.* (2019). The present studies also revealed that abiotic factors accounted for 37-63 percent (R^2) variations in survival of immature stages of *B. tabaci* on brinjal. These results are in close conformity with the findings of Kedar *et al.* (2016), who reported that weather parameters contributed 39 to 59 percent (R^2) variability in nymphal population of *B. tabaci* on *Bt* cotton at Hisar, Haryana. Sitaramaraju *et al.* (2010) observed that abiotic factors wer responsible for 66.1 per cent variability in *B. tabaci* population on *Bt* cotton in Andhra Pradesh. Similarly, Shera *et al.* (2013) observed that all the weather parameters exhibited 50-69 per cent variability in *B. tabaci* population on *Bt* cotton at Ludhiana.

The shorter development period and higher survival was recorded in generations completed during July -September months, where mean temperature of 29.9-30.4°C was recorded. Our results were in close conformity with earlier reports on optimum temperature conditions for *B. tabaci* on different host plants. A favourable range of 29-32°C for development of *B. tabaci* on tomato has been reported (Wang and Tsai, 1996; Qui *et al.,* 2003; Delatte *et al.,* 2009; Guo *et al.,* 2013; Tsueda and Tsuchida, 2011). Similarly, an optimum temperature of 30°C had been reported for *B. tabaci* on cotton (Butler *et al.,* 1983; Nava-Camberos *et al.,* 2001) and on cucurbits (Nava-Camberos *et al.,* 2001; Bayhan *et al.,* 2006; Tsueda and Tsuchida, 2011). Our study is the first report on annual life cycle of *B. tabaci* on brinjal under north Indian conditions. The study also explained the role of different abiotic factors on development and survival of *B. tabaci* on brinjal. This information can be used for monitoring as well as forecasting of this pest and devising effective IPM strategy for *B. tabaci* under north Indian conditions. However, the long term investigations over a wider area are needed for more precise information on this pest.

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Evaluation of insecticides against foliage feeding beetles of potato

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ABSTRACT: A field experiment was conducted to evaluate the efficacy of insecticides against foliage feeding beetles *viz., Henosepilachna vigintioctopunctata* F. and potato flea beetle, *Epitrix cucumeris* on potato (*Solanum tuberosum* L.) during *Rabi*, 2019-20 and 2020-21 at Odisha University of Agriculture and technology (OUAT), Bhubaneswar, India. The treatments consisted of azadirachtin 0.03% w/w@1500ml/ha, cypermethrin 25% EC @200ml/ha, fipronil 5% SC@1000ml/ha, spinosad 45% SC @187.5ml/ha, cartap hydrochloride 50% SP @1000g/ha, chlorpyriphos 20% EC @2000ml/ha and untreated control. The results revealed that, cartap hydrochloride 50% SP @1000g/ha was found to be most effective against epilachna beetle (0.7beetles/plant) and flea beetle (0.8beetles/plant) with 85.41% and 82.98% reduction over control and also recorded maximum potato tuber yield (14.1t/ha) with 48.42% yield improvement over untreated control.

Keywords: Potato, cartap hydrochloride, cypermethrin, fipronil, epilachna beetle, flea beetle

INTRODUCTION

Potato, *Solanum tuberosum* L. is one of the most widely cultivated food crops in the world. This can be attributed to the fact that it has a wide range of adaptability to both temperate and tropical climates. Potato is also one of the few crops which are grown even at an elevation of about 4000 m. In terms of human consumption, it comes in third place among the food crops behind rice and wheat. Insect pests affect potato productivity and tuber quality. More than 100 distinct types of arthropods attack potatoes over the world (Simpson, 1977). Of them, leaf beetle (The Epilachna beetle), *Henosepilachna vigintioctopunctata* F. and potato flea beetle, *Epitrix cucumeris*, are major defoliators. The pest management programme should incorporate different pest control measures such as cultural practices, bio agents, herbicides, insecticides, and resistant cultivars in order to keep the pest population below the economic threshold. It is difficult to totally ignore the role that insecticides play in pest management, even while we are prioritizing a variety of non chemical based means of pest control. New generation insecticide compounds in particular provide a variety of advantages, including great pest selectivity, outstanding efficacy at low rates or dosage, and less harm to the environment and natural enemies (Kodandaram *et al*., 2010). Therefore, it is a continuous and crucial activity to assess the effectiveness of new generation insecticides against insect pests of potatoes. In light of these considerations, a field experiment was carried out to assess how several pesticides of a new generation affected potato foliage-eating beetles.

MATERIALS AND METHODS

Field studies on the potato variety "Kufri Jyoti" were conducted during *Rabi*, 2019–20 and 2020–21 in a Randomized Block Design with three replications and seven treatments at Regional Research and Technology Transfer Station (RRTTS), Coastal zone, OUAT, Bhubaneswar, Odisha. Standard agronomic procedures were followed to plant at a seed rate of 20q/ha, with each plot measuring (3m x 2m) 6m^2. The healthy potato tubers were arranged in rows at a 60 cm row and 20 cm plant spacing. The insecticide treatments were applied to each replicated plot with a knapsack sprayer at 30 and 45 days after planting. The treatments were included azadirachtin 0.03% w/w@1500ml/ha, cypermethrin 25% EC @200ml/ha, fipronil 5% SC@1000ml/ha, spinosad 45% SC @187.5ml/ha, cartap hydrochloride 50% SP @1000g/ha, chlorpyriphos 20% EC @2000ml/ha and an untreated control. Five numbers of plants were selected randomly to draw an unbiased sample from the treatment plot. From each plant, total number of epilachna beetle and flea beetle were recorded. Average number of epilachna beetle and flea beetle per plant were calculated in each treatment plot. Observations were recorded prior to one day of first spray; three, seven and fourteen days after each spray.

For both the flea beetle and the epilachna beetle, the observations on mean leaf damage were recorded. The data were then transformed using the square root using the Gomez and Gomez's methods (1984). The

Table 1. The effect of insecticides on epilachna beetle population (*Rabi*, 2019-20, 2020-21 and pooled mean)

Treatment	Epilachna beetles (adults and grubs)/ plant																		Pooled Mean	Percent reduction over control
	Rabi, 2019-20									*Rabi*, 2020-21										
	First spray					Second spray				First spray					Second spray					
	1 DBS	3 DAS	7 DAS	14 DAS	Mean	3 DAS	7 DAS	14 DAS	Mean	1 DBS	3 DAS	7 DAS	14 DAS	Mean	3 DAS	7 DAS	14 DAS	Mean		
Azadirachtin 0.03% w/w@1500ml/ha	3.50 (2.13)	2.00 (1.73)	2.50 (1.89)	3.00 (2.00)	2.50 (1.88)	1.60 (1.62)	2.50 (1.87)	3.10 (2.04)	2.40 (1.85)	5.50 (2.55)	2.50 (1.88)	2.70 (1.94)	3.20 (2.06)	2.80 (1.96)	1.80 (1.69)	2.60 (1.92)	3.20 (2.06)	2.60 (1.90)	2.60 (1.90)	45.83
Cypermethrin 25% EC @200ml/ha	3.60 (2.16)	0.30 (1.14)	1.00 (1.41)	2.70 (1.94)	1.30 (1.54)	0.50 (1.21)	1.30 (1.54)	2.50 (1.88)	1.40 (1.57)	5.00 (2.46)	0.50 (1.25)	1.10 (1.46)	2.80 (1.96)	1.50 (1.58)	0.70 (1.32)	1.50 (1.59)	2.70 (1.93)	1.60 (1.63)	1.50 (1.58)	68.75
Fipronil 5% SC@1000ml/ha	3.80 (2.17)	1.80 (1.69)	1.60 (1.62)	2.00 (1.73)	1.80 (1.68)	1.50 (1.58)	1.30 (1.53)	1.70 (1.66)	1.50 (1.59)	5.20 (2.51)	1.90 (1.71)	1.80 (1.67)	2.10 (1.78)	1.90 (1.72)	1.60 (1.64)	1.50 (1.58)	1.80 (1.67)	1.60 (1.63)	1.70 (1.63)	64.58
Spinosad 45% SC @187.5ml/ha	3.70 (2.59)	1.00 (1.41)	1.20 (1.50)	1.80 (1.69)	1.30 (1.54)	1.10 (1.47)	1.00 (1.41)	2.00 (1.73)	1.30 (1.54)	5.30 (2.52)	1.10 (1.47)	1.40 (1.57)	2.00 (1.73)	1.50 (1.59)	1.30 (1.53)	1.20 (1.50)	2.10 (1.77)	1.50 (1.60)	1.40 (1.55)	70.83
Cartap hydrochloride 50% SP @1000g/ha	3.70 (2.64)	0.50 (1.24)	0.50 (1.24)	0.60 (1.29)	0.60 (1.26)	0.30 (1.15)	0.50 (1.25)	1.00 (1.41)	0.60 (1.28)	5.40 (2.54)	0.70 (1.32)	0.60 (1.27)	0.80 (1.36)	0.70 (1.31)	0.20 (1.11)	0.40 (1.18)	1.10 (1.46)	0.60 (1.25)	0.70 (1.28)	85.41
Chlorpyriphos 20% EC @2000ml/ha	3.80 (2.61)	1.30 (1.52)	1.80 (1.69)	2.60 (1.90)	1.90 (1.71)	1.00 (1.41)	1.50 (1.60)	2.20 (1.80)	1.60 (1.62)	5.10 (2.49)	1.50 (1.60)	1.70 (1.66)	2.70 (1.94)	2.00 (1.74)	1.10 (1.47)	1.80 (1.68)	2.40 (1.86)	1.80 (1.68)	1.90 (1.69)	60.41
Control (Untreated check)	3.70 (2.63)	3.80 (2.20)	3.90 (2.22)	4.00 (2.24)	3.90 (2.22)	3.80 (2.20)	3.70 (2.17)	3.50 (2.13)	3.60 (2.17)	5.20 (2.50)	5.80 (2.62)	5.70 (2.60)	5.30 (2.52)	5.60 (2.58)	5.90 (2.63)	5.90 (2.63)	5.70 (2.59)	5.80 (2.62)	4.80 (2.39)	
SE(m)±	0.022	0.068	0.032	0.029	0.033	0.063	0.029	0.019	0.029	0.032	0.028	0.028	0.025	0.020	0.035	0.044	0.019	0.055	0.047	
C.D (p=0.05)	NS	0.21	0.10	0.09	0.10	0.20	0.09	0.06	0.09	NS	0.09	0.09	0.08	0.06	0.11	0.14	0.06	0.17	0.10	

DAS: days after spraying DBS: Days Before Spraying NS: Non significant; Figures in the parentheses are √(x+1) transformed values of original data

statistical analysis was done using OPSTAT, online Agriculture Data Analysis Tool created by O.P. Sheoran, Computer Programmer at CCS HAU, Hisar, India (http://14.139.232.166/opstat/index.asp). Treatment means were compared using critical difference (CD). Pooled mean analysis was done taking data of both the seasons.

RESULTS AND DISCUSSION

Epilachna beetle

The pre-spray epilachna beetle population during *rabi*, 2019–20 ranged between 3.50–3.80 beetles/plant. After the first foliar application of insecticides (Table I), the plots treated with Cartap hydrochloride 50% SP @1000g/ha had the lowest mean population of epilachna beetles, (0.6 beetle/plant) followed by Cypermethrin 25% EC @200ml/ha and Spinosad 45% SC @187.5ml/ ha, which had a mean population of 1.3 beetles/plant and were statistically at par with each other. Fipronil 5% SC@1000ml/ha and Chlorpyriphos 20% EC @2000ml/ ha had mean populations of 1.8 and 1.9 beetles/plant respectively, being statistically superior to the untreated check. The plots treated with azadirachtin 0.03% w/w@1500ml/ha recorded the highest epilachna beetle population (2.5 beetles/plant). All treatments showed superiority over untreated control where 3.9 beetles/ plant was noted. After the second foliar spray, same trend of effectiveness was noticed where cartap hydrochloride 50% SP @1000g/ha recorded the lowest mean epilachna beetle population. The plots treated with Spinosad 45% SC at 187.5 ml/ha, cypermethrin 25% EC at 200 ml/ha, Fipronil 5% SC at 1000 ml/ha, and Chlorpyriphos 20% EC were equally effective where 1.30, 1.40, 1.50, and 1.60 beetles/plant were recorded. Azadirachtin 0.03% w/w@1500ml/ha (2.4beetles/plant) showed superiority over untreated control (3.6 beetles/plant).

During the second season *Rabi*, 2020–21, the pre-spray epilachna beetle population ranged from 5.00 to 5.50 beetles per plant. The plot treated with cartap hydrochloride 50% SP @1000g/ha with a mean population of 0.7 beetle/plant had the lowest mean population of epilachna beetles after the first foliar application of insecticides (Table I). The crop treated with cypermethrin 25% EC @200ml/ha and spinosad 45% SC @187.5ml/ha recorded same level of infestation (1.5 beetles/plant). Fipronil 5% SC@1000ml/ ha treated crop had 1.9 beetles/plant statistically equivalent in effectiveness with chlorpyriphos 20% EC @2000ml/ha (2 beetles/plant). In this season also, plants treated with azadirachtin 0.03% w/w@1500ml/ha harbored highest epilachna beetle population (2.8 beetles/plant) among the treated plots. All treatments showed superiority over untreated control where on an average 5.6 beetles/ plant was found. After the second foliar application, the treatment with cartap hydrochloride 50% SP @1000g/ ha performed better with the lowest mean population (0.6 beetle/ plant). Spinosad 45% SC @187.5ml/ha (1.50 beetles/ plant). Cypermethrin 25% EC @200ml/ha (1.60 beetles/ plant), Fipronil 5% SC@1000ml/ha (1.60 beetles/ plant), and chlorpyriphos 20% EC @2000ml/ha (1.80 beetles/ plant) were statistically similar in efficacy against epilachna beetle infestation. All treatments were superior over untreated control (5.80 beetles/ plant).

When the pooled mean of two seasons is considered (Table I), cartap hydrochloride 50% SP was found to be most effective where lowest mean population (0.7beetle/ plant) was recorded. 85.41% reduction in epilachna beetle population over control was caused in this treatment (Fig. 1). Spinosad 45% SC, cypermethrin 25% EC and Fipronil 5% SC were statistically at par in effectiveness harbored 1.40, 1.50 and 1.70 beetles/ plant causing 70.83%, 68.75% and 64.58% reduction over untreated control. Azadirachtin 0.03% harbored highest epilachna beetle population among the treated plots with 45.83% reduction over control. However, all treatments showed their superiority over untreated control significantly. The present findings about the efficacy of cartap hydrochloride50% SP against epilachna beetle is corroborated with Ghosh and Chakraborty (2012) and Das (2016). Bala *et al*. (2016) came to the conclusion that cypermethrin 25 EC @ 0.4 kg a.i/ha was the most effective treatment against epilachna beetle. Birju *et al*. (2020) tested the efficacy of newer insecticides against epilachna beetle on spine gourd and revealed that spinosad 45 SC was the second-best insecticide amongst the pesticides tested. All the above findings of different scientists are in line with the present findings.

Flea beetle

The flea beetle population prior to the commencement of spray during *Rabi*, 2019–20 varied from 4.80 to 5.40 beetles per plant (Table 2). Against flea beetle, cartap hydrochloride 50% SP @1000g/ha showed maximum efficacy, with lowest mean population (1.10 beetles/plant) followed by spinosad 45% SC @187.5ml/ha(1.60beetles/ plant). Cypermethrin 25% EC @200ml/ha and fipronil 5% SC @1000ml/ha were statistically at par with each other, with mean populations of 2.00beetles/ plant and were superior to the untreated check. Azadirachtin 0.03% w/w@1500ml/ha harbored highest flea beetle population among the treated plots with a mean population of 3.10 beetles/ plant. All treatments showed superiority over untreated control (5.00 beetles/ plant). After the second foliar application, both spinosad 45% SC @187.5ml/

Table 2. The effect of insecticides on flea beetle population (*Rabi*, 2019-20, 2020-21 and pooled mean)

Treatment	Flea beetles (adults and grubs)/ plant																			Pooled Mean	Percent reduction over control
	Rabi, 2019-20									*Rabi*, 2020-21											
	First spray					Second spray				First spray					Second spray						
	1 DBS	3 DAS	7 DAS	14 DAS	Mean	3 DAS	7 DAS	14 DAS	Mean	1 DBS	3 DAS	7 DAS	14 DAS	Mean	3 DAS	7 DAS	14 DAS	Mean		
Azadirachtin 0.03% w/w@1500ml/ha	5.20 (2.49)	1.40 (1.55)	3.00 (2.00)	5.00 (2.55)	3.10 (2.02)	1.00 (1.41)	2.80 (1.95)	3.60 (2.14)	2.50 (1.87)	3.60 (2.14)	3.20 (2.05)	3.20 (2.05)	5.20 (2.49)	3.40 (2.10)	1.60 (1.61)	3.00 (2.00)	4.00 (2.24)	2.90 (1.97)	3.0 (2.00)	36.17
Cypermethrin 25% EC @200ml/ha	5.00 (2.45)	0.00 (1.00)	2.20 (1.79)	3.80 (2.19)	2.00 (1.73)	0.00 (1.00)	2.00 (1.73)	3.00 (2.00)	1.70 (1.64)	4.00 (2.23)	2.00 (1.73)	2.00 (1.73)	4.20 (2.28)	2.30 (1.82)	0.00 (1.00)	2.40 (1.84)	2.80 (1.95)	1.70 (1.64)	2.0 (1.72)	57.45
Fipronil 5% SC@1000ml/ha	4.80 (2.41)	0.80 (1.34)	2.00 (1.73)	3.20 (2.05)	2.00 (1.73)	0.60 (1.26)	1.40 (1.55)	2.80 (1.95)	1.60 (1.61)	3.80 (2.19)	1.60 (1.61)	1.60 (1.61)	2.80 (1.95)	1.80 (1.67)	0.80 (1.34)	1.80 (1.67)	3.00 (2.00)	1.90 (1.70)	1.9 (1.69)	59.57
Spinosad 45%SC@187.5ml/ ha	5.00 (2.45)	0.60 (1.26)	1.40 (1.55)	2.80 (1.95)	1.60 (1.61)	0.20 (1.09)	0.80 (1.34)	2.20 (1.79)	1.10 (1.45)	4.20 (2.28)	1.00 (1.41)	1.00 (1.41)	2.20 (1.79)	1.30 (1.51)	0.00 (1.00)	1.20 (1.48)	2.60 (1.90)	1.30 (1.52)	1.40 (1.53)	70.12
Cartap hydrochloride 50%SP@1000g/ha	5.40 (2.53)	0.00 (1.00)	1.40 (1.55)	2.00 (1.73)	1.10 (1.45)	0.00 (1.00)	0.40 (1.18)	1.80 (1.67)	0.70 (1.30)	3.80 (2.19)	0.60 (1.26)	0.60 (1.26)	1.60 (1.61)	0.70 (1.30)	0.00 (1.00)	0.80 (1.34)	1.20 (1.48)	0.70 (1.30)	0.8 1.34)	82.98
Chlorpyriphos 20% EC @2000ml/ha	5.20 (2.49)	0.40 (1.18)	3.00 (2.00)	4.00 (2.24)	2.50 (1.87)	0.00 (1.00)	2.00 (1.73)	3.20 (2.05)	1.70 (1.64)	4.00 (2.23)	2.60 (1.90)	2.60 (1.90)	4.60 (2.37)	2.60 (1.90)	0.00 (1.00)	2.40 (1.84)	3.00 (2.00)	1.80 (1.67)	2.2 (1.77)	53.19
Control (Untreated check)	4.80 (2.41)	5.00 (2.45)	4.60 (2.36)	5.40 (2.53)	5.00 (2.45)	5.20 (2.45)	4.80 (2.41)	4.60 (2.37)	4.90 (2.43)	4.20 (2.28)	4.00 (2.24)	4.00 (2.24)	4.80 (2.41)	4.50 (2.35)	5.00 (2.45)	4.20 (2.28)	4.00 (2.24)	4.40 (2.32)	4.7 2.39)	
SE(m)±	0.038	0.047	0.041	0.035	0.047	0.048	0.058	0.044	0.048	0.049	0.064	0.057	0.041	0.037	0.024	0.044	0.039	0.059	0.055	
C.D (p=0.05)	NS	0.15	0.13	0.11	0.15	0.15	0.18	0.14	0.15	NS	0.2	0.18	0.13	0.11	0.08	0.14	0.12	0.18	0.11	

DAS: days after spraying DBS: Days Before Spraying NS: Non significant; Figures in the parentheses are √(x+1) transformed values of original data

Table 3. The effect of insecticides on potato tuber yield (*Rabi*, 2019-20, 2020-21and pooled mean)

Treatment details	Potato tuber yield (t/ha)			yield increase over control (%)	B: C Ratio
	Rabi, 2019-20	*Rabi*, 2020-21	Pooled Mean		
Azadirachtin 0.03% w/w@1500ml/ha	9.5	11.0	10.2	7.36	2.21
Cypermethrin 25% EC @200ml/ha	10.5	12.1	11.3	18.94	2.48
Fipronil 5% SC@1000ml/ha	11	12.6	11.8	24.21	2.35
Spinosad 45% SC @187.5ml/ha	11.8	13.5	12.6	32.63	2.98
Cartap hydrochloride 50% SP @1000g/ha	13.2	15.0	14.1	48.42	3.03
Chlorpyriphos 20% EC @2000ml/ha	10.2	11.6	10.9	14.73	2.35
Control (Untreated check)	8.9	10.2	9.5		2.11
SE (m)±	0.27	0.073	0.14		
C.D (p=0.05)	0.8	0.2	0.4		

ha and cartap hydrochloride 50% SP @1000g/ha were at par where 1.10 and 0.70 beetles/plant were recorded, respectively. The treated plots with fipronil 5% SC@1000ml/ha, cypermethrin 25% EC @200ml/ha, and chlorpyriphos 20% EC@2000ml/ha were statistically equal in efficacy against the flea beetle and harbored 1.60, 1.70, and 1.70 beetles/plant respectively. With a mean population of 2.50 beetles/ plant, azadirachtin 0.03% w/w@1500ml/ha was significantly superior to the untreated control (4.90 beetles/plant).

During *rabi*, 2020-21, the pre spray population of flea beetle ranged between 3.60-4.20 beetles/ plant (Table 2). After the first foliar application of insecticides, the lowest mean population of flea beetle was observed in plot treated with cartap hydrochloride 50% SP @1000g/ ha with a mean population of 0.70 beetle/ plant, followed by spinosad 45% SC @187.5ml/ha with mean population of 1.30 beetles/ plant and fipronil 5% SC@1000ml/ ha with mean population of 1.80 beetles/ plant. This is followed by cypermethrin 25% EC @200ml/ha (2.30 beetles/ plant) and chlorpyriphos 20% EC @2000ml/ha (2.60 beetles/ plant). Azadirachtin 0.03% w/w@1500ml/ ha harbored highest flea beetle population among the treated plots with a mean population of 3.40 beetles/ plant. All treatments showed superiority over untreated control (4.5 beetles/ plant). The treatment with cartap hydrochloride 50% SP @1000g/ha showed the lowest mean flea beetle population of 0.70 beetle/plant after the second foliar spray. Second best performer was Spinosad 45% SC at 187.5 ml/ha (1.30 beetles/plant) followed by cypermethrin 25% EC (1.70 beetles/plant), chlorpyriphos 20% EC at 2000 ml/ha (1.8 beetles/ plant) and Fipronil 5% SC (1.90 beetles/plant). The Azadirachtin 0.03% w/w could not compete with the chemical insecticide treatment, where highest flea beetle population (2.90 beetles/plant)was noticed and the untreated control, had 4.40 beetles/plant.

The pooled mean of two seasons data (Table 2) indicated the superiority of cartap hydrochloride 50% SP in flea beetle management where least population (0.80 beetle/plant) was recorded causing 82.98% reduction over control. Spinosad 45% SC @187.5ml/ha had a mean population of 1.40 beetles/ plant showed 70.12% reduction. Fipronil 5% SC (1.90 beetles/ plant) was the third best treatment where 59.57% population reduction was recorded. All treatments were superior to untreated control. Azadirachtin 0.03% w/w harbored highest flea beetle population among the treated plots (3.00 beetles/ plant).

The results of the current field study are comparable to those of the study conducted by Mahato (2017), who found that cartap hydrochloride 50% SP @ 375 g a.i./ ha was superior in suppressing flea beetle populations during both seasons of the study and exerted a reduction of 72.25 and 83.83% compared to control. In a field experiment, Mahato and Mishra (2019) assessed the bio-efficacy of eight insecticides against the flea beetle, which infested cucumbers (*Cucumis sativus* L). They discovered that spinosad 45 SC and cartap hydrochloride 50% SP recorded the lowest populations of flea beetle adults/5 leaves. According to a field trial conducted by Shanmuga *et al*. (2019), fipronil was the best chemical for controlling flea beetles since it resulted in an 81.6–87.1% decrease in flea beetle population. The results of the present experiment are consistent with those of the experiments conducted by the aforementioned scientists.

The pooled mean of marketable potato yield of the season 2019-20 and 2020-21 was highest (14.1t/ha) in the treatment cartap hydrochloride 50% SP @1000g/ha with 48.42% increase in yield over untreated control (Table 3). The second highest yield (12.6 t/ha) was obtained from the plots treated with spinosad 45% SC @187.5ml/ ha with 32.63% increase in yield over untreated control followed by Fipronil 5% SC@1000ml/ha (11.8t/ha0 with 24.21% increase in yield over untreated control. The treatment cartap hydrochloride 50% SP @1000g/ha gave the highest monetary benefit resulting in BC ratio of 3.03 followed by Spinosad (2.98) and cypermethrin (2.48). The results of the present experiment are in line with the findings of Deshmukh and Bhamare (2006), Reddy (2015) and Bala (2016) who found these chemicals to be effective against leaf feeding insects and resulted in higher BC ratios. The results indicated that foliar application of cartap hydrochloride 50% SP @1000g/ha at 30 and 45 days after planting was the most effective treatment against foliage feeding epilachna beetle and flea beetle in potato under Odisha conditions.

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Lepidopteran pest complex of *Dhataki*, *Woodfordia fruticosa* with special reference to occurrence of leafroller, *Strepsicrates* sp. in India

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ABSTRACT: Surveys were conducted to record pest complex damaging a forest medicinal plant dhataki, *Woodfordia fruticosa*. Four lepidopteran defoliators were observed as pests causing significant damage to the plants. The leaf roller, *Strepsicrates* sp. was reported as a major defoliator of *dhataki* and the identity of the pest was confirmed through male and female genitalia and amplified product of *Cytochrome c oxidase subunit I (COI) gene* (GenBank no. OP648297). Further, the biology, morphometry, seasonal incidence and natural enemy complex of the leaf roller were recorded in the present study. The detailed information on different aspects like bio-ecology, seasonality and biocontrol of this leafroller, *Strepsicrates* sp. can be utilized for further development of viable management strategy as this was already reported as one of the major pests in economic plants like guava and eucalyptus in other countries.

Keywords: Dhataki, *Woodfordia fruticosa*, defoliators, *Strepsicrates* sp., bio ecology, seasonal incidence

INTRODUCTION

Woodfordia fruticosa (L.) Kurz. (Family: Lythraceae) is a forest medicinal plant, locally known as *Dhataki* or *Dhaiphul.* It is a spreading, deciduous shrub, distributed throughout India, but rarer in Southern India and the plant has a long history of use in traditional medicine to treat bowel disorders (Das *et al.,* 2007). The plant grows in Gangetic plains, North-Eastern states and in West Bengal, it is limited to the northern part adjacent to Sikkim, where folks use the leaves to relieve fever (Tayab *et al.,* 2021). The flowers are tubular, attractive and crimson red in colour, borne on twigs near the leaf axil as clusters (2 to 16 flowered cymes) with short stalks, hence it is known as fire flame bush (Kumar, 2016). The flowers possess great therapeutic potential and both in its fresh and dried powder forms are used to heal cut wounds on skin. Flower and leaf extracts have several phytochemical compounds such as anthraquinones, flavonoids, glycosides, tannins and polyphenols responsible for properties like antimicrobial, hepato protective, cardio protective, antioxidant, antiulcer, immune-modulatory, antifertility and anti-tumor (Thakur *et al.,* 2021).

Earlier studies reported many larval lepidopterans were found destructive to several forest trees and also emphasized that the importance of identification, biodiversity, biology, nature of damage and management of these pests are necessary for conservation of forest plants (Sathe and Pandharbale, 2008). *W.fruticosa* is a major non-timber forest product (NTFP) in the West Bengal especially in sub Himalayan region (Ghoshal, 2010). Hence, it is essential to study the abiotic and biotic stresses inflicting damage and threatening the survival of plants in their natural habitat. In the present study, attempts have been made to survey and record the major insect pests feeding on the plants. Detailed studies on biology, morphometry, seasonal incidence and natural enemy complex of *Strepsicrates* sp. were carried out.

MATERIALS AND METHODS

Study site

The surveys on lepidopteran pest complex on dhataki, the occurrence of *St. repsicrates sp.* its seasonal incidence, and the natural enemy complex were carried out in the medicinal plants garden, UBKV, Pundibari, Coochbehar, West Bengal during 2021-2022. The experiments on morpho-taxonomical identification, life history, and morphometric studies of *St. repsicrates sp.* were conducted at the entomology laboratory, Regional Research Station (TZ), Directorate of Research, UBKV, Pundibari, Coochbehar, West Bengal from May to August 2022.

Table 1. Lepidopteran pest complex recorded on *dhataki* during 2021 and 2022

Order	Family	Common name	Scientific name	Occurrence	Relative abundance*	Pest status**
Lepido-ptera	Nolidae	Defoliator	*Selepa discigera*	Throughout the year	+++	Major, polyphagous
	Tortricidae	Leaf webber	*Strepsicrates* sp.	January - May	+++	Major, polyphagous
	Geometridae	Looper	*Pingasa alba*	June- September	++	Moderate, polyphagous
	Erebidae	Yellow tussock moth	*Artaxa guttata*	January- March	+	Minor, polyphagous

* +: 1-2 individuals per plant; ++: 2-5 individuals per plant; +++: 5-10 individuals per plant
**Minor: Upto 10%; Moderate: 10-30%; Major: more than 30% plant infestation.

Survey of pest complex

The field was monitored regularly at alternative days for the observation of insect pests on the crop. The immature stages of the pests were collected and brought to the laboratory for rearing them by providing their respective host plants. After the emergence of adult insects, they were collected and killed in killing bottle, mounted either on insect pins or paper points depending on their size and labelled properly. The common specimens were identified by comparing with previous collections in the Entomology lab, Regional Research Station (TZ), Directorate of Research, UBKV, Pundibari and Department of Entomology, Faculty of Agriculture, UBKV, Pundibari as well as available literature *viz.,* Japir *et al.* (2018) and Srikumar *et al.* (2022). Furthermore, these specimens were sent to experts at ICAR-NBAIR for molecular confirmation of the insect species. The pest status was judged based on percent incidence on the crop.

Biology and morphometric studies

The leafroller infested leaves were collected from the field and carried to the laboratory to rear them individually in petri dishes into adults at 24±2°C and 70±5 % RH. The fresh dhataki leaves were provided daily till pupation and allowed to emerge as adults. A newly emerged male and female adult pair was collected into plastic jars of 10×5 cm size and observed for mating. Terminal shoot buds along with two to three tender leaves placed in a micro vial containing water was provided at the bottom of the jars to facilitate egg laying. Total ten such pairs were maintained to observe egg incubation period, fecundity, and adult longevity. Insect rearing was done by following the methodology of Shivakumara *et al.* (2021). A cotton swab dipped in a 10% honey solution was provided as food for adults. The fresh shoot tips were placed on alternative days and the replaced shoots were examined under the stereo zoom microscope daily for the presence of eggs.

The shoots containing freshly laid eggs were collected and transferred into a petri dish for observing egg hatching and to record the incubation period. After hatching, the neonate larvae (n=15) were transferred individually into individual Petri dishes (9 cm dia.) containing tender leaves carefully with the help of a fine hairbrush. The tips of the leaves were covered with a moistened cotton swab to avoid desiccation. The larvae were reared to the pupal stage on *dhataki* leaves and they were monitored regularly to notice moulting which was indicated by the presence of left overhead capsules and exuviae. The observations on number of larval instars, larval and pupal periods were taken, also the morphometric parameters viz. head capsule width, body length, and width of each successive larval instars, pupae, and adults (male and female) were recorded. The same microscope mentioned previously, fitted with Carl Zeiss Zen 2.5 lite (blue edition) imaging and calibration software was used to take morphometric measurements of body parts of the insect.

Seasonal incidence

To study the percent plant incidence around 20 plants of *W. fruticosa* were selected randomly andto assess the leaf injury, a total of a hundred randomly selected leaves covering all directions of the plant were observed. The meteorological data for two years (rainy season) of the survey period i.e., 2021 and 2022 were collected to correlate the pest population with various

Table 2. Duration of various life stages of leaf webber, *Strepsicrates* sp. on dhataki

Stages	Range (days)	Mean ± SE
Egg period (days)**	4-6	5.10±0.70
1st Instar*	3-4	3.46±0.48
2nd Instar*	3-4	3.66±0.47
3rd Instar*	4-5	4.40±0.48
4th Instar*	4-5	4.33±0.47
5th instar*	4-5	4.66±0.47
Total larval period (days)*	18-23	20.53±1.62
Pupal period (days)*	8-11	9.73±0.99
Total life cycle (days)*	36-49	43.40±4.37
Adult longevity*	6-9	7.93±1.06
Fecundity (Nos.)**	42-57	50.80±4.85

* Mean of 15 observations **Mean of 10 observations

SE- Standard Error

weather parameters like maximum temperature (X1), minimum temperature (X2), maximum relative humidity (X3),minimum relative humidity (X4) and rainfall (X5) to understand the effect of various weather parameters on the population of *St. repsicrates sp.*

Natural enemies

The larvae (n = 50) of *St. repsicrates sp* were collected from the field and brought to the laboratory, where they were reared individually in Petri dishes by providing fresh dhataki leaves daily till they reach the pupal stage. Natural larval parasitization was observed in larvae while rearing. The Petri dishes containing parasitized host larvae were separated and allowed for emergence into adult parasitoids. The adult parasitoids that emerged were killed and collected into collection vials containing 70% alcohol. The preserved parasitoid specimens were examined under a ZEISS Stemi508 stereo zoom microscope. Photographs of the wasps were taken using a stereo-zoom micro scope fitted with a ZEISS Axiocam 105 color camera and Carl Zeiss Zen 2.5 lite (blue edition) imaging software. The parasitoid specimens were sent for identification to the experts at ICAR-National Bureau of Agricultural Insect Resources (NBAIR), Bangalore, India.

RESULTS AND DISCUSSION

The medicinal shrub *dhataki* was observed to be attacked by several lepidopteran pests, among which four species (Fig. 1) were found more dominant and were reported in this study. Detailed description of pest species and its nature of damage has been documented (Table 1).

Biology and morphometry of leaf roller

The biological cycle of leaf roller *Strepsicrates* sp. was studied on their host plant dhataki. To study the biology and morphometry of the pest, duration of different life stages *i.e.,* egg, larva, pupa and adult (Table 2) and also observation of morphometric characteristics *viz.,* head capsule width, larval body length and body width measurements were taken from 15 individuals. The eggs were very minute and scaly with an incubation period ranging between 4-6 days and on average 5.10±0.70 days required to hatch out of the neonate larva from the egg.

Table 3. Morphometry of different life stages of *Strepsicrates* sp. on *dhataki*

Stage	Width of head capsule (mm) Mean ± SE	Length of body (mm) Mean ± SE	Width of the body (mm) Mean ± SE
Egg		0.23±0.01	0.21±0.01
		Larva	
1st instar	0.19±0.02	1.75±0.16	0.57±0.04
2nd instar	0.30±0.02	2.99±0.30	0.81±0.06
3rd instar	0.54±0.02	5.59±0.17	1.25±0.07
4th instar	0.84±0.02	8.60±0.14	1.62±0.16
5th instar	1.13±0.01	12.23±0.74	2.07±0.11
Pupa	-	6.38±0.15	1.52±0.01
Adult	-	6.96±0.07	1.71±0.08

Mean of 15 observations SE – Standard Error

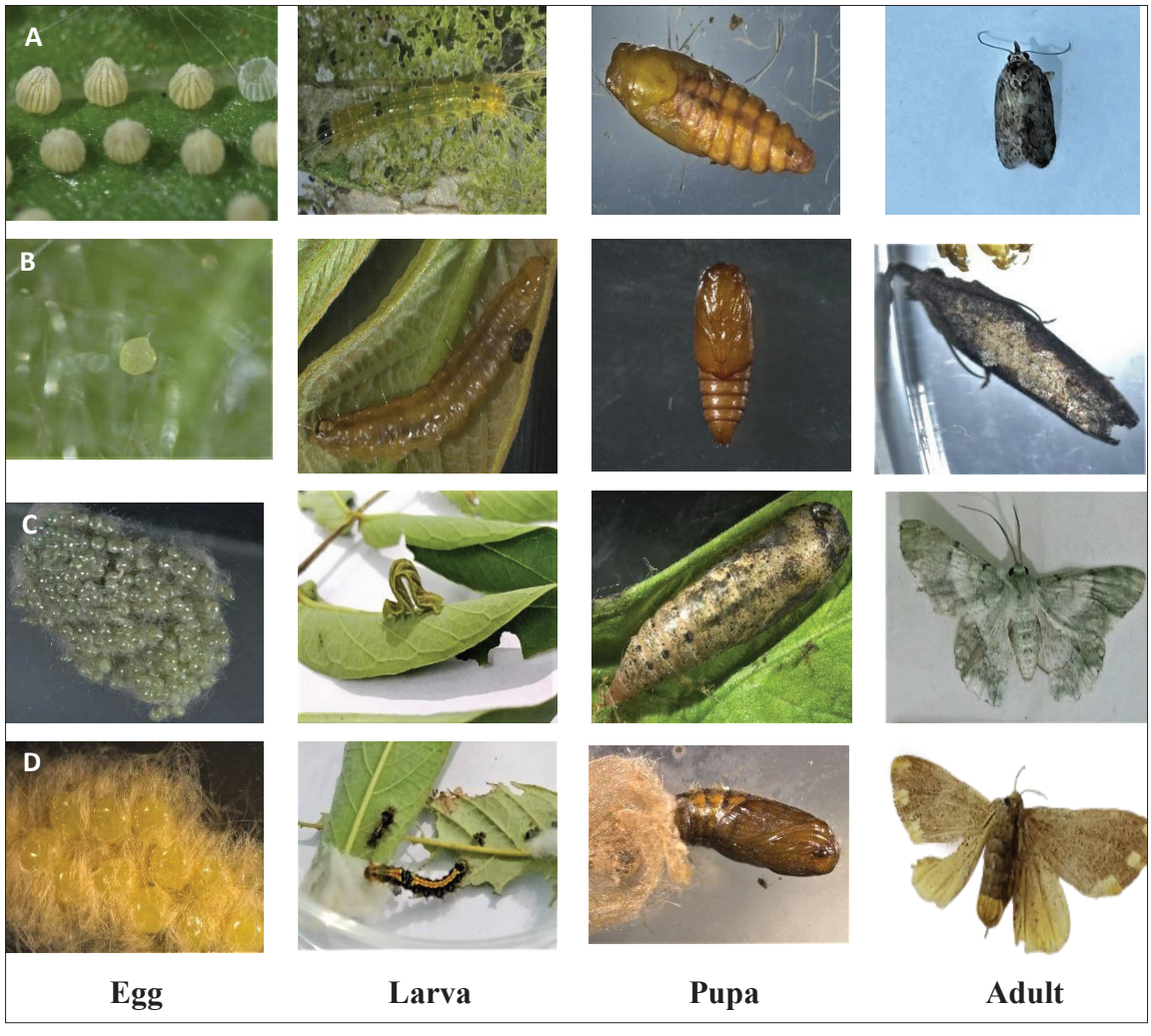

Fig. 1. Life stages of lepidopteran defoliators on *Woodfordia fruticosa*
A) *Selepa discigera* B) *Strepsicrates* sp. C) *Pingasa alba* D) *Artaxa guttata*

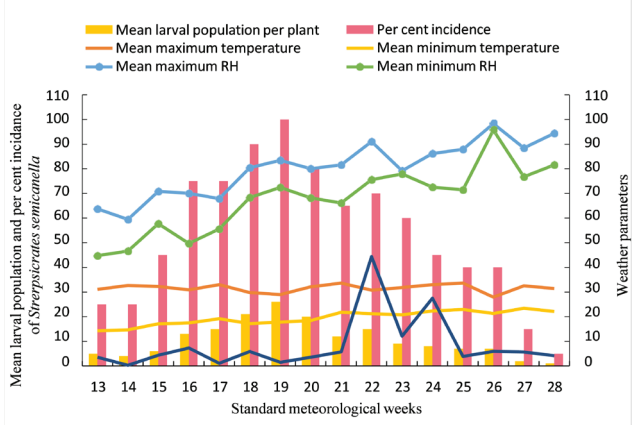

Fig. 2. Seasonal incidence of leaf roller (2021)

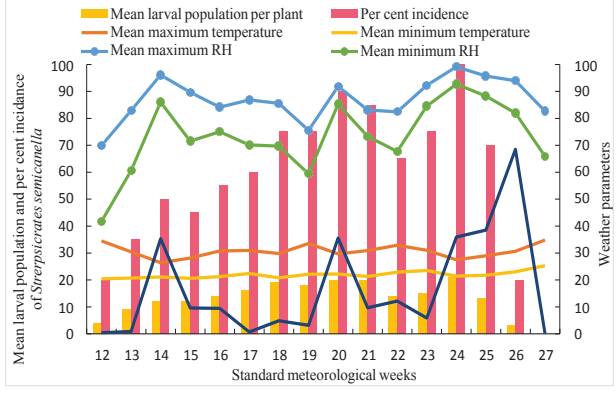

Fig. 3. Seasonal incidence of leaf roller (2022)

The young larvae were pale yellowish to green in colour with a sub dorsal line, as they become old the body colour turned into dark pinkish tinge. The mean larval duration of 1st, 2nd, 3rd, 4th and 5thinstars were 3.46±0.48 days, 3.66±0.47 days, 4.40±0.48 days, 4.33±0.47 days and 4.66±0.47 days, respectively. The pupa was brownish in colour with a row of spines on dorsal side of each abdominal segment and also there were few hook-like hairs at the end of the abdomen. The mean pupal period recorded was 9.73±0.99 days with a range of 8-11 days.

The total life cycle was completed in 36-49 days with an average of 43.40±4.37 days. The adult moth was small sized, body including head, antenna, legs were greyish brown in colour. The average number of eggs laid by a female was 50.80±4.85 eggs. The eggs were spherical, small, creamy white in colour and the average length and width of an egg was 0.23±0.01 mm and 0.57±0.04 mm, respectively. The larva was medium sized with hard yellowish head capsule and a small pro-thoracic sclerite. The width of head capsule of each successive instars was recorded *viz.,* 0.19±0.02 mm, 0.30±0.02 mm, 0.54±0.02 mm, 0.84±0.02 mm and 1.13±0.01mm for 1st, 2nd, 3rd, 4th and 5th instars, respectively. The mean body length and width of egg, larvae, pupae and adults were showed in the table 3.

Seasonal incidence of leaf webber, *Strepsicrates* sp. on *dhataki*

In the first year, the leafroller infestation started during 13th SMW with 25 per cent plant infestation and mean larval population of 5 per plant. The infestation continued till 28th SMW (Standard Meteorological Week) when the per cent infestation was 5% and mean larvae was 1 per plant. The peak percent infestation was observed during 19th SMW when the 100% infestation was noticed and the average larval population per plant was also observed during the same period having approximately 26 larvae per plant. The pest population was gradually reduced and became the minimum during the 28th SMW and terminated by 29th SMW of 2021 (Fig. 2). In the second year, the trend followed a different pattern; the infestation started early in the 12th SMW with 20 per cent plant infestation and 3 larvae per plant on an average. The peak infestation (100%) was noticed during 24th SMW, also maximum mean larval population *i.e.,* 21 larvae per plant occurred during the same period and then the population drastically reduced by 26th SMW when only 20 per cent plants were infested with a minimum larval population per plant *i.e.,* 3 per plant (Fig. 3).

The correlation analysis between the population of leafroller and weather parameters revealed a strong positive association between per cent plant infestation and minimum relative humidity (r=0.500*). Both mean larval population and per cent plant infestation had a weak negative association with maximum and minimum temperatures. Whereas, the number of larvae per plant showed a weak negative association with total weekly rainfall (r=-0.045 NS) but the percent plant infestation registered a non-significant positive correlation with rainfall (r=0.092NS).

Natural enemy complex of leafroller, *Strepsicrates* sp. on *dhataki*

Two larval parasitoids *viz.*, *Mesochorus* sp. (Ichneumonidae: Hymenoptera) and *Pholestesor*sp. (Braconidae: Hymenoptera) (Fig. 4) were found attacking the larvae of *St. repsicrates sp.* on dhataki. The natural parasitism due to *Mesochorus* sp. and *Pholestesor*sp. were recorded at 12% and 18%, respectively. The adult parasitoid emergence from host larvae was 80% and 70% for *Mesochorus*sp. and *Pholestesor* sp., respectively.

Japir *et al.* (2018) reported that the caterpillars of *Woodfordia* defoliator, *Selepa discigera* was found to feed on the forest tree, *Terminalia copelandi* in Sabah, Malaysia. The species was found to be distributed in the oriental tropics of India and Srilanka (Koçak and Kemal, 2012). The alluvial forests were reported as a habitat of leafroller *St. repsicrates sp.* (Razowski, 2013). Besides *Woodfordia fruticosa,* the other host plants known to attacked by the larvae were *Eukalyptus* and *Psidium* (Nasu *et al.,* 2004; Wakamura *et al.,* 2005). The looper *Pingasa alba* has been reported from Bonai forest of Odisha (Kumar *et al.,* 2022). The tussock moth *Artaxa guttata* are commonly found in India (Sondhi and Sondhi, 2016), Bangladesh and Srilanka. It was considered as a minor pest of several agricultural, horticultural and forest plants such as castor, pigeon pea, rose, jasmine, mango, citrus, ber, oak, sal, *Terminalia myriocarpa* and *T.tomentosa* (Robinson *et al.,* 2010 and Singh *et al.,* 2019).

The male and female genitalia of leafroller *St. repsicrates sp.* which were dissected during the course of the present study, were compared with previous literature *viz.,* Nasu *et al.* (2004); Rose and Pooni (2005); Deng *et al.* (2011) and there was similarity with present findings which confirmed the identity of the pest species concerned. Biology of *St. repsicrates sp.* on woodfordia has been studied for the first time during this study. However, Mauchline (2000) studied life history of *S. macropetana* on the host eukalyptus and recorded that approximately 54 days were required for completion of its life cycle. The average fecundity observed was 40 eggs per female. The biology and life history of leaf roller *S. rhothia* has been studied on guava in Karachi, Pakistan

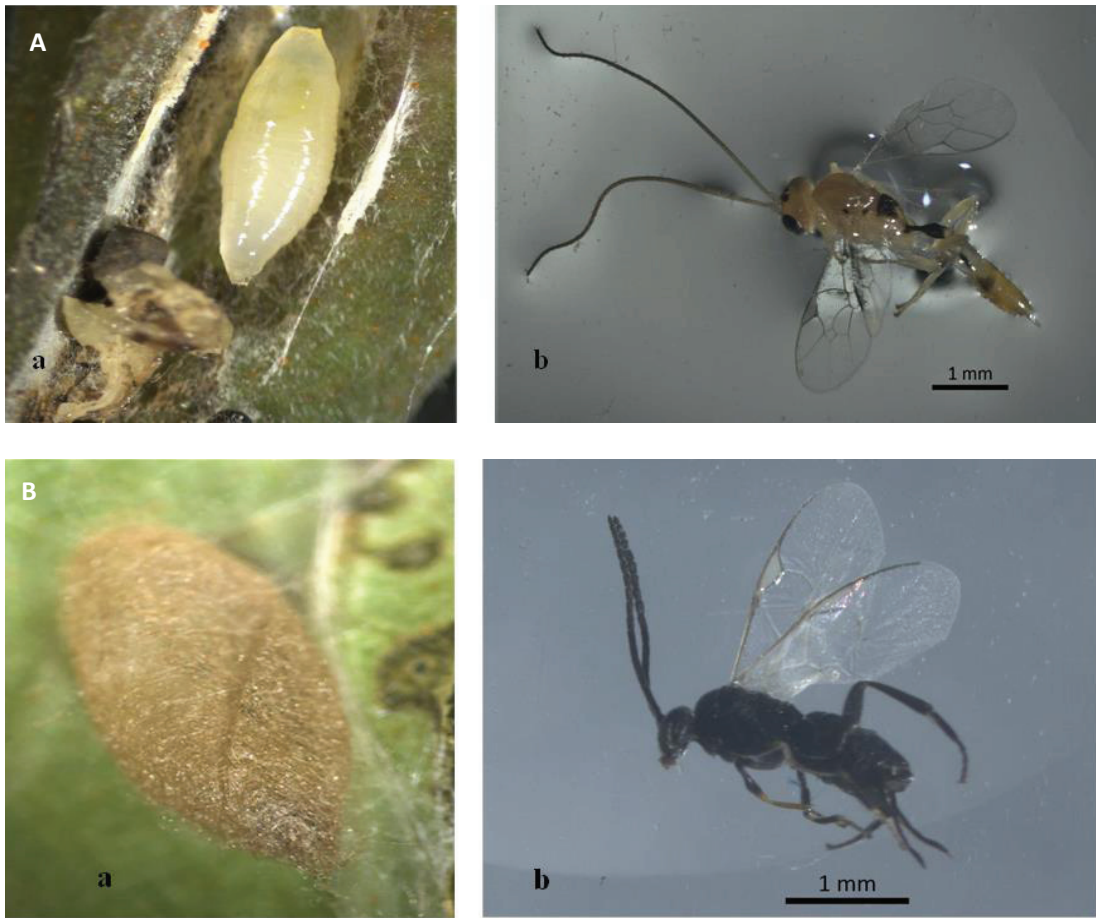

Fig. 4. Natural enemy complex of leafroller *Strepsicrates* sp. A) *Mesochorus* sp. B) *Pholestesor* sp.: a) Parasitoid pupa b) Adult parasitoid

by Ahmad (1972). Canacuán-Nasamuez, and Carabalí-Muñoz (2015) reported that the leaf roller *S. smithiana* caused economic damage to guava in Columbia. They conducted the biological studies and their results were consistent with our present study on *St. repsicrates sp.* on *Woodfordia fruticosa*. The larva had five instars and the total duration of life cycle was approximately 42.93 days while the incubation period was 5.07 days. The average duration of larval, pupal and adult stages was recorded as 18.17 ± 2.03; 10.57 ± 1.04 and 5.87 ± 1.2 days, respectively. These studies suggested more or less similar trend to the present investigation results on biology of *St. repsicrates sp.* on dhataki.

The leafroller infestation on dhataki was noticed for a specific period during the present study under sub-tropical humid climatic conditions of sub-Himalayan West Bengal. This observation is partly supported by earlier reports of Srikumar*et al.* (2022) who found infestation of *St. repsicrates sp.* on Eucalyptus plantations throughout the year in the tropical forests of Indonesia. The number of generations of pests and its period of occurrence mainly depend on the prevailing climatic conditions. The species *S. mecropetana* went through many more generations, perhaps six and eight depending on climate (Miller, 1925; Mauchline *et al.,* 1999). There were at least four generations of *S. macropetana* in the study at Bay of Plenty, New Zealand (Mauchline, 2000).

The ichneumonid *Mesochorus* sp. and braconid *Pholestesor*sp. has been reported to parasitize the leaf roller *Strepsicrates sp.* for the first time from forest cum medicinal plant *Woodfordia fruticosa.* Previously, Nuttall (1983) reported that the population of eucalyptus leafroller *Strepsicrates macropetana* was significantly reduced (45% natural parasitism was recorded) by pupal parasitoid *Trigonospila brevifacies* which was introduced into New Zealand for the control of leafrollers of forest and horticultural ecosystems. Also, the association of ichneumon wasp *Xanthopimpla rhopaloceros* has been observed with larvae of *S. macropetana*. Braconid *Dolichogenideata smanica* was reported as an efficient biocontrol agent for management of tortricid moth the apple leaf roller *Epiphyaspost vittana* (Scarratt, 2005).

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Efficacy of insecticides against citrus leaf miner, *Phyllocnistis citrella* Stainton (Gracillariidae: Lepidoptera) in acid lime (*Citrus aurantifolia*)

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ABSTRACT: The citrus leaf miner (*Phyllocnistis citrella*) Stainton is one of the key pests of acid lime. A field experiment on the efficacy of selected new molecules of insecticides against citrus leaf miner revealed that two applications of spinosad 45 SC (0.30 ml/l) and flonicamid 50 WG (0.30 g/l) were significantly effective. Other insecticides *viz*., thiamethoxam 25 WG (0.25 g/l), emamectin benzoate 5SG (0.40 g/l) and chlorantraniliprole 18.5 SC (0.10 ml/l) were found moderately effective in control of the pest. The imidacloprid 70 WG (0.30 g/l) and fipronil 5 SC (1.00 ml/l) were found to be least effective against citrus leaf miner. The effective insecticides can be used in scheduling for control of citrus leaf miner on acid lime.

Keywords: Acid lime, *Phyllocnistis citrella*, spinosad 45 SC, flonicamid 50 WG, thiamethoxam 25 WG

INTRODUCTION

Citrus assumes prominent place in contribution to the world's fruit area and production. In India, citrus is the third most important fruit crop after mango and banana. The acid lime, *Citrus aurantifolia* Swingle is one of the important citrus crops grown in India. In recent times, the remunerative nature of crop has resulted in bringing large proportion of area under cultivation of acid lime. The changed scenario of cultivation led to severe incidence of citrus leaf miner, *Phyllocnistis citrella* on acid lime (Dileep kumar *et al*., 2022). The pest attacks acid lime crop both at nursery and orchard conditions (Patil, 2013). The larvae prefer to feed on young and new flush of the plant. Larva mines the leaves and feeds on mesophyll tissues by remaining inside the mines. As a result of feeding long tail like serpentine mining can be seen on affected portions of the plant (Sarada *et al*., 2014). The curling, crumpled and distortion of leaves is observed at the later stage of infestation. Overall, photosynthetic activity and vigour of plant reduces and finally affects the fruit production in mature trees (Heppner, 1993; Grafton-Cardwell *et al*., 2008). In addition to direct damage, the pest is also known to predispose the plant to canker infection (Junior *et al*., 2006).

The activity of pest is normally observed to be throughout the year with overlapping generations (Dileepkumar *et al*., 2023). About 45 % new leaf area is estimated to lose due to infestation of citrus leaf miner(Garcia-Mari *et al*., 2002).The pest is reported to cause 17 to 57 per cent damage on citrus crops (Boughdad *et al*., 1999). So the management of this pest largely revolves around use of synthetic insecticides. Keeping in view the importance of the crop and damage potential of pest, the present study was conducted with an objective of evaluating the efficacy of selected insecticides against citrus leaf miner on acid lime.

MATERIALS AND METHODS

A field experiment was conducted in Randomized Block Design (RBD) at College of Agriculture, Vijayapura, Karnataka (16°49'39.1620" N 75°43'31.1772" E) during *rabi* 2020-21 and *kharif* 2021-22 to evaluate the efficacy of insecticides against citrus leaf miner. The experiment consisted of eight treatments including untreated check and replicated thrice. The acid lime crop (cv. Kagzi lime) was grown with all the package of practice (except plant protection measures) recommended with row to row and plant to plant geometry of 6 × 6 m. The weekly observations were made to check for incidence of pest. The insecticides applications were taken up as per treatment details (Table 1.) when pest reached economic threshold status. Two acid lime plants were considered as one replication and five branches were tagged in each plant for taking observation on pest density. During the study, two applications were taken up with the help of knapsack sprayer. The insecticides *viz*., chlorantraniliprole 18.5 SC(0.10 ml/l), emamectin benzoate 5SG (0.40 g/l), spinosad 45 SC (0.30 ml/l), flonicamid 50 WG (0.30 g/l), fipronil 5 SC(1.00 ml/l), imidacloprid 70 WG (0.30 g/l) and thiamethoxam 25 WG (0.25 g/l) (standard check) along with untreated control (water spray) were used

Table 1. Efficacy of insecticides against citrus leaf miner, Phyllocnistis citrella Stainton infesting acid lime during rabi 2020-21

Treatment	First spray					ROC (%)	Second spray					ROC (%)
	Number of live mines/ shoot						Number of live mines/ shoot					
	1DBS	1DAS	3DAS	5DAS	10DAS		1DBS	1DAS	3DAS	5DAS	10DAS	
Chlorantraniliprole 18.5 SC	12.13 (3.55)	10.17 (3.26)^{b}	6.83 (2.71)^{bcd}	5.00 (2.34)^{bc}	3.00 (1.86)^{c}	54.06	6.25 (2.60)^{ab}	5.00 (2.34)^{b}	3.25 (1.94)^{b}	1.83 (1.53)^{b}	1.25 (1.31)^{bc}	79.27
Emamectin benzoate 5 SG	12.04 (3.54)	9.96 (3.23)^{b}	6.50 (2.64)^{abc}	4.63 (2.26)^{abc}	2.18 (1.63)^{ab}	57.24	6.17 (2.58)^{a}	4.92 (2.33)^{b}	3.04 (1.88)^{b}	1.67 (1.47)^{b}	1.08 (1.26)^{b}	80.41
Spinosad 45 SC	12.33 (3.58)	8.00 (2.91)^{a}	5.33 (2.41)^{a}	3.50 (2.00)^{a}	1.50 (1.41)^{a}	66.31	5.75 (2.50)^{a}	3.04 (1.88)^{a}	1.50 (1.41)^{a}	0.54 (1.02)^{a}	0.25 (0.86)^{a}	90.24
Flonicamid 50 WG	12.38 (3.59)	9.38 (3.14)^{ab}	5.79 (2.51)^{ab}	3.92 (2.10)^{ab}	1.54 (1.43)^{a}	62.09	5.96 (2.54)^{a}	3.75 (2.06)^{a}	1.96 (1.57)^{a}	0.84 (1.16)^{a}	0.38 (0.92)^{a}	87.34
Fipronil 5 SC	12.04 (3.54)	10.71 (3.35)^{b}	7.92 (2.90)^{d}	6.25 (2.60)^{d}	4.83 (2.31)^{e}	45.41	7.21 (2.78)^{bc}	6.42 (2.63)^{c}	4.50 (2.23)^{c}	3.25 (1.93)^{d}	2.29 (1.67)^{d}	69.89
Imidacloprid 70 WG	12.13 (3.55)	10.08 (3.25)^{b}	7.29 (2.79)^{cd}	5.42 (2.43)^{cd}	4.00 (2.12)^{d}	50.77	7.84 (2.89)^{c}	6.00 (2.55)^{c}	4.08 (2.14)^{c}	2.58 (1.75)^{c}	1.75 (1.50)^{c}	73.63
Thiamethoxam 25 WG	12.08 (3.54)	9.75 (3.20)^{b}	6.50 (2.64)^{abc}	4.92 (2.32)^{bc}	2.42 (1.71)^{bc}	56.66	6.17 (2.58)^{a}	4.75 (2.29)^{b}	3.00 (1.87)^{b}	1.67 (1.47)^{b}	1.00 (1.22)^{b}	80.95
Untreated control	12.17 (3.56)	12.42 (3.59)^{c}	13.29 (3.71)^{e}	13.96 (3.80)^{e}	14.75 (3.90)^{f}		12.33 (3.58)^{d}	12.58 (3.62)^{d}	13.42 (3.73)^{d}	14.13 (3.82)^{e}	14.54 (3.88)^{e}	
S.Em±	0.57	0.55	0.42	0.37	0.26		0.33	0.32	0.25	0.20	0.16	
CD @ 5%	NS	1.68	1.27	1.13	0.78		1.02	0.98	0.77	0.62	0.50	
CV (%)	8.13	9.57	9.80	10.86	10.53		8.12	9.67	10.14	10.76	10.27	

ROC- Reduction over control, DBS-Days before spray, DAS-Days after spray

during this investigation.

Data recording and analysis: The observations were recorded from five randomly selected young shoots per tree from different direction of the tree. To record the incidence of citrus leaf miner, from each shoot, number of leaves having live citrus leaf miner larvae were counted, later average number of live mines per shoot was worked out. The observations on pest density were recorded at one day before and one, three, five and ten days after imposition of treatments. The data of each spray was pooled and later transformed data was subjected to ANOVA and Duncan's multiple range tests (Gomez and Gomez, 1984). Further, obtained data was converted into per cent reduction of pest population over untreated control by using formula suggested by Abbott (1925).

RESULTS AND DISCUSSION

Efficacy of insecticides against citrus leaf miner during *rabi* 2020-21

At one day before spray, the average number of live mines ranged from 12.04 to 12.38 per shoot (Table 1). Prior to imposition of treatments, non-significant difference was observed among treatments with respect to number of live mines per shoot. The application of insecticides resulted in considerable decrease in pest density in the experimental plot. At ten days after first application, a significantly less number of live mines per shoot were recorded in spinosad 45 SC treated plants (1.50 live mines/ shoot) and which was found on par with flonicamid 50 WG (1.54 live mines/ shoot) and emamectin benzoate 5 SG(2.18 live mines/shoot). The insecticides, thiamethoxam 25 WG (2.42 live mines/ shoot)and chlorantraniliprole 18.5 SC(3.00 live mines/ shoot) were found on par in controlling the pest. However, imidacloprid 70 WG (4.00) and fipronil 5 SC (4.83) were found to be least effective against this pest. Second round of application further reduced the pest population. At 10 days after spray, significantly less population of citrus leaf miner was observed in spinosad 45 SC treated plants (0.25live mines/ shoot) and which was found on par with flonicamid 50 WG (0.38 live mines/ shoot). The insecticides *viz*., thiamethoxam 25 WG, emamectin benzoate 5 SG and chlorantraniliprole 18.5 SC were found at par with 1.00, 1.08 and 1.25 live mines per shoot, respectively. The imidacloprid 70 WG (1.75) and fipronil 5 SC (2.29) were found to be least effective in control of pest. With respect to per cent reduction in mine population over untreated control, a significantly higher per cent reduction was noticed in spinosad 45 SC (90.24 %) treatment, which was followed by flonicamid 50 WG (87.34), thiamethoxam 25 WG (80.95), emamectin benzoate 5 SG (80.41), chlorantraniliprole 18.5 SC (79.27), imidacloprid 70 WG (73.63) and fipronil 5 SC (69.89) treated plots.

Efficacy of insecticides against citrus leaf miner during *kharif* 2021-22

During *kharif*, before imposition of treatments a non-significant variation was observed among all the treatments with population ranging from 11.84 to 12.17 live mines per shoot. The imposition of treatments in the experimental plot resulted in decrease in pest population. At ten days after first application, spinosad 45 SCwas found to be superior in controlling citrus leaf miner (1.33 live mines/ shoot) and which was found on par with flonicamid 50 WG (1.46 live mines/ shoot) and emamectin benzoate 5 SG (2.00 live mines/shoot). Thiamethoxam 25 WG and chlorantraniliprole 18.5 SC were found on par with 2.25 and 2.75 live mines per shoot, respectively where as imidacloprid 70 WG (4.00) and fipronil 5 SC(4.92) were found less effective against this pest. Second round of sprays further reduced the pest population. At 10 days after second spray, spinosad 45 SC (0.33live mines/ shoot) and flonicamid 50 WG (0.42live mines/ shoot) were found highly effective in controlling citrus leaf miner. The insecticides *viz*., thiamethoxam 25 WG, emamectin benzoate 5 SG and chlorantraniliprole 18.5 SC were found at par with 1.08, 1.08 and 1.17 live mines per shoot, respectively. However, imidacloprid 70 WG (1.92) and fipronil 5 SC(2.29) were found to be least effective in control of pest. With respect to per cent reduction in mine population over untreated control, a significantly higher per cent reduction was observed in spinosad 45 SC (90.35 %) treatment, which was followed by flonicamid 50 WG (88.23), thiamethoxam 25 WG (81.75), emamectin benzoate 5 SG (81.00), chlorantraniliprole 18.5 SC(79.04), imidacloprid 70 WG(74.43) and fipronil 5 SC (69.38) treated plots. The population of mines were at high density in untreated control plots (Table 2).

Pooled data on efficacy of insecticides

At ten days after the first spray, a significantly less population of live mines were observed in spinosad 45 SC (1.42) treatment and it was at par with flonicamid 50 WG (1.50 live mines/ shoot) and emamectin benzoate 5 SG (2.09 live mines/shoot). Thiamethoxam 25 WG (2.33) and chlorantraniliprole 18.5 SC (2.88) were found on par with respect to efficacy on citrus leaf miner. The imidacloprid 70 WG (4.00) and fipronil 5 SC (4.88) were found to least effective against the pest. Similar trends were observed after second round of application. Spinosad 45 SC (0.29live mines/ shoot) and flonicamid 50 WG (0.40) treated plots were recorded significantly

Table 2. Efficacy of insecticides against citrus leaf miner, *P. citrella* infesting acid lime during *kharif* 2021-22

Treatment	First spray					ROC (%)	Second spray					ROC (%)
	Number of live mines/ shoot						Number of live mines/ shoot					
	1DBS	1DAS	3DAS	5DAS	10DAS		1DBS	1DAS	3DAS	5DAS	10DAS	
Chlorantraniliprole 18.5 SC	11.92 (3.52)	9.96 (3.23)^{b}	6.50 (2.64)^{bcd}	4.83 (2.31)^{cd}	2.75 (1.80)^{b}	56.52	6.50 (2.64)^{ab}	5.33 (2.41)^{bc}	3.17 (1.91)^{bc}	1.92 (1.55)^{b}	1.17 (1.28)^{b}	79.04
Emamectin benzoate 5 SG	12.17 (3.56)	9.75 (3.20)^{b}	6.50 (2.64)^{bcd}	4.58 (2.25)^{bc}	2.00 (1.58)^{ab}	58.71	6.25 (2.60)^{a}	5.00 (2.34)^{bc}	3.00 (1.87)^{b}	1.42 (1.38)^{b}	1.08 (1.25)^{b}	81.00
Spinosad 45 SC	12.25 (3.57)	7.58 (2.84)^{a}	5.04 (2.35)^{a}	3.50 (1.99)^{a}	1.33 (1.35)^{a}	68.42	5.92 (2.53)^{a}	3.00 (1.87)^{a}	1.50 (1.41)^{a}	0.50 (0.99)^{a}	0.33 (0.91)^{a}	90.35
Flonicamid 50 WG	12.08 (3.54)	9.17 (3.11)^{b}	5.34 (2.41)^{ab}	3.63 (2.03)^{ab}	1.46 (1.40)^{a}	64.57	6.08 (2.57)^{a}	3.50 (2.00)^{a}	1.88 (1.54)^{a}	0.71 (1.10)^{a}	0.42 (0.96)^{a}	88.23
Fipronil 5 SC	11.84 (3.51)	10.54 (3.32)^{b}	7.71 (2.86)^{d}	5.83 (2.51)^{d}	4.92 (2.33)^{d}	47.55	7.42 (2.81)^{bc}	6.67 (2.68)^{d}	4.46 (2.23)^{d}	3.50 (2.00)^{d}	2.29 (1.67)^{c}	69.38
Imidacloprid 70 WG	11.96 (3.53)	10.00 (3.24)^{b}	7.00 (2.74)^{cd}	5.29 (2.41)^{cd}	4.00 (2.12)^{c}	52.45	7.92 (2.90)^{c}	5.50 (2.45)^{c}	3.92 (2.10)^{cd}	2.79 (1.81)^{c}	1.92 (1.55)^{c}	74.43
Thiamethoxam 25 WG	12.00 (3.53)	9.75 (3.20)^{b}	6.42 (2.63)^{bc}	4.50 (2.24)^{abc}	2.25 (1.66)^{b}	58.55	6.33 (2.61)^{ab}	4.50 (2.23)^{b}	2.92 (1.85)^{b}	1.58 (1.43)^{b}	1.08 (1.26)^{b}	81.75
Untreated control	12.08 (3.54)	12.33 (3.58)^{a}	13.50 (3.74)^{e}	14.38 (3.86)^{e}	15.08 (3.95)^{e}		12.42 (3.59)^{d}	12.58 (3.62)^{e}	13.50 (3.74)^{e}	14.21 (3.84)^{e}	14.96 (3.93)^{d}	
S.Em±	0.56	0.48	0.42	0.35	0.25		0.37	0.32	0.25	0.19	0.17	
CD @ 5%	NS	1.46	1.28	1.07	0.76		1.12	0.97	0.77	0.58	0.52	
CV (%)	8.10	8.43	10.14	10.59	10.30		8.73	9.69	10.32	10.01	10.25	

ROC- Reduction over control, DBS-Days before spray, DAS-Days after spray

Table 3. Pooled data on efficacy of insecticides against citrus leaf miner (2020-21 and 2021-22)

Treatment	First spray						ROC (%)	Second spray						ROC (%)
	Number of live mines/ shoot							Number of live mines/ shoot						
	1DBS	1DAS	3DAS	5DAS	10DAS	Mean		1DBS	3DAS		5DAS	10DAS	Mean	
Chlorantraniliprole 18.5 SC	12.02 (3.54)	10.06 (3.25)^{bc}	6.67 (2.68)^{c}	4.92 (2.33)^{c}	2.88 (1.83)^{c}	6.13	55.30	6.38 (2.62)^{ab}	5.17 (2.38)^{bc}	3.21 (1.93)^{b}	1.88 (1.45)^{b}	1.21 (1.30)^{b}	2.86	79.15
Emamectin benzoate 5 SG	12.11 (3.55)	9.86 (3.22)^{bc}	6.50 (2.64)^{bc}	4.61 (2.26)^{bc}	2.09 (1.61)^{ab}	5.76	57.98	6.21 (2.59)^{a}	4.96 (2.34)^{b}	3.02 (1.88)^{b}	1.54 (1.43)^{b}	1.08 (1.26)^{b}	2.65	80.70
Spinosad 45 SC	12.29 (3.58)	7.79 (2.88)^{a}	5.19 (2.38)^{a}	3.50 (1.99)^{a}	1.42 (1.38)^{a}	4.47	67.38	5.83 (2.51)^{a}	3.02 (1.87)^{a}	1.50 (1.41)^{a}	0.52 (1.01)^{a}	0.29 (0.89)^{a}	1.33	90.29
Flonicamid 50 WG	12.23 (3.57)	9.27 (3.13)^{b}	5.57 (2.46)^{ab}	3.77 (2.07)^{ab}	1.50 (1.41)^{a}	5.03	63.34	6.02 (2.55)^{a}	3.63 (2.03)^{a}	1.92 (1.55)^{a}	0.77 (1.13)^{a}	0.40 (0.94)^{a}	1.68	87.79
Fipronil 5 SC	11.94 (3.53)	10.63 (3.34)^{c}	7.81 (2.88)^{d}	6.04 (2.56)^{d}	4.88 (2.32)^{e}	7.34	46.48	7.31 (2.79)^{bc}	6.54 (2.65)^{d}	4.48 (2.23)^{c}	3.38 (1.97)^{d}	2.29 (1.67)^{d}	4.17	69.63
Imidacloprid 70 WG	12.04 (3.54)	10.04 (3.24)^{bc}	7.15 (2.77)^{cd}	5.36 (2.42)^{cd}	4.00 (2.12)^{d}	6.64	51.61	7.88 (2.89)^{c}	5.75 (2.50)^{c}	4.00 (2.12)^{c}	2.69 (1.78)^{c}	1.83 (1.53)^{c}	3.57	74.03
Thiamethoxam 25 WG	12.04 (3.54)	9.75 (3.20)^{bc}	6.46 (2.64)^{bc}	4.71 (2.28)^{c}	2.33 (1.68)^{bc}	5.81	57.61	6.25 (2.60)^{a}	4.63 (2.26)^{b}	2.96 (1.86)^{b}	1.63 (1.54)^{b}	1.04 (1.24)^{b}	2.56	81.35
Untreated control	12.13 (3.55)	12.38 (3.59)^{d}	13.40 (3.73)^{e}	14.17 (3.83)^{e}	14.92 (3.93)^{f}	13.71		12.38 (3.59)^{d}	12.58 (3.62)^{e}	13.46 (3.73)^{d}	14.17 (3.83)^{e}	14.75 (3.91)^{e}	13.74	
S.Em±	0.43	0.42	0.34	0.30	0.24			0.31	0.22	0.23	0.15	0.11		
CD @ 5%	NS	1.30	1.05	0.91	0.73			0.95	0.68	0.71	0.46	0.35		
CV (%)	7.28	7.45	8.19	8.89	9.80			7.50	8.19	9.42	8.94	8.73		

ROC- Reduction over control, DBS-Days before spray, DAS-Days after spray

less population of citrus leaf miner. The insecticides *viz*., thiamethoxam 25 WG (1.04), emamectin benzoate 5 SG (1.08) and chlorantraniliprole 18.5 SC (1.21) were found on par in control of the pest. Imidacloprid 70 WG (1.83) and fipronil 5 SC (2.29) were found comparatively less effective in control of this pest. After two rounds of spray, spinosad 45 SC recorded significantly higher per cent reduction (90.29) of population of citrus leaf miner which was followed by flonicamid 50 WG (87.79), thiamethoxam 25 WG (81.35), emamectin benzoate 5 SG (80.70), chlorantraniliprole 18.5 SC (79.15), imidacloprid 70 WG(74.03) and fipronil 5 SC (69.63) treated plots in decreasing order of toxicity. The population of live mines were at high density in untreated control plots (Table 3).

It is evident from present investigation that spinosad 45 SC and flonicamid 50 WG were highly effectively in control citrus leaf miner on acid lime.The present findings are supported by Besheli (2009) who found that spinosad was superior in controlling the larvae of citrus leaf miner where about 98 per cent mortality of pest was observed after 96 hours of exposure to insecticide. Similarly, Bhut and Jethva (2019) reported that spinosad 45 SC was found to reduce leaf damage caused by *P. citrella* on Kagzi lime. More recently, Sharma (2021) also reported that spinosad 45 SC was highly effective in control of citrus leaf miner. Spinosad, a spinosyn group of insecticide produced from actinomycetes, *Saccharopolyspora spinosa* consists of mixture of spinosyn A and spinosyn D, two active metabolites responsible for insecticidal activity of spinosad. Spinosad has two modes of action, the first mode of action involves disrupting the binding of acetylcholine at nicotinic acetylcholine receptors located at the post-synaptic cell junctures, which prolongs stimulation of the nicotinic acetylcholine receptors. Consequently, this results in excitation of the insect central nervous system, paralysis and eventually death. The second mode of action is affiliated with negatively affecting GABA-gated ion channels. Therefore, these two kinds of novel modes of action may have resulted in improved efficacy of spinosad over other selected insecticides in this study.

Flonicamid of pyridincarboxamide group has excellent translaminar and systemic activity, rapidly inhibits the feeding behavior of pests. The citrus leaf miner larva mainly feed on the epidermal tissues of the young leaves, and act as sucking pest. The translocation of flonicamid through vascular bundles of plant system may have contributed to effective control of citrus leaf miner on acid lime. Similarly, Kattebennnuru (2017) reported significant control of citrus leaf miner upon exposure to flonicamid 50 WG. The treatments emamectin benzoate 5 SG and chlorantraniliprole 18.5 SC were found moderately effective in controlling citrus leaf miner on acid lime. The observations made during this study are supported by Kattebennuru (2017) who found that emamectin benzoate 5 SG and chlorantraniliprole 18.5 SC were recorded 35.57 and 32.36 per cent reduction in larval population, respectively after single application of insecticides. A slight change in the efficacy may be due to frequency and numbers of application taken up during the study. The citrus leaf miner is known to occur throughout the year with decreasing and increasing population, so multiple applications are needed for successful control of pest on acid lime. On the contrary, Sharma (2021) found that emamectin benzoate 5 SG was least effective in managing citrus leaf miner. The possible reason may be weather factors that were existing and quantity of insecticide used during the investigation.

The neonicotinoids, thiamethoxam 25 WG and imidacloprid 70 WG were found moderately effective in controlling citrus leaf miner. These observations are supported by Mohamed and Satti (2015), they reported that thiamethoxam 25 WG and imidacloprid 200 SL were highly effective in minimizing pest load on citrus seedlings, and kept seedlings pest free for more than a month. Similarly, Shinde *et al*. (2017) found that thiamethoxam 25 WG and imidacloprid 17.8 SL showed lowest leaf infestation by larvae of *P. citrella* on Nagpur mandarin. Iqbal *et al*. (2018) also observed that thiamethoxam 25 WG and imidacloprid 20 SL recorded significantly higher mortality of citrus leaf miner after 96 hours of exposure to insecticides. The present study reveals effectiveness of insecticides for management this severe pest of acid lime thus widening the choice of chemicals as use of insecticides of different chemistries will also help to delay development of resistance in the pest against insecticides.

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Population dynamics and development of weather-based prediction model for the incidence of whitefly, *Bemisia tabaci* Gennadius and its predator, *Nesidiocoris tenuis* (Reuter) in tomato

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ABSTRACT: Population of whiteflies and its natural enemy *Nesidiocoris tenuis* were recorded for the period of three years and averages were computed and subjected to simple correlation by considering weather parameters as the dependent variable. During observed years, population of whiteflies peakranged within 33rd to 37th SMW, the mean occurrence of the *N. tenuis* started with the build-up of its prey population and peaked at 40th SMW, declined thereafter and the populationof whiteflies had significantly positively correlated with maximum temperature, minimum temperature, evening relative humidity, and wind speed, respectively. Rainfall had a positive correlation but was not significant. In the present study, the population of *N. tenuis* was dependent only on the prey density but not on the weather parameters. The established model validated satisfactorily(R^2=0.75; RMSE = 2.05).

Keywords: Whitefly, *Nesidiocoris tenuis,* tomato, weather, forecast, population.

Tomato, *Solanum lycopersicum* L. (Solanaceae) is a highly valued, all-season vegetable commodity cultivated extensively worldwide for its edible fruits which are rich in antioxidants, dietary fibers, minerals, and vitamins. Globally, 177 MT of tomatoes are being produced every year, in India, tomato stands second after China with production of 21.9 MT (Agricultural statistics at glance, 2020). Tomato cultivation demands significant investment in crop protection against biotic stress, as their management needs costly pesticides, apart from that resistance, resurgence, and outbreak due to change in climate takes a big toll on farmers. Among pests whiteflies, *Bemisia tabaci* Gennadius are major followed by thrips *Thrips tabaci* Lindeman, fruit borer, *Helicoverpa armigera* (Hubner) and tomato pinworm, *Tuta absoluta* (Meyrick). Whiteflies suck sap from the phloem, which results in chlorosis of leaf, spotting, curling, irregular fruit ripening, and honeydew favoured sooty mould growth affect photosynthesis. It affects plants through the transfer of Begomovirus, Crinivirus, Closterovirus, and Ipomovirus (Tiwari *et al.,* 2013) and causes 100 % damage when control is not undertaken at right time (Schoonhoven *et al.,* 2005). To take the right management action against whiteflies at right time to evade the plants from damage, understanding on changing status of the population with weather factors and their interaction with its predator *N. tenuis* is of prime importance.

Change in weather or more precisely change in climate would directly influence the occurrence and dynamics of pests and their natural enemies, favourable weather favours the pest, and unfavourable would deter. Among the weather factors, the influence of temperature, rainfall, relative humidity on pests had reported in cotton against sap feeders (Vennila *et al.,* 2018), tomato fruit borer, *H. armigera* (Khokhar *et al.,* 2019), and beet armyworm, *Spodoptera exigua* Hubner (Kamakshi *et al.,* 2018) e. t. c. Establishing the relationships of pest dynamics and prevailing natural enemy incidence with weather factors through models would guide when to undertake pest management which is lacking in the case of whiteflies infesting in tomatoes. Keeping this backdrop in view, the influence of weather variables was worked out concerning pest and prey population in the present study.

MATERIALS AND METHODS

Field experiments were conducted for three years at ICAR-Indian Agricultural Research Institute, New Delhi. Tomato variety Pusa Ruby was planted in an acre of land in July based on the recommended horticultural practices and harvested in May. For whiteflies, data were collected for the development and validation of the forecast model by direct counting and the yellow sticky trap was used for counting *N.tenuis*. In the case of the direct count method, numbers of whiteflies were counted from the lower, mid,

Table 1. Correlation of population of *B. tabaci* and *N. tenuis* with weather factors

	B. tabaci			*N. tenuis*		
Weather Factor	**2017**	**2018**	**2019**	**2017**	**2018**	**2019**
Tmax °C	**0.667****	0.444	**0.731****	0.343	0.185	0.072
Tmin °C	**0.808****	**0.653****	**0.833****	-0.066	-0.003	-0.035
RH1(%)	0.441	-0.134	0.195	0.319	0.145	0.142
RH2 (%)	**0.760****	**0.635**	**0.667****	-0.272	-0.176	-0.285
RF (mm)	0.450	0.409	0.316	0.000	-0.227	-0.332
SS (hr)	0.103	-0.256	0.043	0.454	0.541*	0.538*
WS (kmph)	**0.564****	0.385	0.188	-0.326	-0.204	-0.472

Tmax (°C)-Temeprature maximum; Tmin °C – Temperature minimum; RH1(%)- Morning relative humidity; RH2 (%) – Evening relative humidity; RF (mm) – Rain fall; SS (hr)-Sunshine; WS (kmph)- Wind speed; ** Correlation significant at 1% and * Correlation significant at 5%.

and upper leaf on randomly selected five plants early in the morning, whereas in the case trap catches, 5 yellow sticky traps were installed and data was collected by counting trapped *N. tenuis*. Counts were made twice a week and expressed as the mean number of flies per each SMW (Standard Meteorological Weeks) and the variation in the data was normalized by subjecting into square root transformation.

The two years population data was used for the development of the model by multiple regression and validated with third year data. Weather variables like maximum temperature (Tmax), minimum temperature (Tmin), rainfall (RF) morning relative humidity (MRH), evening relative humidity (ERH), sunshine hours (SSH), and wind speed (WS) were collected from the Division of Agricultural Physics, ICAR-Indian Agricultural Research Institute, New Delhi and correlated using simple correlation co-efficient with the whiteflies population for current week. A multiple linear regression model was developed for positively correlated weather factors then step-wise regression was done to know the magnitude of influence of different weather factors on the build-up of whiteflies population.As weather parameters were not significant for *N. tenuis* it was not considered for development and validation.

RESULTS AND DISCUSSION

Seasonal dynamics of whiteflies and its predator *N. tenuis*

The initial occurrence of whiteflies was observed right after transplanting during 27th SMW during all the observed years, due to the presence of alternate hostsand weed hosts around the experimental area. Peak occurrence was noticed at 35th SMW @ 8 whiteflies per plant during 2017,bi-peaks on 33rd and 36th SMW with 16 and 18 whiteflies per plant, during 2018, and during 2019, the peak was noticed at 37th SMW @12 whiteflies per plantand gradually declined thereafter (Fig. 1). Observations of the present study results are similar to that of observations of the Marabi *et al.,* (2017a), who reported the occurrence of whiteflies from 28th SMW and peak was recorded at 30th SMW in Blackgram. Mean occurrence of the *N. tenuis* started with the build-up of whiteflies population, its appearance was recorded at 30th SMW and gradually increased with increase in population density of prey and peaked at 40th SMW and declined with respect to decline in the prey density (Fig 2). Increasing the population peaks of predators after an increase in the prey proves that the availability of the prey is the prime driving factor for the occurrence of predators.

Correlation of whiteflies and its natural enemy *N. tenuis* with different weather factors

Correlation studies between whitefly and *N. tenuis* with the prevailing weather factors revealed that the population of whiteflies had a significantly positive correlation with maximum temperature (r=0.666, r=0.731 during 2017 and 2018), minimum temperature (r=0.808; r=0.653, r=0.833 during 2017, 2018, 2019), evening relative humidity (r=0.760, r=0.635, r=0.667 during 2017, 2018 2019) and wind speed (r=0.564 during 2017), respectively. In the case of *N. tenuis* maximum temperature, morning relative humidity and

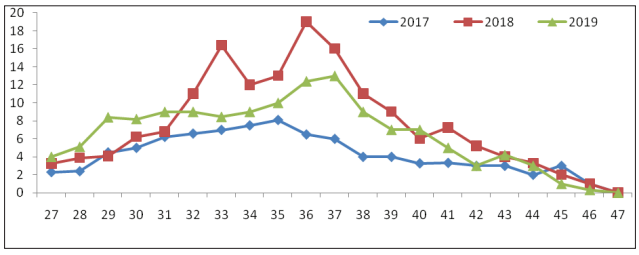

Fig. 1. Population dynamics of whiteflies *B. tabaci* with respect to standard meteorological week in Tomato

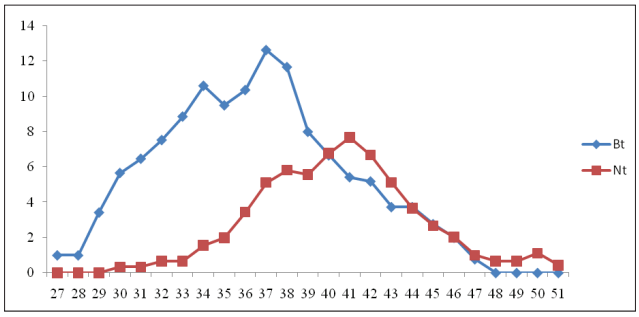

Fig. 2. Population dynamics of whiteflies *B. tabaci* in response to its predator *N. Tenuis*

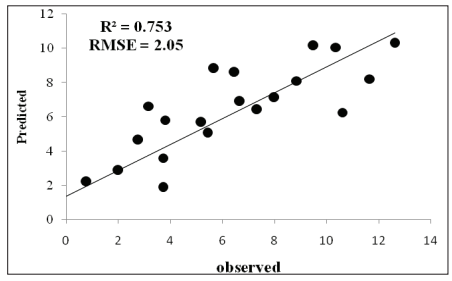

Fig. 3. Validation of Whiteflies B. tabaci weather based model

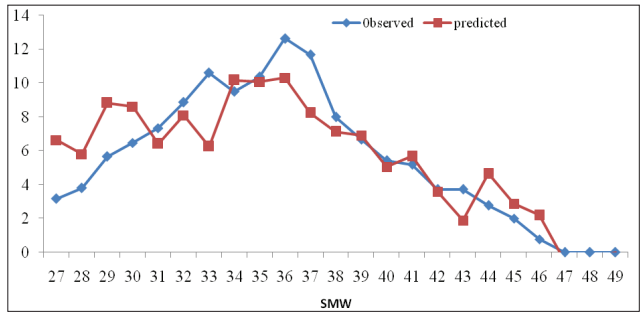

Fig. 4. Observed and Expected population of Whiteflies B. tabaci with respect to standard meteorological week

sunshine hours had positively correlated and minimum temperature, evening relative humidity, and wind speed were negatively correlated but not significant, this shows the population dynamics of *N. tenuis* was majorly influenced by the density of prey compared to weather factors (Table 1). Marabi *et al*., (2017b) reported the significant positive correlation of whitefly population with maximum temperature, minimum temperature, evaporation, and morning vapour pressure and non-significant correlation of morning and evening relative humidity in soybean. In blackgram, Miraba *et al.,* (2017a) reported a significant positive correlation of whiteflies with maximum temperature and whereas wind speed and rainfall had negatively correlated. All reports had shown a significant positive correlation with maximum temperature but Patidar (2015) had contrasting evidence of negative correlation of maximum temperature in blackgram.

Development and validation of the weather-based model

Step-wise regression equationswere developed for the four weather factors which are significantly correlated *viz.,* temperature maximum, temperature minimum, evening relative humidity, and wind speed turned out as Y= 8.37-0.055 (Temperature maximum) +1 (Temperature minimum) +0.02 (Evening relative humidity) -1.79 (Wind speed) (R^2=0.75; RMSE=2.05). The equation revealed that for every unit increase in maximum temperature and wind speed the population of whiteflies decreases by 0.055 and 1.79 units. Whereas for every unit increase in minimum temperature and evening relative humidity the population of whiteflies increases by 1.0 and 0.02 units, respectively. Effect of weather parameters on the population of whiteflies indicates that 75 % of the change in their population was influenced by maximum temperature, minimum temperature, evening relative humidity, and wind speed and the remaining 25 % is due to some other unidentified factors. Whiteflies activity was greatly influenced by the surrounding temperature so low temperature inhibited the population and higher stimulated it. Rainfall had an insignificant impact this may be due to heavy showers physically affecting the adult flies but not the sessile immatures, having short life cycle population was surged by the existing immature population and by getting the favourable humidity amid rainfall. The findings of the current work are corroborated with the results of previous work by Marabi *et al*. (2017a) and Srinivasa (2014) reported that abiotic factors like temperature and humidity explain the 65% variation in the population dynamics of the whiteflies. The established model was validated by keeping the 2017 and 2018 predicted whitefly count with the 2019 whitefly count. The developed model was validated satisfactorily with RMSE = 2.05 (Fig.3). The observed and expected population of whiteflies were followed a similar trend (Fig. 4).

Considering the direct or indirect influence of abiotic factors on population abundance and crop damage,

developing a real-time monitoring system supported by information and communication technological (ICT) tools and its forecasting to farmers with the help of electronic message, social media, web hosting, and broadcasting media would provide information at right time to take up the management of whiteflies to reduce damage.

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Droplet spectrum of spray from nozzles of a wheel operated boom sprayer used in agriculture

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ABSTRACT: The aim of the study was to evaluate the droplet spectrum of commonly used agricultural nozzles i.e., Flat fan, Hollow cone and Flood jet nozzle with the change in height of spraying and number of nozzles on the boom of awheel operated boom sprayer. The experimental study was carried out using water sensitive papers (WSP) laid on the ground in line to the sprayer nozzle. The droplet spectrum parameters like number of droplets, droplet diameter, $DV_{0.1}$, $DV_{0.5}$ and $DV_{0.9}$ were measured using mobile based software namely Dropleaf. The software captured the stained image of the water sensitive paper after spraying operation using water was completed. The study revealed that the height of spraying and number of nozzles on a boom have a significant effect on droplet spectrum. The droplet diameter increases with the corresponding decrease in the number of the droplets by increasing the height of spraying. The span factor was found to be ideal at the maximum height and among the nozzles the flood jet was better in terms of uniformity of the spray.

Keywords: Spray spectrum, Droplet diameter, VMD, $DV_{0.1}$, $DV_{0.9,}$ Span factor Water sensitive paper,

INTRODUCTION

Pesticides play a crucial role in agricultural development by decreasing the losses of agricultural products and increasing the affordable yield and quality of the food. The spraying of pesticides is usually done using a pump attached with the nozzle so to use the pressure energy for converting fluid into fine droplets (Beyaz *et al*., 2017). Nozzle is the most critical component for the application of the pesticide and directly controls by breaking the liquid into fine droplets to form the suitable spray pattern. The size of the spray droplets formed by the nozzles is crucial because it affects the efficacy of the application of an herbicide, insecticide, or fungicide (Bari *et al.,* 2019). The droplet size is a measure of atomization efficiency and a guide for nozzle design and selection. The studies have revealed that if the droplet size is not optimum the problems like waste loss or drift and inefficacy occurs. Only when the droplet size is in the optimal range, the target crop can capture the droplets and the best control effects can be achieved.

MATERIALS AND METHODS

The present study was carried out using a wheel operated boom sprayer developed at Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu (Zaffar, 2020). The droplet spectrum of three commonly used agriculture nozzles namely fan type, hollow cone and flood jet nozzle at three types of booms i.e., boom carrying two, three and four nozzles respectively at three heights of spraying (0.4, 0.5 and 0.6 m)

Description of a wheel operated boom sprayer

The wheel operated sprayer consisted of a bicycle wheel of 640 mm diameter attached at the front end of the main frame. On the rear end of the main frame, a sprayer pump is mounted and the sprayer consisted of an eccentric mechanism by which the rotational motion of the front wheel is converted into the reciprocating motion of the pump. The pump is attached with the hose pipe which in turn is connected with the boom carrying nozzles for the spraying operation. The main components of the wheel operated sprayer are main frame, sprayer tank cum pump, boom stand, boom and nozzles (Fig.1)

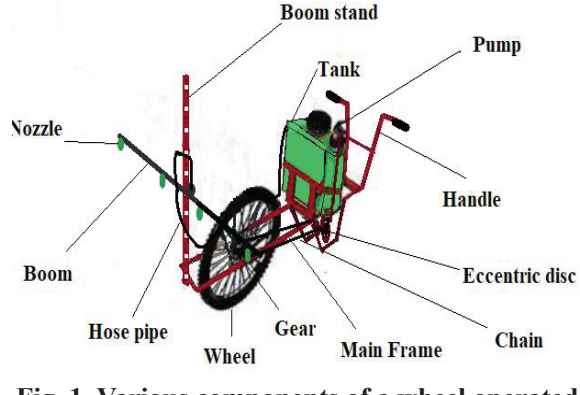

Fig. 1. Various components of a wheel operated boom sprayer

Study area

The study was conducted at Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu (SKUAST J) on the open flat concreate surface under open atmospheric conditions. The area of the concreate plot was 50 × 50 m^2 in which a straight line of 30 m was marked for straight running of the wheel operated boom sprayer. The surface was also marked with dots where the water sensitive paper's (WSP) were laid on every treatment to find the spectrum of the sprayer from all three types of nozzles.

Experimental Setup

During the experimental study the calibration of the speed for spraying operation was done so to maintain the constant speed of 3.2 km/h in all the treatments assuring that the speed will have constant effect on the spray pattern. The study involved the use of water sensitive papers (WSP) which were laid on the flat surface during spraying operation for all types of the nozzles. A total of 81 trials were performed to determine the droplet spectrum of all three nozzles. All stained WSP's were analysed using mobile software namely Drop leaf and to calculate the droplet characteristics like Number of droplets, droplet diameter, $D_{V0.1}$, $D_{V0.5}$, $D_{V0.9}$ and span factor.

Type of Nozzles

Flat fan nozzle

The flat fan nozzle is used for most of the broadcast spraying of herbicides and for certain insecticides when foliar penetration and coverage are not required. The nozzle has elliptical shaped orifice type in nozzle tip by which the spray pattern is formed. The components of the nozzles are; body, filter, washers, nozzle tip and nozzle head as shown in Fig. 2.

Fig. 2. Components of a nozzle

Hollow cone nozzle

The hollow cone nozzles are primarily used when plant foliage penetration is essential for effective insect or disease control and when drift is not a major concern. The hollow cone contains a whirl chamber inside it which sets the whirl motion to the fluid. The resulting turbulence breaks up the fluid into the droplets which are then shaped into a hollow cone as they exit the orifice. The components of the hollow cone nozzles are; body, whirl chambers, washers and nozzle head as shown in Fig. 3.

Fig. 3. Hollow cone and its components

Flood jet nozzle

The flood jet nozzles also called solid stream nozzles has a little more than a circular orifice at the end of a funnel. The flood jet nozzles give the highest impact of any spray pattern as the full momentum of liquid is concentrated into a small area. The various component of flood jet are; Body, washer, nozzle tip and head as shown in figure 4.

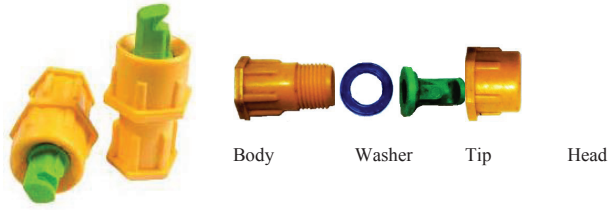

Fig. 4. Flood jet and its components

Dropleaf

In order to calculate the parameters like droplet diameter, Number of droplets, $D_{V0.1}$, DV0.5 and DV0.9 drop leaf was used which is simply a mobile based software used to measure the quality of pest control spraying machine via image analysis. (Zaffar and Khar, 2022a).

Number of droplets

The number of droplets is the total count of the stained dots on the water sensitive paper after the spraying operation is completed. The number of droplets was calculated using the Drop leaf software.

Droplet diameter

The droplet diameter or droplet size is generally referred to the mean diameter of the droplets present in spray and was measured in microns. The droplet size was measured using Drop leaf software with the help of WSP (Zaffar and Khar, 2022b)

Table 1. Droplet Spectrum of fan type nozzle

Spraying Height (cm)	No. of droplets	Droplet diameter (μm)	$D_{V0.1}$ (μm)	$D_{V0.5}$ (μm)	$D_{V0.9}$ (μm)	Span factor
Boom carrying two fan nozzles (B1)						
40	1693	305.3	92.3	228.2	566.0	2.08
50	1244	367.1	89.5	269.7	777.6	2.55
60	1225	370.6	126.0	283.6	669.2	1.92
Mean	1387	347.6	102.6	260.5	670.9	2.18
Boom carrying three fan nozzles (B2)						
40	1117	375.5	90.20	286.6	768.8	2.37
50	1039	400.2	157.30	271.0	594.5	1.86
60	966	411.0	89.52	288.2	652.3	1.72
Mean	1040	395.5	112.34	281.9	671.8	1.98
Boom carrying four fan nozzles (B3)						
40	1006	402.8	89.50	349.2	1020.7	2.67
50	901	436.8	88.81	210.3	431.4	1.63
60	826	440.7	156.3	300.3	565.9	1.36
Mean	911	426.7	111.5	286.6	627.6	1.88

Table 2. Droplet Spectrum of Hollow cone type nozzles

Spraying Height (cm)	No. of droplets	Droplet diameter (μm)	$D_{V0.1}$ (μm)	$D_{V0.5}$ (μm)	$D_{V0.9}$ (μm)	Span factor
Boom carrying two hollow cone nozzles (B_1)						
40	1406	379.5	90.02	201.1	836.24	3.71
50	1284	393.0	90.32	287.7	782.82	2.41
60	913	469.2	126.30	357.3	927.51	2.24
Mean	1201	413.9	102.60	282.03	848.85	2.79
Boom carrying three hollow cone nozzles (B2)						
40	1354	384.5	127.00	299.8	722.96	1.99
50	1171	391.8	127.20	271.6	683.33	2.05
60	1135	398.8	90.51	271.3	626.13	1.97
Mean	1220	391.7	114.90	280.9	677.47	2.00
Boom carrying four hollow cone nozzles (B3)						
40	1225	494.4	90.15	284.2	1088	3.51
50	863	487.6	89.34	297.7	1053.2	3.24
60	553	537.4	126.80	360.1	1289.2	3.23
Mean	880	506.4	102.09	314.0	1143.4	3.32

$D_{V0.1}$

$D_{V0.1}$ refers to the value where 10 percent of the total volume of liquid sprayed is made up of drops with diameters smaller or equal to this value. In order to reduce the losses due off target spraying or drift the $D_{V0.1}$number should be near or above 200 microns (NSDU, 2017).

Volume mean diameter ($D_{V0.5}$)

The volume median diameter also known as VMD or MVD expresses drop size in terms of the volume of liquid sprayed. The VMD refers to a value where 50 percent of the total volume of liquid sprayed is made up of drops with diameters larger than the median value and 50 percent smaller than the median value.

$D_{V0.9}$

$D_{V0.9}$ refers to the value where 90% of the total volume (or mass) of liquid sprayed is made up of drops with diameters smaller or equal to this value. This diameter is best suited when complete evaporation of the spray is required and used to determine the efficiency of spraying i.e., with large increase in $D_{V0.9}$ value results in poor leaf coverage or droplets lost to non-target areas such as soil (Bari *et al.,* 2019).

Related span factor (RSF)

Relative span factor (RSF) refers to a dimensionless parameter indicative of the uniformity of the drop size distribution. (Bari *et al.,* 2019). The closer this number to one, more uniform the spray will be and is expressed as

$$\text{Relative span factor (RSF)} = \frac{DV0.9 - DV0.1}{DV0.5}$$

RESULTS AND DISCUSSION

The observations recorded regarding various droplet characteristics are presented below.

Droplet spectrum for fan type nozzle

The results revealed that with the increase in the height of spraying for a boom carrying two fan nozzles the number of droplets decreased and the mean diameter of the droplet increased in correspondence to it (Table 1). The decrease in number of droplets from 0.4 to 0.5 m and 0.5 to 0.6 m was in the range of 26.5% and 1.52%respectively with the corresponding increase in the mean diameter of 20.2 and 1.0% for the increase height of 0.4 to 0.5 and 0.5 to 0.6 m respectively. Similar trends in number of droplets and droplet diameter was observed for the boom carrying three and four nozzles. The decrease in the number of the droplets due to increase in the height of spraying was due to the decrease in the pressure of the individual nozzle. The decrease in pressure results in less atomization of the fluid and less droplets are formed which in turn results in formation of large sized droplets. In case of type of boom i.e., boom carrying two, three and four nozzles the number of droplets decreases with the increase in the number nozzles with the corresponding increasing in droplet diameter at all spraying heights i.e., 0.4, 0.5 and 0.6 m.

The values of $Dv_{0.1}$ on changing height and number of the nozzles in all cases was observed to be less than 200µm (susceptible to spray drift) but changes with respect to the change in height and number of nozzles on the boom. Which implies that the height and the number of nozzles on boom has significant effect. In case of $D_{V0.9}$ no such general trend was observed however the maximum value was obtained at the lowest height of spraying i.e., 0.4 m which implies that spray was distributed unevenly at the height of 0.4 m. The same non-uniformity of spray at the height of 0.4 m was supported by the estimated span factor which was farthest from the ideal value (1). The span factor or uniformity of spray was observed to be approaching to one with the increase in the height of spraying. The minimum values of span factor i.e., 1.92, 1.72 and 1.36 for boom carrying two, three and four fan type nozzles were obtained at the height of 60 cm.

The $D_{V0.5}$ values of the spray produced by fan type nozzle ranged from 228.3 to 283.6, 286.6 to 288.2 and 300.3 to 349.2µm representing medium spray for all three types boom i.e., boom carrying two, three and four nozzles respectively.

Droplet Spectrum of Hollow Cone Nozzle

The effect on droplet spectrum of a hollow cone nozzles with respect to change in height of spraying and number of the nozzles is given in table 2.

The data related to the droplet spectrum of hollow cone nozzles given in table 3 depicts that with the increase in the height of the spraying the number of droplets decreased with the corresponding increase in the mean diameter of the droplets. The decrease in number of droplets in terms of percentage ranged from 3 to 36 % with the corresponding range in the increase in the mean diameter as 1.5 to 16%. The increase in mean droplet diameter might be due to the merging of droplets with increase in the height of the spraying.

Table 3. Droplet spectrum of flood jet nozzles

Spraying Height (cm)	No. of droplets	Droplet diameter (μm)	$D_{V0.1}$ (μm)	$D_{V0.5}$ (μm)	$D_{V0.9}$ (μm)	Span factor
Boom carrying two flood jet nozzles (B1)						
40	1522	326.56	90.13	221.2	712.2	2.81
50	964	403.1	96.24	236.4	957.9	3.64
60	591	429.04	89.89	353.8	1123.1	2.92
Mean	1025	386.23	92.09	270.47	931.07	3.12
Boom carrying three flood jet nozzles (B2)						
40	1259	411.01	156.40	326.9	813.1	2.01
50	809	434.83	156.00	372.7	895.1	1.98
60	734	461.97	128.10	385.1	896.1	1.99
Mean	934	435.94	146.83	361.57	868.10	1.99
Boom carrying four flood jet nozzles (B3)						
40	607	571.43	202.60	504.2	1213.7	2.01
50	504	647.87	201.40	394.1	828.4	1.59
60	374	704.57	240.40	461.5	913.8	1.46
Mean	495	641.29	214.80	453.27	985.30	1.69

Table 4. Comparison of fan, hollow cone and flood jet nozzles on the basis of droplet spectrum

	FB1	HB1	JB1	FB1	HB1	JB1	FB1	HB1	JB1
Number of droplets	1387	1201	1025	1040	1220	934	911	880	495
Droplet diameter	347.6	413.9	386.2	395.5	391.7	435.9	426.7	506.4	641.3
$D_{V0.1}$	102.6	102.60	92.1	112.3	114.9	146.8	111.5	102.9	214.8
$D_{V0.5}$	260.5	282.03	270.5	281.9	280.9	361.6	286.6	314.0	453.3
$D_{V0.9}$	670.9	848.85	931.0	671.8	677.5	868.1	627.6	1143.4	985.3
Span factor	2.18	2.79	3.12	1.98	2.00	1.99	1.88	3.32	1.69

FB1, FB2, FB3 stands for fan nozzle with boom carrying two, three and four nozzles
HB1, HB2, HB3 stands for hollow cone nozzle with boom carrying two, three and four nozzles
JB1, JB2, JB3 stands for flood jet nozzle with boom carrying two, three and four nozzles

The values of $D_{V0.1}$ ranged from 90.0 to 127.0μm in all treatment combination which implies that ten percent of volume contribution was of size less than 127μm i.e., ten percent of spray volume which are in the form very small spray pattern are susceptible to the spray drift.

The $D_{V0.5}$ values of the spray produced by hollow cone type nozzle ranged from 201.1 to 357.3, 271.3 to 299.8 and 284.2 to 360.1μm representing medium spray for all three types boom i.e., boom carrying two, three and four nozzles respectively.

In terms of $D_{V0.9}$ no such general trend was observed however maximum value was obtained at the higher height of spraying i.e., 60 cm which might be due to increase in the size of droplets with the increase in the height of spraying. The span showed same trend as in case of fan nozzle i.e., The span factor or uniformity of spray was observed to be approaching to one with the increase in the height of spraying.

Droplet Spectrum of Flood Jet Nozzles

The effect on droplet spectrum of a flat fan nozzles with respect to change in height of spraying and number of the nozzles is given in table 3.

The number of droplets decreased significantly with the corresponding increase in mean diameter at the higher height of spraying. The $D_{V0.1}$ value in flood jet nozzle are comparably better than the flat fan and hollow cone nozzle. In case of boom carrying four flood jet nozzles the $D_{V0.1}$ values are higher than 200µm values which clearly depicts the flood jet nozzle have less spray drift. On the basis of $D_{V0.5}$, the values ranged from 221.2 to 461.5µm which lies in the large sized spray category which are mostly uniform in distribution. The span factor in the flood jet nozzle was found to be approaching to one with the increase in the height of spraying and the number of the nozzles on the boom.

Comparison of Agricultural nozzles on the basis of droplet spectrum

On comparing various droplet characteristics (Table 4) for the boom carrying two nozzles, the number of droplets and $D_{V0.1}$was found maximum for fan type nozzle with span factor near to one. The droplet diameter and $D_{V0.5}$ (VMD) was found maximum for hollow cone nozzle with two nozzles. In case of boom carrying three nozzles, the maximum droplet diameter, $D_{V0.1}$, $D_{V0.5}$ was found for flood jet nozzle with span factor of 1.99. Similar results were found for the boom carrying nozzle with the span factor 1.69.

CONCLUSION

As per the results obtained, it can be concluded the height of the spraying has a significant effect on the droplet spectrum of all three types of nozzles. The droplet diameter increases with the increase in the height of the spraying by merging of various droplets due to decrease in the pressure. The droplet diameter in all cases were found maximum in flood jet nozzles with minimum number of the droplets. Also, the span factor in flood jet nozzles was near to ideal value i.e., 1 for flood jet nozzles in all treatment combinations except that in boom carrying two nozzles. The study directs that the flood jet nozzles have an ideal droplet spectrum in terms of drift, uniformity etc. However, the wide range of application of flat fan and hollow cone nozzles like foliar application to the crops cannot be ignored.

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Natural enemy complex associated with insect pests of acid lime, *Citrus aurantifolia*

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ABSTARCT: A fixed plot survey was carried out at College of Agriculture, Vijayapura, Karnataka, India during November 2020 to June 2022 to record the natural enemy fauna associated with insect pests of acid lime, *Citrus aurantifolia* Swingle. During the study, a neuropteran predator green lacewing, *Chrysoperla zastrowi sillemi,* three species of coccinellids *viz., Cheilomenes sexmaculata* (F.), *Coccinella transversalis* F. and *Illeis cincta* (F.) and several species of spiders *viz., Carrhotus viduus* (Koch), *Telamonia dimidiate* (Simon), *Thyene imperialis* (Rossi), *Phintelloides* sp. *Phintella* sp. and *Telamonia* sp. were noticed to be associated with insect pests of acid lime. In addition, a braconid parasitoid, *Distatrix papilionis* was found parasitizing the larvae of citrus butterfly in acid lime orchards. The efforts can be made to utilize these identified natural enemies in biological control of insect pests of acid lime.

Keywords: Acid lime, natural enemy complex, green lacewings, coccinellids, spiders, *Distatrix papilionis,* parasitization, biological control

INTRODUCTION

Citrus fruits are third most important fruit crops after mango and banana. Globally, citrus fruits are grown over an area of 11.42 million ha with 179.0 million tonnes of production (Anonymous, 2020). Acid lime, *Citrus aurantiifolia* Swingle is one of the important citrus crops grown extensively in Karnataka. As many as 250 species of insect and mite pests have been reported to infest citrus plants in both the nurseries and orchards and inflicting heavy economic losses (Nayar *et al*., 1976; Butani, 1979; Shivashankar and Singh, 2005). The natural enemies such as predators, parasitoids and entomopathogenic organisms assume paramount importance in natural and human induced biological control programmes. Although different natural enemies reported in citrus ecosystem (Narayanamma *et al*., 2004; Deka *et al*., 2016; Kattebennuru, 2017), comprehensive information regarding the relationship between incidence of insect pests and natural enemies is lacking. Hence present study was carried out to identify the natural enemy complex associated and their relationship with insect pests of acid lime.

MATERIALS AND METHODS

A fixed plot survey was carried out at College of Agriculture, Vijayapura, Karnataka, India (16°49'39.1620" N 75°43'31.1772" E) to record the natural enemy complex associated with insect pests of acid lime. The population of different natural enemies were recorded at fortnightly interval starting from November 2020 to June 2022 to assess the seasonal fluctuation in population in relation to pest densities. The observations on incidence of insect pests and different natural enemies were recorded on ten randomly selected plants of three replications in the acid lime orchard. In case of parasitoid, *Distatrix papilionis* (Viereck), the larvae of citrus butterfly *Papilio demoleus* L. were collected from the field at fortnightly interval starting from November 2020 to June 2022. The collected larvae were observed for parasitoid emergence under laboratory condition, later per cent parasitization was worked out.

Correlation studies

The data on natural enemy population was correlated with insect pest populations that occurred on acid lime plants to know the relationship between same parameters by using SPSS statistical software. The extent of influence of insect pest population on natural enemies was studied by performing multiple linear regression using SPSS statistical software.

RESULTS AND DISCUSSION

Coccinellids: The coccinellids were the major insect predators found in acid lime ecosystem. During the study, three species of coccinellids *viz*., *Cheilomenes sexmaculata* (F.), *Coccinella transversalis* F. and *Illeis*

Table 1. Natural enemy complex associated with insect pests of acid lime, *Citrus aurantifolia*

Months		Green lacewings/ plant	Coccinellids/ shoot	Spiders/plant	Parasitization by *Distatrix papilionis* (%)
November 2020	I FN	0.51	0.65	1.20	32.00
	II FN	0.64	0.70	1.30	40.00
December 2020	I FN	0.73	0.60	1.35	33.33
	II FN	0.71	0.85	1.30	40.00
January 2021	I FN	0.84	1.20	1.43	33.33
	II FN	0.86	1.00	1.50	32.00
February 2021	I FN	0.81	1.10	1.50	35.00
	II FN	0.85	0.95	1.58	25.00
March 2021	I FN	0.86	1.10	1.50	13.33
	II FN	0.88	1.05	1.55	0.00
April 2021	I FN	0.96	0.90	1.65	0.00
	II FN	1.13	1.10	1.68	0.00
May 2021	I FN	0.80	1.00	1.50	0.00
	II FN	0.75	1.15	1.40	0.00
June 2021	I FN	0.93	0.90	1.10	0.00
	II FN	0.76	0.80	0.98	15.00
July 2021	I FN	0.71	0.80	1.20	20.00
	II FN	0.76	0.95	1.08	44.00
August 2021	I FN	0.61	1.00	1.05	40.00
	II FN	0.59	1.10	0.95	28.00
September 2021	I FN	0.48	0.85	0.88	30.00
	II FN	0.45	0.80	0.85	20.00
October 2021	I FN	0.56	0.65	0.60	33.33
	II FN	0.63	0.80	0.75	26.67
November 2021	I FN	0.58	0.75	1.28	30.00
	II FN	0.59	0.65	1.13	36.00
December 2021	I FN	0.66	0.65	1.33	44.00
	II FN	0.66	0.75	1.35	32.00
January 2022	I FN	0.85	0.90	1.40	28.00
	II FN	0.83	0.85	1.45	20.00
February 2022	I FN	0.78	1.15	1.40	25.00
	II FN	0.74	1.00	1.33	13.33
March 2022	I FN	0.83	1.30	1.40	20.00
	II FN	0.88	1.05	1.38	0.00
April 2022	I FN	0.99	1.00	1.35	0.00
	II FN	1.08	1.15	1.40	0.00
May 2022	I FN	0.75	1.00	0.93	0.00
	II FN	0.76	1.05	1.05	0.00
June 2022	I FN	0.78	0.80	1.03	13.33
	II FN	0.71	0.75	0.90	25.00

Table 2. Relationship between of population of natural enemies with pest density in acid lime ecosystem

Insect pests	Green lacewing	Coccinellid	Spiders
	Correlation co-efficient		
Citrus leaf miner	-0.215^{NS}	-0.142^{NS}	0.121^{NS}
Citrus butterfly	-0.581**	-0.565**	-0.197^{NS}
Citrus psyllids	0.540**	0.503**	0.119^{NS}
Blackflies	0.782**	0.456**	0.341**
Mealybug	0.480**	0.429**	0.659**
Aphids	0.774**	0.662**	0.522**
	Multiple linear regression equation		
Regression analysis	$Y=0.34+0.06X_1+0.02X_2+0.05X_3+0.02X_4+0.11X_5-0.03X_6$	$Y=0.48+0.03X_1-0.01X_2+0.01X_3+0.04X_4+0.03X_5+0.01X_6$	$Y=0.18+0.04X_1+0.04X_2+0.03X_3+0.03X_4+0.32X_5-0.03X_6$
	Coefficient of determination (R^2)		
	0.852	0.651	0.654

cincta (F.) were recorded in acid lime ecosystem. The average population of coccinellids ranged from 0.60 to 1.30 grub and adults per shoot. The maximum population of coccinellids was recorded during first fortnight of March 2022 (1.30) and minimum population was recorded during first fortnight of December 2020 (0.60). The correlation of population of coccinellids with different insect pests found on acid lime crop revealed significantly positive correlation with citrus psyllids (r=0.503**), blackflies (r=0.456**), mealybug (r=0.429**) and aphids (r=0.662**). Whereas, significant negative correlation with larval population of citrus butterfly (r=-0.565**). The multiple linear regression analysis indicated that population of different insect pests influenced the population dynamics of coccinellids to an extent of 65.10 per cent (Table 1).

Green lacewing, *Chrysoperla zastrowi* sillemi

The average population of green lacewings ranged from 0.45 to 1.13 grubs and adults per plant. The maximum population of green lacewing were recorded during second fortnight of April 2021 (1.13) and minimum population was recorded during first second fortnight of September 2021 (0.45). The correlation studies revealed that green lacewings had significantly positive correlation with citrus psyllids (r=0.540**), blackflies (r=0.782**), mealybug (r=0.480**) and aphids (r=0.774**). Whereas significant negative correlation with larval population of citrus butterfly (r=-0.581**). The multiple linear regression analysis indicated that population of different insect pests influenced the population dynamics of green lacewings to an extent of 85.20 per cent (Table 1).

Spiders

The spider fauna were major non-insect predators occurred in acid lime ecosystem. During the study spiders *viz*., *Carrhotus viduus* (Koch), *Telamonia dimidiate* (Simon), *Thyene imperialis* (Rossi), *Phintelloides* sp. *Phintella* sp. and *Telamonia* sp. were encountered in the experimental plot. The average population of spiders ranged from 0.60 to 1.68 spiders per plant. The maximum population of spiders noticed during second fortnight of April 2021 (1.68) and minimum population were observed during first fortnight of October 2020 (0.60).The correlation data revealed that spiders had significantly positive correlation with blackflies (r=0.341**), mealybug (r=0.659**) and aphids (r=0.522**). The multiple linear regression analysis indicated that population of different insect pests influenced the population dynamics of spiders to an extent of 65.40 per cent (Table 1).

The present findings on natural enemies recorded in acid lime ecosystem are supported by Deka *et al*., (2016) and Kattebennuru (2017) where they opined that coccinellids, green lacewings and spiders were the major predatory fauna found in citrus orchards. However, the species of natural enemy found in the current study differs compared to earlier reports.

Parasitization of citrus butterfly by *D. papilionis* on acid lime

An endo-larval parasitoid, *D. papilionis* (Braconidae: Hymenoptera) was found to parasitize citrus butterfly, *Papiliodemoleus* L. on acid lime. The parasitization of larval stage of citrus butterfly by *D. papilionis* ranged from 0.00 to 44.00 per cent. The peak per cent parasitization was recorded during second fortnight of July 2021 (44.00) and first fortnight of December 2021 (44.00) which was coincide with peak activity of pest. The overall data indicated 24.87 per cent parasitization of citrus butterfly larvae by *D. papilionis* (Table 1). Similarly, Narayanamma *et al*., (2004) found maximum rate of parasitization of citrus butterfly by *Apanteles*

Fig 1. ***Coccinella transversalis*** **F**

Fig 2. ***Cheilomenes sexmaculata*** **(F.)**

Fig 3. ***Illeis cincta*** **(F.)**

Fig. 4. ***Carrhotus viduus***

Fig. 5. ***Telamonia dimidiate***

Fig. 6. ***Thyene imperialis***

Fig. 7. ***Phintella*** **sp.**

Grubs

Pupae

Adult

Fig. 8. An endo-larval parasitoid, ***Distatrix papilionis*** **on citrus butterfly larvae**

papilionis during first fortnight of November to January and rate of parasitism was synchronised with the pest activity. Recently, Bhoje and Charaple (2020) opined that *A. papilionis* can be efficiently used in biological control of citrus butterfly.

The present study through a light on natural enemy complex associated with the insect pests of acid lime. The efforts can be made to encourage the activity of these natural enemies in acid lime ecosystem, at the same time efficiently utilized for biological control of insect pests of acid lime.

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Chinese citrus fly, *Bactrocera minax* (Enderlein) (Diptera: Tephritidae) in Sikkim: a study on its morphometrics

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ABSTRACT: A study on the morphology of adult Chinese citrus fly, *Bactrocera minax* was carried out on April 2023, at State Bio-control Lab, Agriculture Department, Gangtok, Sikkim. The mean body length of female recorded significantly higher, i.e. 11.28 ± 0.18mm, than male, i.e. 10.10 ± 0.25mm, with the mean difference of 1.17mm (p = ≤0.01). Female had a wider body (3.60 ± 0.06 mm) compared to male (3.09 ± 0.10 mm) (p = ≤0.01) which differed significantly by 0.51mm. Adult female possessed a wider wingspan, i.e. 23.30 ± 0.26mm significantly different than adult male, i.e. 22.25 ± 0.4mm with the mean difference of 1.04 mm (p = ≤0.01). Similarly the average wing length measured 8.65 ± 0.21mm in male and 10.26 ± 0.06 mm in female with the mean difference of 1.61mm. The ovipositor length recorded 4.00 ± 0.20 mm. This information is useful to distinguish between Chinese citrus fly and other fruit fly species of citrus orchards and useful in planning of the suitable management options.

Keywords: Adult, *Bactrocera minax*, fruit fly, morphometrics, Sikkim mandarin

INTRODUCTION

Mandarin orange (*Citrus reticulata* Blanco) a highly polyembryonic species belonging to family Rutaceae is the most common among Citrus fruits grown in India. It occupies nearly 50% of the total citrus area in India. Mandarin group includes all types of loose jacket oranges commonly called as Santra or mandarin such as Nagpur Santra, Coorg Santra, the Khasi Mandarin, Sikkim Mandarin etc. Sikkim Mandarin is a commercially desirable ecotype of mandarin group native to Sikkim. It is the most important traditional fruit of Sikkim and is similar to Nepal or Assam or Darjeeling or Khasi mandarin. Insect pests are one of the major constraints for increasing the production and productivity of crops.

A large number of insect pests attack mandarin right from immature fruiting stage and continue till harvest of the fruit. Among them, Chinese citrus fly *Bactrocera minax* (Enderlein) (Diptera: Tephritidae) is a major pest causing both qualitative and quantitative loss. The Chinese citrus fly is a major citricultural pest species in China, Bhutan, India and Nepal (Adhikari *et al*., 2020; Chauhan *et al*., 2020; Dong *et al*., 2014; White and Wang, 1992). It had been reported to be well distributed to a wide range of temperate regions of Asia, including Nepal, Bhutan, China and India (West Bengal and Sikkim) (Fan *et al.,* 1994, Dorji *et al.,* 2006, Drew *et al.,* 2006; Jha *et al.,* 2019). The size of adults and other stages of *B. minax* is larger than other fruit fly species like *Bactrocera dorsalis* (Hendel), *B. zonata* (Saunders), *Zeugodacus cucurbitae* (Coquillett) etc., they are oligophagus in food habit, univoltine in life cycle and is never attracted to para-pheromones like other common frugivorous Bactrocera species (Adhikari *et al*., 2020; Adhikari and Joshi, 2018; Xia *et al*., 2018). Therefore, this is a unique fruit fly species among horticultural pests.

Evidence suggests that this species has originated in the high temperate Southern Yunnan Guizhou Plateau and dispersed through China's waterways system (Xia *et al*., 2018). Because of its flying capacity to great distances, this insect has made its way from China through Bhutan, Sikkim, India and extended to citrus orchards in the eastern middle mountain regime of Nepal (Adhikari *et al*., 2022b). Biology and behavior including morphological traits of fruit fly species are highly affected by climate factors (Dominiak *et al*., 2006). The female fruit flies puncture the peel and lay eggs into the soft and tender fruits (Zhang 2007). Maggots feed inside the developing fruits causing rapid decay, which later becomes inedible and finally dropped prematurely (Wang *et al*, 2009).

The maggots of *B. minax* were found escaped out of the fruits while attached to the tree and pupate in the soil. The lifecycle of this species is reported to be one of the longest amongst *Bactocera* spp. (Adhikari *et al*., 2021; Li *et al*., 2019). Effective management of this dreaded pest is very much difficult due to its concealed feeding habit and typical life history.

The farmers of Sikkim (a Himalayan state of India), practices organic farming system, as the entire state is organically certified following all the guidelines of NPOP (National Programme of Organic Farming). Due to complete ban on synthetic pesticides, there has been upsurge in the many pests, including the fruit fly population. Over the last 5-6 years, fruit drop in *C. reticulata* due to infestation of fruit fly is also increased with damage extent ranging from 50-70%. So far, *B. minax* is not reported to be the major pest for causing the fruit drop in the state of Sikkim. Recommended management practices like use of methyl eugenol trap, dumping of fallen fruits and orchard sanitation have been practiced by the farmers for management of fruit drop, considering the species of Bactrocera. However, the *B. minax* cannot be managed by the above practices. Due to lack of in depth knowledge on the characteristics of *B. minax*, and the identification of the pest there is high implication on the management practices.

Keeping in view the facts, present investigation is envisaged to study the morphological traits/characteristics of Chinese citrus fly, *Bactrocera minax* which will help in field diagnosis to differentiate it from the other fruit fly species of citrus orchards and in turn, it will be useful in planning of the suitable management options.

MATERIALS AND METHODS

The present study was conducted during 2022-23 at State Bio-control Lab, IPM, Agriculture Department, Gangtok, Sikkim, India (27.310576 Latitude and 88.597589 Longitude). Citrus fruit drop led by Chinese citrus fly infestation was reported from Beng-Bhirkuna, Khamdong, East Sikkim (27.26º N Latitude, 88.48º E Longitude, Altitude 1148 meters) and infested fruits of Sikkim mandarin (Local cultivar) were collected from the orchard during the last week of November, 2022. The collected samples were then brought to the laboratory. Then the collected samples were carefully opened and maggots were taken out from the infested fruits. Maggots were then reared (n=100) in room condition (average temperature 9-10° C and relative humidity 90%) at IPM Lab. Maggots were then placed in glass jar filled with soil upto the height of 5cm height and mouth of glass jar was tightened with muslin cloth and rubber band to prevent the escape of maggots and maggots were replicated 10 times. Fully mature larvae transformed into pupae within one month and pupae were counted by gentle stirring the soil and placed in the same glass jar and covered with muslin cloth and partially filled with moist sand. Emergence of adult were also recorded. Adults emerged after four-five months and ten numbers of randomly selected freshly emerged adults were taken for study of major morphometrics parameters like length and breadth of adult flies, wingspan, length of wing and ovipositor on May, 2023 at IPM Lab, Tadong and others were preserved as specimen in the laboratory. Ten replicates of each parameter were measured and recorded.

Measurement of adult flies

Calibrated digital Vernier Caliper (Serial No: B22036450, Model No. CD-8”ASX) was used to measure body length, breadth, wingspan and length of wing of both male and female individually, and female fly ovipositor. The breadth of adult fly was recorded measuring the mesothorax portion. Apical tip to tip of forewings including the thorax was measured to compute wingspan, length of wing was calculated from joint part of the wing to apical tip of the wing. Similarly, the length of ovipositor was measured from joint portion at abdomen to the tip of the ovipositor (Roccia *et al*., 2013). In addition to the above parameters, body shape and color were also recorded. Statistical Analysis was done by using SAS Software to study the mean comparison of

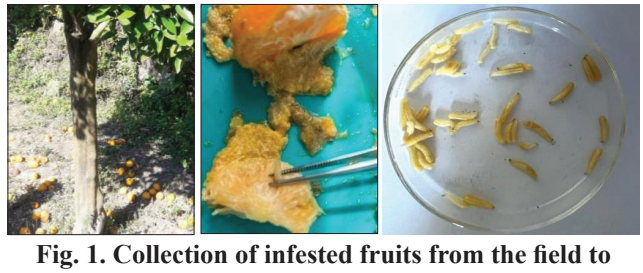

Fig. 1. Collection of infested fruits from the field to study the life cycle of *B. minax*

Table 1. Body length and breadth of adult *B. minax*

Sex	Length (mm)		Breadth (mm)	
	Range	Mean ± SE	Range	Mean ± SE
Male (n = 25)	9.44 -11.65	10.10 ± 0.25	2.66-3.56	3.09 ± 0.10
Female (n = 25)	10.34 -11.88	11.28 ± 0.18	3.32-3.96	3.60 ± 0.06

Table 2. Wingspan and length of adult *B. minax*

Sex	Wingspan (mm)		Length of wing (mm)	
	Range	Mean ± SE	Range	Mean ± SE
Male (n = 25)	20.54 -23.98	22.25 ± 0.40	7.93 – 9.88	8.65 ± 0.21
Female (n = 25)	21.59-24.12	23.30 ± 0.26	9.87 – 10.53	10.26 ± 0.06

body size (length and breadth) and wing length and wing span of the adult male and female.

RESULTS AND DISCUSSIONS

Body size of *B. minax*

The Chinese citrus fly, *B. minax* is the largest one among horticultural fruit fly pests (Xia *et al*., 2018) and other Bactrocera species. The length of body of adult male ranged from 9.44 mm to 11.65 mm; with a mean of 10.10 ± 0.25 mm (Table 1) whereas the average body length of an adult female fly was recorded to the tune of 11.28 ± 0.18 mm, with a range of 10.34 to 11.88 mm. The body length of male and female adult flies was significantly different, (mean difference =1.17mm, t Value = 3.72, p =≤0.01).

The adult female fly has a wider body width, i.e. 3.60 ± 0.06 mm (ranging from 3.32 to 3.96 mm) significantly different than adult male fly, measuring 3.09 ± 0.10 mm (ranging from 2.66 to 3.56 mm) (Table 1). The matured male and female flies significantly varied in breadth (mean difference = 0.51mm, t Value = 4.09, p=≤0.01). Whereas, Adhikari *et al*., 2022a measured bigger body size viz. body length of male (12.52 mm) and female (14.20 mm), and width of body 3.30 mm and 3.90 mm of male and female respectively in Nepal. The difference in locality and the type of citrus fruit they consumed might have been the reason for variation in body size of same species of fruit fly.

Wingspan and wing length of adult *B. minax*

The adult female has a larger wingspan (23.30 ± 0.26 mm) ranging from 21.59 mm to 24.12 mm which is significantly different from adult male fly (22.25 ± 0.40 mm) ranging 20.54 mm to 23.98 mm (Table 2). The wingspan of adult flies differed between male and female, (mean difference = 1.04mm, t Value = 2.16, p=≤0.01). The adult female fly wings measured 10.26 ± 0.06 mm long, ranging from 9.87 mm to 10.53 mm, compared to male, which measured 8.65 ± 0.21mm, ranging from 7.93 mm to 9.88 mm. The mean difference was 1.61mm in this case. In general, the wing length of different fruit fly species varies from 2 to 8 millimetres (White, 1988; Drew, 1979).

Table 3. Length of ovipositor of *B. minax*

Length of ovipositor (mm) (n = 10)	
Range	Mean ± SE
3.07-4.87	4.00 ± 0.20

Length of ovipositor of adult *B. minax*

The ovipositor length of female varied from 3.07 mm to 4.87 mm, with an average of 4.00 ±0.20 mm (Table 3). Adhikari *et al*., 2022a reported that the average length of ovipositor of female *B. minax* approximately 4.52 mm.

Shape and color of *B. minax*

Adult *B. minax* is clearly different from other species of Bactrocera. Face fulvous with elongate black spot on each furrow. It has an elongate oval and petiolate abdomen which is bigger sized (larger Dacus

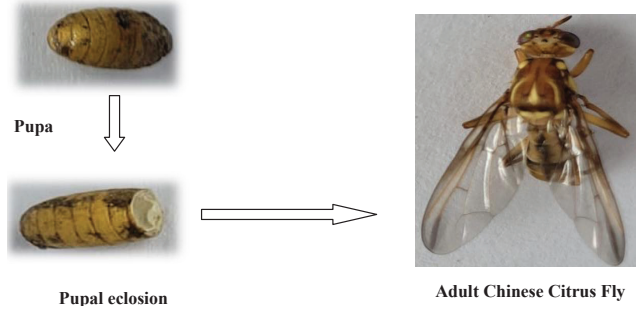

Fig. 2. Adult emergence from pupa

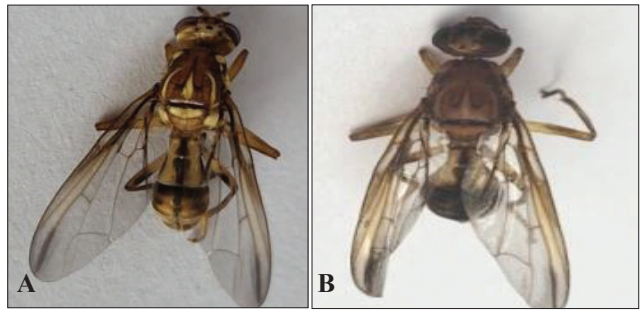

Fig. 3. Adults of *B. minax* (A: Male, B : Female)

like) species among other horticultural pest species of *Bactrocera.* The body of adult fly is red-brown in color which has yellow colored lateral and medial vittae and distinct T-pattern on the abdomen as well as broad costal band well overlapping R 4+5 with a dark spot at the apex of wing (Fig. 3). This fly is brownish in color with yellow markings, with a black band along the outer border of their wings, and a wasp-like look (Chen and Xie, 1955). Drew *et al*., 2007 described a morphological description of the adult Chinese citrus fly, noting that the fly is likely the biggest of all Bactrocera species. Ecological situation may be a key factor that influence in the morphological characteristics such as body shape and size of fruit flies within the species (Zhou, 2020). The larval diet and nutritional content are thought to be the most critical variables determining juvenile growth and eventual adult body size. In fruit flies, body size is an indication of fitness, with larger males and females having higher mating success and egg production, respectively (Newman *et al*., 2021).

CONCLUSION

It was observed that *B. minax* has sexual dimorphism in body size. The body length (10.10 ±0.25 mm and 11.28 ± 0.18 mm), breadth (3.09 ± 0.10 mm and 3.60 ± 0.06 mm) and wingspan (22.25 ± 0.4 mm and 23.30 ± 0.26 mm) and length of wing (8.65 ± 0.21 mm and 10.26 ± 0.06 mm), respectively of male and female Chinese citrus fly. The length of ovipositor was measured 4.00 ± 0.20 mm in this study. Sikkim's farmers call the fruit fly as "KANCHI KIRA," which is a local term for smaller insects. The Chinese citrus fly is larger than other fruit fly species as far as size concerned. However "JETHI KIRA" would be an ideal local name of this fruit fly, which will also illustrate its behaviour, including its univoltine life cycle and oligophagous nature. This fruit fly is not attracted to parapheromone lure traps.

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Studies on biology and host preference of South American Leaf Miner, *Phthorimaea absoluta* Meyrick (Lepidoptera: Gelechiidae)

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ABSTRACT: The invasive South American Leaf miner, *Phthorimaea* (=*Tuta*) *absoluta* Meyrick (Lepidoptera: Gelechiidae) is now getting a status of key pest in India. Biology studies carried out on tomato revealed that the *P. absoluta* had four larval instars. The total life cycle of *P. absoluta* lasted for 20.62 ± 0.66 days with an egg, larval and pupal periods of 2.54 ± 0.15, 9.54 ± 0.31 days and 8.54 ± 0.20 days, respectively. The longevity of female (40.00 ± 0.49 days) was found longer than the males which lasted for 36.45 ± 0.21 days. The biology studies carried out at different temperature conditions revealed the lowest egg (3.00 ± 0.24), larval (10.00 ± 0.27), pupal (9.00 ± 0.27) period, high fecundity (211.00 ± 2.54/female), highest female (40.00 ± 0.49) and male (36.45 ± 0.21) longevity at 30ºC. Studies on the spatial distribution of eggs by *P. absoluta* revealed that the *P. absoluta* adults mostly preferred to lay the eggs on upper leaf surface (6.07 eggs) followed by lower surface of leaves (5.79 eggs). Ovipositional preference studies on different solanaceous crops *viz.,* tomato, brinjal, potato, chilli and European black nightshade revealed that the adults of *P. absoluta* highly preferred tomato (233.70 and 326.00 eggs plant^{-1}) followed by potato (95.90 and 143.20 eggs plant^{-1}) both under free and no choice conditions, respectively. Biology of *P. absoluta* on other solanaceous crops revealed that the total life cycle was the shortest on tomato (22.00 ± 0.61) followed by European black nightshade (27.75 ± 0.84 days). However, no eggs hatched on chilli.

Key words: *Phthorimaea absoluta,* solanaceous crops, biology, host preference, spatial distribution

INTRODUCTION

The South American leaf miner, *Phthorimaea* (=*Tuta*) *absoluta* (Meyrick) (Lepidoptera: Gelechiidae), a key pest of tomato and native to the western part of South America, recently invaded India. It was initially observed in polyhouse and field grown tomato in Pune during 2014 (Shashank *et al.,* 2015) and at Indian Institute of Horticultural Research (IIHR), Bengaluru (13°8.12"N 77°29.45"E, altitude 890 m), Karnataka, India during the *rabi* season, 2014. It was also reported that the yield loss due to *P. absoluta* was 87 per cent in Shivakote, Karnataka (Sridhar *et al.,* 2014) and 14.4 to 97.9 per cent at Vegetable Research Station, Rajendranagar, Telangana (Kumari *et al.,* 2015) and is now getting a status of key pest in Tamil Nadu, India. *Phthorimaea absoluta* is a neotropical, oligophagous pest infesting many solanaceous crops. It mostly prefers tomato, but it can also feed, develop and reproduce on other cultivated solanaceous crops such as eggplant (*Solanum melongena* L.), potato (*S. tuberosum* L.) sweet pepper (*Capsicum annuum* L.), sweet cucumber (*S. muricatum* AiP.) and tobacco, *Nicotiana tabacum* L. (EPPO, 2005) as well as on non-cultivated solanaceous crops *viz., S. nigrum* L., *S. eleagnifolium* L., *S. bonariense* L., *S. sisymbriifolium* Lam., *S. saponaceum*, *Lycopersicum puberulum* Ph., *Lycopersicon hirsutum* (C.H.Mull.) Luckwill, *S. lyratum* Thunb, *S. nigrum*, *S. puberulum* NutP., *N. glauca*, Aubergine, *Datura ferox* L., *D. stramonium* L., *N. glauca* Grahamandon alfalfa, *Medicago sativa* L.*,* (Tosevski *et al.,* 2011).

In Europe, it was also reported in a Sicilian green-house of Cape gooseberry (*Physalis peruviana* L.) (Garzia *et al.,* 2009) and in Italy it was reported on *Lycium* sp. and *Malva* sp. which indicates that the *P. absoluta* shows a high propensity to use various plants as secondary hosts, notably species within the family Solanaceae. Ogur *et al.* (2014) also reported that *P. absoluta* mostly preferred tomato, but it also developed and reproduced on leaves of the weed, *Chenopodium album* L. and this paved way for its continuous existence in the absence of tomato.

Application of chemical insecticides is the most commonly recommended practice for the suppression of *P. absoluta*. Chemicals may provide sufficient control, but extensive use of these insecticides may lead to

Table 1. Biology of *P. absoluta* on tomato at ambient temperature

Stage	Period (in days ± SE)[#]
Egg	2.54±0.15
Larval period	
1st instar	1.74±0.11
2nd instar	2.20±0.10
3rd instar	2.47±0.03
4th instar	3.07±0.07
Total larval period	9.54±0.31
Pupal period	8.54±0.20
Adult longevity	
Male	36.45±0.21
Female	40.00±0.49
Total life cycle of *P. absoluta*	20.62±0.66
Total life span of *P. absoluta*	60.62±1.15

[#] Mean of twelve replications

development of resistance, as previously reported in South America (Lietti *et al.,* 2005). Hence, the study on the bioecology and host preference of this new invasive pest is the need of the hour to provide information for its ecofriendly managemenP. Keeping this in view, the present investigations were carried out on the bioecology and host preferences of *P. absoluta.*

MATERIALS AND METHODS

Culturing of *P. absoluta*

The population of *P. absoluta* required for the laboratory experiments were mass cultured in the Insectary, Department of Agricultural Entomology, Tamil Nadu Agricultural University (TNAU), Coimbatore. Mined leaves with *P. absoluta* larvae collected from tomato fields were kept in plastic trays (60 x 45 x 15 cm) lined with filter paper. When the leaves were fully mined fresh tomato leaves were provided for the larvae until pupation.

The pupae collected from the tray were placed in a Petri dish and kept in adult emergence cage (60 x 60 x 60 cm). Newly emerged adults were provided with ten per cent sugar solution fortified with multivitamin (ABDEC®) in 5 ml glass vial with cotton swab to prevent moths from drowning. Twenty days old tomato seedlings grown in 10 x 10 x 10 cm pro-tray were kept in the adult emergence cage for oviposition. Fresh seedlings were provided on every 24 h until the completion of oviposition by the adults. The seedlings with eggs were kept in separate cages and observed for hatching. The larvae thus hatched were maintained by providing fresh seedlings as and when needed and the culture was maintained continuously. Freshly emerged adults from these cultures were utilized for various experiments outlined below.

Experimental design for the bioecology studies

To study the biology of *P. absoluta*, a freshly mated adult female was released individually on to twelve tomato seedlings (20 days old) kept in separate cages (30 x 30 x 30 cm). Twenty four hours after release, the seedlings with fresh eggs were taken and observed under stereo zoom microscope (Model: MZ16). Single egg was left and the remaining was brushed off from each seedling and kept separately in individual cages (30 x 30 x 30 cm). Observations on egg incubation, larval (different instars), pupal period and total life cycle were recorded periodically. The temperature and the RH prevailed during the study period ranged from 28 to 32°C and 65 to 88 %.

Biology of *P. absoluta* was also studied at different temperature conditions *viz.,* 20°C (80% RH), 25°C (75% RH), 30°C (60% RH) and 35°C (50% RH) to find out the optimum temperature for its growth and developmenP. The experiment was conducted in completely randomized design (CRD) with twelve replications. For each temperature conditions, 12 eggs each representing one replication were used and the observations on egg incubation, larval, pupal period and total life cycle were recorded periodically.

Spatial distribution of *P. absoluta* eggs on tomato

Experiment was also carried out to study the spatial distribution of eggs within the tomato plant by the *P. absoluta* adulP. Twelve (45 days old) tomato plants grown in tubular mud pots (15 x 10 x 10 cm) each representing one replication were used for the study. The plants were kept in separate cages and freshly mated female was released into each cages. After 24 h of egg laying the number of eggs in upper and lower surface of leaves, stem, buds and calyx were counted and the spatial preference for egg laying by the adults were worked ouP.

Table 2. Biology of tomato leaf miner, *P. absoluta* at different temperature conditions

Temperature	Days ± SE[#]					
	Egg period	Larval period	Pupal period	Total life cycle	Male adult longevity	Female adult longevity
20°C	5.50±0.15	15.75±0.32	14.00±0.24	35.25±0.71	23.00±0.25	26.50±0.19
25°C	4.75±0.35	14.75±0.13	10.50±0.18	30.00±0.66	26.50±0.21	29.50±0.39
30°C	3.00±0.24	10.00±0.27	9.00±0.27	21.00±0.78	36.45±0.21	40.00±0.49
35°C	2.75±0.13	10.00±0.24	10.75±0.28	23.50±0.65	28.75±0.18	31.50±0.19

[#] Mean of twelve replications

Ovipositional preference and biology of *P. absoluta* on selected solanaceous crops

Five solanaceous hosts *viz.,* tomato (*Solanum lycopersicum*), brinjal (*S. melongena)*, potato (*S. tuberosum),* chilli *(Capsicum annum*) and European black nightshade (*S. nigrum)* was used to study the ovipositional preference of *P. absoluta.* The host plants were grown in mud pots (30 x 30 x 30 cm) at Insectary, Department of Agricultural Entomology, TNAU, Coimbatore. Single leaf of brinjal and compound leaves of other four host crops were kept separately in a glass vial with water and secured with cotton. The vials were randomly arranged in a circular manner inside a (60 × 60 × 60 cm) rearing cage (Fekri *et al.,* 2013). Ten pairs of freshly emerged adults were released at the centre of the cage. Adults were provided with ten per cent sugar solution fortified with multivitamin (ABDEC®) in 5 ml glass vial with cotton swab to prevent moths from drowning. The host leaves were changed daily until the completion of oviposition period of seven days. The number of eggs laid in each hosts were counted daily and the total number of eggs laid per host were worked out with the help of stereo zoom microscope (10x). The experiment was conducted in CRD with five replications. Similar procedure was also followed for no choice tesP. Instead of five host crops, each crop was kept separately in individual cages and the number of eggs laid per host crop was assessed daily until the completion of oviposition period of seven days and the total number of eggs laid per host was worked ouP. The experiment was conducted in CRD with five replications.

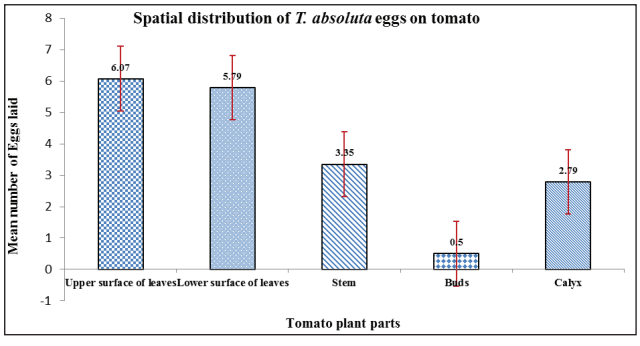

Fig. 1 Spatial distribution of eggs by *P. absoluta* on tomato

To study the biology of *P. absoluta* on different solanaceous crops *viz.,* brinjal, potato,, chilli, and European black nightshade, freshly mated adult female was released individually on to twelve seedlings of each hosts kept in separate cages (30 x 30 x 30 cm). Twenty four hours after release, the seedlings with fresh eggs were taken and observed under stereo zoom microscope (Model: MZ16). Single egg was left and the remaining was brushed off from each seedling and kept separately in individual cages (30 x 30 x 30 cm). Tomato, the most preferred crop was also included along with other host crops for comparison of biology. The experiment was conducted in CRD with twelve replications. Observations on egg incubation, larval, pupal period and total life cycle were recorded periodically. The temperature and the RH prevailed during the study period ranged from 28 to 32°C and 65 to 88 per cent.

Data analysis

The data obtained in percentages from various experiments were transformed to square root (X+0.5). The analysis of variance for different experiments were carried out in AGRES and the means were separated by least significant difference (LSD) available in the package.

RESULTS AND DISCUSSION

Knowledge on the bioecology of insect pests is the pre-requisite for evaluating methods compatible with Integrated Pest Management. The research works carried out on the biology of *P. absoluta* under different temperature conditions and host crops were scanty. In view of limited availability of information, the present

Table 3. Ovipositional preference of *P. absoluta* under free choice condition

Crop	No. of eggs laid plant^{-1} (DAR*)#							Total no. of eggs laid plant^{-1}
	1	2	3	4	5	6	7	
Tomato *(S. esculentum)*	22.10 (4.70)^{a}	28.90 (5.38)^{a}	45.50 (6.75)^{a}	34.30 (5.86)^{a}	36.90 (6.07)^{a}	33.30 (5.77)^{a}	32.70 (5.72)^{a}	233.70 (15.29)^{a}
Brinjal (*S. melangena)*	1.50 (1.22)^{b}	2.50 (1.58)^{b}	7.10 (2.66)^{bc}	4.90 (2.21) ^{bc}	6.90 (2.63)^{b}	1.50 (1.22)^{b}	2.10 (1.45)^{b}	26.50 (5.15)^{cd}
Potato (*S. tuberosum)*	14.50 (3.81)^{a}	15.90 (3.99)^{a}	16.10 (4.01)^{b}	14.50 (3.81) ^{ab}	16.10 (4.01)^{ab}	12.10 (3.48) ^{ab}	6.70 (2.59)^{b}	95.90 (9.79)^{b}
Chilli (*C. annum)*	0.50 (0.71)^{b}	0.50 (0.71)^{b}	0.80 (0.89)^{c}	0.50 (0.71)^{c}	1.80 (1.34)^{b}	1.70 (1.30)^{b}	0.80 (0.89)^{b}	6.60 (2.57)^{d}
European black nightshade (*S. nigrum)*	2.70 (1.64)^{b}	2.70 (1.64)^{b}	3.90 (1.97)^{c}	7.10 (2.66)^{b}	11.50 (3.39)^{b}	6.1 (2.47)^{b}	5.30 (2.30)^{b}	39.30 (6.27)^{c}
SE (d)	0.62	0.70	0.86	0.82	1.05	1.29	1.10	1.33
CD (0.05)	1.30	1.48	1.80	1.71	2.19	2.75	2.29	2.77

* Days after release
# Mean of five replications
Figures in the parentheses are $\sqrt{x+0.5}$ transformed values
Means followed by the common letter (s) are not significantly different at P=0.05 level by LSD

Table 4. Ovipositional preference of *P. absoluta* under no choice condition

Host plant	No. of eggs laid plant^{-1} (DAR*)#							Total no. of eggs laid plant^{-1}
	1	2	3	4	5	6	7	
Tomato *(S. esculentum)*	60.20 (7.76)^{a}	51.40 (7.17)^{a}	45.80 (6.77)^{a}	44.00 (6.63)^{a}	60.80 (7.80)^{a}	39.40 (6.28)^{a}	24.40 (7.80)^{a}	326.00 (18.06)^{a}
Brinjal (*S. melangena)*	11.60 (3.41)^{c}	14.80 (3.85)^{bc}	12.20 (3.49)^{c}	10.20 (3.19)^{bc}	10.60 (3.26)^{c}	10.40 (3.22)^{bc}	8.20 (2.86)^{b}	78.00 (7.71)^{c}
Potato (*S. tuberosum)*	20.40 (4.52)^{b}	28.80 (5.37)^{ab}	26.40 (5.14)^{b}	21.80 (4.67)^{ab}	23.20 (4.82)^{b}	13.60 (3.69)^{b}	9.00 (3.00)^{b}	143.20 (11.97)^{b}
Chilli (*C. annum)*	1.00 (1.00)^{d}	1.20 (1.10)^{d}	1.00 (1.00)^{d}	1.20 (1.10)^{d}	1.20 (1.10)^{d}	1.20 (1.10)^{d}	1.20 (1.10)^{d}	8.00 (2.83)^{e}
European black nightshade (*S. nigrum)*	2.60 (1.61)^{d}	3.40 (1.84)^{cd}	8.80 (2.97)^{c}	9.00 (3.00)^{ab}	9.60 (3.10)^{c}	6.80 (2.61)^{c}	3.20 (1.79)^{d}	43.40 (6.59)^{d}
SE (d)	0.65	0.96	0.61	0.75	0.68	0.40	0.38	0.59
CD (0.05)	1.35	2.00	1.27	1.57	1.42	0.84	0.78	1.23

* Days after release
# Mean of five replications
Figures in the parentheses are $\sqrt{x+0.5}$ transformed values
Means followed by the common letter (s) are not significantly different at P=0.05 level by LSD

Table 5. Life cycle of *P. absoluta* on other solanaceous hosts

Host plant	Developmental period (in days ± SE)[#]			
	Egg	Larva	Pupa	Total life cycle
Brinjal (*S. melangena)*	5.50±0.15	14.75±0.13	9.75±0.13	30.00±0.41
Potato (*S. tuberosum)*	4.00±0.24	11.75±0.35	12.75±0.13	28.50±0.72
Chilli (*C. annum)*	No egg hatching	-	-	-
European black nightshade (*S. nigrum)*	3.50±0.15	12.50±0.34	11.75±0.35	27.75±0.84
Tomato (*S. esculentum*)	3.25±0.22	10.25±0.28	9.25±0.26	22.00±0.61

[#] Mean of twelve replications

study was carried out and the results obtained were discussed with the available literatures.

Biology of *P. absoluta* on tomato

The female *P. absoluta* laid the eggs singly on both upper and lower surface of leaves, stems, calyx and buds. The eggs were small, oblong or oval, microscopic, light yellow or creamy in colour. The incubation period of an egg lasted for 2.54 ± 0.15 days (Table 1) which is in agreement with the findings of Estay (2000) who documented an incubation period of 3.90±0.91 days. *Phthorimaea absoluta* had four larval instars, of which, the first and second instars were white or cream with a black head with a developmental period of 1.74 ± 0.11 days and 2.20 ± 0.10 days, respectively. Third and fourth instars turned greenish to pink with a brown head with a pale prothoracic shield and the larval period lasted for 2.47 ± 0.03 days and 3.07 ± 0.07 days, respectively and the total larval period lasted for 9.54 ± 0.31 days (Table 1). Estay (2000) also documented four well-defined larval instars with different size and colour in *P. absoluta*. The present finding was also in accordance with Erdogan and Babaroglu (2014) who reported four larval instars with a developmental period of 2.49 ± 0.09, 2.32 ± 0.07, 2.57 ± 0.07 and 3.79 ± 019 days, respectively with a total larval period of 10.97 days.

Newly formed pupae were greenish and turned to dark brown as they mature which was in line with the reports of Estay (2000). The present observation on the pupal period (8.54 ± 0.20 days) was in consonance with Erdogan and Babaroglu (2014) who observed mean pupal period of 9.53±0.25 days.

The mean longevity of female (40.00 ± 0.49 days) was found to be longer than the males (36.45 ± 0.21 days). Estay (2000) also reported similar results, however, he reported comparatively less longevity of 10 to 15 days for females and 6 to 7 days for males which is in contrary with our results. The variation in the duration observed in the present study may be attributed to the geographical variation in the population.

In the present investigation, the total life cycle of *P. absoluta* lasted for 20.62 ± 0.66 days on tomato. This corroborates with the results of Barrientos *et al.* (1998) who reported a total life cycle of 23.8 days for *P. absoluta* on tomato.

Biology of *P. absoluta* on tomato plants at different temperature indicated a profound impact on the biology. Among the temperatures studied, the life cycle was shortest (21.00 ± 0.78) at 30°C and this was in close agreement with Attwa *et al.* (2015) who reported the life cycle of *P. absoluta* as 24.1 ± 1.1 days at 28°C. The total life cycle was observed to be 4.75 30.00 ± 0.66 days at 25°C. This was in close agreement with the findings of Erdogan and Babaroglu (2014) who reported the total life cycle of 30.18 ± 1.70 days at 25°C.

The life cycle of *P. absoluta* was determined as 35.25 ± 0.71 days at 20°C which was in agreement with the findings of Barrientos *et al.* (1998) and Cuthbertson *et al.* (2013) who reported the developmental period of 39.8 and 37 days, respectively at 19°C. The total life cycle of *P. absoluta* was longest at lowest temperature and shortest at 30°C on tomato plants. It may be due to the reason that the physiological age of insects increase more slowly at lower temperatures (Table 2).

Spatial distribution of *P. absoluta* eggs on tomato

Phthorimaea absoluta adults preferred to lay eggs on upper leaf surface (6.07 eggs) followed by lower surface of leaves (5.79 eggs) and least preferred to lay eggs on buds (0.50 eggs) (Fig. 1). This was in close agreement with Estay (2000) who reported that the *P. absoluta*

females oviposited preferentially on leaves (73%) and to lesser extent on leaf veins and stem margins (21%), sepals (5%) or green fruits (1%).

The preference for oviposition by females may be determined by the volatiles released from host crops. Ovipositional preference studies carried out with different solanaceous crops *viz*., tomato, brinjal, potato, European nightshade and chilli both under free and no choice conditions revealed that the tomato was the most preferred host followed by potato. This was in accordance with the reports of Visser (2015) who reported that the *P. absoluta* preferred potato equal that of tomato for feeding. Several other workers have also documented many solanaceous crops as host for *P. absoluta* (Galarza, 1984 and EPPO, 2005). The variation in host preferences may be attributed to the biophysical and biochemical characters of the plants.

Ovipositional preference and biology of *P. absoluta* on selected solanaceous crops

Ovipositional preference of *P. absoluta* studied under free choice condition revealed that the *P. absoluta* adults could lay eggs in all the host crops. However, the total number of eggs (233.70 eggs plant^{-1}) laid per plant was maximum in tomato followed by potato, European black nightshade and brinjal which recorded 95.90, 39.30 and 26.50 eggs plant^{-1}, respectively. Chilli was found to be the least preferred host with 6.60 eggs plant^{-1} (Table 3).

Studies under no choice condition also revealed that the tomato was the most preferred host (326.00 eggs plant^{-1}) followed by potato, brinjal and European black nightshade. Chilli was the least preferred host with 8.00 eggs plant^{-1} (Table 4).

Among the hosts, tomato was the most preferred host and recorded shortest developmental period of 22.00±0.61 days followed by European black nightshade (27.75 ± 0.84 days), potato (28.50 ± 0.72 days) and brinjal (30.00 ± 0.41 days). However, not even a single eggs were hatched on chilli and hence, the biology could not be studied (Table 5).

Overall the biology of *P. absoluta* studied on other solanaceous crops *viz.,* brinjal, potato, chilli and European black nightshade in comparison with tomato revealed the shortest life cycle on tomato followed by European black nightshade, potato and brinjal. No such studies were reported earlier about the biology of *P. absoluta* on above mentioned solanaceous crops. Hence, this may be the first report on the biology of *P. absoluta* on other solanaceous crops.

Comparison of biology of *P. absoluta* on tomato and other solanaceous crops revealed the suitability of tomato over other hosts studied. Host preferences showed a strong heritable component and are found to represent the suitability of hosts for larval survival. Suitability can depend upon a number of factors such as nutritional quality, host plant defence chemicals, prevalence of natural enemies or microenvironment. However, completion of life cycle with minimum variation in the developmental days in the present finding may be due to the learning process which is gradual in insects and is reversible on encountering other most abundant host species. Further, studies on the biochemical or biophysical attributes of chilli that prevents the development of *P. absoluta* may render prospective results for resistance breeding and its sustainable management.

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Effect of host species and host age on the reproductive performance and morphometrics of progenies of parasitoid, *Tetrastichus howardi* (Olliff)

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ABSTRACT: Laboratory investigations were undertaken at the Department of Studies in Sericulture Science, University of Mysore, Manasagangotri, Mysuru, to understand the effects of host species and host age on the reproductive performance and morphometric characteristics of progenies of an indigenous endo-pupal parasitoid, *Tetrastichus howardi* (Olliff) (Hymenoptera: Eulophidae). The parasitoid developmental durations were significantly longer in younger pupae of *S. litura* and older pupae of *S. frugiperda.* The mean values for progeny production were superior when the parasitoid developed in younger host when compared with older host of both the species. The longevity values for the progeny females did not differ when developed in pupae of both the ages of the hosts. Regarding morphometric parameters of the progeny males and females resulted from either age of hosts of both the species, the values were significantly superior fora greater number of parameters with younger hosts of *S. frugiperda* when compared with those with younger hosts of *S. litura* where the parameters have been shared by either category of hosts in terms of their superiority.

Keywords: Endo-pupal parasitoid, developmental duration, progeny female longevity, progeny production, progeny sex ratio.

INTRODUCTION

Parasitic hymenopterans are known for employing reproductive strategies that are invariably oriented towards maximizing progeny production with the progeny individuals being female-biased accompanied with superior fitness. Progeny production by a parasitoid female is accompanied by certain *trade-off* mechanisms, as developmental strategies, concerning certain progeny-related aspects such as adult number, adult size, and adult sex ratio *vis-à-vis* host-related factors like age, size, density, and quality where a decrease in the expression of one trait is compensated by an increase in the other. In explicit terms, for example, where progeny adult size needs to be bigger its number would be lesser and where the male number needs to be greater the female number would be lesser (reduced sex ratio) and *vice versa*. It is, therefore, appropriate to perceive that the above-mentioned parasitoid-related aspects (number, size, and sex ratio) are correlated with host-related aspects (age, size, density, and quality) that regulate the parasitoid larval foraging efficiency.

Parasitoid fitness (quality) is chiefly considered for its females with their body size being biggerby which they acquire enhanced longevity, higher temperature tolerance, superior host searching ability, and elevated parasitism level with concomitant effective suppression in pest populations after their release in the field. When the idea for mass production of parasitoids is contemplated, as a pre-requisite for field release, the focus obviously falls on the female fitness which is the outcome of combined influences of 1) host-related factors (age, size, density, quality, multi-parasitism, etc.), 2) parasitoid-related factors (female age, size, density, diet, con-specific and inter-specific competition, mated condition, etc.), and 3) environment-related (chiefly temperature and relative humidity)factors (Gordh *et al*., 1999; Aruna, 2007; Veena, 2008; Narendra Kumar,2019). Keeping these factors in view, concerted efforts have been made by specialists in biological control of crop pests so that the desired level of pest suppression can be ensured.

Confronting the hosts of different species for breeding is not uncommon among parasitoids in nature as they mostly have a broad host spectrum. Obviously, the hosts would differ in quality as well as consistency (palatability) and abundance of resources. The consistency and abundance also would change according to host age, thereby have implications on progeny production, progeny sex ratio, and progeny fitness (Sandlan, 1982). When hosts of two or more species are parasitized by a parasitoid female, her progenies are expected to differ in terms of number, fitness, and sex ratioin relation to host age (King, 1887; Aruna, 2007; Veena, 2008; Narendra Kumar, 2019), host size(Charnov *et al*., 1981; Jenner and Kuhlmann, 2006; Aruna, 2007, Narendra Kumar, 2019), host density (Bai and Smith, 1993; Aruna, 2007; Kraft and Nouhuys, 2013), host quality (Charnov and Skinner, 1984), etc. in addition to the ones associated

Table 1. Impact of host age on the progeny production of *Tetrastichus howardi* when *Spodoptera litura* was parasitized

Host age	Developmental duration (days)	Progeny production (No.)		Total Progeny production (No.)	Sex ratio (No. of females/ male)	Progeny Female longevity (days)
		Male	Female			
Young (2 days)	23.60 ± 0.40	7.80 ± 0.80	46.00 ± 1.70	53.80 ± 2.47	6.10 ± 0.50	20.40 ± 0.24
Old (7 days)	20.20 ± 0.80	3.60 ± 0.24	29.0 ± 1.04	32.60 ± 0.87	8.28 ± 0.86	20.80 ± 0.58
T- test	*	*	*	*	*	NS
Value	5.01	6.33	6.57	6.59	4.29	1.00

Data are the means of 5 replications (Mean ± SE) each with one host pupa

*- Significant *(P≤ 0.05)*; NS- Significant

with environmentto which the parent female as well as her developing progenies are exposed while breeding (Lysyk, 1998; Gordh *et al*., 1999; Ahmed *et al*., 2013). The information thus generated by studying the impact of these factors would create an opportunity to precisely work out as to how the mass production of parasitoids can be undertaken by ensuring superiority of their fitness.

Tetrastichus howardi (Olliff) is an indigenous gregarious endo-pupal parasitoid with immense potential to suppress the field populations of a host of lepidopteran pests in the fields of Sericulture (Sathyaprasad *et al.*, 2006), Agriculture (Pereira *et al*., 2015; Sankar and Rao, 2016), and Horticulture (Favoreto *et al*., 2021). In the field of Sericulture, small-scale field trials have demonstrated the potential of this parasitoid to keep the field populations of the leaf roller pest, *Diaphania pulverulentalis* Hampson, in check. *T. howardi* has been included as a biological control component of an IPM package that also comprises chemical and cultural measures (Sathyaprasad*et al.*, 2006). Under laboratory conditions, the parasitoid successfully parasitizes another leaf eating pest, the cut worm, *Spodoptera litura* Fabricius. However, for mass production and large-scale field trials employing this parasitoid, identification of a couple of suitable hosts is required based on screening of a few lepidopteran hosts for parasitism and progeny production. This apart, colonization of the identified host (s) itself is a matter of great importance to ensure the availability of the parasitoid required for field release.

MATERIALS AND METHODS

For experimentation, younger (2-day-old) and older (7-day-old) pupae of *S. litura* and *S. frugiperda* (as hosts) and 2-day-old gravid females of *T. howardi* were used. The values for fresh weight (g) of younger and older pupae, based on 5 pupae, for *S. litura* ranged from 0.207 to 0.224 (av.0.214 ± 0.006) and from 0.160 to 0.190 (av.0.178 ± 0.01), respectively. The corresponding values for *S. frugiperda* varied from 0.179 to 0.186 (av. 0.184 ± 0.002) and from 0.132 to 0.140 (av. 0.136±0.003). The host pupae of each category were exposed for parasitism (oviposition) by *T. howardi* in glass test tubes (15 x 1.5 cm) plugged with cotton for 2 days at a host-parasitoid ratio of 1:1. During this period, honey (30%) served as the parasitoid female diet. After2 days, the host pupae were separated from the parasitoid females and maintained at 23-28°C and 60-80% RH for the parasitoid development. After eclosion of the parasitoid progenies (1st generation), data were recorded on the reproductive parameters *viz*. developmental duration, progeny production, sex ratio, progeny female longevity as well as morphometric parameters of the progenies. The measurements regarding morphometric parameters such as body length, wingspan, and head width of male and female progeny individuals as well as abdominal length and width of male and females were recorded using a stage micrometer under a light microscope (40 X). Each of the treatments consisted of 5 replications. The accrued data were subjected to t-test at 1 and 5% levels of significance by SPSS package (version 21.0).

RESULTS

Impact of host age on the progeny production of *Tetrastichus howardi* when *Spodoptera litura* was parasitized

The results are presented in Table1. There was a significant increase (P<0.05) in the parasitoid developmental duration when it developed in younger host (23.60 ± 0.40 days) as against older host (20.20 ± 0.80 days). Regarding progeny production (number), it was significantly more when the parasitoid oviposited in younger pupae (53.80 ± 2.47) as against older pupae (32.60 ± 0.87) with the progenies being significantly female biased irrespective of host age. The parasitoid progeny sex ratio, however, was significantly lesser when the parent female exploited the older host with the values being 6.10 ± 0.50 for younger host in contrast to 8.28 ± 0.86 for older host. Further, the survival durations of the progeny females, when maintained on 30% honey, remained almost identical regardless of age categories of the host.

Effect of host age on the progeny morphometric parameters of *Tetrastichus howardi* when it developed in *Spodoptera litura*

The results are furnished in Table 2.Of8 morphometric parameters of the progeny individuals, only 2 of them *viz*. wingspan of male (1.24 ± 0.02 mm) and head widths of male and female (0.75 ± 0.05 and 0.79 ± 0.01 mm) were significantly superior when developed in older host, while body length of male (1.41 ± 0.06 mm) was significantly so when developed in younger host.

Influence of host age on the progeny production of *Tetrastichus howardi* when *Spodoptera frugiperda* was parasitized

The results are depicted in Table 3. The parasitoid developmental duration was significantly longer when it developed in older host (15.00 ± 0.00 days) as against younger host (14.00 ± 0.31 days). With progeny production (number), it was significantly greater (P≤0.01) when the parent female parasitized younger hosts (137.80 ± 2.45) in sharp contrast to older host (56.60 ± 2.54) with the values for males and females with younger pupae being significantly more when compared with older hosts. The parasitoid progeny sex ratio too was far superior when the progenies developed in younger host (7.99 ± 0.53) as against older host (4.34 ± 0.37). Further, the longevity of 30% honey-fed parasitoid progeny females remained almost similar irrespective of the category of host the parent female parasitized.

Impact of host age on the progeny morphometric parameters of *Tetrastichus howardi* when it developed in *Spodoptera frugiperda*

The results are presented in Table 4. Body length was significantly higher for males when they developed in younger host pupae (1.55 ± 0.01 mm), while it was so

Table 2. Effect of host age on the progeny morphometric parameters of *Tetrastichus howardi* when it developed in *Spodoptera litura*

Host Age	Body length (mm)		Body width (mm)		Wing span (mm)		Head width (mm)		Female abdomen (mm)		Male abdomen (mm)	
	Male	Female	Male	Female	Male	Female	Male	Female	Length	Width	Length	Width
Young (2 days)	1.41 ± 0.06	2.10 ± 0.02	0.36 ± 0.01	0.90 ± 0.02	1.15 ± 0.01	1.50 ± 0.04	0.57 ± 0.06	0.70 ± 0.01	0.97 ± 0.05	0.82 ± 0.02	0.74 ± 0.13	0.36 ± 0.01
Old (7 days)	0.75 ± 0.01	2.17 ± 0.07	0.68 ± 0.02	0.84 ± 0.31	1.24 ± 0.02	1.59 ± 0.05	0.75 ± 0.05	0.79 ± 0.01	1.12 ± 0.09	0.84 ± 0.03	0.75 ± 0.33	0.70 ± 0.02
T- test	**	NS	*	NS	*	NS	*	*	NS	NS	NS	**
Value	10.89	1.81	9.69	1.04	4.75	1.08	3.60	4.00	2.46	0.52	0.17	13.70

Data are the means of 5 replications (Mean ± SE) at one host pupa

** - Highly Significant *(P≤ 0.01)*; * - Significant *(P≤ 0.05)*; NS - Non significant

Table 3. Influence of host age on the progeny production of *Tetrastichus howardi* when *Spodoptera frugiperda* was parasitized

Host age	Developmental duration (days)	Progeny production (No.)		Total Progeny production (No.)	Sex ratio (No. of females/ males)	Female longevity (days)
		Male	Female			Progeny
Young (2 days)	14.00 ± 0.00	15.60 ± 1.20	122.20 ± 1.82	137.80 ± 2.45	7.99 ± 0.53	18.80 ± 0.37
Old (7 days)	15.00 ± 0.31	10.80 ± 0.80	45.80 ± 2.28	56.60 ± 2.54	4.34 ± 0.37	20.80 ± 0.58
T- test	*	*	**	**	*	NS
Value	3.16	4.31	23.40	22.06	7.59	2.39

Data are the means of 5 replications (Mean ± SE) at one host pupa.

** - Highly Significant *(P≤ 0.01)*; * - Significant *(P≤ 0.05)*; NS - Non significant.

for females when they developed in older host pupae (1.96 ± 0.01 mm). The values for wingspan of both males (0.92 ± 0.01 mm) and females (0.97 ± 0.02 mm) were significantly greater when older host pupae were parasitized. Head width of males remained almost similar irrespective of host age, while their female counterparts had significantly higher values when the parent females oviposited in younger host (0.54 ± 0.00 mm).Looking at the female abdomen length and width of progenies, there was a similarity in the measurements for the progenies obtained from host pupae of either category.

Influence of host species of identical age (young vs young and old vs old) on the progeny production of *Tetrastichus howardi*

The results are presented in Tables 5 and 6. When a comparison was brought out on the reproductive performance of *T. howardi* parasitizing the young hosts of *S. litura and S. frugiperda*, the parasitoid has shown significantly superior performance in the production of progenies in the latter host (137.80± 2.45), as opposed to the former host (53.80 ± 2.47), while significantly (P≤0.01) reducing its developmental duration. Considering the individual sexes of the progenies too, the parasitoid reproductive performance, including the parasitoid sex ratio, was far superior for both the sexes when *S. frugiperda* was exploited. In respect of longevity of the parasitoid progeny females, they lived significantly longer when the progenies were developed in *S. litura* (Table 5). Production of the parasitoid progenies in older hosts too was significantly higher when the parasitoid oviposited in *S. frugiperda* (56.60 ± 2.54), against 32.60 ± 0.87 in *S. litura*, with the individuals of both the sexes being significantly more in number but with significantly reduced sex ratio (4.34 ± 0.37 in *S. frugiperda* and 8.28 ± 0.86 in *S. litura*). Further, the results for longevity of the parasitoid female progenies emerging from both the hosts were comparable (Table 6).

DISCUSSION

Developmental duration of *T. howardi* was substantially longer in both younger and older pupae of *S. litura* when compared with *S. frugiperda*. An appreciable increase in production of progenies of the parasitoid was noticed when it developed in younger pupae of both *S. litura* and *S. frugiperda*. The increase was of the order of 1.65, 1.58, and 2.17 times for total, female, and male populations, respectively with *S. litura* when compared with its older counterparts; the corresponding values with *S. frugiperda* were 2.43, 2.67, and 1.44, thus demonstrating the suitability of younger hosts for enhanced production of both male and female progenies. Though production of progenies in the pupae of both the age categories was female biased, the sex ratio (number of females/male) among the progenies generated in older pupae was significantly higher with *S. litura*, which was due to relative decrease in male numbers in relation to those of females. This was not the case with younger host for the parasitoid progeny production where the number of males being relatively morein relation to those of females.

Though the parasitoid female produced relatively greater number of males when the older pupae were parasitized, it doesn't hold much significance as even a few males would be adequate to mate with several females owing to their polygamous nature. As opposed to *S. litura*, the sex ratio for the parasitoid progenies developing in *S. frugiperda* was significantly higher with younger pupae, which was in excess by1.84 times. Knowing fully well that female being the performing sex in terms of host mortality, greater the number of female productions per host would have distinct advantage in terms of host suppression under field conditions when released under biological control program. An examination of the overall reproductive performance of *T. howardi* indicated that *T. frugiperda* could serve as relatively a better host regardless of whether it is younger or older as evidenced by substantially greater number of progenies being produced, more so of females. Interestingly, it may be noted that the reproductive performance of the parasitoid in the older host of *S. frugiperda*, despite being significantly low when compared with its younger counterpart, is comparable with that of younger host of *S. litura*. The longevity of the progeny females generated from both younger and older pupae of both the hosts was comparable, thus indicating similarity in one of their quality parameters.

The superiority/suitability of *S. frugiperda* for progeny production by *T. howardi* could be attributed to its nutritional aspects that seem to be more suited to nourish the foraging larvae of the parasitoid. The fact that the younger host pupae were found more suitable for the parasitoid breeding when compared with older pupae of both the species could be explained based on the following: a)relative abundance of resources that the parasitoid female estimates as an important pre-oviposition behavior so that she can allocate progenies in accordance with that estimate and b) better palatability (suitable consistency) of host resources for the foraging larvae that would facilitate effective development of the progenies. The reason indicated under the point (a) above is quite evident from the fresh weights of younger pupae that were substantially higher in comparison to their older counterparts that had relatively lesser amounts of resources as these appear to have been utilized by the hosts for their own development as the age advanced, thus compelling the parasitoid female to limit (reduce) her progeny allocation to some extent as to facilitate effective development of progenies. Moreover, it's quite possible that the resources in the older host pupae have been transformed into structural forms, thus proving to be relatively less palatable to the foraging larvae. If that is being the case, then the adults emerging from the younger pupae should have been bigger than their counterparts emerging from smaller pupae. But this hasn't been clearly reflected in the morphometric parameters of the progeny individuals. To make it more explicit, some of the morphometric parameters are inferior when the parasitoid developed in younger host and *vice versa*. As such the trend observed for progeny production with younger hosts proving to be more suitable than older ones in both the host species used in the present investigations cannot be discerned when the morphometric parameters were considered.

It's matter of great interest to record that progeny production by *T. howardi* female was 2.56 times greater

Table 4. Impact of host age on the progeny morphometric parameters of *Tetrastichus howardi* when it developed in *Spodoptera frugiperda*

Host Age	Body length (mm)		Body width (mm)		Wing span (mm)		Head width (mm)		Female abdomen (mm)		Male abdomen (mm)	
	Male	Female	Male	Female	Male	Female	Male	Female	Length	Width	Length	Width
Young (2 days	1.55 ± 0.01	1.69 ± 0.01	0.45 ± 0.08	0.45 ± 0.01	0.79 ± 0.01	0.86 ± 0.02	0.53 ± 0.06	0.54 ± 0.00	0.79 ± 0.06	0.81 ± 0.00	0.81 ± 0.01	0.56 ± 0.31
Old (7 days	1.31 ± 0.08	1.96 ± 0.01	0.36 ± 0.00	0.51 ± 0.15	0.92 ± 0.01	0.97 ± 0.02	0.42 ± 0.05	0.48 ± 0.00	0.81 ± 0.03	0.70 ± 0.05	0.54 ± 0.01	0.46 ± 0.10
T- test	**	**	*	NS	**	*	NS	*	NS	NS	**	*
Value	20.92	10.53	6.39	2.58	16.74	0.29	1.01	6.12	0.99	2.16	13.90	4.25

Data are the means of 5 replications (Mean ± SE) at one host pupa.
** - Highly Significant *(P≤ 0.01)*; * - Significant *(P≤ 0.05)*; NS - Non significant.

Table 5. Influence of host species of identical age (young vs young) on the progeny production of *Tetrastichus howardi*

Host age	Developmental duration (days)	Progeny production (No.)		Total Progeny production (No.)	Sex ratio (No. of females/ males)	Female longevity (days)
		Male	Female			Progeny
Young (SL)	23.60 ± 0.40	7.80 ± 0.86	46.00 ± 1.70	53.80 ± 2.47	6.10 ± 0.50	20.40 ± 0.24
Young (SF)	14.00 ± 0.00	15.6 ± 1.20	122.20 ± 1.82	137.80 ± 2.45	7.99 ± 0.53	18.80 ± 0.37
t- test	**	*	**	**	*	*
t-value	24.00	7.64	33.61	29.88	3.22	3.13

Data are the means of 5 replications (Mean ± SE) at one host pupa.
** - Highly Significant *(P≤ 0.01)*;* - Significant *(P≤ 0.05)*; NS - Non significant.

in younger and 1.74 times higher in older pupae of *S. frugiperda* than that generated in *S. litura* despite the pupae of the former host being smaller by 1.16 times with younger pupae and 1.31 times with older pupae when compared with the latter host. Suitability of *S. frugiperda* is justifiable when the progenies (males, females, and total) produced in the older pupae were comparable with those generated in the younger pupae of *S. litura*. In fact, *S. frugiperda* produced progenies of 10.80 ± 0.80 males and 45.80 ± 2.28 females (total 56.60 ± 2.54) in older pupae as opposed to 7.80 ± 0.86 males and 46.00 ± 1.70 females (total 53.80 ± 2.47) in younger pupae of *S. litura*. From the foregoing account, it becomes amply clear that host age matters from the viewpoint of progeny production in each host species but the importance of host species from the viewpoint of quality of resources for parasitoid progeny production cannot be underestimated. However, it is important to understand whether a parasitoid female restricts her progeny allocation when the host resource quality is inferior, or the survival of progenies would be reduced under such circumstances where the *fittest of the progenies* only would survive.

Literature is replete with the information related to impact of host age and host species (quality) on the reproductive performance, including fitness returns of progenies, of parasitoids. Progeny production by a parasitoid differs according to whether the parasitoid is an *idiobiont* (parasitizing a host with fixed resources like egg and pupa) or a *koinobiont* (parasitizing a host that continues to feed and grow even after parasitism like larva). In both the kind of parasitoids, the progeny allocation per host, be it a natural one or a factitious one, is based on precise estimation of host resources by the parasitoid female at the time of oviposition. Efforts to record the impact of host age on the reproductive performance of parasitoids included egg, larval, larvi-pupal, and pupal parasitoids of solitary as well as gregarious nature. King (1998) working with *Spalangia cameroni*, Husni *et al*. (2001) with *Brachymeri alasus* (Walker), Nakamura and Noda (2002) with *Oomyzus sokolowskii* Kurdjumov, Aruna with *Nesolynx thymus* Girault, Veena with *Trichopria* sp., and Narendra Kumar (2019) with *Trichomalopsis uziae* Sureshan & Narendra Kumarhave observed that the parasitoids preferred to parasitize the younger hosts with concomitant significant increase in progeny production and sex ratio. Regarding host quality (species), which relates to nutritional status of host, King (1998) found that *S. cameroni* allocated more female progenies to the pupae of stable fly (*Stomoxy scalcitrans* L.) when compared with pupae of house fly (*Musca domestica*L.) with associated increase in their survival when developed on the former host where their developmental duration was shorter by about 2%. In a recent study, Simanato *et al*. (2020) working with *T. howardi* using *Helicoverpa armigera* (Hubner) and *Diatraea saccharalis* (Fabricius) as hosts have presented an explicit account as to the impact of host age/stage and host quality where the importance of these host-related factors on the rate of parasitism, progeny developmental duration, progeny production, sex ratio, and longevity of progeny individuals has become evident. From the foregoing account regarding impact of host species and hostage on the reproductive performance of *T. howardi*, what could be understood/ concluded is that both these

Table 6. Influence of host species of identical age (old vs. old) on the progeny production of *Tetrastichus howardi*

Host age	Developmental duration (days)	Progeny production (No.)		Total Progeny production (No.)	Sex ratio (No. of females/ males)	Female longevity (days)
		Male	Female			
Old (SL)	20.20 ± 0.80	3.60 ± 0.24	29.0 ± 1.04	32.60 ± 0.87	8.28 ± 0.86	20.80 ± 0.58
Old (SF)	15.00 ± 0.31	10.80 ± 0.80	45.8 ± 2.28	56.60 ± 2.54	4.34 ± 0.37	20.80 ± 0.58
t- test	*	**	*	*	*	NS
t-value	6.04	10.85	5.88	7.40	6.79	1.08

Data are the means of 5 replications (Mean ± SE) at one pupa / replication.
** - Highly Significant *(P≤ 0.01)*;* - Significant *(P≤ 0.05)*; NS - Non significant.

host-related factors assume importance. However, it is even more important to identify a couple of suitable hosts, as also their age, based on screening of many potential hosts so that large-scale production of the parasitoid could be undertaken while keeping the fitness qualities of the progenies intact. Further, it is also important to develop a suitable technology for colonization of the identified host(s) as a prerequisite for undertaking mass production of the parasitoid in question.

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Bio-efficacy of novel insecticides and biorationals against invasive thrips, *Thrips parvispinus* (Karny) (Thripidae:Thysanoptera) on chilli

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ABSTRACT: Invasive thrips, *Thrips parvispinus* (Karny) is a relatively new pest on chilli crop. This species has been occurring in serous proportions and causing significant damage to chilli crop in most of the chilli growing areas of India.In this study we assessed the bio-efficacy of new generation molecules and biorationals against *T. parvispinus*. The results suggested that new molecules *viz*., broflanilide 30 SC (18.60g a.i/ha) and fluxametamide 10 EC (40 g a.i/ha) were found highly effective in reducing the thrips population on chilli crop, followed by spinetoram 11.7 SC (60 g a.i/ha) and tolfenpyrad 15 EC (150 g a.i/ha). Other insecticides *viz*., spinosad 45 SC (73 g a.i/ha), cyantraniliprole 10.26 OD (60 g a.i/ha) and thiamethoxam 25 WG (37.50 g a.i/ha) were found moderately effective on this species. Biorationals *viz*., *Lecanicillium lecanii* (2.5 kg /ha), *Beauveria bassiana* (2.5 kg /ha) and azadirachtin 1 % (2.00 ml/l) recorded comparatively higher thrips populations. The results of this investigation may be useful forthe management of invasive thrips on chilli using insecticides. Further, broflanilide and fluxametamide exhibit similar mode of action and hence must be used prudently to delay the evolution of resistance.

Keywords: Invasive thrips, *Thrips parvispinus*, chilli, bio-efficacy, broflanilide 30 SC, fluxametamide 10 EC

INTRODUCTION

Chilli is considered as one of the important commercial spice and vegetable crops in India. It is a widely used universal spice and named as "wonder spice". India is the largest producer, consumer and exporter of dry chilli in the world. Chilli was cultivated on an area of 852,000 hectares with 1578000 MT of production and 1.90 MT productivity per hectare during 2021-22 (Anon., 2023a). On chilli crop over 35 species of insects and mites have been reported as pests. Thrips and mites are considered as major constraints for successful production of chilli. Among the thrips, *Scirtothrips dorsalis* (Hood) was reported as a major Thrips species infesting chilli. However, of late, a new invasive thrips, *Thrips parvispinus* (Karny) has been causing serious damage to leaves, flowers and fruits of chilli plants in major chilli growing regions of the country. Occurrence of this species in India was first reported on papaya from Bangalore, Karnataka State (Tyagi *et al.,* 2015). Later, an outbreak of *T. parvispinus* on chilli crop was reported from southern states *viz*., Andhra Pradesh, Karnataka and Telangana, causing 50 to 80 per cent damage (Anon., 2022). It is a polyphagous pest, infesting mainly fruits, vegetables and ornamental crops *viz.,* coffee, chilli, *Gardenia* sp., papaya, potato, sweet pepper, green bean, tobacco, *Vigna* sp., strawberry, watermelon, eggplant and cucurbits (Moritz *et al.,* 2013). The nymphs and adults predominantly colonize on underside of leaves and flowers, cause damage by sucking the plant sap (Kalshoven, 1981). Deep punctures and scratches can be seen on infested leaves. Brownish streaks appear on petals of flowers due to laceration by thrips, resulting in drying and withering of flowers. Severe infestation affects the growth of the plant, causes flower drop, reduces fruit set and development, ultimately resulting in yield loss. In severe infestation conditions, the yield loss could reach more than 85% (Prasannakumar *et al.,* 2021).

The damage caused by *T. purvispinus* to chilli crop can be minimized by adopting proper pest control tactics. Along with other integrated control options, application of insecticides plays a prominent role in reducing yield losses associated with thrips infestation. Owing to short developmental time and completion of multiple generations within single cropping season, insecticides are applied several times for the control of this pest. Further, *T. parvispinus* is a new pest on chilli in India and information regarding efficacy of insecticides against this invasive species is scanty. Therefore, the present study was carried out to assess the efficacy of insecticides and biorationals against *T. parvispinus* on chilli. The information generated in the present study may form valid basis for choosing appropriate insecticides for the control *T. parvispinus* on chilli crop.

MATERIALS AND METHODS

The bio-efficacy of insecticides and biorationals against *T.parvispinus*, *Thrips parvispinus* on chilli was assessed during *rabi* 2022 and summer 2023. The experiment was laid out in Randomized Block Design (RBD). The study

Table 1. Bio-efficacy of insecticides and biorationals against *T. parvispinus* on chilli (*rabi* 2022)

Treatments	g a.i/ha	PTC	I Spray		II Spray		Overall Mean	Reduction (%)
			7 Days	14 Days	7 Days	14 Days		
Thiamethoxam 25% WG	37.50	14.33 (3.92)	8.75 (3.12)	5.58 (2.56)	3.83 (2.17)	2.50 (1.87)	5.17 (2.48)	72.86
Cyantraniliprole 10.26% OD	60.00	13.42 (3.8)	7.33 (2.89)	4.67 (2.38)	3.42 (2.1)	2.00 (1.73)	4.35 (2.31)	75.57
Spinosad 45.0% SC	73.00	13.67 (3.83)	6.58 (2.75)	4.17 (2.27)	3.25 (2.06)	1.75 (1.65)	3.94 (2.22)	78.31
Broflanilide 30% SC	18.60	14.92 (3.99)	3.75 (2.18)	1.33 (1.53)	0.75 (1.30)	0.25 (1.11)	1.52 (1.59)	92.33
Fluxametamide 10% EC	40.00	14.67 (3.96)	4.50 (2.34)	2.25 (1.79)	1.33 (1.53)	0.75 (1.32)	2.21 (1.79)	88.67
Spinetoram 11.7 % SC	60.00	13.58 (3.82)	5.67 (2.58)	3.08 (2.02)	2.00 (1.73)	1.08 (1.44)	2.96 (1.99)	83.60
Tolfenpyrad 15EC	150.00	13.00 (3.74)	6.33 (2.7)	3.83 (2.19)	2.50 (1.87)	1.50 (1.58)	3.54 (2.13)	79.49
Azadirachtin 1%	-	12.83 (3.72)	11.75 (3.57)	10.42 (3.38)	9.58 (3.25)	8.83 (3.14)	10.15 (3.34)	40.49
Beauveria bassiana	-	12.42 (3.66)	11.50 (3.54)	10.58 (3.4)	9.42 (3.23)	8.33 (3.05)	9.96 (3.31)	39.63
Lecaniciliumlecanii	-	13.08 (3.78)	12.50 (3.67)	10.75 (3.43)	9.00 (3.16)	8.08 (3.01)	10.08 (3.33)	41.97
Control	-	12.50 (3.67)	14.50 (3.93)	16.17 (4.14)	17.25 (4.27)	18.50 (4.42)	16.60 (4.20)	-
SEm±		0.09	0.07	0.08	0.07	0.07	0.04	-
CD		NS	0.23	0.24	0.21	0.21	0.13	-

*PTC= Pre-treatment count; NS- Non-significant

consisted of eleven treatments and every treatment was replicated thrice (Table 1). The chilli crop was grown as per the recommeded package of practice (except plant protection measures). The crop was regularly monitored to assess the incidence of thrips. The treatments were imposed when adequate thrips population was noticed in the field. The insecticides were sprayed two times at 14 days interval using knapsack sprayer.

Data recording and analysis:

The observations were recorded from five randomly selected plants in each replication. Number of thrips present in five flowers were recorded on every selected plant and later average number of thrips per flower was worked out. The thrips population was recorded at one day before, seven and fourteen days after spraying of insecticides. The data were subjected to square root transformation and transformed data was analysed using ANOVA (Gomez and Gomez, 1984). Reduction in thrips population (per cent) in insecticide treated plots over untreated control was calculated using Henderson and Tilton formula (Henderson and Tilton, 1955).

RESULTS AND DISCUSSION

Efficacy of insecticides and biorationals against *Thrips parvispinus* during *rabi* 2022

At one day before spray, average number of thrips ranged from 12.42 to 14.92 thrips per flower (Table 1). Prior to the imposition of treatments, thrips population across treatment plots did not vary significantly. Application of insecticides resulted in considerable decrease in pest density in the experimental plots. After two sprays, significantly less population of thrips was observed in broflanilide 30 SC (18.60 g a.i/ha) (1.52 thrips/flower), followed by fluxametamide 10 EC (40.00 g a.i/ha) (2.21 thrips/flower) treated plots. The insecticides *viz*., spinetoram 11.7 SC (60.00 g a.i/ha),tolfenpyrad 15 EC (150 g *a.i*/ha), spinosad 45 SC (73.00 g *a.i*/ha), cyantraniliprole 10.26 OD (60.00 g *a.i*/ha)and

Table 2. Bio-efficacy of insecticides and biorationals against *T. parvispinus* on chilli (Summer 2023)

Treatments	g *a.i*/ha	PTC	I Spray		II Spray		Overall Mean	Reduction (%)
			7 Days	14 Days	7 Days	14 Days		
Thiamethoxam 25% WG	37.50	18.08 (4.37)	10.33 (3.37)	6.75 (2.78)	4.50 (2.32)	3.58 (2.14)	6.29 (2.70)	69.04
Cyantraniliprole 10.26% OD	60.00	16.17 (4.14)	8.50 (3.08)	5.00 (2.44)	3.83 (2.19)	2.50 (1.87)	4.96 (2.44)	72.71
Spinosad 45.0% SC	73.00	16.00 (4.12)	7.25 (2.87)	5.00 (2.44)	3.58 (2.14)	2.83 (1.96)	4.67 (2.38)	74.05
Broflanilide 30% SC	18.60	18.25 (4.39)	4.25 (2.29)	2.00 (1.72)	0.92 (1.38)	0.50 (1.22)	1.92 (1.71)	90.65
Fluxametamide 10% EC	40.00	18.17 (4.38)	5.00 (2.45)	2.92 (1.98)	1.75 (1.66)	0.83 (1.35)	2.63 (1.90)	87.14
Spinetoram 11.7 % SC	60.00	18.00 (4.36)	6.33 (2.70)	4.33 (2.31)	2.33 (1.82)	1.75 (1.65)	3.69 (2.16)	81.77
Tolfenpyrad 15EC	150.00	17.33 (4.28)	6.75 (2.78)	5.17 (2.48)	3.25 (2.06)	2.25 (1.8)	4.35 (2.31)	77.65
Azadirachtin 1%	-	17.83 (4.34)	15.00 (4.00)	13.00 (3.74)	11.00 (3.46)	9.42 (3.23)	12.10 (3.62)	39.60
Beauveria bassiana	-	16.92 (4.23)	15.17 (4.02)	12.50 (3.67)	9.75 (3.28)	9.42 (3.23)	11.71 (3.56)	38.41
Lecaniciliumlecanii	-	17.50 (4.30)	15.00 (4.00)	13.00 (3.73)	9.67 (3.27)	9.08 (3.17)	11.69 (3.56)	40.57
Control	-	17.00 (4.24)	17.92 (4.35)	19.08 (4.48)	19.33 (4.51)	20.08 (4.59)	19.10 (4.48)	-
SEm±		0.07	0.08	0.07	0.06	0.05	0.03	-
CD		NS	0.25	0.22	0.19	0.16	0.10	-

* PTC= Pre-treatment count; NS- Non-significant

thiamethoxam 25 WG (37.50 g a.i/ha) recorded 2.96, 3.54, 3.94, 4.35 and 5.17thrips per flower, respectively. On the other hand, biorationals *viz., Beauveria bassiana* (2.50 kg/ha), *Lecanicillium lecanii* (2.50 kg/ha) and azadirachtin 1 % (2ml/l) recorded higher populations of 9.96, 10.08 and 10.15 thrips per flower, respectively. The maximum per cent reduction in thrips population over untreated control was recorded in broflanilide 30 SC (92.33 %), followed by fluxametamide 10 EC (88.67 %), spinetoram 11.7 SC (83.60%) and tolfenpyrad 15 EC (79.49 %).

Efficacy of insecticides and biorationals against *T. parvispinus* during summer 2023

Prior to imposition of treatments, the mean number of thrips ranged from 16.00 to 18.25 thrips per flower (Table 2). Thrips populations reduced considerably in the treated plots after spraying of insecticides. Application of broflanilide 30 SC @ 18.60 g a.i/ha resulted in significant control of thrips (1.92 thrips/flower) and was followed by fluxametamide 10 EC @ 40 g *a.i*/ha (2.63), spinetoram 11.7 SC @ 60.00 g a.i/ha (3.69) and tolfenpyrad 15 EC @ 150 g a.i/ha (4.35). The insecticides *viz*., spinosad 45 SC (73.00 g a.i/ha), cyantraniliprole 10.26 OD (60.00 g *a.i*/ha) and thiamethoxam 25 WG (37.50 g a.i/ha) were found moderately effective in controlling thrips on chilli. Comparatively higher thrips population was noticed in biorationals applied plots. The plots treated with *Lecanicillium lecanii* (2.50 kg/ha), *Beauveria bassiana* (2.50 kg/ha) and azadirachtin 1 % (2ml/l) recorded 11.69, 11.71 and 12.10 thrips per flower, respectively. Maximum reduction in thrips population over the untreated control was recorded in broflanilide 30 SC (90.65%), followed byflux ametamide 10 EC (87.14%), spinetoram 11.7 SC (81.77%) and tolfenpyrad 15 EC (77.65%).

Pooled data on efficacy of insecticides against *T. parvispinus* (*Rabi* 2022 and Summer 2023)

Analysis of the data recorded during two seasons suggested significantly higher reduction in thips

Table 3. Pooled data on bio-efficacy of insecticides and biorationals against *T. parvispinus* on chilli

Treatments	g *a.i*/ha	PTC	I Spray		II Spray		Overall Mean	Reduction (%)
			7 Days	14 Days	7 Days	14 Days		
Thiamethoxam 25% WG	37.50	16.21 (4.15)	9.54 (3.25)	6.17 (2.68)	4.17 (2.25)	3.04 (2.01)	5.73 (2.59)	70.80
Cyantraniliprole 10.26% OD	60.00	14.79 (3.97)	7.92 (2.99)	4.83 (2.41)	3.63 (2.15)	2.25 (1.80)	4.66 (2.38)	73.99
Spinosad 45.0% SC	73.00	14.83 (3.98)	6.92 (2.81)	4.58 (2.36)	3.42 (2.1)	2.29 (1.81)	4.30 (2.30)	76.04
Broflanilide 30% SC	18.60	16.58 (4.19)	4.00 (2.23)	1.67 (1.63)	0.83 (1.34)	0.38 (1.17)	1.72 (1.65)	91.44
Fluxametamide 10% EC	40.00	16.42 (4.17)	4.75 (2.4)	2.58 (1.89)	1.54 (1.59)	0.79 (1.34)	2.42 (1.85)	87.84
Spinetoram 11.7 % SC	60.00	15.79 (4.10)	6.00 (2.64)	3.71 (2.17)	2.17 (1.78)	1.42 (1.55)	3.32 (2.08)	82.62
Tolfenpyrad 15EC	150.00	15.17 (4.02)	6.54 (2.74)	4.50 (2.34)	2.88 (1.97)	1.88 (1.69)	3.95 (2.22)	78.50
Azadirachtin 1%	-	15.33 (4.04)	13.38 (3.79)	11.71 (3.56)	10.29 (3.36)	9.13 (3.18)	11.13 (3.48)	40.06
Beauveria bassiana	-	14.67 (3.96)	13.33 (3.79)	11.54 (3.54)	9.58 (3.25)	8.88 (3.14)	10.83 (3.44)	38.98
Lecaniciliumlecanii	-	15.29 (4.04)	13.75 (3.84)	11.88 (3.59)	9.33 (3.21)	8.58 (3.10)	10.89 (3.45)	41.19
Control	-	14.75 (3.97)	16.21 (4.15)	17.63 (4.32)	18.29 (4.39)	19.29 (4.50)	17.85 (4.34)	-
SEm±		0.13	0.07	0.05	0.05	0.04	0.03	-
CD		NS	0.21	0.16	0.15	0.12	0.09	-

*PTC= Pre-treatment count; NS- Non-significant

population in broflanilide 30 SC @ 18.60 g a.i/ha treated plants (1.72 thrips/flower), followed by fluxametamide 10 EC @ 40 g a.i/ha (2.42), spinetoram 11.7 SC @ 60.00 g a.i/ha (3.32) and tolfenpyrad 15 EC @ 150 g a.i/ha (3.95). The treatments *viz*., spinosad 45 (73.00 g a.i/ha), cyantraniliprole 10.26 OD (60.00 g a.i/ha) and thiamethoxam 25 WG (37.50 g a.i/ha) were found moderately effective with 4.30, 4.66 and 5.73 thrips per flower, respectively. The biorationals *viz*., *Beauveria bassiana* (2.50 kg/ha), *Lecanicillium lecanii* (2.50 kg/ha) and azadirachtin 1 % (2ml/l) recorded relatively higher thrips populations compared to other treatments. Maximum per cent reduction in thrips population was recorded in broflanilide 30 SC (91.44%) sprayed plots, followed by fluxametamide 10 EC (87.84%), spinetoram 11.7 SC (82.62%) and tolfenpyrad 15 EC (78.50%).

It was noticed that among the assessed chemicals, broflanilide and fluxametamide were found highly effective. Broflanilide is a meta-diamide insecticide with a novel mode of action and exhibits insecticidal activity against various insect pests belong to order Lepidoptera, Coleopteran and Thysanoptera (Katsuta *et al*., 2019). Translaminar action of broflanilide offers ability to control targeted insect populations such as thrips that may feed on the underside of the leaf, even when the chemical

is applied on the upper leaf surface. Fluxametamide is another new insecticide molecule belonging to isoxazoline group. However, both broflanilide and fluxametamide are GABA-gated chloride channel allosteric modulators and exhibit similar mode of action (Anon., 2023b). As both these chemicals are effective on invasive thrips, *T. parvispinus*, it is possible that both of these chemicals may be applied on the same crop. This situation may trigger to evolution of resistance in thrips against these molecules at an accelerated rate. Therefore, it is necessary to educate the chilli growers to use these insecticides more prudently. Chilli is a relatively long duration crop and may require application of insecticides multiple times for the effective control of thrips.

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Eco-friendly management of rugose spiralling whitefly, *Aleurodicus rugioperculatus* Martin on coconut under coastal ecosystem of Maharashtra

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ABSTRACT: An experiment on eco-friendly approaches for the management of coconut Rugose spiralling whitefly (RSW), *Aleurodicus rugioperculatus* Martin under coastal ecosystem of Maharashtra was conducted during 2018-21 at Regional Coconut Research Station, Dapoli, Maharashtra, India. The data indicated that the IPM package consisting of neem oil application followed by water spray coupled with yellow sticky traps was found effective in reducing RSW incidence. It recorded lowest incidence (31.5%), intensity (20.0%), grade index (0.6) and population (33.6/four leaflet) of RSW) compared to natural control. The RSW per cent reduction over pre-count was noticed incidence (33.3%), intensity (37.1%) and live colony (37 nos.) in neem oil alone spray. The maximum *Encarsia* emergence from parasitized pupae of RSW was observed in T_8-Control treatment (96.6%) was at par with T_4-Neem oil @ 5 ml/litre of water (83.3 %).

Keywords: Coconut, rugose spiralling whitefly, biological suppression, neem oil, *Encarsia*, IPM

INTRODUCTION

The Coconut palm (*Cocos nucifera* Linn.) has great socio-economic significance as it is the source of livelihood for more than 20 million people globally, especially small and marginal farmers. It provides people basic needs such as food, drink, shelter, fuel, furniture, medicine, decorative materials and much more (Punchihewa and Arancon, 1999). They are a necessity and a luxury. It is the most intensively grown and used nut in 80 countries of the world. The rugose spiralling whitefly, *Aleurodicus rugioperculatus* Martin (Hemiptera:Aleyrodidae), has been recently reported from Tamil Nadu, India (Sundararaj *et al.,* 2017). It is an invasive pest that attacks a wide range of host plants including palms, woody ornamentals and fruits. Coconut and banana are among the most preferred host plants. *Aleurodicus rugioperculatus* Martin was originally described from Belize (Martin, 2004) and it is mainly infesting coconut palms and other broad-leaved hosts in its native range and naturally distributed in Belize, Guatemala, Mexico (Martin, 2008) and subsequently, it has spread to 22 other countries in Central and South America, including Florida, USA. India is the only country in the Oriental region where the whitefly has been introduced. Mandal (2011) listed 116 exotic insect species in India. Among the insect pests, exotic whiteflies have invaded several countries causing direct losses in agriculture, horticulture and forestry. Currently, there are 442 species of whiteflies belonging to 63 genera known from India; of these, a few are economically important. Two invasive whiteflies *viz*., the spiraling whitefly, *Aleurodicus dispersus* Russell (David and Regu, 1995) and the solanum whitefly, *Aleurothrixus trachoides* Back (Dubey and Sundararaj, 2015). Karthik *et al.,* 2018 was detected rugose spiralling whitefly from coastal areas of Karnataka, Kerala and Andhra Pradesh. It has become an escalating problem for coconut farmers. The RSW was distributed unevenly along national highways, isolated garden near water bodies, restricted garden etc. This was observed on coconut seedlings at Regional Coconut Research Station, Bhatye, Ratnagiri during August, 2017 in Maharashtra, attended pest status in coconut garden after May, 2018 and was noticed on banana, custard apple, mango, cashew nut, almond, areca palm and bush pepper everywhere in Konkan region of Maharashtra. The maximum temperature had positive impact on the incidence and intensity of RSW. However, intensity of RSW was negatively correlated with rainfall and evening humidity (Wankhede *et al*., 2021). The immature and adult whitefly by their sucking feeding habit, siphon out coconut sap by selective feeding from the abaxial of the coconut leaflets. De-sapping by RSW would induce stress on the palms due to removal of water and nutrients, but neither colour change nor necrosis has been reported. The whitish mat of flies on lower side and black shooty mould on upper side was noticed. Considering the fast-growing status of this pest and its impact on coconut, the present study was conducted on the integrated management of rugose spiralling whitefly in coconut under coastal ecosystem of Maharashtra State.

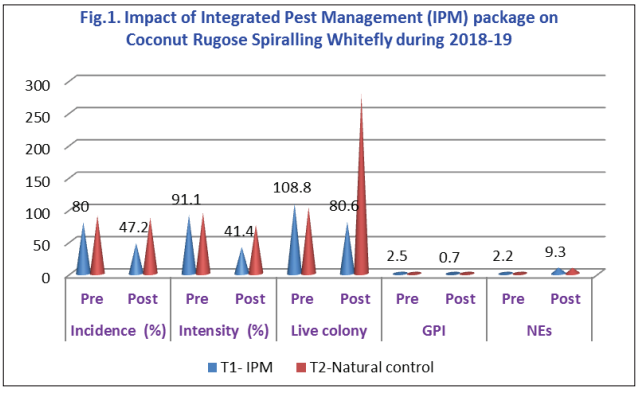

Fig. 1. Impact of IPM package on rugose spiralling whitefly (2018-19)

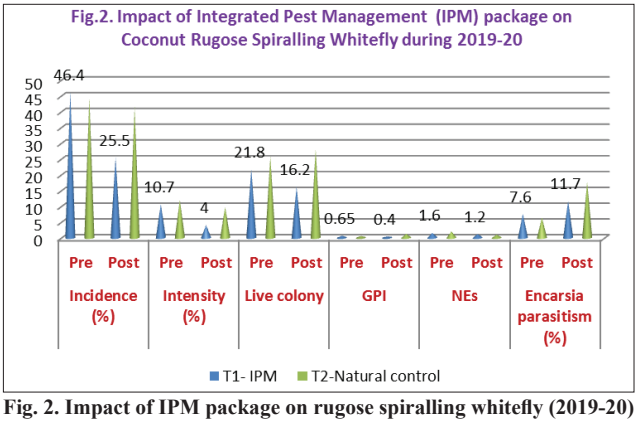

Fig. 2. Impact of IPM package on rugose spiralling whitefly (2019-20)

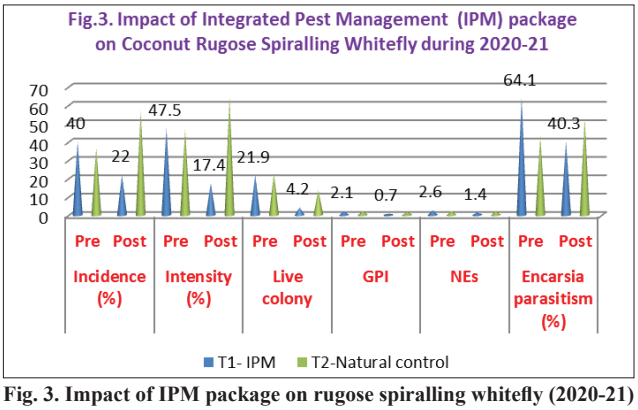

Fig. 3. Impact of IPM package on rugose spiralling whitefly (2020-21)

MATERIALS AND METHODS

An experiment on eco-friendly approaches for the management of coconut Rugose Spiralling Whitefly (*Aleurodicus rugioperculatus* Martin) under coastal ecosystem of Maharashtra State was conducted at AICRP (Palms), Regional Coconut Research Station, Bhatye Dist. Ratnagiri (M.S.) during 2018-19 to 2020-21. It consists of four sub experiments a) Evaluation of IPM package against coconut rugose spiralling whitefly (CRSW) b) Impact of yellow sticky traps at different heights against CRSW c) Individual effect of neem oil and water for the management of CRSW and d) Effect of different concentrations of neem oil on emergence of *Encarsia* from parasitized pupae of CRSW.

a) Evaluation of IPM package against coconut rugose spiralling whitefly (CRSW)

The experiment was initiated in every year during November with 25 palms of Gangabondam Green Dwarf coconut variety was selected for assessment of the efficacy of IPM strategies including three sprays of neem oil 0.5 per cent @ 5 ml/litre of water at fifteen days intervals in synergy with bands of yellow sticky traps followed by three rounds of water sprays at fifteen days intervals. The observations of per cent incidence (no. of leaves infested by RSW/total leaf per palm x100), intensity (no. of leaflets infested by RSW/total leaflets per leaf), grade pest intensity, RSW populations, natural enemies and *Encarsia* parasitism (%) per four leaflets were recorded one day prior as pre-treatment observations and post treatments observations were recorded after three months of superimposition of treatments.

b) Impact of yellow sticky trap at different height against coconut rugose spiralling whitefly

The said experiment was carried out for assessment of yellow sticky traps (YST) impact against RSW at different height. The six treatments *viz*., T_1-YST @ 1 feet from ground, T_2-YST @ 2 feet from ground, T_3-YST @ 3 feet from ground, T_4-YST @ 4 feet from ground, T_5-YST @ 5 feet from ground and T_6-Closed to crown region trap were tested with three replications in randomized block design. No. of whiteflies trapped on YST were recorded at 5 days interval and generated data was subjected for statistical analysis.

c) Individual effect of neem oil and water for the management of rugose spiralling whitefly

The present experiment was conducted for study the impact of neem oil and water spray alone on RSW. The pre-treatment observations were taken at 24 hours before imposition of treatments. Three sprays of neem oil @0.5% and water sprays three round were taken separately on coconut palms at 15 days interval and post treatment observations was recorded after 1.5 months after spraying. The per cent reduction over control of RSW incidence, intensity and populations were calculated over pre-count observations.

d) Effect of different concentrations of neem oil on emergence of *Encarsia* from parasitized pupae of coconut rugose spiralling whitefly

The set of laboratory experiment on safety of neem oil for *Encarsia* parasitism was conducted in Entomology laboratory, RCRS, Bhatye with eight treatment and three replications in completely randomized block design. The twenty *Encarsia* parasitized pupae of RSW on coconut

Table 1. Cumulative effect of integrated pest management package against rugose spiraling whitefly during three year 2018-21

Treat ments	Pre-treatment observations						Post treatment observations					
	Incidence of RSW (%)	Intensity of RSW (%)	RSW live colony /four leaflet	Grade pest index	Natural enemies (predators/ spiders)	*Encarsia* parasitism (%)	Incidence of RSW (%)	Intensity of RSW (%)	RSW live colony / four leaflet	Grade pest index	Natural enemies (predators/ spiders)	*Encarsia* parasitism (%)
T_1- IPM	55.4 ± 1.9	49.7 ± 1.8	50.8 ± 5.0	1.75 ± 0.7	2.13 ± 0.4	35.8 ± 2.6	31.5 ± 1.3	20.9 ± 1.3	33.6 ± 1.1	0.60 ± 0.3	3.9 ± 0.3	26.0 ± 3.8
T_2- Natural control	57.0 ± 1.5	51.0 ± 1.8	50.4 ± 4.4	1.6 ± 0.6	2.13 ± 0.3	24.6 ± 0.1	61.7 ± 1.7	49.7 ± 3.3	106 ± 4.8	1.63 ± 0.6	4.0 ± 0.3	35.1 ± 3.5
Sig. (P=0.05)	N.S.	N.S.	N. S	Low - < 1,	N.S.	N.S.	Sig.	Sig.	Sig.	Low - < 1,	N.S.	N.S.
't' value	0.48	0.41	0.55	Median - 1-2, High - 2-3	0.75	0.29	6.17	2.78	3.36	Median - 1-2, High - 2-3	1.04	0.38

(*mean ± standard error)*

leaflets were kept in each petri dish and applied different treatments *viz*., T_1- neem oil @ 0.1%, T_2- neem oil @ 0.3%, T_3- neem oil @ 0.4%, T_4- neem oil @ 0.5%, T_5- neem oil @ 0.6%, T_6- neem oil @0.7%, T_7- neem oil @ 1% and T_{10}-control. The *Encarsia* emergences from parasitized pupae of RSW were recorded at 15 days after imposition of treatments. The generated data were subjected for statistical analysis.

RESULTS AND DISCUSSION

The T1-IPM treatment was reduced the incidence, intensity, GPI and RSW population over T2-Natural control during 2018 (Fig.1). The grade pest intensity was recorded 0.70 (low) in T1-IPM as compared to pre-treatment count 2.5 (high). The T1-IPM treatment recorded minimum rugose spiralling whitefly population (80.6 nos.) which was significantly superior over T2-Natural control (278 nos.). The T2- natural control registered incidence, intensity and grade pest intensity of RSW which recorded 86.8, 75.7 per cent and 1.9 (medium) as compared to pre-count observation was noticed 90.0, 94.5 per cent and 2.10 (high), respectively. The non significant result was noticed about natural enemies (predators/spiders).

The incidence (25.5%) and intensity (4%) of RSW was recorded minimum in T1-IPM over pre-count (46.4% incidence and 10.7% intensity). The incidence was found significantly superior over the natural control (Fig.2). The T1-IPM treatment was found minimum rugose spiralling whitefly population (16.2 nos.) and *Encarsia* (11.7%) which was significantly superior over natural control (28.2 and 17.8 %, respectively).

The non significant results registered in pre-count observations. The T1-IPM treatment was recorded minimum incidence (22%) and intensity (17.4%) of rugose spiralling whitefly over pre-count (40 and 47.5%, respectively). The IPM treatment was found significantly superior over the natural control. The grade pest intensity was reduced in IPM 0.70 as over to pre-treatment count 2.1 (Fig.3). Moreover, the T1-IPM treatment was found minimum no. of RSW live colonies (4.2) which was significantly superior over T2-Natural control (13.4/ leaflet).

The non significant results were observed in natural enemies (predators/other) and *Encarsia* parasitism associated with RSW. The T2-Natural control registered the increased of incidence and intensity of RSW were recorded 56.9 and 63.9 as compared to pre-count observations were noticed 36.7 and 46.7 per cent, respectively.

Table 2. Impact of yellow sticky traps (YST) at different heights against rugose spiralling whitefly

Treatments Details		Mean no. of rugose spiralling whitefly trapped on YST per Sqft²			
		5th day	10th day	15th day	Mean
T_1	YST @1 feet from ground	4.75 (2.34) *	10.75 (3.42)	4.75 (2.32)	6.75 (2.69)
T_2	YST @ 2 feet from ground	9.25 (3.26)	12.25 (3.56)	10.75 (3.31)	10.75 (3.37)
T_3	YST @ 3 feet from ground	28.75 (5.36)	22.75 (4.61)	36.25 (6.27)	29.25 (5.41)
T_4	YST @ 4 feet from ground	40.50 (5.68)	31.50 (4.84)	39.75 (5.84)	37.25 (5.45)
T_5	YST @ 5 feet from ground	23.25 (4.33)	22.25 (4.45)	19.50 (3.99)	21.66 (4.25)
T_6	Closed to crown region trap	12.25 (3.69)	16.00 (3.44)	17.0 (4.02)	15.08 (3.71)
S.Em. ±		**0.42**	**0.54**	**0.45**	**0.47**
C.D. @ 5%		**1.55**	**1.99**	**1.66**	**1.73**
C.V.		**3.00**	**3.90**	**3.08**	**3.32**

(Figures in parenthesis are square root transformed values)*

Table 3. Efficacy of neem oil spray alone on rugose spiralling whitefly in coconut

Treatments		Incidence of RSW (%)	Intensity of RSW (%)	RSW live colony /four leaflet	Grade pest index	Natural enemies (predators/ spiders)	*Encarsia* parasitism (%)
Neem oil @ 0.5%	**Pre-count**	17.4 ± 1.8	28.3 ± 3.6	23.2 ± 0.4	1.67	0.4 ± 0.2	79.0 ± 3.2
	Post-count	11.6 ± 1.7	17.8 ± 2.2	14.6 ± 0.7	0.31	0.8 ± 0.0	83.0 ± 2.0
Sig. (P=0.05)		N.S.	Sig.	Sig.	Low - < 1, Median - 1-2, High - 2-3	N.S.	N.S.
't' value		2.92	4.41	3.98		1.00	0.01
(%) reduction over control		33.3	37.1	37.0	-	-	-

(Average mean ± standard error)

Table 4. Efficacy of water spray alone on rugose spiralling whitefly in coconut

Treatments		Incidence of RSW (%)	Intensity of RSW (%)	RSW live colony /four leaflet	Grade pest index	Natural Enemies (Predators/ spiders)	*Encarsia* parasitism (%)
Water spray	**Pre-count**	18.1 ± 2.4	29.5 ± 3.5	33.8 ± 5.3	1.3	1.0 ± 0.4	78.0 ± 2.3
	Post-count	16.0 ± 3.1	23.4 ± 2.0	26.4 ± 1.4	1.0	1.2 ± 0.6	82.0 ± 2.0
Sig. (P=0.05)		N.S.	N.S.	N.S.	Low - < 1, Median - 1-2, High - 2-3	N.S.	N.S.
't' value		0.49	0.18	0.65		0.77	0.31
(%) reduction over control		11.6	20.6	21.8	-	-	-

Average mean ± standard error

The non significant results were observed in natural enemies (predators/other) and *Encarsia* parasitism associated with RSW. The T2-Natural control registered the increased of incidence and intensity of RSW were recorded 56.9 and 63.9 as compared to pre-count observations were noticed 36.7 and 46.7 per cent, respectively.

The data presented in table 2 indicated that the maximum whiteflies was recorded on T_4-YST @ 4 feet from ground (37.25 nos.) found significantly superior over T_6- YST closed with crown region (15.08 nos.), T_2-YST @ 2 feet from ground (10.75 nos.) and T_1-YST @ 1 feet from ground (6.75 nos.). It was on par with T_3-YST @ 3 feet from ground (29.25 nos.) and T5-YST @ 5 feet from ground (21.66 nos.). The yellow coloured sticky traps, made with sheets (100x50cm) and smeared with white grease recorded the maximum catch of rugose spiralling whiteflies (18.3 nos.) by Wankhede *et al.* (2022). Atakan and Canhilal (2004) assessed the sticky yellow traps at 60, 80, 100, and 120 cm above ground level in various developmental stages of cotton for their relative efficiency in capturing the leafhoppers, whitefly and thrips. Dewangan *et al.* (2019) assessment of variability of yellow sticky trap heights in soybean whitefly taking into consideration of six trap heights and it is found that the lower trap height three feet differs significantly with all the trap heights. Idris *et al*. (2012) found that the yellow was the most attractive colour to alate whitefly. Elango *et al*., 2017 found that the yellow was most attractive for white fly (22.1 whiteflies/per trap/per week) followed by pale yellow (13.8 whiteflies/per trap/per week) and green (13.1 whiteflies/per trap/per week). Generated results of field trials confirmed that yellow sticky trap attracted a greater number of whiteflies as compared to the others, may be used in methods of insect population monitoring (Khuhro *et al*., 2020). These results agree with Premalatha and Rajangam (2011) who reported that maximum number of whiteflies *Trialeurodes vaporariorum* (Westwood) attracted towards yellow sticky trap in gerbera. Likewise, Lu *et al.* (2012) reported that yellow sticky traps can be used as an effective method for the control of whiteflies, *Bemisia tabaci* in the greenhouse.

The data depicted in table 3 revealed that the neem oil @ 5 per cent found effective against RSW which recorded minimum incidence (11.6 %), intensity (17.8 %) and live colony of RSW (14.6 nos.) over pre-count observations *viz.,* 17.4, 28.3 and 23.2 nos., respectively. The per cent reduction over pre-count was noticed incidence (33.3%), intensity (37.1%) and live colony (37.1 nos.).

Table 5. Effect of different concentrations of neem oil on emergence of *Encarsia* from parasitized pupae of rugose spiralling whitefly

Treatments Details		*Encarsia* Emergence (%) from parasitized pupae of RSW		
		First application	Second application	Mean
T_1	Neem oil 0.1% @ 1ml/litre of water	91.0 (72.8)	93.3 (74.9)	92.1 (73.8)
T_2	Neem oil 0.3% @ 3ml/litre of water	88.8 (70.6)	88.8 (70.6)	88.8 (70.6)
T_3	Neem oil 0.4 @ 4ml/litre of water	84.4 (67.2)	86.6 (68.9)	85.6 (68.0)
T_4	Neem oil 0.5% @ 5ml/litre of water	82.2 (65.1)	84.4 (66.8)	83.3 (65.9)
T_5	Neem oil 0.6% @ 6ml/litre of water	79.9 (63.6)	79.9 (63.6)	79.9 (63.6)
T_6	Neem oil 0.7% @ 7ml/litre of water	75.5 (60.4)	77.7 (61.9)	76.6 (61.1)
T_7	Neem oil 1% @ 10ml/litre of water	66.6 (54.6)	68.8 (56.0)	67.7 (55.3)
T_8	Control	95.5 (79.9)	97.7 (84.9)	96.6 (82.4)
S.Em. ±		2.97	2.72	2.84
C.D. @ 5%		9.01	8.26	8.63

(Figures in parenthesis are Arc sign transformed values)

Ghosh *et al.* (2013) found the satisfactory control (>60% population suppression) was achieved with neem oil. Sridhar *et al.* (2017) found that the (75%) mortality of *B. tabaci* with neem/pongamia/fish oils were used together @3ml/l each. Oils alone gave upto (48.75%) mortality of *B. tabaci* and highest synergism was recorded with neem oil followed by fish oil and pongamia oil.

The forcibly application of water sprays was observed incidence (16%), intensity (23.4%) and 26.4 nos. of live colony of RSW which found better results than pre-treatment observations (18.1, 29.5 and 33.8 nos., respectively). The water sprays were reduced RSW incidence (11.6%), intensity (20.6%) and 21.8 live colony of RSW over pre-count (Table 4).

The data presented in table 5 revealed that the maximum *Encarsia* emergence from parasitized pupae of RSW was noticed in T_8-control treatment (96.6%). The next effective treatment was T1-neem oil @ 1 ml/litre of water (92.1 %) which found significantly superior over T_5-neem oil @ 6 ml /litre of water (79.9 %), T_6-neem oil @ 7 ml /litre (76.6 %) and T_7-neem oil @ 10 ml /litre of water (67.7 %) emergence of *Encarsia* from parasitized pupae of RSW and was noticed at par with T_2-neem oil @ 3ml/litre (88.8 %), T_3-neem oil @ 4 ml/litre of water (85.6 %) and T_4-neem oil @ 5 ml/litre of water (83.3 %). Aziz *et al.* (2019) found that the population of predators was not affected significantly by application of 2 per cent of neem seed extract because of predators are not phytophagous like other pests. Neem oil of biological origin (bio-pesticides) have less or no hazardous effects on human health and the environment, therefore, it can be incorporated in IPM programmes and organic farming in vegetable cultivation by Ghosh *et al.* (2013).

CONCLUSION

The T_1- IPM treatment (neem oil @ 0.5 % with yellow sticky traps 1 ft sized wrapped around the palm @ 4 feet height from ground level) was found effective for the management of rugose spiralling whitefly infesting coconut palms when applied at three sprays at 15 days intervals followed three rounds of forcibly water sprays at fortnightly interval which are safety to the natural enemies.

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Efficacy of thiamethoxam against whitefly, *Bemisia tabaci* (Gennadius) under open field conditions in okra

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ABSTRACT: A field experiment was conducted at Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar, India during the summer season, 2021-22 to evaluate a neonicotinoid, thiamethoxam against whitefly, *Bemisia tabaci* (Gennadius) along with other new molecules. Among the various doses of foliar application thiamethoxam, sprayed twice at an interval of 10 days on okra, resulted in 87-90 per cent reduction over untreated control. Seed treatment with thiamethoxam 30% FS formulation was also effective against *B. tabaci* upto 45 days from seed treatment. Foliar application of thiamethoxam (50 g a.i. per ha) gave highest yield and ICBR ratio and it was in line with the appliaction of thiamethoxam 37.5 and 25 g a.i. per ha. All the tested insecticide formulations were found to be safe for coccinellid beetles, except dimethoate 30 EC @ 600 g a.i. / ha, which have negative effect on coccinellid beetles as recorded in the okra ecosystem in comparison to the higher dose of thiamethoxam 25 WG (double dose @ 50 g a.i. ha^{-1}). Results also showed that none of the insecticide formulations had phytotoxicity effect in okra ecosystem.

Keywords: Okra, thiamethoxam, field bioefficacy, *B. tabaci*, phytotoxicity coccinellids beetle, phytotoxicity

INTRODUCTION

Okra, *Abelmoschus esculentus* (L.) Moench, belongs to the Malvaceae family and is commonly known as lady's finger. In various tropical countries, okra is one of the most widely grown vegetables. India is the world's largest okra producer, and its contribution to okra production is 72.9 per cent globally. In India, it is cultivated on 531 thousand hectares and has an annual production of 6466 thousand metric tonnes and a productivity of nearly 12.2 metric tonnes ha^{-1}. In Bihar, it is cultivated on 59.20 thousand hectares, with annual production of 794.10 thousand metric tonnes and a productivity of nearly 13.72 metric tonnes ha^{-1} (Anonymous, 2022). Different kinds of biotic and abiotic factors reduce okra yield. Biotic factors is considered to be major constraints on okra yield. Okra crop is infested by more than 37 species of insect pests, from seedlings to fruiting stage like sucking insect pests *viz.,* leaf hopper, *Amrasca biguttula biguttula* Ishida, whitefly, *Bemisia tabaci* (Gennadius), spider mites, *Tetranychus cinnabarinus* Boisduval, aphids, *Aphis gossypii* (Glover), yellow thrips, *Scirtothrips dorsalis* Hood and the borers, *i.e.,* fruit borer, *Helicoverpa armigera* (Hubner), and shoot and fruit borer, *Earias vittela* and *E. insulana* (Fabricius). In okra crops, sucking insect pests like whiteflies, leafhoppers, aphids, and thrips are the most prevalent. During the early stages of the crop, whitefly desap the plants, make them weak, and reduces yield by 54.04 per cent (Chaudhary and Dadeech, 1989).

Insecticidal sprays are frequently used to manage these destructive sucking pest, but this has resulted in toxic residues, the eradication of natural enemies, environmental disruption, and the emergence of resistance. In order to meet these problems, insecticides from a more recent generation have lower toxicity toward non-target species, stronger efficacy against the pests they are intended to control, and are not as tenacious as earlier insecticides. The study on new formulation of neonicotinoid insectcides lacks bioefficacy, phytotoxicity, and safety towards coccinellid beetles. Chemical management is the most effective strategy since the okra whitefly multiplies and spreads quickly in a short amount of time under favourable climatic circumstances. In light of this, the current interpretation was employed to analyze thiamethoxam's field evaluation against whitefly, *B. tabaci* in okra ecocsytem under North Bihar conditions.

Table 1. Efficacy of selected insecticide formulations used in okra for the management of whitefly, *Bemisia tabaci* (Gennadius) during summer season in 2021-2022

Treatments	Mean number of whiteflies/three leaves/plants I spray				Reduction over untreated control (%)	Mean number of whiteflies/three leaves/plants II spray				Reduction over untreated control (%)	Overall reduction over untreated control (%)
	34 DAS	38 DAS	42 DAS	45 DAS		45 DAS	48 DAS	52 DAS	55 DAS		
Seed treatment											
Thiamethoxam 30.00 % FS @ 1.7 g a.i. /kg of seed	7.67 (2.86)^{bc}	8.33 (2.97)^{b}	9.33 (3.13)^{b}	12.67 (3.63)^{b}	44.84	12.67 (3.63)^{b}	14.33 (3.85)^{b}	17.00 (4.18)^{b}	18.33 (4.34)^{b}	26.95	34.97
Thiamethoxam 30.00 %FS @ 2.55 g a.i./kg of seed	6.40 (2.63)^{c}	7.74 (2.86)^{bc}	8.74 (3.04)^{b}	12.07 (3.55)^{b}	48.11	12.07 (3.55)^{b}	14.07 (3.81)^{b}	15.40 (3.99)^{b}	16.40 (4.11)^{b}	32.55	39.51
Thiamethoxam 30.00 % FS @ 3.4 g a.i. /kg of seed	6.00 (2.55)^{c}	7.33 (2.80)^{bc}	8.67 (3.03)^{b}	10.33 (3.29)^{b}	52.10	10.33 (3.29)^{b}	13.33 (3.71)^{b}	14.67 (3.89)^{b}	16.00 (4.05)^{b}	35.28	42.82
Foliar spray											
-	1DBT	3 DAT	7 DAT	10 DAT	-	1 DBT	3 DAT	7 DAT	10 DAT	-	-
Thiamethoxam 25 WG @ 25 g a.i. / ha.	14.47 (3.85)^{a}	5.80 (2.50)^{bc}	2.13 (1.62)^{c}	3.13 (1.89)^{cd}	79.86	3.13 (1.89)^{cd}	2.10 (1.61)^{cd}	1.13 (1.27)^{c}	0.80 (1.12)^{c}	94.04	87.70
Thiamethoxam 25 WG @ 37.5 g a.i. / ha.	13.66 (3.74)^{ab}	5.66 (2.48)^{bc}	1.99 (1.57)^{c}	2.66 (1.78)^{cd}	81.28	2.66 (1.78)^{cd}	1.96 (1.56)^{cd}	0.99 (1.20)^{c}	0.66 (1.07)^{c}	94.66	88.68
Thiamethoxam 25 WG @ 50 g a.i. / ha.	13.15 (3.65)^{ab}	4.82 (2.30)^{c}	1.82 (1.42)^{c}	2.49 (1.73)^{d}	83.41	2.49 (1.73)^{c}	1.79 (1.50)^{d}	0.82 (1.14)^{c}	0.49 (0.99)^{c}	95.41	90.04
Pyriproxyfen 10 EC @ 50 g a.i. / ha.	13.65 (3.76)^{ab}	7.32 (2.79)^{bc}	3.32 (1.95)^{c}	4.98 (2.33)^{c}	71.57	4.98 (2.33)^{c}	3.98 (2.11)^{c}	1.98 (1.57)^{c}	1.65 (1.47)^{c}	88.79	81.12
Imidacloprid 17.80 SL @ 20 g a.i. / ha.	15.01 (3.94)^{a}	6.34 (2.61)^{bc}	2.34 (1.62)^{c}	3.34 (1.96)^{cd}	78.12	3.34 (1.96)^{cd}	2.31 (1.66)^{cd}	1.21 (1.30)^{c}	0.87 (1.16)^{c}	93.51	86.63
Dimethoate 30 EC @ 600 g a.i. / ha.	15.86 (4.04)^{a}	6.86 (2.70)^{bc}	2.86 (1.83)^{c}	3.86 (2.06)^{cd}	75.28	3.86 (2.06)^{cd}	3.20 (1.92)^{cd}	1.86 (1.52)^{c}	1.53 (1.42)^{c}	90.29	83.60
Untreated control	14.89	16.22	18.89	19.89		19.89	20.55	23.22	24.22		
(Water spray)	(3.92)^{a}	(4.09)^{a}	(4.40)^{a}	(4.52)^{a}	-	(4.52)^{a}	(4.59)^{a}	(4.87)^{a}	(4.97)^{a}	-	-
F value		*	*	*	*	-		*	*	*	*	-	-
SEM±	0.19	0.12	0.19	0.11	-	0.11	0.11	0.10	0.11	-	-
CD (P=0.05)	0.58	0.37	0.55	0.33	-	0.33	0.34	0.30	0.30	-	-
CV%	9.64	7.65	13.61	7.30	-	7.30	7.44	7.07	7.74	-	-

*Significant at (P≤0.05); Figures within the parentheses indicates √x+0.5 transformed values; Mean followed by the same letter do not differ significantly by TUKEY test (P=0.05)
DAS= Day after sowing DBT= Day before treatment DAT= Day after treatment

MATERIALS AND METHODS

Field experiment

An open field experiment was conducted at RPCAU, Pusa, Samastipur (25.98 °E longitude; 85.68 °N latitude), Bihar, India in a Randomized Block Design (RBD) to evaluate thiamethoxam's field effectiveness against whitefly, *B. tabaci* in okra crop under North Bihar conditions during *summer* season of 2021-22 with ten treatments *viz.,* T_1) thiamethoxam 30% FS @ 1.7 g a.i. /kg of seed; T_2) thiamethoxam 30%FS @ 2.55 g a.i./kg of seed; T_3) thiamethoxam 30 % FS @ 3.4 g a.i. /kg of seed; T_4) thiamethoxam 25 WG @ 25 g a.i. / ha; T_5) thiamethoxam 25% WG @ 37.50 g a.i. per ha; T_6) thiamethoxam 25% WG @ 50 g a.i. per ha; T_7) pyriproxyfen 10 EC @ 50 g a.i. / ha; T_8) imidacloprid 17.80 SL @ 20 g a.i. / ha; T_9) dimethoate 30 % EC @ 600 g a.i per ha (standard check); T_{10}) untreated control (water spray). Each treatment is having an area of 6 x 5 m^2 with three replications. Sowing of the okra crop (var. Kashi kranti) was sown in March, 2022 according to the standard recommended agronomic practices. Spray solution was calculated with 500 litre of water for one spray for one hectare and in total, two sprays were given with a gap of 10 days. The first application was given when the pest population reached at Economic Threshold Level (ETL). Spraying was done using a knapsack sprayer.

Bioefficacy against *B. tabaci*

For identification of the okra whitefly, five plants were chosen randomly and tagged. The population of nymphs and adults of whitefly were counted from three leaves per plant, one from the top, middle, and bottom of those plants that were pre-selected. The sightings were identified as pretreatment count (1 day prior to treatment) and post treatment observations on the whitefly population at 3, 7, and 10 days after each spray. In case of seed treatments the whitefly population was recorded at 34 days after sowing in each seed treated plot. For each treatment, after every spray, the percentage reduction (PR) of whiteflies over the untreated control was computed using the given formula PR = [(control count-treatment count/ control count)] × 100. Marketable okra fruit yields per treatment were tallied at each harvest, combined, and expressed in kg ha^{-1}. Using the following formula, the yield was converted to a ha^{-1} basis *i.e.,* yield (kg ha^{-1}) = [(yield per plot (kg)/plot size (m^2)] × 10000 then it was analyzed statistically. To combat okra whitefly, the ICBR (Incremental Cost Benefit Ratio) of several treatments was computed.

Safety evaluation of coccinellid beetles

The safety evaluation of several insecticide formulations on coccinellid beetles in okra was also investigated. In each plot, ten plants were randomly chosen one day before treatment, then 3, 7, and, 10 days following after each application. Later the observed result was analyzed statistically.

Phytotoxicity in the okra ecosystem

The phytotoxic effects of different formulations of insecticides on okra leaves, flowers, and fruits were also studied. Five plants were randomly selected in each plot. The plants were examined for phytotoxic symptoms *viz.,* necrosis, epinasty, hyponasty, chlorosis, and wilting one day before spraying, 3, 7, and 10 days after each application. The per cent leaf injury was calculated by using the following equation *i.e.,* % leaf injury = [(total grade point/maximum grade × no. of leaves observed)] ×100. The phytotoxicity symptoms were graded based on the per cent injured leaves as per the Central Insecticides Board and Registration Committee's (CIB & RC, India) grade scale *viz.,* no. phytotoxicity grade 0; 1-10% - grade 1; 11-20% - grade 2; 21-30% - grade 3; 31-40% - grade 4; 41-50% - grade 5; 51-60% - grade 6; 61-70% - grade 7; 71-80% - grade 8; 81-90% - grade 9; 91-100% - grade 10.

Statistical analysis

The data on the okra whitefly population and coccinellid beetles in different treatments were subjected to Analysis of Variance (ANOVA) following Randomized Block Design (RBD) using the statistical software SPSS. TUKEY test was used to compare the mean differences between the treatments at 5% level of significance.

RESULTS AND DISCUSSION

Bioefficacy of selected insecticide formulations against *B. tabaci*

The incidence of okra whitefly, before and after two spray of insecticidal treatments in 2021-22 are illustrated in Table 1. The nymphs and adults mean population of whitefly prior to spraying was ranged in 7.67 to 14.98 per three leaves/plants. After the first insecticidal application, whitefly population was significantly reduced in all the treated plots, but augmented in control plots. Three days after 1st application of insecticides spray, results showed that the thiamethoxam (50 g a.i. per ha) treated plot had the least mean whitefly population (4.82) followed by thiamethoxam at 37.5 g a.i. per ha (5.66), thiamethoxam at 25 g a.i. per ha (5.80), imidacloprid 17.80 SL @ 20 g a.i. / ha (6.34), and dimethoate 30 EC

Table 2. Economics of selected insecticide formulations used in okra for the management of whitefly, *Bemisia tabaci* (Gennadius) during summer season in 2021-22

Treatments	Yield (kg ha^{-1})	ICBR
Thiamethoxam 30.00 % FS @ 1.7 g a.i. /kg of seed	8168	1:2.69
Thiamethoxam 30.00 %FS @ 2.55 g a.i./kg of seed	8184	1:2.83
Thiamethoxam 30.00 % FS @ 3.4 g a.i. /kg of seed	8197	1:2.93
Thiamethoxam 25 WG @ 25 g a.i. / ha.	8261	1:3.89
Thiamethoxam 25 WG @ 37.5 g a.i. / ha.	8282	1:3.97
Thiamethoxam 25 WG @ 50 g a.i. / ha.	8310	1:4.14
Pyriproxyfen 10 EC @ 50 g a.i. / ha.	8234	1:2.35
Imidacloprid 17.80 SL @ 20 g a.i. / ha.	8253	1:3.73
Dimethoate 30 EC @ 600 g a.i. / ha.	8242	1:1.24
Untreated control (Water spray)	7919	

@ 600 g a.i. / ha (6.86). Comparatively less effective treatments were pyriproxyfen 10 EC @ 50 g a.i. / ha (7.32). Seven days after 1st spray application, again least mean whitefly population was recorded per treatement at three diffrerent dose of thiamethoxam 50, 37.5 and 25 g a.i. per ha were1.82, 1.99, and 2.13, respectively. Furthermore, followed by imidacloprid 17.80 SL @ 20 g a.i. / ha (2.34), dimethoate 30 EC @ 600 g a.i. / ha (2.86) and pyriproxyfen 10 EC @ 50 g a.i. / ha (3.32). After ten days of 1st spray, the population of whitefly started increasing in comparison to 7 days in all the treatments.

Three days after 2nd application of insecticides spray, it was noticed that the whitefly population was least in thiamethoxam at 50 and 37.5 g a.i per ha *i.e.,* 1.79 and 1.96 and followed by thiamethoxam at 25g a.i per ha (2.10), imidacloprid at 20 g a.i. / ha (2.31), and dimethoate at 600 g a.i. / ha (3.20) which was statistically at par. Comparatively less effective treatments were pyriproxyfen at 50 g a.i. / ha (3.98). Seven days after 2nd spray application, it was reflected in line with the one-day post-application in terms of efficacy, again thiamethoxam at 50 g a.i per ha (0.82) showed a significant reduction in whitefly population followed by thiamethoxam at 37.5 g a.i per ha (0.99), thiamethoxam at 25g a.i per ha (1.13), imidacloprid at 20 g a.i. / ha (1.21), and dimethoate at 600 g a.i. / ha (1.86). Again the comparatively less effective treatments were pyriproxyfen at 50 g a.i. / ha (1.98). Ten days after the 2nd spray post-appliance, the same trend was followed. In case of seed treatements, thiamethoxam 30% FS @ 1.7 g a.i. /kg of seed, thiamethoxam 30 %FS @ 2.55 g a.i./ kg of seed, and Thiamethoxam 30% FS @ 3.4 g a.i. /kg of seed were effective upto 45 days after sowing, then the population of whitefly gradually increased in all the treatemets over untreated control. Hence, the order of efficacy of these treatments were T_{6-} thiamethoxam 25 WG @ 50 g a.i. per ha > T_5 -thiamethoxam 25 WG @ 37.5 g a.i. per ha > T_6 - thiamethoxam 25 WG @ 25 g a.i. per ha > T_8 - imidacloprid 17.80 SL @ 20 g a.i. / ha > T_9 - Dimethoate 30 EC @ 600 g a.i. per ha > T_9 - pyriproxyfen 10 EC @ 50 g a.i. / ha > T_3 - thiamethoxam 30 % FS @ 1.7 g a.i. /kg of seed > T_2 - thiamethoxam 30%FS @ 2.55 g a.i./kg of seed > T_1 - thiamethoxam 30% FS @ 3.4 g a.i. /kg of seed.

The current findings correspond closely to those of (Ghosal and Chatterjee, 2013), who found that imidacloprid (17.8 SL), thiamethoxam (25 WG), and oxydemeton methyl (25 EC) were applied to brinjal in decreasing order. According to Ghosal *et al.,* 2013), imidacloprid 17.8 SL was the most efficient neonicotinoids pesticide against aphids, with a population reduction of 84.54% compared to control. In addition to being found at par with imidacloprid, the other two neonicotinoids, thiamethoxam 25 WG (84.36%) and acetamiprid 20 SP (84.25%), also performed better than acephate 75 WP (76.38%) and dimethoate 30 EC (73.53%). (Berwa *et al.,* 2017) reported that imidacloprid 17.8% SL (35.6 g a.i./ha) treatments were significantly effective against the jassids, *Amrasca biguttula biguttula* (Ishida), aphid, *Aphis gossypii* Glover, and whitefly, *Bemisia tabaci* (Gennadius) as it recorded the lowest population. The cumulative effect of foliar spraying with thiamethoxam 25 WG @ 0.006% was shown to be the most efficient against aphids among the treatments evaluated according to Patil *et al.* (2014). Lambda cyhalothrin 5 EC @ 0.004% was ranked second. Karthik *et al.* (2020) evaluated thiamethoxam 25% WG 25 g a.i. ha^{-1} (84.71-91.73, 94.12 - 98.11% reduction over control was highly effective against aphid, whitefly, and leaf hoppers which was on par with 50 g a.i. ha^{-1} (64.28 - 76.90, 83.70 – 87.92 % reduction over control) and 75 g a.i. ha^{-1} (73.48 - 81.26 and 85.26 - 92.42% reduction over control) after first and second spray, respectively. Imidacloprid was the next best effective control against arecanut whitefly and scale insects (Dubey *et al.,* 2020).

able 3. Safety evaluation of selected insecticide formulations against coccinellids in okra (summer 2021-22)

Treatments	Mean number of coccinellids/ten plants					Mean number of coccinellids/ten plants					Overall mean
	I spray				Mean	II spray				Mean	
	34 DAS	38 DAS	42 DAS	45 DAS		45 DAS	48 DAS	52 DAS	55 DAS		
Seed treatment											
Thiamethoxam 30.00 % FS @ 1.7 g a.i. /kg of seed	4.20 (2.13)^{ab}	4.87 (2.31)^{b}	5.20 (2.39)^{bc}	6.53 (2.64)^{a}	5.53 (2.45)^{cd}	6.53 (2.64)^{a}	7.20 (2.77)^{ab}	7.87 (2.89)^{b}	8.20 (2.95)^{ab}	7.76 (2.74)^{b}	6.64 (2.62)^{bc}
Thiamethoxam 30.00 %FS @ 2.55 g a.i./kg of seed	4.13 (2.15)^{ab}	4.80 (2.30)^{b}	5.13 (2.37)^{bcd}	6.13 (2.57)^{b}	5.36 (2.42)^{cd}	6.13 (2.57)^{b}	6.80 (2.70)^{ab}	7.47 (2.82)^{b}	8.13 (2.93)^{ab}	7.47 (2.82)^{bcd}	6.41 (2.62)^{bc}
Thiamethoxam 30.00 % FS @ 3.4 g a.i. /kg of seed	3.40 (1.97)^{b}	3.73 (2.06)^{b}	4.40 (2.21)^{cd}	5.40 (2.43)^{b}	4.51 (2.23)^{de}	5.40 (2.43)^{b}	6.07 (2.56)^{ab}	6.73 (2.69)^{b}	7.73 (2.86)^{ab}	6.84 (2.71)^{cd}	5.68 (2.47)^{c}
Foliar spray											
-	1 DBT	3 DAT	7 DAT	10 DAT	Mean	1 DBT	3 DAT	7 DAT	10 DAT	Mean	-
Thiamethoxam 25 WG @ 25 g a.i. / ha.	5.77 (2.49)^{ab}	5.43 (2.43)^{ab}	7.77 (2.87)^{ab}	8.43 (2.99)^{b}	7.21 (2.77)^{ab}	8.43 (2.99)^{b}	6.77 (2.68)^{ab}	7.77 (2.87)^{b}	8.44 (2.98)^{ab}	7.66 (2.85)^{bc}	7.43 (2.82)^{b}
Thiamethoxam 25 WG @ 37.5 g a.i. / ha.	6.70 (2.67)^{ab}	5.04 (2.35)^{b}	6.70 (2.68)^{abc}	7.37 (2.80)^{b}	6.37 (2.61)^{bc}	7.37 (2.80)^{b}	6.04 (2.54)^{ab}	6.70 (2.68)^{b}	7.70 (2.85)^{ab}	6.81 (2.70)^{cd}	6.59 (2.66)^{bc}
Thiamethoxam 25 WG @ 50 g a.i. / ha.	7.57 (2.83)^{a}	4.90 (2.32)^{b}	6.57 (2.64)^{abc}	7.23 (2.74)^{b}	6.23 (2.59)^{bc}	7.23 (2.74)^{b}	5.90 (2.53)^{ab}	6.57 (2.66)^{b}	7.57 (2.83)^{bc}	6.68 (2.68)^{d}	6.46 (2.64)^{bc}
Pyriproxyfen 10 EC @ 50 g a.i. / ha.	5.32 (2.40)^{ab}	4.98 (2.33)^{b}	6.32 (2.61)^{abc}	7.32 (2.79)^{b}	6.21 (2.58)^{bc}	7.32 (2.79)^{b}	6.98 (2.73)^{ab}	7.65 (2.85)^{b}	7.65 (2.85)^{ab}	7.43 (2.82)^{bcd}	6.82 (2.70)^{bc}
Imidacloprid 17.80 SL @ 20 g a.i. / ha.	5.01 (2.34)^{ab}	4.67 (2.27)^{b}	5.34 (2.42)^{bc}	6.67 (2.67)^{b}	5.56 (2.46)^{cd}	6.67 (2.67)^{b}	6.01 (2.52)^{ab}	7.01 (2.73)^{b}	8.01 (2.91)^{ab}	7.01 (2.74)^{bcd}	6.29 (2.60)^{bc}

	5.53	3.53										
Dimethoate 30 EC @ 600 g a.i. / ha.	(2.45)^{ab}	(1.99)^{b}	2.86	4.53	3.64	4.53	3.86	3.53	4.53	3.97		3.81
			(1.83)^{d}	(2.22)^{b}	(2.03)^{e}	(2.22)^{b}	(2.08)^{b}	(2.00)^{e}	(2.21)^{c}	(2.11)^{e}		(2.07)^{d}
	6.55	7.89										
Untreated control	(2.65)^{ab}	(2.90)^{a}	8.55	8.89	8.44	8.89	9.89	10.55	11.55	10.67		9.55
(Water spray)			(3.00)^{a}	(3.06)^{b}	(2.99)^{a}	(3.06)^{b}	(3.22)^{a}	(3.32)^{a}	(3.46)^{a}	(3.34)^{a}		(3.17)^{a}
F value	*	*	*	*	*	*	*	*	*	*		*
SEM±	0.15	0.10	0.11	0.24	0.21	0.16	0.15	0.08	0.12	0.21		0.22
CD(P=0.05)	0.44	0.30	0.32	0.50	0.61	0.49	0.46	0.24	0.37	0.63		0.71
CV%	10.56	7.41	7.39	10.80	14.24	10.80	10.09	5.02	7.41	13.42		11.97

*Significant at (P≤0.05); Figures within the parentheses indicates √x+0.5 transformed values;
Mean followed by the same letter do not differ significantly by TUKEY test (P=0.05)

DAS= Day after sowing

DBT= Day before treatment

DAT= Day after treatment

Economics of selected insecticide formulations in okra

Maximum marketable fruit yield of 8310 kg ha^{-1} was recorded in thiamethoxam 25 WG @ 50 g a.i. / ha, which was on par with thiamethoxam 25 WG @ 37.5 g a.i. / ha of yield 8282 kg ha^{-1}, followed by thiamethoxam 25 WG @ 25 g a.i. / ha giving 8261 kg ha^{-1} and imidacloprid 17.80 SL @ 20 g a.i. / ha giving 8253 kg ha^{-1}**.** The maximum incremental cost benefit ratio (4.14) was achieved in thiamethoxam 25 WG @ 50 g a.i. / ha treatment. This was followed by thiamethoxam 25 WG @ 37.5 g a.i. / ha (3.97), thiamethoxam 25 WG @ 25 g a.i. / ha (3.89) and imidacloprid 17.80 SL @ 20 g a.i. / ha (3.73) (Table 2). Raghuraman and Gupta (2006) showed that neonicotinoids were a cost-effective way to control the population of cotton-sucking bugs while increasing production. Neonicotinoids have been recommended by Saha et al. (2011); Kencharaddi and Balikai (2012) as a superior alternative for controlling a variety of sucking pests with a high C: B ratio. Here, imidacloprid 17.8 SL, thiamethoxam 25 WG, and Acetamiprid 20 SP at 40 g a.i. ha^{-1} were effective in reducing aphid and recorded increased yields with the highest cost-benefit ratio.

Phytotoxicity of selected insecticide formulation on okra

No phytotoxic symptoms were seen to have appeared on the okra leaves, flowers or fruits which were used during the insecticidal treatments for the management of whitefly, comprising of three dosages of thiamethoxam 30% FS (1.7, 2.55, and 3.4 g a.i. kg^{-1} of seed) and thiamethoxam 25 WG (25, 37.5, and 50 g a.i. ha^{-1}) and three other insecticides with field recommended dosages namely pyriproxyfen 10 EC @ 50 g a.i. ha^{-1} imidacloprid 17.80 SL @ 20 g a.i. ha^{-1}, and dimethoate 30 EC @ 600 g a.i. ha^{-1}**.**

Safety of selected insecticide formulations on okra

Coccinellids were the main predators of the sucking pests in the okra ecosystem during the study period. Results revealed that among all the treatments, the highest mean population of coccinellids was observed in thiamethoxam 25 WG @ 25 g a.i. / ha (7.43) followed by pyriproxyfen 10 EC @ 50 g a.i. / ha (6.82), thiamethoxam 30% FS @ 1.7 g a.i. /kg of seed (6.64), thiamethoxam 25 WG @ 37.5 g a.i. / ha (6.59), thiamethoxam 25 WG @ 50 g a.i. / ha (6.46), thiamethoxam 30% FS @ 2.55 g a.i. / kg of seed (6.41), imidacloprid 17.80 SL @ 20 g a.i. / ha (6.29), and recorded the lowest population in dimethoate 30 EC @ 600 g a.i. / ha (3.81) over untreated control (Table 3). The results also showed that dimethoate @ 600 g a.i. / ha gave negative effect on coccinellid beetle

population. Ghosal et al. (2013) reported that dimethoate showed toxicity towards a population of coccinellids.

CONCLUSION

Farmers are unaware of the damage caused by whitefly which causes both direct and indirect damage to okra crops. On brief account of the field evaluation carried out, to cope with the rapidly multiplying whitefly population, the insecticidal application would reduce the populations drastically over the control plots. Although the highest yield, economics, and lowest whitefly population were encountered in plots treated by thiamethoxam 25 WG @ 50 g a.i. per ha followed by 37.5 g a.i. per ha and 25 g a.i. per ha. But, keeping in view of the economic and judicious usage of the insecticides, thiamethoxam 25 WG @ 25 g a.i. per ha could be employed in obtaining good fruit yields as well as reducing whitefly populations. All the tested insecticide formulations were found to be safer for coccinellids except for dimethoate 30 EC @ 600 g a.i. / ha, which have negative effect on coccinellid beetles, as observed in the okra ecosystem, when it was compared with the higher doses of thiamethoxam 25 WG at double dose of 50 g a.i. ha^{-1}. None of the insecticide formulations have phytotoxic effect in okra ecosystem.

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Integrated management of *Phytopthora capsici* foot rot in black pepper

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Abstract: Black pepper (*Piper nigrum* L.) is one of the most commonly used spice crops. Foot rot caused by *Phytopthora capsici* is a major bottleneck in black pepper production, resulting in significant crop losses in pepper-growing areas. To address this issue, a field study was conducted to test the efficacy of potential fungicides, bioagents, and botanicals in combination at two locations during 2017-18. It was found that soil application of *Trichoderma harzianum* @ 50 g/vine + neem cake @ 1 kg/vine before the onset of monsoon followed by drench and spray with fenamidone + mancozeb @ 2g/lit thrice at monthly intervals had the least leaf infection (7.52%), foliar yellowing (5.38%), defoliation (2.17%), and resulted in the highest dry pepper yield 4.70 kg/vine, with a higher benefit-cost ratio. These findings suggest that the use of a combination of bioagents, fungicides, and botanicals can effectively manage *Phytophthora* foot rot in black pepper cultivation, leading to increased yield and higher profitability for farmers.

Keywords: *Phytopthora capsici,* management, fungicide, bioagent, botanical, black pepper

INTRODUCTION

Black pepper (*Piper nigrum* L.), is an economically important spice crop and India is the fourth largest producer of black pepper next to Vietnam, Brazil and Indonesia, contributing more than 8% of the world's black pepper production, is susceptible to various pathogens, in particular to *Phytophthora capsici* which causes foot rot, commonly known as quick wilt considered as the most devastating disease of black pepper, has been reported to cause an annual crop loss of 5-10 per cent (Manohara *et al.,* 2004) but it is significantly higher in India (Shivakumar *et al.,* 2022). In India, foot rot of black pepper usually occurs mainly during the South-West monsoon period (June to September) as the disease is favoured by high soil moisture, poor drainage and well distributed rain rainfall. Disease progress is very rapid and infects all parts of the vine under favorable conditions thereby hindering the prevention and management of the disease. Hence, for effective management of this disease, an integrated strategy incorporating, botanical, biological agent and novel chemical control is required. Currently growers are being following prophylactic application of copper based contact fungicides (KAU, 2011) which in turn do not provide satisfactory control of the disease during heavy monsoon period. Moreover, repeated application of systemic fungicide like metalaxyl has resulted in evolution of insensitivity to metalaxyl has been widely observed in *P. capsici* (Parra *et al.,* 2001; Silvar *et al.,* 2006; Wang *et al.,* 2021). Over the past two decades, a number of new fungicides with recognized effectiveness against this oomycete pathogen have been discovered (Thind, 2011). On the other hand, biological control of diseases based on the application of natural plant and microbial agents against pathogens is thought to be harmless and ought to be promoted, as it requires low amounts of chemicals. Considering the foregoing facts, the current studies were carried out in order to develop effective management strategies involving the new generation molecules and bio-control options which can bring down the pathogen population in soil and can control leaf, stem, spike, root and collar infections in black pepper plantations.

MATERIALS AND METHODS

Field studies were conducted during 2017-18 at two locations: KVK Gonikoppal, Kodagu farm with variety, Penniyur of 10-15 years old and other location at farmer's field, Maldare village of Virajpet taluk, Kodagu district, Karnataka, India. Eight different combinations of fungicides, bio control agent and neem cake and one treatment was kept for combination of chitosan with bioagents and botanicals were used to evaluate their effect against *Phytophthora* foot rot. Neem cake was incorporated into top 10 cm layer of soil around the vines at 1 kg/vine before onset of monsoon. *T. harzianum* (Th-B2) procured from the Department of Plant Pathology, College of Agriculture, UAS, Bangalore was mass multiplied on moist sorghum grains and it was added to soil at rate of 50 g of preparation per vine during pre-monsoon season. The chitosan and fungicides were

Table 1. Disease Rating Scale

Index	Description
0	Healthy
1	1-25% leaf infection, yellowing and defoliation
2	26-50% leaf infection, yellowing and defoliation
3	51-75% leaf infection, yellowing and defoliation
4	76-100% leaf infection, yellowing and defoliation

applied as drench and spray at 30 days intervals thrice. Observation on per cent leaf infection, defoliation, yellowing was recorded using the disease below formula Rajan *et al.* (2002) (Table 1). The complete death of the vines were recorded and presented as per cent wilted vines.

Statistical Analysis

The experiment was carried out in a randomized complete block design (RCBD). The critical difference (CD, $p \leq 0.05$) was used to compare treatment means using Duncan's multiple range test.

RESULTS AND DISCUSSION

The results of pooled analysis from both locations (KVK Farm, Gonikoppal and Maldare village of Virajpet taluk, Kodagu district) revealed that treatment, soil application of *T. aharzianum* @ 50 g/vine + neem cake @ 1kg/vine before onset of monsoon followed by drench and spray with fenamidone + mancozeb @ 2g/lit thrice at monthly intervals out formed with less leaf infection (7.52 %), foliar yellowing (5.38 %), defoliation (2.17 %), no death of vines and highest dry pepper yield of 4.70 kg/vine followed by treatment, soil application of *T. harzianum* @ 50g/vine + neem cake @ 1kg/vine with higher benefit cost ratio of (1:3.52) and which was also found superior treatment over existing management measure i.e., soil application of Arka Microbial Consortia (*Bacillus aryabhattai* + *Pseudomonas thivervalensis* + *Azotobacter tropicalis*) 20 g/lit + drench and spray with Bordeaux mixture (1%) spray before onset of monsoon and followed by copperoxychloride (COC) drench and spray @ 3g/vine. This is followed by drench and spray with Metalaxyl + Mancozeb @ 2g/lit found in the next order with leaf infection, foliar yellowing, defoliation and dry pepper yield of 12.15, 10.21, 4.8 per cent and 4.09 kg/vine respectively in comparison to untreated control where in infection, foliar yellowing, defoliation, death of vines and yield of 44.54, 44.18, 44.33, 26.07 per cent and 1.18 kg/vine recorded respectively with lowest benefit cost ratio of (1:1.64) (Table2).

The mode of action of the fungicides mentioned in the study is well-documented in literature. Copper oxychloride acts as a contact fungicide and kills fungi because of its strong bonding affinity to amino acids and carboxyl groups, reacts with protein and acts as an enzyme inhibitor in target organisms (Mehta *et al.,* 1990). Numerous studies have provided evidence for the effectiveness of metalaxyl-based or mixed fungicides in the suppression of oomycete pathogens (Mayton *et al.,* 2008). Phenylamides such as metalaxyl-M inhibit ribosomal RNA synthesis, specifically polymerization of r-RNA (Davidse, 1995). Fungicides such as famoxadone, fenamidone, pyraclostrobin are well known Quinone outside respiration inhibitors (QoIs) revealed its strong antifungal nature against many oomycete pathogens (Thomas and Naik, 2017; Sindhu *et al.,* 2021; Neupane and Baysal-Gurel, 2022) by interrupting electron transport in cytochrome b (complex III) by binding to the Qo site, the ubiquinol oxidizing pocket which is located at the positive, outer side of mitochondrial membranes (Gisi, 2002).

Rajan *et al.* (2002) reported that *T. harzianum-26* was found to be more effective to control the disease and more adaptable to the rhizosphere of black pepper. Similarly, in a study by Ahmed *et al.* (2000) *T. harzianum* was found to be highly effective in managing *P. capsici* in pepper plants by suppressing pathogen growth and inducing systemic resistance. Moreover, the results also suggest that the efficacy of bio-agents in controlling *P. capsici* can vary depending on the specific strain used. This finding is consistent with previous studies that have reported the efficacy of different strains of *T. harzianum* in managing *P. capsici.* (Timila and Manandhar, 2020).

The field studies in two locations revealed that the treatment involving soil application of *T. harzianum* + neem cake before the onset of monsoon, followed by drench and spray with fenamidone + mancozeb thrice at monthly intervals was the most effective. These treatments were significantly better than the existing management measure. Rini and Remya (2020) observed improved survival of pepper plants in soil that was infested with *P. capsici* when it was subjected to treatment with a combination of fenamidone + mancozeb @ 2g/lit. Similar kind of findings also reported by Shashidhara *et al.* (2009) where in application of Metalaxyl MZ along with *T. harzianum* and *P. fluorescens* found effective to combat foot rot of black pepper.

Table 2. Effect of integrated management practices on foot rot of black pepper (pooled data of two locations)

Treatment	Leaf infection (%)	Yellowing (%)	Defoliation (%)	Wilt incidence (%)	Yield/ Vine (kg)	B:C ratio
T_1= = Copper oxychloride spray and drench (3g l^{-1}) + *Trichoderma harzianum* (50 g vine-1) + neem cake (1 kg $vine^{-1}$)	20.75 c (27.09)	21.47 b (27.60)	13.4 b (21.47)	10.55 c (18.95)	2.41 i (8.93)	2.89
T_2 = Chitosan spray and drench (2g l^{-1}) + *Trichoderma harzianum* (50 g vine-1) + neem cake (1 kg $vine^{-1}$)	27.22 b (31.44)	21.30 bc (27.48)	12.93 b (21.07)	9.44 cd (17.89)	2.51 h (9.11)	2.72
T_3 = Famoxadone + cymoxanil spray and drench (2g l^{-1}) + *Trichoderma harzianum* (50 g vine-1) + neem cake (1 kg $vine^{-1}$)	18.01 de (25.11)	14.65 e (22.50)	8.18 cd (16.62)	0.55 f (4.25)	3.38 d (10.59)	2.71
T_4 = Fenamidone + mancozeb spray and drench (2g l^{-1}) + *Trichoderma harzianum* (50 g vine-1) + neem cake (1 kg $vine^{-1}$)	7.52 g (15.91)	5.38 g (13.41)	2.17 f (8.47)	0.00 f (0.00)	4.70 a (12.52)	3.52
T_5 = Metalaxyl + mancozeb spray and drench (2g l^{-1}) + *Trichoderma harzianum* (50 g $vine^{-1}$) + neem cake (1 kg $vine^{-1}$)	12.15 f (20.40)	10.21 f (18.63)	4.8 e (12.65)	0.00 f (0.00)	4.09 b (11.67)	3..31
T_6 = Fluopicolide + fosetyl spray and drench (2g l^{-1}) + *Trichoderma harzianum* (50 g $vine^{-1}$) + neem cake (1 kg $vine^{-1}$)	18.68 d (25.60)	16.10 de (23.65)	8.6 c (17.05)	9.44 cd (17.89)	3.20 e (10.30)	2.92
T_7 = Iprovalicarb + propineb (2g l^{-1}) Fosetyl spray and drench (2g l^{-1}) + *Trichoderma harzianum* (50 g $vine^{-1}$) + neem cake (1 kg $vine^{-1}$)	16.49 e (23.96)	18.31 cd (25.33)	10.12 c (18.55)	8.88 d (17.33)	3.04 g (10.04)	2.67
T_8 = Pyraclostrobin + metiram Fosetyl spray and drench (2g l^{-1}) + *Trichoderma harzianum* (50 g $vine^{-1}$) + neem cake (1 kg $vine^{-1}$)	18.52 d (25.49)	14.91 e (22.71)	8.16 cd (16.60)	12.22 b (20.46)	3.11 f (10.16)	2.77
T_9 = Bordeaux mixture (1%) spray + copper oxychloride (3g l^{-1}) drench + drenching of Arka Microbial Consortia (20 g^{-1})	13.6 f (21.64)	13.88 e (21.87)	6.10 de (14.30)	4.99 e (12.91)	3.92 c (11.42)	3.23
T_{10} = Control	44.54 a (41.86)	44.18 a (41.65)	44.33 a (41.74)	26.07 a (30.70)	1.18 j (6.24)	1.64
p value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	
C.D. (0.05)	1.92	2.98	2.44	1.38	0.58	
CV	5.69	9.64	11.98	9.85	8.17	

Values in table marked with different letters differ significantly; $p < 0.05$, Duncan's multiple range test; Non-significant.

CONCLUSION

In conclusion, the use of an integrated management approach that combines different treatments such as the application of *Trichoderma harzianum*, neem cake and fungicides, can effectively manage foot rot/quick wilt of black pepper. The success of this approach is evident from the significant reduction in disease incidence, less defoliation, and higher yields recorded in the field trials. Moreover, this approach is environmentally friendly and economically feasible, making it a sustainable way of managing plant diseases.

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Influence of fungicides, nutrients and bioagents on leaf twisting disease and yield of onion (*Allium cepa* L.)

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ABSTRACT: Influence of fungicides, nutrients and bioagents on yield, quality enhancement and management leaf twisting in onion was studied at Regional Agricultural Station, Vijayapur, Karnataka, during *kharif* and *rabi* 2021-22. The variety of 'Bhima Super' seeds collected from two sources (normal and twisting affected seeds) with nine treatments combination of polymer (3 ml kg^{-1}), chemicals, captan (2 g/kg), carboxin 37.5 % + thiram 37.5 % (3 g kg^{-1}), captan 70 % + hexaconazole 5 % (3 g kg^{-1}) and bioagents of *Trichoderma harzianum*, *Pseudomonas fluorescens*, and *Bacillus subtilis* each @ 5 g kg^{-1}. The results obtained from combination of all three bioagents recorded significantly higher bulb yield (23.82 t ha^{-1}) followed by all three bioagents along with fungicides carboxin 37.5 % + thiram 37.5 % (3 g kg^{-1}) (23.15 t ha^{-1}) as compared to control (15.22 t ha^{-1}) due to significant increase in the yield attributes. *Kharif* harvested bulbs treated with nine different treatment combinations and planted during *Rabi* season to know the effect of nutrients, fungicides and bioagents on field performance and management of leaf twisting. Among treatments application of N: P: K @ 125: 50: 125 kg ha^{-1} + Mg @ 30 kg ha^{-1} + S @ 45 kg ha^{-1} + B @ 3 kg ha^{-1} + Zn @ 4 kg ha^{-1} + foliar spray of hexaconazole 0.05 % at 30 and 60 days after planting recorded significantly higher plant growth parameters, lesser leaf twisting (17.44 %) and higher seed yield (504.49 kg ha^{-1}) as compared to control (34.99 % and 312.47 kg ha^{-1} respectively).

Keywords: Nutrients, fungicides, bioagents, leaf twisting, seed yield

INTRODUCTION

Onion (*Allium cepa* L.) belonging to the family Amaryllidaceae, is said to be native to Central Asia and Mediterranean region (McCollum, 1976). Indian onions are famous for their pungency due to the presence of a volatile compound 'Allyl propyl disulphide' ($C_6H_{12}S_2$). India is the second largest onion bulb producer in the world after China and occupies an area of 1.62 m ha with a production of 26.64 mt and 16400 kg ha^{-1} of productivity. This crop is affected by various diseases and pests. Some of the diseases like purple blotch, downy mildew, *Stemphylium* blight, basal rot, storage rots and now recently twisting disease. Prior to 1997, leaf twisting disease was not an important disease in onion crop, but in the recent years this is one of major diseases not only in low land areas, but also in highlands. In Karnataka, leaf twisting disease complex severity has varied from 7.9 to 52.4 per cent (Anon., 2005). Patil *et al*. (2017) reported twisting of leaves, stem and bulbs of onion which has caused serious threat to cultivation and loss was estimated to extent of 40-60 per cent. At present, onion is extensively cultivated in all the parts of Karnataka. Both seed and bulb crops are infected with disease severity of 20-30 per cent and 50-70 per cent respectively (Anon., 2011).

The seed treatments help in protecting seedlings against pests and diseases. Also, the treated seeds could improve root development, seedling emergence, inducing the structural and ultrastructural modifications for water to imbibe, decreasing the stress at the germination stage, establishment rates and enhancing the activity of enzymes which convert macromolecules to materials needed and applied for the embryo's growth and development (Bewley and Black, 2012 and Galhaut *et al*., 2014). Along with seed treatment a new formulation technology for treating the seeds called polymer coating, has been developed. Polymer coating provides growers with high quality, seed treatments that are safer to use, offer additional protection from pathogens and improve flow ability of seeds. Application of micronutrients along with macronutrients to the soil or foliar spray showed remarkable increase in yield of several crops. Nutrients play an active role in the plant metabolic process from cell wall development to respiration, photosynthesis, chlorophyll formation, enzyme activity and nitrogen fixation *etc.* In addition they play an essential role in improving better plant growth, quality and crop yield (Ballabh *et al.,* 2013).

The higher yield and better quality bulb or seed can be produced by treating with fungicides, nutrients and bioagents. As the detailed information on these aspects

in onion is lacking, present study was conducted with special reference to leaf twisting in onion.

MATERIALS AND METHODS

A field experiment was carried out at Regional Agricultural Research Station, Vijayapur during *kharif* and *rabi* 2021-2022 to study the effect of chemicals, nutrients and bioagents on yield and management of leaf twisting in onion. The experimental site was located at latitude of 16˚ 77' North, longitude of 75˚ 74' East and an altitude of 516.29 meters above mean sea level in Northern Dry Zone of Karnataka (Zone 3). Two source of onion seeds, seed collected from normal plant (M_1) and seed collected from affected plant showing twisting symptoms (M_2) were treated with different combination of fungicides, nutrients and bioagents along with polymer coat before sowing. The harvested *Kharif* bulbs of 'Bhima Super' variety were treated with micro nutrients, fungicides and bioagents prior to planting. The seeds or bulbs were directly mixed with the micro nutrients, fungicides and bioagents as per the treatment and dosage and were thoroughly mixed for 10 to 15 min to ensure the uniform application of nutrients, fungicides and bioagents.

The experiment was laid out in a by simple factorial randomized block design with three replications during *kharif* (seed to bulb) and randomized complete block design with three replications during *rabi* (bulb to seed). The experiment consisted of nine treatments involving different combination of nutrients, fungicides and bioagents. The land was brought to a fine tilth by once deep ploughing and two times repeated harrowing followed by puddling. The treated onion seeds were sown by line sowing at the congenial field condition. Planting of treated bulbs of onion was done as per the treatment details with one bulb per hill by hand dibbling on one side of the ridge at a spacing of 45 cm × 15 cm.

The flowering parameters, yield attributes, per cent incidence of leaf twisting and economics of bulb production were recorded from the net plots and yield was converted to hectare basis in kilograms. The data collected from the experiment at different growth stages and at harvest were subjected to statistical analysis as described by Sundarrajan *et al.* (1972). The level of significance used for 'F' and 't' tests was P=0.05. Critical Difference (CD) values were calculated at 5 per cent probability level if the F test was found to be significant.

RESULTS AND DISCUSSION

Influence of fungicides, nutrients and bioagents on flowering parameters, yield attributing characters, management of leaf twisting and economics of bulb production

The yield attributes (Table 1) of onion were greatly influenced by chemicals and bioagents. differences with respect to different sources of seeds *i.e.,* seeds from normal plant (M_1) and seeds from plant showing twisting (M_2). Normal seeds (M_1) recorded maximum weight of bulb (88.68 g) as compared to seeds collected from affected plant showing twisting symptoms (M_2) (84.85 g). A significant difference was noticed on weight of bulb due to different seed treatments. Among the seed treatments, T_7 (*T. harzianum* + *P. fluorescens* + *B. subtilis* each @ 5 g kg^{-1} of seeds) recorded maximum weight of bulb (96.68 g) which was on par with T_8 (*T. harzianum* + *P. fluorescens* + *B. subtilis* each @ 5 g kg^{-1} of seeds + carboxin 37.5 % + thiram 37.5 % @ 3 g kg^{-1} seeds) as (95.00 g), T_3 (Captan 70 % + hexaconazole 5 % WP @ 3 g kg^{-1} of seeds + Polymercoat @ 3 ml kg^{-1} seeds) as (91.76 g) and T_2 (Carboxin 37.5 % + thiram 37.5 % @ 3 g kg^{-1} seeds + Polymercoat @ 3 ml kg^{-1} of seeds) as (90.56 g), whereas lowest weight of bulb (72.98 g) was recorded in T_9 (control). Results on interaction effects due to different sources of seeds and seed treatment with polymercoat, chemicals and bioagents were non-significant for weight of bulb.

Similar results were noticed on bulb yield per hectare, M_1 recorded significantly higher bulb yield (21.30 t ha^{-1}) per hectare as compared to M_2 (19.97 t ha^{-1}). Among the treatments, T_7 recorded significantly higher bulb yield per ha^{-1} (23.82 t) and was on par with T_8, T_3, and T_2 as (23.15 t ha^{-1}, 22.28 t ha^{-1} and 21.98 t ha^{-1} respectively while minimum bulb yield 15.22 t ha^{-1}) was found in T_9 (control). Interaction between the different source of seeds and seed treatment with polymercoat, chemicals and bioagents did not differ significantly in terms of bulb yield per hectare. However, numerically higher bulb yield (24.80 t) per hectare was found in M_1T_7 followed by M_1T_8 (23.92 t), M_1T_3 (23.28 t) and lower bulb yield was found in the M_2T_9 (14.37 t) combination due to difference in the quality of seeds which were free from pathogens and enhanced better growth habit and yielding ability helps in growth habit and yielding ability. These results are in conformity with the observations of Pramodkumar and Palakshappa (2010), Prakasam and Sharma (2012), Yadagir and Gupta (2017) and Manthesha *et al*., (2022) in onion.

On similar lines: the flowering parameters and yield attributes of onion (Table 2) were greatly influenced by nutrients, fungicides and bioagents treatments. The observations on number of umbel per plant and diameter

Table 1. Effect of fungicides and bioagents treatment on yield parameters of onion bulb

Treatment	Weight of bulb (g)			Bulb yield (t ha^{-1})		
	M_1	M_2	Mean	M_1	M_2	Mean
T_1 : Captan @ 2 g kg^{-1} of seeds + Polymercoat @ 3 ml kg^{-1} of seeds	90.80	88.00	89.40	21.20	20.43	20.82
T_2 : Carboxin 37.5 % + thiram 37.5 % @ 3 g kg^{-1} seeds + Polymercoat @ 3 ml kg^{-1} of seeds	91.70	89.42	90.56	22.81	21.15	21.98
T_3 : Captan 70 % + hexaconazole 5 % WP @ 3 g kg^{-1} of seeds + Polymercoat @ 3 ml kg^{-1} seeds	93.52	90.00	91.76	23.28	21.27	22.28
T_4 : *Trichoderma harzianum* @ 5 g kg^{-1} of seeds	89.64	86.20	87.92	20.30	19.30	19.80
T_5 : *Pseudomonas fluorescens* @ 5 g kg^{-1} of seeds	84.50	75.50	80.00	19.97	19.20	19.58
T_6 : *Bacillus subtilis* @ 5 g kg^{-1} of seeds	78.80	74.35	76.58	19.30	18.77	19.03
T_7 : T_4 + T_5 + T_6 (*T. harzianum* + *P. fluorescens* + *B. subtilis* each @ 5 g kg^{-1} of seeds)	97.30	96.07	96.68	24.80	22.83	23.82
T_8 : T_7 + carboxin 37.5 % + thiram 37.5 % @3 g kg^{-1} seeds	96.80	93.20	95.00	23.92	22.37	23.15
T_9 : Control	75.05	70.90	72.98	16.07	14.37	15.22

	S.Em ±	CD @ 5 %	S.Em ±	CD @ 5 %
M	1.27	3.67	0.44	1.27
T	2.71	7.79	0.94	2.70
M× T	3.83	NS	1.32	NS

NOTE: *NS - Non significant

M_1 Seed collected from normal plant

M_2 Seed collected from affected plant showing twisting symptoms

of umbel differed significantly due to different bulb treatments. T_6 (T_5 + foliar spray of hexaconazole 0.05 % at 30 and 60 days after planting) recorded significantly higher number of umbel per plant (2.47) and diameter of umbel (70.40 mm) which was on par with T_4 (bulb treatment with carboxin 37.5 % + thiram 37.5 % @ 2 g kg^{-1} bulb + foliar spray of hexaconazole 0.05 % at 30 and 60 days after planting) with 2.33 and 69.53 mm, and T_8 (T_7 + foliar spray of propiconazole 0.1 % at 45 and 60 days after planting) with 2.27 and 68.13 mm and T_7 (foliar spray of Zn @ 0.05 % + B @ 0.1 % + 19:19:19 @ 3 g L^{-1} at 45 days after planting) with 2.20 and 67.60 mm per plant and umbel diameter respectively. However, lower number of umbel per plant (1.60) and minimum diameter 58.73 mm was noticed in T_9 (control). These treatments indicated probable beneficial impact of boron in pollen tube growth, pollen viability, stigma receptivity and pollination (Pandey and Gupta, 2012) and biosynthesis of endogenous hormones responsible for better development of reproductive organs (Battal, 2004 and Hansch and Mendel, 2009). Thangasamy *et al*., (2010) and Kumar *et al*., (2018) also supported the results which revealed that B deficiency affects the reproductive yield than biomass yield, even in the absence of any visible symptoms of deficiency. Foliar spray of hexaconazole after 30 and 60 days of planting was found effective in management of pathogens and increase flowering parameters. These findings were similar to Selim *et al*., (2018).

The data on number of seeds per umbel as influenced by bulb treatments was found to differ significantly. Among Treatments, T_6 recorded significantly more number of seeds per umbel (994.6) which was on par with T_4, T_8 and T_7 as (957.6, 933.6 and 907.3 respectively) when compared to T_9 (control) as (685.6). Similarly the significant difference was recorded on seed yield per hectare. While, T_6 recorded significantly higher seed yield as (504.4 kg) per hectare which was on par with T_4, T_8, T_7 and T_5 as (443.8 kg, 439.7 kg, 438.6 kg and 428.2 kg per hectare respectively), minimum seed yield (312.4 kg) per hectare was found in the T_9 (control). The highest number of seeds per umbel and seed yield per hectare can be attributed to positive effects of these elements in activation of metabolic enzymes for photosynthates, translocation, carbohydrate metabolism, synthesis of

Table 2. Effect of chemicals, nutrients and bioagents treatment on flowering and seed yield parameters

Treatment	No. of umbels/ plant	Diameter of umbel (mm)	No. of seeds/ umbel	Seed yield (kg/ ha	B:C ratio
T_1: Bulb treatment with Zn @ 0.05 % + B @ 0.1 % + *Pseudomonas fluorescens* @ 10 g L^{-1}	1.87	63.17	792.33	365.47	3.21
T_2: Bulb treatment with carboxin 37.5 % + thiram 37.5 % @ 2 g kg^{-1} bulb + soil application of *Trichoderma harzianum* @ 2 kg ha^{-1} + *Pseudomonas fluorescens* @ 2 kg ha^{-1}	1.93	65.33	863.67	392.50	3.39
T_3: Bulb treatment with carbendazim @ 2 g L^{-1}	1.73	62.47	766.33	357.55	3.44
T_4: Bulb treatment with carboxin 37.5 % + thiram 37.5 % @ 2 g kg^{-1} bulb + foliar spray of hexaconazole 0.05 % at 30 and 60 days after planting	2.33	69.53	957.67	443.89	3.06
T_5: N: P: K @ 125: 50: 125 kg ha^{-1} + Mg @ 30 kg ha^{-1} + S @ 45 kg ha^{-1} + B @ 3 kg ha^{-1} + Zn @ 4 kg ha^{-1}	2.13	67.60	875.00	428.28	3.02
T_6: T_5 + foliar spray of hexaconazole 0.05 % at 30 and 60 days after planting	2.47	70.40	994.67	504.49	2.94
T_7: Foliar spray of Zn @ 0.05 % + B @ 0.1 % + 19:19:19 @ 3 g L^{-1} at 45 days after planting	2.20	66.50	907.33	438.68	3.68
T_8: T_7 + foliar spray of propiconazole 0.1 % at 45 and 60 days after planting	2.27	68.13	933.67	439.70	3.57
T_9: Control	1.60	58.73	685.67	312.47	2.35
S.Em ±	0.16	2.11	152.49	26.97	
CD @ 5 %	0.48	6.32	152.49	80.86	

proteins and activation of oxidation process resulting into better vegetative growth and accumulation of higher food materials which finally converted into higher seed yield. Habib (2009), Rafique *et al*., (2011), Yaseen *et al.,* (2013) and Thangasamy *et al*., (2010) also reported similar results for application of mineral nutrients on yield attributing traits.

There were significant differences in per cent incidence of leaf twisting (Table 3) observed during 40 DAP, 80 DAP and at harvest stage as influenced by bulb treatments. Lesser incidence of disease was observed in T_6 as (14.58 %, 17.44 % and 20.30 % at 40 DAP, 80 DAP and at harvest stage respectively) which was on par with T_4 and T_8 (17.73 %, 18.20 % and 21.06 % at 40 DAP, 80 DAP and at harvest stage respectively) and (24.89 %, 19.14 % and 22.00 % at 40 DAP, 80 DAP and at harvest stage respectively). While maximum per cent incidence of disease was observed in T_9 (Control) as (32.13 %, 34.99 % and 37.85 %) at 40, 80 DAP and at harvest. The reduction in disease incidence and severity as compared to control could be due to antifungal property of Zn and vital role of other minerals in development of disease resistance in plants, synthesis of tryptophan, which is a precursor of growth promoting substance (indole acetic acid). Similar results have been reported by Kumar *et al*., (2018) in onion. Spray of hexaconazole after 30 and 60 days of planting was found effective in management of pathogens and increase growth parameters. These findings were similar to Nargund *et al*., (2013), Patil (2013)

Table 3. Effect of chemicals, nutrients and bioagents treatment on per cent incidence of leaf twisting of onion bulbs

Treatment	Leaf twisting (%)		
	40 DAP	80 DAP	At harvest
T_1: Bulb treatment with Zn @ 0.05 % + B @ 0.1 % + *Pseudomonas fluorescens* @ 10 g L^{-1}	20.25	27.75	30.61
T_2: Bulb treatment with carboxin 37.5 % + thiram 37.5 % @ 2 g kg^{-1} bulb + soil application of *Trichoderma harzianum* @ 2 kg ha^{-1} + *Pseudomonas fluorescens* @ 2 kg ha^{-1}	16.28	23.11	25.97
T_3: Bulb treatment with carbendazim @ 2 g L^{-1}	19.04	30.67	33.53
T_4: Bulb treatment with carboxin 37.5 % + thiram 37.5 % @ 2 g kg^{-1} bulb + foliar spray of hexaconazole 0.05 % at 30 and 60 days after planting	17.73	18.20	21.06
T_5: N: P: K @ 125: 50: 125 kg ha^{-1} + Mg @ 30 kg ha^{-1} + S @ 45 kg ha^{-1} + B @ 3 kg ha^{-1} + Zn @ 4 kg ha^{-1}	15.34	21.90	24.76
T_6: T_5 + foliar spray of hexaconazole 0.05 % at 30 and 60 days after planting	14.58	17.44	20.30
T_7: Foliar spray of Zn @ 0.05 % + B @ 0.1 % + 19:19:19 @ 3 g L^{-1} at 45 days after planting	27.81	20.59	23.45
T_8: T_7 + foliar spray of propiconazole 0.1 % at 45 and 60 days after planting	24.89	19.14	22.00
T_9: Control	32.13	34.99	37.85
S. Em.±	1.05	0.84	1.03
CD @ 5 %	3.015	2.53	3.08

Note: DAP – Days after plant

Effect of seed treatment on economics of bulb production

The results pertaining to net returns and B: C ratio were found significantly higher in the normal plant seeds (M_1) as (₹ 2,96,323 ha^{-1} and 3.29) when compared to seeds collected from affected plant (M_2) *i.e.,* (₹ 2,69,723 ha^{-1} and 3.08). The highest B:C ratio (3.68) was recorded from T_7 which in turn was statistically on par with T_8, T_3 and T_2 compared to other treatments (Table 2).

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Survival and infectivity of *Heterorhabditis indica* Poinar in different formulations against pests of bitter gourd

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ABSTRACT: Epilachna beetle (*Henosepilachna septima* Dieke) and melon fruit fly (*Zeugodacus cucurbitae* Coquillett) are serious pests of bitter gourd in Kerala. Studies were conducted to evaluate pathogenicity of Entomopathogenic nematodes (EPNs) against *H. septima and Z. cucurbitae* under laboratory conditions. NBAIR isolates of EPNs *viz. Heterorhabditis indica* Poinar and *Steinernema carpocapsae* Weiser were tested for their pathogenicity against 3rd instar larvae of *H. septima*. Among EPN species, *H. indica* @100 IJs recorded highest percentage mortality (100.00) followed by *S. carpocapsae* (90.00) at 48 hours after treatment (HAT). Three different formulations *viz.* sponge, talc and alginate gel of effective EPN strain was prepared and stored for 11 weeks. Infective juveniles stored in alginate gel formulation showed more than 50.00 per cent survival upto eight weeks after storage and recorded 72.22 per cent mortality of *H. septima* larvae at 72 HAT. Results of laboratory experiment on the effect of EPN formulation on adult emergence of fruit fly revealed that both alginate gel and talc based formulations of *H. indica* is equally effective to chemical. The study highlighted the efficacy of *H. indica* formulations as soil application for the management of *Z. cucurbitae*.

Keywords: Epilachna beetle, melon fruit fly, entomopathogenic nematode, shelf life, formulation

INTRODUCTION

Bitter gourd is cultivated throughout the year in Kerala and pests and diseases are major constraints. Among pests, *Henosepilachna septima* Dieke and *Zeugodacus cucurbitae* Coquillett are the major problems. Grubs of *H. septima* damage the crop by scraping the surface of leaves resulting in skeletonization while adults make semicircular holes on leaves causing great debilitation to the crop (Sreekala and Ushakumari, 1999). The most severe economic damage in cucurbits is caused by maggots of *Z. cucurbitae* by feeding inside the fruits and make them unfit for consumption. About 60-80 per cent yield loss has been reported in cucurbits due to pest attack (Shivalingaswamy *et al*., 2002). Even though the use of chemical pesticides is an easy approach to minimize pest population, it causes pesticide resistance and residues which results public health issues as well as considerable damage to natural ecosystem. As bitter gourd is an export-oriented crop, pest management using biopesticides is an important alternative to minimize use of chemical pesticides. EPNs of genus *Steinernema* and *Heterorhabditis* are lethal endo parasites of insects having a symbiotic relationship with bacteria of the genus *Xenorhabdus* and *Photorhabdus* respectively. The bacteria are carried in the gut of EPNs and injected into haemocoel of host causing septicaemia and death (Adams and Nguyen, 2002). Although the infective juveniles of EPNs can be stored in water under refrigerated condition, high cost and difficulties in maintaining quality reduce its acceptability as a component in IPM. So, development of formulations which can enhance its survival and infectivity lead to increased adoption of EPN technology for pest management. Hence the present study is undertaken to evaluate the pathogenicity and survival of EPN in different formulations and its effectiveness against *H. septima* and *Z. cucurbitae* in bitter gourd.

MATERIALS AND METHODS

Insect culture

H. septima, Z. cucurbitae and *Galleria mellonella* L. (greater wax moth) were maintained in the laboratory conditions. *H. septima* was reared using bitter gourd leaves in a rearing jar (30x20x20 cm). *Z. cucurbitae* was reared using ripened fruits of bitter gourd and last instar larvae were transferred to soil for pupation and emergence in pupation jar (30x20x20 cm). *G. mellonella* reared using artificial diet was used for mass multiplication of EPNs.

Table 1. Mortality percentage of *H. septima* at different concentrations of EPN

Treatments		Mortality* (%) Hours after treatment (HAT)					Emergence (IJs/insect)
EPN	Dose (IJs)	24	36	48	60	72	
H. indica	10	0.00 (0.00)^{b}	42.50 (40.61)^{c}	80.00 (63.80)^{bc}	100.00 (90.00)^{a}	100.00 (90.00)^{a}	$1.3x10^{4}$
	20	5.00 (9.21)^{b}	65.00 (53.84)^{b}	82.50 (65.46)^{b}	100.00 (90.00)^{a}	100.00 (90.00)^{a}	$2x10^{4}$
	50	5.00 (9.21)^{b}	80.00 (63.80)^{a}	95.00 (80.78)^{a}	100.00 (90.00)^{a}	100.00 (90.00)^{a}	$7.2x10^{4}$
	100	40.00 (39.16)^{a}	85.00 (67.50)^{a}	100.00 (90.00)^{a}	100.00 (90.00)^{a}	100.00 (90.00)^{a}	$9.8x10^{4}$
S. carpocapsae	10	0.00 (0.00)^{b}	12.50 (20.46)^{e}	50.00 (45.00)^{d}	94.87 (80.65)^{b}	100.00 (90.00)^{a}	$0.7x10^{4}$
	20	0.00 (0.00)^{b}	22.50 (28.22)^{d}	70.00 (57.16)^{c}	94.87 (80.65)^{b}	100.00 (90.00)^{a}	$1.3x10^{4}$
	50	0.00 (0.00)^{b}	47.50 (43.55)^{c}	80.00 (63.80)^{bc}	100.00 (90.00)^{a}	100.00 (90.00)^{a}	$3x10^{4}$
	100	2.50 (4.60)^{b}	50.00 (45.00)^{c}	90.00 (74.14)^{ab}	100.00 (90.00)^{a}	100.00 (90.00)^{a}	$9.1x10^{4}$
CD (0.05)		(9.440)	(6.983)	(11.677)	(7.362)	NS	

Figures in the parenthesis are arc sine transformed values *Mortality corrected using Abbott's formula

EPN culture

Two EPN strains, *S. carpocapsae* and *H. indica* (NBAIR isolate) were stored in tissue culture flasks at 15^{o}C in BOD incubator. Freshly harvested juveniles were collected through white trap method from infected *G. mellonella* cadavers and used for further experiments.

Pathogenicity of EPN against *H. septima*

Infectivity of *S. carpocapsae* and *H. indica* were assessed against 3rd instar grubs of *H. septima* at different concentrations (10, 20, 50 and 100 IJs/grub) under *in vitro*. Each treatment was replicated four times with ten grubs of *H. septima* in separate Petri plates. Mortality of grubs was noted at 24, 36, 48, 60 and 72 HAT. The infected cadavers were transferred to white trap and emerging IJs were collected and counted under stereoscopic microscope.

Preparation of sponge formulation

Polyurethane sponges were cut into rectangular pieces with dimension 3x3x2 cm. These sponges were

Table 2. Survival of infective juveniles of *H. indica* in different formulations

Treatment	Survival (%) at weekly intervals										
	1st week	2nd week	3rd week	4th week	5th week	6th week	7th week	8th week	9th week	10th week	11th week
Sponge	97.50 (83.62)^{a}	89.37 (71.02)^{b}	75.83 (60.62)^{c}	63.75 (52.99)^{c}	51.04 (45.59)^{c}	36.66 (37.24)^{c}	19.16 (25.88)^{c}	6.45 (14.60)^{c}	0.00 (0.00)^{c}	0.00 (0.00)^{b}	0.00 (0.00)^{b}
Talc	98.75 (86.77)^{a}	96.75 (81.04)^{a}	88.00 (70.03)^{b}	80.12 (63.58)^{b}	66.25 (54.51)^{b}	51.87 (46.07)^{b}	42.50 (40.68)^{b}	17.50 (24.44)^{b}	8.37 (16.56)^{b}	0.00 (0.00)^{b}	0.00 (0.00)^{b}
Alginate gel	100.00 (90.00)^{a}	98.75 (86.77)^{a}	94.60 (76.63)^{a}	88.20 (70.04)^{a}	82.65 (65.41)^{a}	75.00 (60.24)^{a}	66.75 (54.88)^{a}	61.00 (51.36)^{a}	32.50 (34.71)^{a}	26.25 (30.68)^{a}	19.40 (26.00)^{a}
Water	85.00 (68.02)^{b}	63.75 (53.01)^{c}	52.50 (46.44)^{d}	31.25 (33.93)^{d}	15.87 (23.29)^{d}	7.40 (15.63)^{d}	0.00 (0.00)^{d}	0.00 (0.00)^{d}	0.00 (0.00)^{c}	0.00 (0.00)^{b}	0.00 (0.00)^{b}
CD (0.05)	(9.718)	(7.333)	(5.2)	(4.063)	(3.997)	(5.25)	(4.181)	(4.538)	(3.656)	(3.426)	(2.739)

Figures in the parenthesis are arc sine transformed values

washed and air dried. The water holding capacity of sponge was determined by soaking in water and then squeezing the water out (Touray *et al*., 2020). Freshly harvested juveniles at a concentration of 1000 IJs/ml were added to each piece of sponge. These sponges were then packed individually in zip lock cover and stored at room temperature.

Preparation of talc formulation

Talc powder (50g) was added to 10 ml distilled water and 10 ml nematode suspension containing freshly harvested juveniles of 1000 IJs/ml was added to it (Jisna *et al*., 2019). The contents were mixed thoroughly till nematode suspension spread evenly on the talc and it was then stored at room temperature.

Preparation of alginate gel formulation

Freshly harvested juveniles were entrapped inside alginate beads using sodium alginate and calcium chloride complexing solution. 100 ml nematode suspension containing freshly harvested juveniles of 1000 IJs/ml was added to 2% sodium alginate solution and mixed it properly. Drops of this solution was added to 0.5 M calcium chloride dihydrate solution which was continuously stirred using a magnetic stirrer to form alginate beads (Kim *et al*., 2021). The formed beads were separated from the complexing solution after 20-30 minutes and then stored under room temperature.

Survival and virulence of infective juveniles in formulations

Different formulations of the effective EPN strain were prepared and stored at room temperature. Number of IJs surviving in sponge, talc, alginate gel and water were observed upto 11 weeks. Freshly harvested juveniles @ 1000 IJs/ml were used for making the formulations. Survival of IJs in sponge formulation was determined by soaking and squeezing each sponge in 50ml distilled water and number of IJs in 1ml of the suspension was counted. One gram of talc formulation was diluted in 5ml distilled water and then counted the number of IJs in 1ml. Alginate beads were diluted using 0.5M sodium citrate solution and IJs were counted. The virulence of IJs emerged from each formulation was tested against 3rd instar larvae of *H. septima* in comparison with freshly harvested juveniles.

Effect of EPN formulation against *Z. cucurbitae*

A laboratory experiment was conducted in Department of Agricultural Entomology, College of Agriculture, Vellayani to evaluate the efficacy of effective EPN formulations against the emergence of fruit fly adults

Table 3. Effect of *H. indica* in different formulations on the mortality of *H. septima* at 72 HAT

Treatments	*Mortality (%)										
	1st week	2nd week	3rd week	4th week	5th week	6th week	7th week	8th week	9th week	10th week	11th week
Sponge	100.00 (90.00)^{a}	100.00 (90.00)^{a}	91.42 (75.18)^{bc}	89.74 (71.32)^{cd}	86.48 (68.67)^{b}	68.57 (55.97)^{c}	60.00 (50.80)^{c}	33.33 (35.11)^{c}	0.00 (0.00)^{d}	0.00 (0.00)^{c}	0.00 (0.00)^{c}
Talc	100.00 (90.00)^{a}	100.00 (90.00)^{a}	94.28 (80.12)^{ab}	92.30 (75.99)^{bc}	89.18 (70.80)^{b}	85.71 (68.04)^{b}	71.42 (57.79)^{b}	66.66 (54.88)^{b}	37.83 (37.93)^{c}	0.00 (0.00)^{c}	0.00 (0.00)^{c}
Alginate	100.00 (90.00)^{a}	100.00 (90.00)^{a}	100.00 (90.00)^{a}	97.43 (85.33)^{ab}	91.89 (75.60)^{b}	85.71 (68.04)^{b}	77.14 (61.82)^{b}	72.22 (53.30)^{b}	43.24 (41.09)^{b}	41.02 (39.73)^{b}	22.22 (28.12)^{b}
Water	100.00 (90.00)^{a}	94.59 (80.40)^{a}	85.71 (68.04)^{c}	76.92 (61.75)^{d}	62.16 (52.08)^{c}	42.85 (40.83)^{d}	0.00 (0.00)^{d}	0.00 (0.00)^{d}	0.00 (0.00)^{d}	0.00 (0.00)^{c}	0 (0.00)^{c}
Freshly harvested juveniles	100.00 (90.00)^{a}	100.00 (90.00)^{a}	100.00 (90.00)^{a}	100.00 (90.00)^{a}	100.00 (90.00)^{a}	100.00 (90.00)^{a}	100.00 (90.00)^{a}	100.00 (90.00)^{a}	100.00 (90.00)^{a}	100.00 (90.00)^{a}	100.00 (90.00)^{a}
CD (0.05)	NS	NS	(10.595)	(10.117)	(7.503)	(6.094)	(5.873)	(6.009)	(3.013)	(3.923)	(0.00)

Figures in the parenthesis are arc sine transformed values

*Mortality corrected using Abbott's formula

from soil in comparison with recommended biocontrol agent (*Beauveria bassiana* NBAIR Bb5 @ 20g/L), botanical (neemazal 1% @ 0.2% + tween 80 @ 1%) and standard insecticide (chlorantraniliprole 18.5SC@ 0.3 ml/L). *Z. cucurbitae* infested fruits were collected from local farmers and the full grown larvae hopped from infested bitter gourds were transferred to a rearing cage. Clean fresh fruits were regularly introduced to the cage to enhance oviposition and larval development. Last instar larvae of length 7 to 11mm were collected from infested fruits in the cage for experiment.

The experiment was laid out in Completely Randomized Design (CRD) with seven treatments and three replications. Two effective formulations of selected EPN strain were prepared at a concentration of one lakh IJs/ml. The experiment was done in plastic containers filled with soil up to a height of 5 cm and the treatments were given to it. Then, ten late instar larvae of melon fruit fly were inoculated into each replication of the treatment along with a piece of bitter gourd fruit. Observations on the emergence of fruit flies from each treatment were taken at 10 and 15 DAT.

Statistical analysis

The tabulated data were subjected to statistical analysis using one-way analysis of variance after suitable transformations. The analysis was done using General R-shiny based Analysis Platform Empowered by Statistics (GRAPES) software (Gopinath *et al*., 2020).

RESULTS AND DISCUSSION

Pathogenicity of EPN against *H. septima*

In the study, *H. indica* and *S. carpocapsae* were evaluated for their pathogenic effect on 3rd instar larvae of *H. septima* in Petri plate bioassay (Table 1). *H. indica* @ 20, 50 and 100 IJs/larva recorded 5.00, 5.00 and 40.00 per cent mortality at 24 h after exposure. But no mortality of *H. septima* was observed in *H. indica* @ 10 IJs/ larva and *S. carpocapsae* @ 10, 20, and 50 IJs/larva. After 36 h of exposure, *H. indica* @ 100 IJs/larva recorded 85.00 per cent mortality and that of *S. carpocapsae* recorded 50.00 per cent mortality of *H. septima*. At 48 h after exposure, 100.00 per cent mortality was recorded with 100 IJs of *H. indica*. Increased susceptibility of *H. septima* to EPN in this study is in conformity with that of Abdel-Moniem and Gesraha (2001) who conducted a laboratory experiment on the pathogenicity of *Heterorhabditis taysearae* Shamseldean, *Heterorhabditis bacteriophora* Poinar and *S. carpocapsae* on different instars of *Epilachna chrysomelina* Fabricius and reported that *Heterorhabditis* sp. caused highest mortality of 2nd instar larvae of *E. chrysomelina* with mortality of 30.00 and 71.40 per cent at two and four days after treatment respectively. The superiority of *H. indica* over *S. carpocapsae* on the mortality of *H. sepima* in this study is attributed to the presence of apical hook in *Heterorhabditis* spp. which can rupture insect body wall more easily compared to *Steinernema* spp. where they lack the apical hook (Lewis *et al.*, 2006). Both *H. indica* and *S. carpocapsae* showed cent per cent mortality of *H. septima* in all concentrations (10, 20, 50 and 100 IJs) at 72h after exposure.

In the study, it was observed that the mortality percentage of *H. septima* by *H. indica* @ 20 and 50 IJs increased from 5.00 to 100.00 on increased exposure time from 24 to 72 h. Increased time of exposure from 36 to 72 h increased the mortality percentage of *H. septima* from 12.50 to 100.00, 22.50 to 100.00, 47.50 to 100.00 and 50.00 to 100.00 by *S. carpocapsae* @ 10, 20, 50 and 100 IJs respectively. This is in line with the findings of Gupta *et al.* (2008) who observed that the mortality of 3rd instar larvae of *Spodoptera litura* Fabricius increased (22.50 to 100.00 per cent) with exposure time (24 to 96 h) when treated with *S. carpocapsae* @ 80 IJs/ larva.

It was observed that mortality percentage of *H. septima* increased from 42.50 to 85.00 and 80.00 to 100.00 percentage at 36 and 48 h after exposure respectively, when concentration of IJs of *H. indica* increased from 10 to 100 IJs/larva. The relationship of mortality on time of exposure and concentration was substantiated by the findings of Adiroubane *et al*. (2010) who observed that increase in dosage decreased the time of exposure of *Steinernema siamkayai* Stock against *S. litura, Plutealla xylostella* Linnaeus, *Leucinodes orbonalis* Guenee, *Earias vitella* Fabricius and *Cnaphalocrocis medinalis* Guenee.

Cadavers infected with *H. indica* were reddish brown in colour and that of *S. carpocapsae* were dark brown. Emergence of IJs was highest for *H. indica* @ 100 IJs with an emergence of $9.8x10^4$ and it was followed by *S. carpocapsae* @ 100 IJs with $9.1x10^4$. *H. indica* @ 10, 20 and 50 IJs recorded an emergence of $1.3x10^4$, $2x10^4$ and $7.2x10^4$ respectively while *S. carpocapsae* @ 10, 20 and 50 IJs recorded an emergence of $0.7x10^4$, $1.3x10^4$ and $3x10^4$ respectively.

Survival and virulence of IJs in different formulations

Based upon the pathogenicity test, *H. indica* was selected as the effective EPN strain against *H. septima*. Thus, *H. indica* was formulated into four different formulations *viz.*, alginate gel, talc, sponge and water for the evaluation of survival and virulence of IJs stored

Table 4. Effect of *H. indica* on the emergence of fruit fly

Treatment	Emergence (%)*		Percentage reduction over control*	
	10 DAT	15 DAT	10 DAT	15 DAT
Alginate gel-based formulation of *H. indica* @ 4g/L+ tween 80 (1%)	3.33 (6.145)^{ab}	16.66 (23.36)^{a}	90.00	83.34
Talc-based formulation of *H. indica* @ 20 g/L+ tween 80 (1%)	3.33 (6.145)^{ab}	16.66 (23.85)^{a}	90.00	83.34
Beauveria bassiana NBAIR Bb5 @20 g/L	10.00 (15.00)^{b}	53.33 (46.92)^{b}	69.99	46.67
Neemazal 1% @ 0.2% + tween 80 (1%)	0.00 (0.00)^{a}	96.66 (83.85)^{cd}	100.00	3.34
Chlorantraniliprole 18.5SC@ 0.3 ml/L	0.00 (0.00)^{a}	13.33 (21.14)^{a}	100.00	86.67
Tween 80 (1%)	0.00 (0.00)^{a}	90.00 (75.00)^{c}	100.00	10
Untreated	33.33 (35.21)^{c}	100.00 (90.00)^{d}	-	-
CD (0.05)	(13.628)	(14.192)	-	-

*Figures in the parenthesis are arc sine transformed values

in these formulations. In the study, highest survival percentage of *H. indica* IJs (100.00) was observed in alginate and it was followed by talc (98.75) after one week of storage (Table 2). More than 50.00 per cent survival was obtained in alginate, talc and sponge until 8th, 6th and 5th week of storage respectively at room temperature. It is substantiated by Grewal (2002) that the viability of IJs decrease as the energy reserves got depleted over time. IJs of *H. indica* survived well in alginate and talc formulation than sponge and water in the present study. In case of alginate gel formulation, IJs are entrapped inside a liquid core where nematode movements are restricted to an extent. This also reduces the metabolic activity of IJs. Moreover, IJs in alginate gel are protected from UV radiation, desiccation and temperature (Grewal 2000). In sponge and water, IJs are free to move which reduces its lipid energy reserves and this attributes to the low survival percentage of *H. indica* in those formulations. While in talc formulation, IJs are subjected to anhydrobiotic condition which induces quiescence and thus reduced the metabolic rate of IJs (Kim *et al*., 2021). This contributes to the higher survival rate of IJs in talc compared to sponge and water. A study conducted by Jisna *et al.* (2019) on the survival of *Oscheius rugaoensis* in different formulations (talc, saw dust, alginate gel, water dispersible granules and compost-charcoal powder mixture) reported 80.60 and 68.00 per cent survival of *O. rugaoensis* in alginate gel and talc respectively in the 6th week of storage at 30^{o}C. Touray *et al.* (2020) reported that the survival percentage of *H. bacteriophora* IJs stored in different sponge types at 27^{o}C ranged from 89.30 to 93.70 during the first week of storage. Nagachandrabose (2022) studied the survival of *H. bacteriophora* (KKMH1) in alginate gel, talc and sponge wherein he reported more than 50.00 per cent survival of IJs up to 10th, 8th and 7th week in alginate gel, talc and sponge respectively at 25^{o}C. Likewise, Lalitha *et al*. (2022) also conducted an experiment on the survival of *S. carpocapsae* in arabic gum and alginate beads where they reported 93.30 per cent survival of IJs after 6 weeks of storage.

IJs stored in alginate, talc and sponge formulations for four weeks recorded 12.50 to 17.50, 60.00 to 67.50,

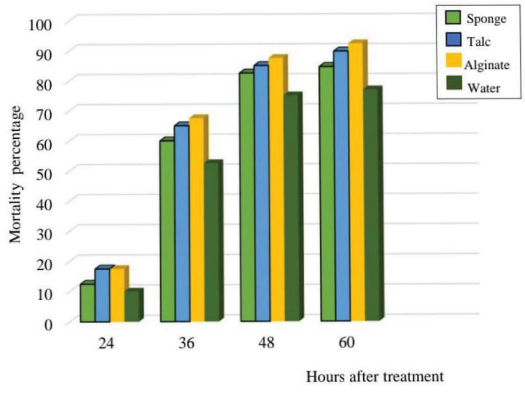

Fig. 1 Infectivity of *H. indica* stored for 4 weeks in different formulations against *H. septima* at 24, 36, 48 and 60h after exposure

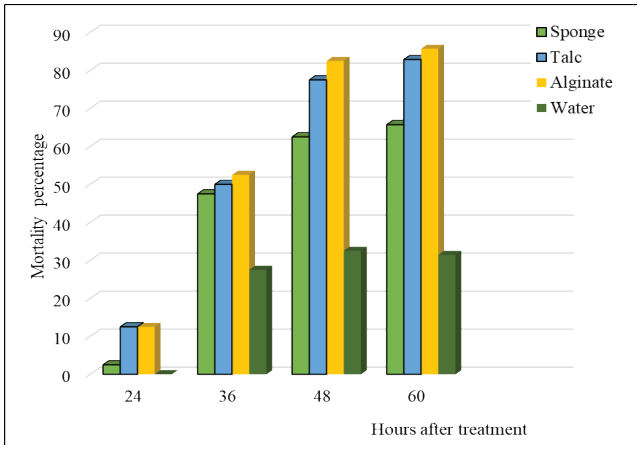

Fig. 2. Infectivity of *H. indica* stored for 6 weeks in different formulations against *H. septima* at 24, 36, 48 and 60h after exposure

82.50 to 87.50, 84.61 to 92.30 and 89.74 to 97.43 per cent mortality of 3rd instar larvae of *H. septima* at 24, 36, 48, 60 and 72h after exposure respectively (Fig. 1). After 6 weeks of storage, IJs stored in alginate, talc and sponge formulations recorded 2.50 to 12.50, 47.50 to 52.50, 62.50 to 82.50, 65.71 to 85.71 and 68.57 to 85.71 per cent mortality of *H. septima* at 24, 36, 48, 60 and 72 HAT respectively. At the same time, IJs stored in water recorded 0.00, 27.50, 32.50, 31.42 and 42.85 per cent mortality of *H. septima* at 24, 36, 48, 60 and 72 HAT (Fig. 2). More than 50.00 percent mortality of *H. septima* by *H. indica* juveniles stored in alginate gel and talc was observed upto 8 weeks (Table 3). Similar study was conducted by Nagachandrabose (2022) where he reported more than 50.00 percent mortality of *E. vitella* by *H. bacteriophora* (KKMH1) upto 9 weeks of storage in alginate gel and 7 weeks in talc. Results of the study confirmed virulence of IJs stored in alginate and talc formulation against *H. septima*.

Effect of EPN formulation against *Z. cucurbitae*

Efficacy of *H. indica* in formulations was tested against last instar larvae of melon fruit fly (*Z. cucurbitae*) by evaluating its effect on the emergence of adults from treated soil. Alginate gel-based formulation of *H. indica* @ 4g/L + tween 80 (1%) and talc-based formulation of *H. indica* @ 20 g/L + tween 80 (1%) were used for the experiment. The effect of these formulations was compared with biocontrol agent, *B. bassiana* NBAIR Bb5 20 g/ L, botanical, neemazal 1% @ 0.2% + tween 80 (1%) and chemical, chlorantraniliprole 18.5SC@ 0.3 ml/L.

The results showed that both alginate gel-based formulation of *H. indica* @ 4g/L+ tween 80 (1%) and talc-based formulation of *H. indica* @ 20 g/L + tween 80 (1%) showed significant reduction in the emergence percentage of *Z. cucurbitae* over untreated control. The effect of alginate gel-based formulation of *H. indica* @ 4g/L + tween 80 (1%) and talc-based formulation of *H. indica* @ 20 g/L + tween 80 (1%) recorded a reduction in emergence of 83.34 per cent over untreated control after 15 days of treatment (Table 4). At the same time, chemical recorded a reduction percentage of 86.67 which was similar to that of EPN formulations. This clearly indicates that the application of EPN in soil reduced adult emergence and its effect was similar to that of chemical treatment. The pathogenicity of EPN against *B. cucurbitae* was earlier studied by Sheela *et al.* (2002) where they reported 100.00 per cent mortality of *B. cucurbitae* larvae treated with *Rhabditis* sp. @ 200IJs larva^{-1} after 72 hours of exposure. Usman *et al.* (2021) conducted a potted soil assay on the pathogenicity of EPNs against *Bactrocera zonata* Saunders and *Bactrocera dorsalis* Hendel and reported that *H. bacteriophora* recorded 95.74 and 86.88 per cent mortality in larvae and 71.27 and 67.65 per cent mortality in pupae of *B. zonata* and *B. dorsalis* respectively. In the present study, neemazal 1% @ 0.2% + tween 80 (1%) recorded 96.66 per cent emergence at 15 DAT while there was no emergence for the treatment at 10 DAT. It is in agreement with the findings of Khan *et al.* (2007) who reported that the commercial neem formulation (Nimbicidine) did not show any effect on the pupation of *B. curcurbitae* and *B. dorsalis* while it delayed the pupation by 2-3 days from control. The effect of EPN was superior than *B. bassiana* NBAIR Bb5 20 g/L which showed 53.33 per cent emergence of *B. cucurbitae* at 15 DAT. It is in contrast with the study conducted by Amala (2010) where she reported 98.29 per cent mortality of *B. cucurbitae* with *B. bassiana* @

$2x10^7$ spore/ml. The variation in results might be due to difference in concentration levels. The emergence of adults increased after 15 days in all the treatments and only 33% emergence was observed in control 10 days after treatment. This may be due to the variation in pupal period of melon fruit fly from 7 to 13 days (Dhillon *et al.*, 2005). This study reveals the biocontrol potential of *H. indica* against the emergence of *Z. cucurbitae* adults from soil. This strategy can be effectively used for the management of fruit flies in integrated pest management programme of bitter gourd.

The study highlighted the biocontrol potential of *H. indica* against *H. septima* and *Z. cucurbitae*. It also revealed that *H. indica* can be stored in alginate gel and talc formulations for the better shelf life of IJs. An effort needs to be directed towards developing more viable and cost-effective formulations for the commercial success of EPN as a biocontrol agent.

ACKNOWLEDGEMENT

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In-vitro studies on the compatibility of *Trichoderma viride* with commonly used agrochemicals in the vegetable cropping system

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ABSTRACT: *In-vitro* studies were conducted to check the compatibility of microbial bioagent, *Trichoderma viride* with seven fungicides, eigtht insecticides, two herbicides, three fertilizers, and two antibiotics at different concentrations. The bioagent was compatible with insecticides *viz.,* imidacloprid 27.8% SL, diafenthiuron 50% WP, chlorantraniliprole 18.5% SC, flubendiamide 20% WG, azoxystrobin 23% SC, deltamethrin 2.8% EC, clothianidin 50% WDG, fenpropathrin 10% EC, and tiamethoxam 25% WG at all the four concentrations. However, fungicides hexaconazole 5% EC, propiconazole 25% EC, tebuconazole 25.9 % EC, and tebuconazole 50% + trifloxistrobin 25% WG and copper oxychloride 50% WP showed incompatibility with *T. viride.* Among the herbicides, glyphosate 41% SL was compatible, while paraquat dichloride 24% SL showed an incompatible reaction. Urea and muriate of potash (MOP) showed varied compatibility at different concentrations, while single super phosphate (SSP) showed a compatible reaction with the microbial bioagent. The results also indicate that antibiotic like streptomycin and gentamycin are compatible with *T. viride*. Knowledge of the compatibility of the microbes and the agrochemicals will be useful to apply biopesticide formulations in combination with inorganic pesticides, targeting different pests to reduce the cost and time.

Keywords: Agrochemicals, fungicides, insecticides, *Trichoderma viride*, compatibility

INTRODUCTION

Management of agricultural pests and pathogens using microbial biopesticides is a non-chemical and sustainable approach under climate-smart agriculture (Hanuman *et al.*, 2018) as the approach is cost-effective and eco-friendly. Sole application of microbial biopesticides is seemed to be useful in controlling agricultural pests and pathogens, however, when used under integrated pest management programmes (IPM) their compatibility with other chemical pesticides like fungicides, insecticides, herbicides, etc. needs to be tested for better bio-efficacy and results (Ons *et al*., 2020). Compatibility assessment of microbial bioagents against chemical pesticides is essential to confirm (i) if the pesticide particles are useful when mixed with the biocontrol agents or not (ii) for reduction of the incurred cost of a single spray (iii) to gather proper knowledge and understanding about detrimental effects of chemicals and pesticides on exposure time, durability, action mechanisms and mode of replication of microbial bioagents (Ons *et al*., 2020).

In several disease and pest management strategies, the addition of fungicides, insecticides, and herbicides at recommended rates in combination with biocontrol agents has tremendously escalated the management of disease and pests, as compared to treatments done with biocontrol agents or chemicals separately on different platforms individually (Cerda *et al*., 2004). Microbial bioagents *viz., Trichoderma viride, Trichoderma harzianum, Bacillus subtilis, Bacillus bassiana, Lecanicillium lecanii,* etc. are found as efficient biopesticides against a wide range of plant pests and pathogens (Reference). According to Shukla *et al.* (2019), there are issues related to microbial biopesticides such as effective spore load and viability (colony forming unit/ml), virulence, self-survival, etc., the application of recommended doses of plant protection formulations (PPFs) needs to be made along with efficacious biopesticides in IPM schedules. Thus, knowledge about compatibility among microbial biopesticides and recommended doses of agrochemicals needs to be explored for future sustainability in agriculture.

MATERIALS AND METHODS

In-vitro Compatibility of *Trichoderma viride* with agrochemicals

The poison food technique (Grover and Moore, 1961) was used for compatibility assessment. Potato Dextrose Agar (PDA) medium was used for carrying out the poison food technique. The media was then mixed with different insecticides (Table 1), fungicides, (Table 2) herbicides

Table 1. *In-vitro* compatibility of *Trichoderma viride* with some commonly used insecticides

Insecticide	Concentration (in ppm)	Mean (±) * (Diameter of mycelia in cm)	Per cent inhibition
Imidacloprid 17.8 SL	100	9.00	0.00
	500	8.95	0.58
	1000	7.81	13.25
	2000	7.63	15.22
Thiamethoxam 25% WG	100	8.44	6.22
	500	8.37	7.03
	1000	3.60	60.00
	2000	2.40	73.33
Deltamethrin 2.8% EC	100	8.73	3.03
	500	7.20	19.96
	1000	6.33	29.63
	2000	6.24	30.63
Diafenthiuron 50% WP	100	9.00	0.00
	500	8.93	0.77
	1000	8.66	3.74
	2000	7.58	15.77
Chlorantraniliprole 18.5%SC	100	9.00	0.00
	500	9.00	0.00
	1000	7.85	12.81
	2000	7.37	18.11
Fenpropathrin 10% EC	100	9.00	0.00
	500	9.00	0.00
	1000	5.74	36.25
	2000	1.75	80.55
Flubendiamide 20% WG	100	9.00	0.00
	500	9.00	0.00
	1000	8.96	0.41
	2000	8.90	1.11
Clothianidin 50% WDG	100	8.97	0.30
	500	7.57	15.88
	1000	7.31	18. 81
	2000	6.63	26.36
Control	Control	9.00	0.00
SE±(d)	**0.10**		
C.D. @ 5 %	**0.27**		

(Table 3), fertilizers (Table 4), and antibiotics (Table 5) at 2000, 1000, 500, and 100 ppm concentrations, and the prepared media were poured into sterile Petri dishes. After the media solidified which was placed inside the laminar, a 5 mm diameter disc of *T. viride* was cut using a cork borer from the growing mycelium colony and it was placed in the center of the solidified Petri dishes. Petri dishes with no agrochemicals in the medium served as checks. For each treatment, 3 replications were maintained, and these Petri dishes were incubated at 28 ±1° C inside a BOD incubator. Observations were recorded periodically for radial growth and sporulation. The inhibition percentage was also recorded for checking compatibility. The record was done by measuring the radial growth, of the colony in each treatment and the inhibition percentage of growth was calculated using the formula given by Vincent (1927).

$$I = C - T/C \times 100$$

where **"I"** stands for percent growth inhibition; **"C"** stands for radial growth in the control(cm) plate; **"T"** stands for radial growth in the treated plates (cm)

RESULTS AND DISCUSSIONS

In-vitro compatibility of *Trichoderma viride* with different insecticides

Fenpropathrin 10% EC, flubendiamide 20% WG, and chlorantraniliprole18.5% SC had the lowest percent inhibition (%) of the eight insecticides tested, with 0% inhibition at 100 and 500 ppm, followed by imidacloprid 17.8% SL and diafenthiuron 50% WP, both with 0% inhibition at 100 ppm. fenpropathrin 10% EC showed the highest inhibition percentage of 80.55% at 2000 ppm and the results are tabulated in Table 1. Since flubendiamide 20% WG was shown to be extremely compatible with *T. viride* at all the tested concentrations, these findings demonstrated that it is the safest of all the compounds to be used with *T. viride*.

In-vitro compatibility of *Trichoderma viride* with different fungicides

Azoxystrobin 23% SC showed the least per cent inhibition (%) at all four different concentrations, thus, recorded its efficacy in disease reduction. The triazole fungicides were shown to be the most incompatible ones. The highest levels of inhibition were determined to be hexaconazole 5% EC, propiconazole 25% EC, tebuconazole 25.9% EC, and tebuconazole 50%

Table 2. *In-vitro* compatibility of *Trichoderma viride* with some commonly used fungicides

Fungicide	Concentration (ppm)	Mean (±) * (Diameter of mycelia in cm)	Per cent inhibition
Hexaconazole 5% EC	100	0.00	100.00
	500	0.00	100.00
	1000	0.00	100.00
	2000	0.00	100.00
Propiconazole 25% EC	100	0.00	100.00
	500	0.00	100.00
	1000	0.00	100.00
	2000	0.00	100.00
Tebuconazole 25.9% EC	100	0.00	100.00
	500	0.00	100.00
	1000	0.00	100.00
	2000	0.00	100.00
Tebuconazole 50% + Trifloxistrobin 25% WG	100	0.00	100.00
	500	0.00	100.00
	1000	0.00	100.00
	2000	0.00	100.00
Azoxystrobin 23% SC	100	9.00	0.00
	500	9.00	0.00
	1000	8.38	6.89
	2000	8.25	8.30
Chlorothalonil 75% WP	100	4.18	53.59
	500	3.49	61.19
	1000	0.00	100.00
	2000	0.00	100.00
Copper Oxychloride 50%WP	100	4.32	52.00
	500	4.11	54.33
	1000	3.77	58.08
	2000	3.34	62.89
Control	Control	9.00	0.00
SE±(d)	**0.06**		
C.D. @ 5%	**0.13**		

+ trifloxystrobin 25%, all of which showed 100% inhibition of the fungus's mycelia development at all dosages. Additionally, mycelia growth was inhibited by chlorothalonil 75% WP and COC 50% WP, with more than 50% inhibition (Table 2 and Fig. 1).

In-vitro compatibility of *Trichoderma viride* with different herbicides

Two herbicides were tested namely, glyphosate 41% SL and paraquat dichloride 24% SL, out of which glyphosate 41% SL comparatively was found to be compatible showing an inhibition rate of less than 50 %, and paraquat dichloride 24% SL showed the highest inhibition at 2000 ppm of 62.81% thus proving it to be highly incompatible, as shown in Table 3.

In-vitro compatibility of *Trichoderma viride* with different fertilizers

Three fertilizers (Urea SSP and MOP) were tested and amongst them, SSP showed excellent results when combined with the fungal bioagent, *T. viride*. It was found to be highly compatible at all the employed concentrations showing per cent inhibition (%) up to zero. Urea and MOP showed varied compatibility at different concentrations. Mycelial growth of *T. viride* was found to be inhibited at 100% application doses of urea and MOP at 2000 ppm and 85.37% (urea) and 85.92 % (MOP) at 1000 ppm, respectively. urea and MOP showed compatibility at 100 and 500 ppm concentrations (Table 4).

In-vitro compatibility of *Trichoderma viride* with different antibiotics

Table 3. *In-vitro* compatibility of *Trichoderma viride* with herbicides.

Agrochemicals	Concentrations(in ppm)	Mean (±) * (Diameterof mycelia in cm)	Per cent inhibition
Glyphosate 41% SL	100	6.85	23.89
	500	6.01	33.19
	1000	5.63	37.44
	2000	5.60	37.78
Paraquat Dichloride 24%SL	100	8.48	5.78
	500	7.29	19.00
	1000	6.99	22.33
	2000	3.35	62.81
Control	Control	9.00	0.00
SE±(d)	**0.17**		
C.D. @ 5 %	**0.37**		

Data in table 5 and figure 2 depict the compatibility of all the antibiotics (streptomycin and gentamycin) with *T. viride* at all tested concentrations. For streptomycin, the inhibition percentage was recorded as (0%, 1.63%, 3.70%, and 5.63%) at 100, 500, 1000, and 2000 ppm in combination with *T. viride*, and for gentamycin, it gave (0%, 1.44%,6.00% and 9.11%) at 100, 500, 1000 and 2000 ppm. The result of the present investigation depicts that antibiotics can be used along with the fungal biopesticides for better bio-efficacy and results.

The present investigation was found to be relatable to the findings of Mareeswaran *et al.* (2016) who did a detailed study on the impact of fungicides, pesticides, and herbicides (propargite, glyphosate, and ammonium salt of glyphosate, propiconazole, hexaconazole, Combination of carbendazim and mancozeb) on the mycelia characteristics of the fungal bio-agents and found that among all the agrochemicals tested Ammonium salt of glyphosate was found to be incompatible with *T. viride*. The compatible nature of the growth media along with the pesticides suggests that these bio-agents may thus be used for bioremediation of pesticides contaminated soil study. The incompatible nature may be due to the toxic trait of the chemicals at a higher concentration, limiting the growth of the mycelium of the fungal bio-agents. Similar results were found by Sharma *et al.* (2016) who did an experiment on the compatibility of biocontrol agents with agrochemicals including azadirachtin 5EC, bifenthrin 8SC, clothianidin 50 WDG, deltamethrin 2.8EC, fenpropathrin 90 EC, thiamethoxam 25WG, COC 50WP, propiconazole 25EC, hexaconazole 5EC, boric acid, zinc, urea, SSP and MOP at 2500 ppm, 1250ppm, 625 ppm, 1000 ppm,2000 ppm, 750 ppm, 375 ppm, 100 ppm, 50 ppm, 25 ppm, 125 ppm, 62.5 ppm, and 31.2 ppm as well and found that the fungal bio-agents

Table 4. *In-vitro* compatibility of *Trichoderma viride* with fertilizers

Fertilizer	Concentration (ppm)	Mean (±) * (Diameterof mycelia in cm)	Per cent inhibition
Urea	100	8.93	0.78
	500	8.99	0.03
	1000	1.32	85.37
	2000	0.00	100.00
MOP	100	9.00	0.00
	500	8.95	0.59
	1000	1.27	85.92
	2000	0.00	100.00
SSP	100	9.00	0.00
	500	9.00	0.00
	1000	9.00	0.00
	2000	9.00	0.00
Control	control	9.00	0.00
SE±(d)	**0.11**		
C.D. @ 5 %	**0.22**		

were found to be highly compatible in nature except for zinc, hexaconazole, propiconazole, boric acid. The compatible reactions of the antagonistic microorganism with the various fungicides may be due to their ability to degrade chemicals and inherent resistance to most of the fungicides (Papavizas, 1985). The compatible reactions may also be due to the high tolerance potential of the native *Trichoderma* spp.

In the present study, all the triazoles showed inhibition against the *T. viride*. The results were in accordance with Gayatri *et al.* (2016) who studied the compatibility nature of the fungal and bacterial bio-agents with the fungicides and fertilizers (copper oxychloride, chlorothalonil, mancozeb, SSP, MOP, and urea) at various concentrations and found that among all the fungicides only mancozeb was incompatible at various concentrations and others were compatible. Also, the findings of Shashikumar *et al.* (2016); Dutta *et al.* (2016); Vyas *et al.* (2020) respectively were found to be similar, where they tested the fungal bio-agents including *Trichoderma viride* against carbendazim, copper oxychloride, mancozeb, mancozeb + carbendazim, methyl -o– demeton, cartap hydrochloride, chloropyrifos, quizalofop, pendimethalin, fenoxyprop – p – ethyl, propiconazole, hexaconazole, trifloxystrobin + tebuconazole, tebuconazole and concluded that mancozeb, carbendazim, and combination of mancozeb and carbendazim were found to be incompatible in nature.

Table 5. *In-vitro* compatibility of *Trichoderma viride* with antibiotics

Chemical	Concentrations (ppm)	Mean (±) * (Diameter of mycelia in cm)	Per cent inhibition
Streptomycin	100	9.00	0.00
	500	8.85	1.63
	1000	8.67	3.70
	2000	8.49	5.63
Gentamycin	100	9.00	0.00
	500	8.87	1.44
	1000	8.46	6.00
	2000	8.18	9.11
Control	control	9.00	0.00
SE±(d)	**0.22**		
C.D. @ 5 %	**0.46**		

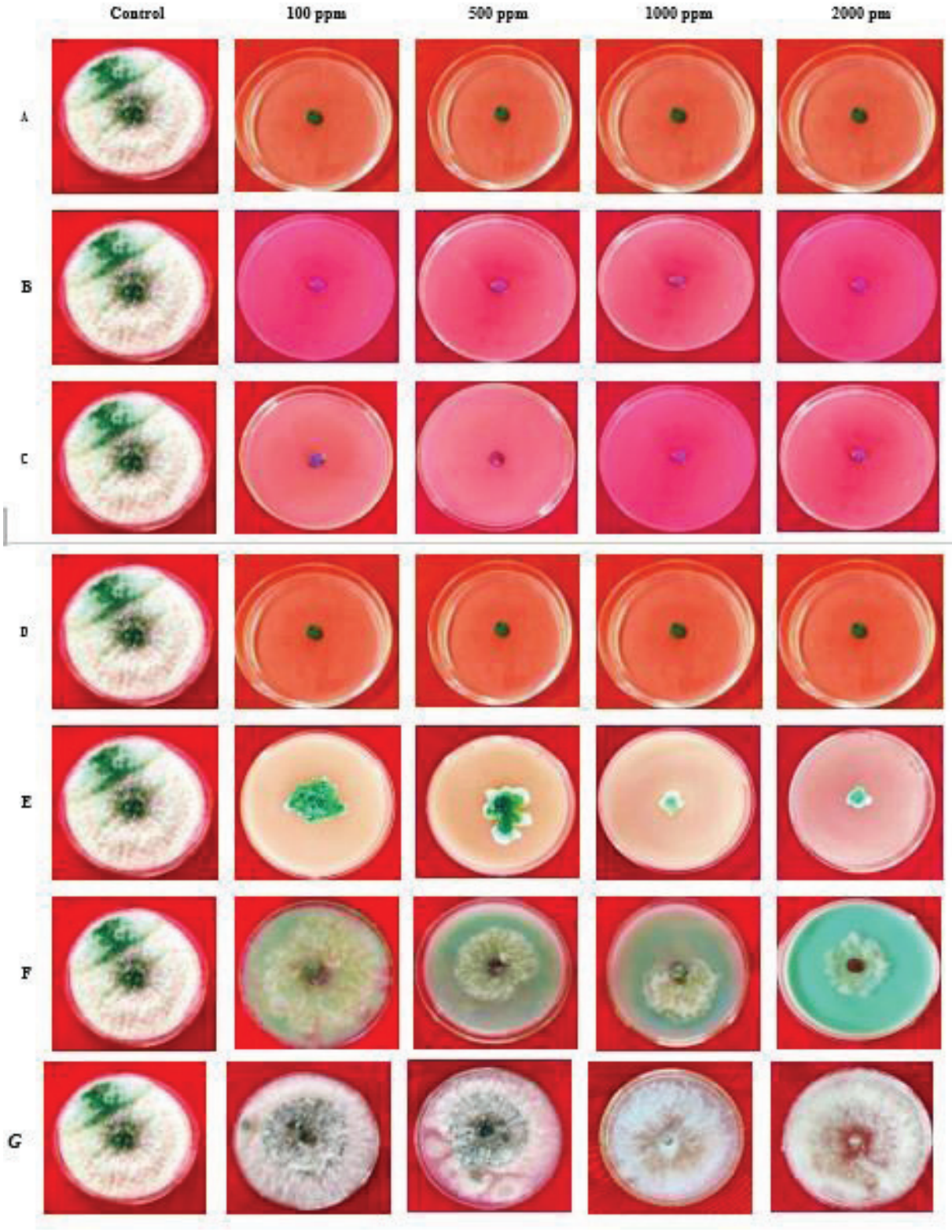

Fig. 1. (A- G). ***In-vitro*** **compatibility of** ***Trichoderma viride*** **with fungicides; (A) Hexaconazole +** ***T. viride*****; (B) Propiconazole +** ***T. viride*****; (C) Tebuconazole +** ***T. viride*****; (D) Tebuconazole 50% + Trifloxystrobin 25% +** ***T. viride*****; (E) Chlorothalonil +** ***T. viride;*** **(F) Copper Oxychloride +** ***T. viride*****; (G) Azoxystrobin +** ***T. viride***

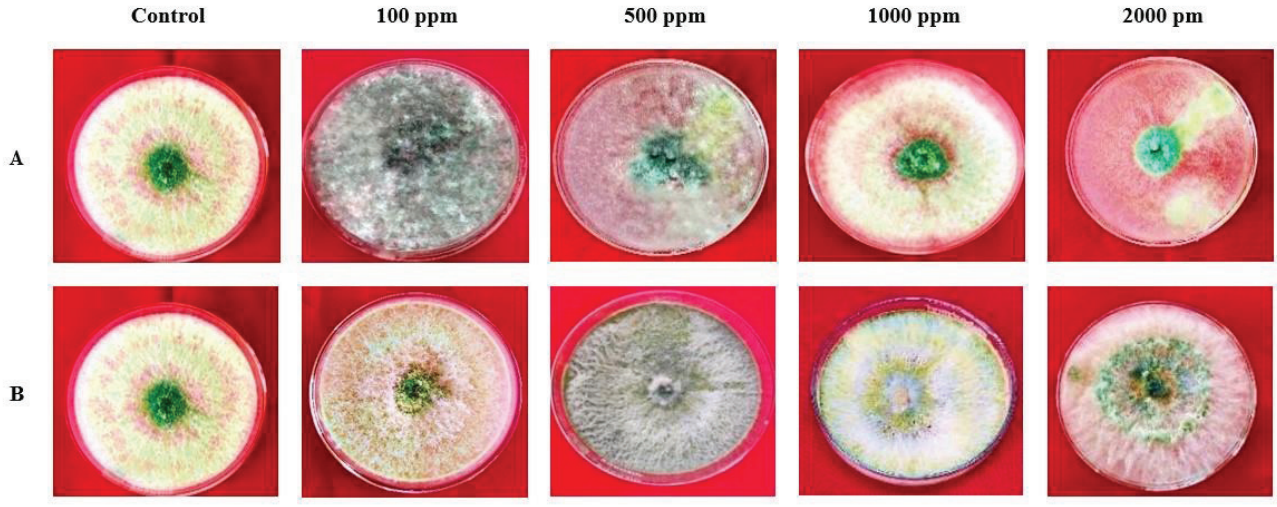

Fig. 2. (A-B). *In-vitro* compatibility of *Trichoderma viride* with antibiotics; (A) Streptomycin + *T. viride*; (B) Gentamycin + *T. viride*

The fungicides can restrict the growth of the mycelium of the fungus completely. This inhibitory effect may be due to the toxicity of the chemicals on the *Trichoderma* spores and cells leading to destruction of the hyphae. The mycelium is not able to grow profusely, and the infection peg is not built up to cause infection. In the case of the beneficial bioagents including *Trichoderma* spp. due to the fungicidal effect, their antagonistic effect against the pathogenic fungus reduces drastically, and thus the combination of fungal bioagent with fungicides is not recommended at all in IPM. The result was found to be in co-relation with the works done by Dutta *et al.* (2016) did a detailed study and were able to conclude that herbicides (atrazine 50 WP, glyphosate 41% SL and paraquat dichloride 24% SL) at lower doses can be incorporated with the fungal bio-agents. The result is in line with Pinnamaneni *et al.* (2010) who did a detailed study on the compatibility of *T. viride* with commonly used pesticides including fertilizers and found that SSP was the most compatible one followed by MOP and then urea. Kumar *et al.* (2017) also studied the compatibility of certain fertilizers against *T. viride* and found their compatibility with the bio-agent. Dutta *et al*. (2016) also did an assessment of certain agrochemicals including SSP, MOP, and urea with microbial biopesticides that are most used in tea of Assam condition basically in Northeast India and found that the fertilizers were compatible at respective concentrations. The results are coinciding with the work done by Gangwar *et al.* (2013)who conducted an experiment to find out the compatibility of fungal bioagents against the most used agrochemicals including streptomycin, and gentamycin where they found the high compatibility of antibiotics at 250, 500, 1000 and 2000 ppm showing maximum radial growth of 66.5 mm to 85.00 mm. Also, similar results were found by Mishra *et al.* (2019) against the compatibility of bioagents with the chemical pesticides including- streptocycline, streptomycin, carbendazim (50% WP), propiconazole (25% EC), tridemorph (BO% EC), hexaconazole (5% EC), chlorothalonil (75% WP) and mancozeb (75% WP) and found that the fungal BCAs were compatible with the antibiotics at all the respective concentrations.

CONCLUSION

The present result indicates that the combined application of compatible bioagents and agrochemicals have showed efficacy in plant protection. The approach eventually explores the for the reduced need of chemical pesticides in agriculture, thus, assists to maintain environmental integrity and safety. Incorporation of microbial biopesticides with recommended doses of PPFs is an effective strategy for adopting suitable IPM modules under climate-smart agriculture for improved plant growth and yield, and plant protection. Development of induced systemic resistance (ISR) in plants is another issue that gets strengthened due to repeated uses of efficacious microbials with potent mode of action. Proper screening and characterization of microbial bioagents with the advent of latest molecular tools and techniques would facilitate their application in sustainable agriculture. Multilocational field trials to test the efficacy of desirable bioagents needs to be made for adoption of suitable IDM under field situations.

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Interaction of *Meloidogyne incognita* and *Fusarium oxysporum* on vegetable cowpea (*Vigna unguiculata* (L.) Walp

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ABSTRACT: Interaction between *Meloidogyne incognita* and *Fusarium oxysporum* in vegetable cowpea, *Vigna unguiculata* was studied at the Department of Nematology, College of Agriculture, Vellayani during 2019-2021. Highest cohabitation of both the pathogens was observed when *M. incognita* was inoculated seven days prior to *F. oxysporum* inoculation. Presence of nematodes prior to fungus caused early disease incidence (23 days) and increased severity of wilt disease. Highest reproduction factor (2.34) was observed in *M. incognita* alone followed by *M. incognita*+ *F. oxysporum* one week after nematode inoculation (1.79). Nematode reproduction and galling showed significant reduction in simultaneous inoculation of both pathogens compared to nematode inoculation one week prior to fungus inoculation. Plants inoculated with *M. incognita* + *F. oxysporum* at one week after nematode inoculation showed significant reduction in growth parameters viz. shoot length (55.40 per cent), fresh weight of shoot (63.44 per cent) and root (49.01 per cent) compared to unincoculated control plants. Lowest number of nodules/5g root (14.00) was recorded in plants treated with *M. incognita* alone followed by *M. incognita*+ *F. oxysporum* one week after nematode inoculation (19.30).

Keywords: Vegetable cowpea, *Meloidogyne incognita*, *Fusarium oxysporum,* interaction

INTRODUCTION

Vegetable cowpea, *Vigna unguiculata* sub sp. *sesquipedalis* (L.) Walp is one among the most cultivated vegetables in Kerala. It is an extensively adapted, stress tolerant vegetable crop produced worldwide in warm to hot regions. Cowpea is cultivated as a vegetable in India, mostly in semi-arid and dry regions, with an area of 654 lakh hectares, a productivity of 916 kg/ha and a production of 599 lakh tonnes (Joshi, 2018). The increasing economic relevance of the crop is owing to its food value as it is good source of protein, vitamin A, iron, phosphorus and potassium. The ability of cowpea to fix atmospheric nitrogen through biological nitrogen fixation enhances soil fertility. Root knot nematode (RKN) *Meloidogyne incognita* (Kofoid and White) Chitwood is one of the main biotic constraints which reduces the quantity and quality of the crop throughout the world. Symptoms of *M. incognita* infection include stunting, yellowing, wilting and galling of roots. The average loss caused by root knot nematode in cowpea is 14.6 per cent in India (Mahantheshwara *et al*., 2020). Besides physiological changes in root, root-knot nematodes act as predisposing agents for entry of many pathogenic organisms like fungi, bacteria and virus. Fusarium wilt (FW) caused by the fungus *Fusarium oxysporum* f. sp. *tracheiphilum* (Fot) is one of the main threats to cowpea production throughout world. Plants show vascular streaks, basal swelling of stem, partial wilting in early stages and complete wilting in later stages leading to ultimate death. The disease complex caused by *M. incognita* and *F. oxysporum* occurs most frequently in vegetable cowpea in Kerala. Disease complexes are formed when two organisms invade a crop at the same time, resulting in major yield losses. The mechanical wounding and the resistance breaking ability of nematode favor the establishment of the fungus. The disease affected plants show brown streaks in vascular system resulting in physiological and biochemical alterations (Troisi *et al*., 2010). The objective of the present study was to assess the interaction between *M. incognita* and *F. oxysporum* in vascular wilt disease of cowpea.

MATERIALS AND METHODS

Identification of nematode and preparation of nematode inoculum

Identification of root-knot nematode was done by observing perineal pattern of adult females (Taylor and Netscher, 1974). Vegetable cowpea plants infected with root-knot nematodes were collected from Instructional Farm, Vellayani and washed thoroughly under running water. Mature females (10-15) were teased from galled roots and kept in a glass slide. They were cut at neck region and internal contents were pushed out by pressing. A cut was given in posterior region and the cuticle was placed in 45% lactic acid for cleaning the remaining body tissues. It was trimmed further under stereoscopic binocular microscope until it acquired square shape. This

Table 1. Effect of *Meloidogyne incognita* and *Fusarium oxysporum* on growth parameters of vegetable cowpea under pot culture condition

Treatments	Shoot*						Root*				No of nodules in root (5 g)*	% reduction over untreated
	Length (cm)	% reduction over control	Fresh weight (g)	% reduction over untreated	Dry weight (g)	% reduction over untreated	Fresh weight (g)	% reduction over untreated	Dry weight (g)	% reduction over untreated		
T1	21.10[b]	15.60	6.63[b]	9.55	3.84[b]	25.87	5.40[a]	19.21	3.33[a]	28.23	14.00 (3.73)[f]	72.55
T2	19.33[c]	22.68	5.13[c]	30.01	3.04[c]	41.31	4.15[c]	8.39	2.07[c]	13.39	36.30 (6.02)[b]	28.82
T3	18.26 [d]	26.96	4.38[d]	40.25	2.44[d]	52.90	3.68[d]	18.76	1.67[d]	30.13	23.30 (4.82)[d]	54.31
T4	11.15[f]	55.40	2.68[f]	63.44	1.12[f]	78.38	2.31[f]	49.01	0.98[f]	59.00	19.30 (4.39)[e]	62.16
T5	15.43[e]	38.28	3.73[e]	49.11	1.95[e]	62.36	2.89[e]	36.20	1.25[e]	33.63	31.00 (5.56)[c]	39.22
T6	25.00[a]	-	7.33[a]	-	5.18[a]	-	4.53[b]	-	2.39[b]	-	51.00 (7.16)[a]	-
CD (0.05)	**0.705**		**0.640**		**0.116**		**0.190**		**0.618**		**(0.359)**	

T1- *M. incognita* alone; T2- *F. oxysporum* alone; T3- Simultaneous inoculation of *M. incognita* and *F. oxysporum*; T4- *M. incognita* + *F. oxysporum* one week after nematode inoculation; T5- *F. oxysporum*+ *M. incognita* one week after fungus inoculation; T6- Uninoculated control with neither nematode nor fungus.

Figures given in parenthesis are square root transformed values *Mean of four replications

was transferred to a drop glycerine on a clean side and observed under microscope after placing cover glass over glycerine drop.

Pure culture of root-knot nematode was maintained in glass house of Department of Nematology, College of Agriculture, Vellayani by collecting egg masses from infected cowpea plants. Collected egg masses were surface sterilized using 0.1% sodium hypochlorite for 3 min and 95% ethanol for 1 min and later washed in sterile water for three times and placed in distilled water for hatching. Newly hatched second stage juveniles were inoculated in twenty five day old tomato seedling variety Vellayani Vijay @two juveniles/g soil for maintenance of culture.

Identification of fungal pathogen and mass multiplication

F. oxysporum was isolated from diseased vegetable cowpea plants from Instructional farm, Vellayani by direct plating method and maintained as pure culture in PDA at 25±2 ^{0}C. Growth of the fungus was observed at seven and ten days after inoculation and identified based on conidial characters. DNA extracted was subjected to PCR amplification using universal primers ITS1 and ITS4 (White *et al*., 1990) for molecular characterization.

Mass multiplication of fungal pathogen was done in sand : maize mixture (9:1) (Lewis and Papavizas, 1984). For the preparation of 100 g of sand maize mixture, 90 g sand and 10 g corn flour were mixed and 20 mL of distilled water was added. The mixture was filled into 250 mL conical flasks and plugged with cotton and sterilized in an autoclave at 121^{o}C and 15 k Pa pressure for 20 min. Fungal discs of size 7 mm were taken from seven days old culture plates using cork borer. 10 to 12 bits were added to each conical flask and the fungus was allowed to multiply for 15 days under room temperature. After 15 days, the sand-maize media was observed to be completely covered with white mycelial growth of fungus.

Interaction studies of nematode- fungus in vegetable cowpea

Pot culture experiment was conducted in glass house of Department of Nematology, College of Agriculture, Vellayani during 2020-21. Nematode culture was maintained at Nematology glass house, College of Agriculture, Vellayani. Earthern pots of size 36x20x20'' were filled with denematized potting mixture containing soil, sand and farm yard manure in 2:1:1 proportion and seeds of vegetable cowpea (variety Vellayani Jyothika) were sown with six treatments and four replications. Inoculation of both pathogens (*M. incognita* and *F. oxysporum* multiplied in sand maize medium (20×10 ^{7}cfu/g) @500g) was done in the rhizosphere of 25 days old cow pea seedlings either alone, simultaneously or sequentially. Nematodes were inoculated @1 juvenile/g soil. The treatments were T1- *M. incognita* alone, T2- *F. oxysporum* alone, T3- Simultaneous inoculation of *M. incognita* and *F. oxysporum,* T4- *M. incognita* + *F. oxysporum* one week after nematode inoculation, T5- *F. oxysporum*+ *M. incognita* one week after fungus inoculation, T6- Control with neither nematode nor fungus.

Observations were recorded on plant growth parameters (shoot length, dry and fresh weight of shoot and root), nematode population characteristics (nematode population in soil (200cc), root (5g), number of females (5g root), number of galls (5g root), egg masses (5g root), eggs per egg mass, disease incidence, days taken for initiation of disease) and number of nodules (5g root). Nematode population in soil was estimated by Cobb's sieving and decanting method and modified Baermann's funnel technique. Reproduction factor was calculated by formula given by Oostenbrink (1966) and disease incidence was documented as per method developed by Singh (2002). Data generated from the experiment were subjected to analysis of variance (ANOVA) test (Cochran and Cox, 1965). Those variables which did not satisfy the basic assumptions of ANOVA were subjected to angular or square root transformation.

RESULTS AND DISCUSSION

Identification of *Meloidogyne* species associated with vegetable cowpea

Perineal pattern of the collected females was identified as *M. incognita* based on identification key (Eisenback, 1985) that include high dorsal arch which were flattened at the top and striae distinct and wavy.

Identification of *Fusarium* species associated with vegetable cowpea

Fusarium species was identified based on morphological characters *viz.* purplish tinged colony with white mycelia as well as presence of macro and micro conidia. Micro conidia were elliptical in shape and macro conidia possessed 4±1.5 septation. The DNA of the internal transcribed spacer regions (ITS) were amplified using the universal primers ITS1 (5'- TCCGTAGGTGAACCTGCGG-3') and ITS4 (5'TCCTCCGCTTATTGATATGC3'). Results of the blast analysis showed homology with matching sequence of *F. oxysporum* in NCBI data base.

Effect of nematode pathogen interaction on growth parameters of vegetable cowpea

There was significant reduction in growth parameters of cowpea plant when nematode and fungus were inoculated at different intervals compared to uninoculated control (Table 1). Inoculation of nematodes one week

Table 2. Effect of *Meloidogyne incognita* and *Fusarium oxysporum* on nematode population characteristics in vegetable cowpea under pot culture condition

Treatments	Nematode population* (30 DAI)			Reproduction factor (RF=Pf/Pi)*	No. of galls (5 g)*	No. of egg masses (5 g)*	No. of eggs in egg mass
	Soil (200 cc)	Root (5 g)	No. of females (5 g)				
M. incognita alone	573.30 (23.95)[a]	58.30 (7.70)[a]	40.66 (6.41)[a]	2.34[a]	66.66 (8.22)[a]	74.00 (8.63)[a]	256.00 (16.03)[a]
F. oxysporum alone	0.00 (1.00)[e]	0.00 (1.00)[e]	0.00 (0.70)[e]	0.00[e]	0.00 (1.00)[e]	0.00 (0.70)[e]	0.00 (0.70)[e]
Simultaneous inoculation of *M. incognita* and *F. oxysporum*	490.00 (22.15)[c]	41.30 (6.50)[c]	20.00 (4.52)[c]	1.46[c]	42.33 (6.58)[c]	52.30 (7.26)[c]	208.60 (14.46)[c]
M. incognita + *F. oxysporum* at one week after nematode inoculation	551.33 (23.50)[b]	51.30 (7.23)[b]	30.66 (5.58)[b]	1.79[b]	56.66 (7.59)[b]	67.30 (8.23)[b]	239.00 (15.47)[b]
F. oxysporum + *M. incognita* at one week after fungus inoculation	433.00 (20.83)[d]	34.3 (5.56)[d]	15.00 (3.93)[d]	1.14[d]	22.33 (4.82)[d]	40.00 (6.36)[d]	122.60 (11.09)[d]
Uninoculated control	0.00 (1.00)[e]	0.00 (1.00)[e]	0.00 (0.70)[e]	0.00[e]	0.00 (1.00)[e]	0.00 (0.70)[e]	0.00 (0.70)[e]
CD (0.05)	**(0.217)**	**(0.277)**	**(0.201)**	**(0.067)**	**(0.175)**	**(0.190)**	**(0.461)**

Pf- Total nematode population (soil+root+ number of females); Pi-Initial nematode population

Figures given in parenthesis are square root transformed values *Mean of four replications

prior to fungus recorded lowest growth parameters of plants (shoot length-11.15 cm, fresh shoot weight-2.68 g, dry shoot weight-1.12 g, fresh root weight-2.31g and dry root weight-0.98 g). Plants inoculated with *M. incognita* + *F. oxysporum* at one week after nematode inoculation showed 55.40, 63.44 and 78.38 percentage reduction in length, fresh weight and dry weight of shoot compared to unincoculated control plants. This finding in this study is in agreement with Samuthiravalli and Sivakumar (2008) who observed that when *M. incognita* combined with fungus *F. oxysporum* f. sp. *lycopersici*, the impact was amplified due to synergism and growth was suppressed in tomato plants, when compared to that with fungal inoculation alone. The highest synergistic effect in sequential inoculation of nematode and pathogen noticed in this study may be attributed to the fact that root knot nematodes enhanced the occurrence, pace of development and severity of wilt resulting in lowering of plant growth indices like plant length, shoot and root weight by providing entry sites for the fungal pathogen (Malhotra *et al*., 2011). Similar trend was observed in the case of fresh weight and dry weight of root also (49 to 59 per cent reduction over control). Meena *et al.* (2016) reported that prior inoculation of nematodes in carnation disrupted the vascular tissues and reduced the transportation of water and nutrients to foliar systems resulting in reduced photosynthetic rate and chlorophyll content in plants. In the present study also, sequential inoculation of nematodes prior to fungus modified host root physiology and caused synergistic effect in reducing plant growth than their individual infection. Lowest number of nodules was recorded in plants inoculated with *M. incognita* alone with 72.55 per cent reduction over uninoculated control. This might be due to the reduction in the capacity of rhizobia bacterial strains to fix nitrogen, especially when the plants are affected with specific pathogens like root knot nematodes. This result corroborated with Izuogu *et al*. (2019), who recorded a reduction in the number of nodules in cowpea plants inoculated with nematode. *M. incognita* infection and gall formation disrupted physiological processes of plants which decreased rhizobium activity in the nodular tissue, resulting in poor nodulation and reduced nitrogen fixation.

Effect of nematode-pathogen interaction on nematode population characteristics

Data presented in Table 2 revealed that there was significant difference in nematode population and disease parameters when both the pathogens were inoculated singly or in combination at different intervals. The highest nematode multiplication was recorded in plants inoculated with *M. incognita* alone followed by *M. incognita* seven days prior to *F. oxysporum* inoculation. *M. incognita* alone inoculated plants recorded highest population of nematodes in soil (573.30/200cc) 30 days after nematode inoculation (DAI) followed by *M. incognita* + *F. oxysporum* one week after nematode inoculation (551.33). Similar trend was observed in root also. This finding is in line with that of Husain and Salman (2019) who reported that nematode population in soil at

Table 3. Effect of *Meloidogyne incognita* and *Fusarium oxysporum* on disease incidence in vegetable cowpea

Treatment	Disease incidence (%)*	Disease index (%)*	Days taken for initiation of disease*
M. incognita (alone)	0.00 (2.86)^{d}	0.00 (2.86)^{d}	No disease
F. oxysporum (alone)	33.33 (35.20)^{c}	25.00 (29.16)^{c}	29
Simultaneous inoculation of *M. incognita* and *F. oxysporum*	33.33 (35.20)^{c}	29.16 (27.57)^{c}	27
M. incognita + *F. oxysporum* at one week after nematode inoculation	100.00 (90.00)^{a}	91.66 (76.17)^{a}	23
F. oxysporum + *M. incognita* at one week after fungus inoculation	66.60 (54.76)^{b}	45.83 (42.59)^{b}	26
Uninoculated control	0.00 (2.86)^{d}	0.00 (2.86)^{d}	No disease
CD (0.05)	**(4.419)**	**(8.920)**	

Figures in parenthesis are arc sine transformed values *Mean of four replications

harvest increased by four folds than its initial population in the plants inoculated with *M. incognita* alone in tomato. This might be due to the fact that the interaction between the nematode and fungus is not helpful always for nematode multiplication as the secondary pathogen may penetrate and feed on nematode feeding sites, causing nematode famine and death. Highest number of galls (66.66/5g root), females (40.66/5g root), egg masses (74.00/5g root) and eggs in egg mass (256.00/5g root) also observed in plants inoculated with *M. incognita* alone. Significant reduction in number of galls (56.66/5g root), females (30.66/5g root), egg masses (67.30/5g root) and eggs/egg mass (239.00/5g root) was observed in plants inoculated with *M. incognita* seven days prior to *F. oxysporum* inoculation. These observations were in agreement with the study conducted by Al-Hazmi and Al-Nadary (2015) who mentioned that inoculation of nematode prior to the fungus in green beans caused anatomical and physiological changes in root leading to formation of root galls and predisposing the plant to fungal infection and its establishment which caused the deleterious effect to nematodes resulting in reduction in their number. Gall formation by nematode was affected due to the attack of fungal mycelia on nematode cells and toxic metabolites produced by the fungus caused decrease in number of juveniles, thus reducing the formation of galls on roots (Askary, 2015). Reproduction factor was highest (2.34) in the plants treated with *M. incognita* alone followed by *M. incognita* at seven days prior to *F. oxysporum* inoculation (1.79). This decrease may be due to the development of mycelial mat on roots following fungal invasion, which created adverse conditions for the developing nematodes causing their sex reversal and formation of males that leave the roots (Hajji-Hedfi *et al.,* 2017).

Effect of nematode-pathogen interaction on disease incidence in vegetable cowpea

The highest disease severity percentage (100.00 %) and early onset of the disease (23 days) were observed in the plants inoculated with *M. incognita* at seven days prior to *F. oxysporum* inoculation (Table 3). This enhancement in disease might be due to the interaction between both the pathogens in rhizosphere. Similar findings were reported by Ramalingam (2019) in tomato and Sanjeevkumar *et al*. (2018) in the banana cv. Monthan. They reported that exudates liberated from *M. incognita* infected plants enhanced the germination of *Fusarium* propagules present in soil. It also hindered the activity of actinomycetes, which inhibit the wilt fungus, in turn allowing *Fusarium* pathogen to grow without any curb. Higher reserve material found in the nurse cells formed by nematodes helped fungal pathogen to grow and invade rapidly on the nutritionally dense giant cells. Disease index was least (25.00) *F. oxysporum* alone than other treatments. The reduction in disease incidence may be due to the late or delayed entry of fungus into the plant because of the absence of predisposing agent i.e., nematode. This finding is in line with that of Haseeb *et al*. (2007) who reported that there was an increase in disease when *M. incognita* was inoculated prior to *F. oxysporum* f. sp. *pisi* in garden pea. The present investigation of *M. incognita* and *F. oxysporum* on vascular wilt disease complex in cowpea clearly demonstrated prior inoculation of nematodes reduced the incubation period of fungus, thereby resulting earlier wilting symptoms. Inoculation of nematode seven days prior to fungus inoculation recorded the maximum disease incidence, confirming the role of *M. incognita* as predisposing factor for the entry of the soil borne pathogen *F. oxysporum* in vegetable cowpea.

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Species diversity and distribution of Megachilidae bees from Chhattisgarh, Central India

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ABSTRACT: This study deals with the species diversity of leaf-cutter and resin bees from three tribes, four genera, and seven subgenera of the family Megachilidae from Central India. Before this study, only a few species were known from Central India. During the surveys undertaken in 2019–2022, 10 species, including two cleptoparasitic bee species of the family Megachilidae, were collected and examined. *Megachile lanata* Fab. was the predominant species in all the survey locations. Seven species were discovered for the first time in Central India. This paper provides details of the Megachilidae species with an updated distribution and brief diagnosis.

Key words: Megachilidae, Bee diversity, pollinator, Chhattisgarh

INTRODUCTION

Solitary bees have been known as important pollinators. Among these, bees under the family Megachilidae are important pollinators offering their crucial role in the wellbeing of the ecosystem. Megachilidae has approximately 4,000 species found worldwide (Ascher and Pickering, 2020; Michener, 2007). In India, 75 species have been reported from the tribe Megachilini (Gupta, 1999), of which 16 are reported from the genus *Megachile* Latreille. Several species of Megachilidae are known as effective pollinators and are now farmed and preserved because of their importance in pollinating commercial crops (Batra, 1977). The most common names for the megachilids are 'mason bees' and 'leafcutter bees,' which refer to the materials used to construct their nest cells (mud or leaves, respectively). Some gather plant or animal fur and fibers and are known as carder bees, while some utilize plant resins in nest construction and are known as resin bees. Most of the species feed on pollen and nectar. However, few cleptoparasites (cuckoo bees) eat pollen gathered by other Megachilid bees. These include genera *Coelioxys* Latreille of the tribe Megachilini and *Euaspis* Gerstaecker of the tribe Anthidiini (Hymenoptera: Megachilidae) and cleptoparasitic bees belonging to the genus *Megachile* Latreille (Michener, 2007). *Coelioxys* is an old-world cleptoparasitic bee genus including several species (Warncke, 1992; Gupta, 1993; Nagase, 2006; Wu, 2006; Michener, 2007; Ascher and Pickering, 2020). Gupta, 1993 reported *M. cephalotes* from Central India (Madhya Pradesh). *Bingham* reported *Coelioxys angulate* from different regions of India and, for the first time, from Central India (1897). *Megachile elfrona* has been reported from Gujrat (Gupta, 1993) and Rajasthan, Madhya Pradesh (Kumari *et al.*, 2020). Three species, *M. anthracina*, *M. carbonaria*, and *M. elizabathae* Bingham, of genus *Megachile*, were reported by Kumari and Kumar (2016) from Punjab, India. Gupta (2015) recorded eight species of the family Megachilidae from Uttarakhand, India, of which six were of the genus *Megachile* and two of the *Coelioxys*. Recently, Sardar *et al*. (2021) reported seven species of the genus *Megachile* in 5 different states of India, and *M. lanata* was reported for the first time from Assam. Veereshkumar and Kumarnag (2018) reported the family Megachilidae with six species*, M. lanata*, *M. anthracina, M. lerma, M. disjuncta, L. atratus* and *M. bicolor* from Bengaluru, Karnataka, India. Even though many workers have been documenting bees, as evident from the above reports, this is not even 1% of the total expected bee diversity from the Chhattisgarh state.

The present study attempts to add and further update the information on the Megachilidae from Central India, specifically Chhattisgarh, which remains an under-explored region for bee fauna. Chhattisgarh has the country's most abundant and pristine set of natural resources. Recent surveys of bees from the forests and plains in Chhattisgarh state conducted by Minz et al., (2020) discovered a few additional solitary bees with a sole representation of one Megachilidae species. Many researchers have worked on the diversity of bees in different parts of India and recorded numerous and diverse solitary bees, including many leafcutter and resin bee species in the family Megachilidae. Central India

Table 1. Survey details for the collection of Megachilid bees in Chhattisgarh state during 2019 to 2022

S. No.	Agro-climatic Zone	District	Location	Geographical coordinates	No. of specimens collected	Most abundant species
1.	Northern Hill Zone	Sarguja	RMD CARS, Ambikapur	23°09'05.4"N 83°09'00.1"E	24	*Megachile anthracina* Smith
			KVK, Ambikapur	23°14'02.7"N 83°14'85.74"E	0	-
2.		Balrampur	KVK, Balrampur	27°69'N 82°65'76.4"E	0	-
3.		Jashpur	Badalkhol WLS	22°89'61.73"N 83°91'58.04"E	0	-
4.		Surajpur	Tamorpingla WLS	23°36'01.8"N 83°00'01.1"E	0	-
5.	Chhattisgarh Plain Zone	Raipur	Lakhna, Somnath	21°56'74.86"N 81°66'95.68"E	12	*Euaspis carbonaria* Smith *Coelioxys angulata* Smith
			IGKV, Raipur	21°14'03.6"N 81°42'51.4"E	6	*Megachile vigilans* Smith
			Energy park, Raipur	21°21'94.77"N 81°69'76.54"E	0	-
6.		Mahasamund	Barnawapara WLS	21°47'98.74"N 82°53'13.15"E	18	*Megachile hera* Bingham
			KVK, Mahasamund	21°03'47.0"N 82°05'04.6"E	0	
7.		Baloda Bazar	Bhatapara	21°44'31.9"N 81°56'13.7"E	2	*Megachile vigilans* Smith
		Bilaspur	Achanakmar WLS	22°26'04.4"N 81°42'11.0"E	0	-
8.		Dhamtari	Dhamtari	20°41'37.7"N 81°33'00.3"E	0	-
9.		Rajnandgaon	Dongargarh	21°13'20."N 80°43'07"E	0	-
10.		MohlaManpur	Mohla	20°35'00.0"N 80°44'56.2"E	0	-
11.		Bemetara	Patharra, Bemetara	21°38'24.1"N 81°36'07.1"E	4	*Megachile lanata* Fabricius *Megachile bicolor* Fabricius
			Semariya	21°51'18.0"N 81°29'35.2"E	78	*Lithurgus* sp. 1
12.		Kawardha	Bhoramdev WLS	22°00'41.4"N 81°05'57.9"E	4	*Megachile lanata* Fabricius *Megachile bicolor* Fabricius
13.		Khairagarh-Chhuikhadan-Gandai	Khairagarh	21°24'53.2"N 80°58'44.8"E	0	-

14.	Bastar plateau zone	Jagdalpur	Shaheed Gundadhur CARS farm, Jagdalpur, Chhattisgarh	19°05'33.9"N 81°57'38.7"E	6	*Megachile lanata* Fabricius
			Kanger valley NP, Jagdalpur	18°57'14.3"N 82°14'11.7"E	2	*Megachile lanata* Fabricius

*WLS: Wildlife Sanctuary; CARS: College of Agriculture and Research station; KVK: Krishi Vigyan Kendra; IGKV: Indira Gandhi Krishi Vishwavidyalaya; RMD: Rajmohini Devi College of Agriculture and Research Station

remains an under-studied region for Megachilid bees, with barely four Megachilid bee species (Bingham, 1897; Minz et al., 2020; Kumari et al., 2020; Gupta, 1993). In this context, extensive surveys were undertaken and the present study aims to summarize the diversity and distribution of Megachilid bees from Chhattisgarh state.

MATERIALS AND METHODS

Extensive surveys were undertaken from July 2019 to August 2022 in three agro-climatic zones of Chhattisgarh state to document Megachilid bees. Different agricultural, horticultural crops and natural forest areas were visited during the surveys and rigorous collections were done. Elaborate details of the surveys are provided in Table 1. Permission was acquired to collect samples from the Office of the Principal Chief Conservator of Forests (Wildlife Management & Bio-diversity Conservation cum-Chief Wildlife Warden) Chhattisgarh via letter no. 4237, dated 07/27/2019.

Sweep net and Yellow Pan Traps were used to collect the samples. The sweep net collection method was chosen for bees foraging on the flowers during bright sunny days. The obtained samples were transferred to a charged killing bottle. After being killed, the bees were curated, labelled and secured in fumigated insect boxes. Specimens were later examined using a Leica S8AP0 microscope and identified up to the species level using Michener, 2000; Batra, 1977 and Bingham, 1897. Microphotographs were taken with a Leica MZ 16A camera using LAS V3.8 imaging software. Seventy identified voucher specimens were deposited in the National Insect Museum (NIM) of ICAR- National Bureau of Agricultural Insect Resources, Bangalore, India, with their respective accession numbers. Another set of specimens were deposited in IGKV, Raipur. Terminology, in general, follows Michener (2007).

Statistical analysis

Samples across the sampling duration were combined for analysis and the following observations were undertaken:

1. The species richness was calculated using following models (Magurran, 2004)
   Menhinick's index ($D_{Mn} = S/\sqrt{N}$)
2. Diversity index was computed following (Hill, 1973)
   Shannon Weaver diversity index ($H' = -\Sigma [p_i \ln (p_i)]$)
3. Species Evenness was calculated following (Hill, 1973): $E = H'/ \ln S$

   Where, H' is the diversity index calculated from Shannon Weaver diversity index.
4. Relative abundance

   Samples from all the colored pan traps were compiled and used to calculate the relative abundance by the following formula (Curtis and McIntosh, 1951)

$$\text{Relative abundance} = \frac{\text{Total number of individuals of one species}}{\text{Total number of individuals of all species}} \times 100$$

RESULTS AND DISCUSSION

A total of 156 specimens were randomly collected in 35 surveys from 21 locations in Chhattisgarh. Ten species were found belonging to four genera and seven subgenera (Table 2). Diversity indices of the Megachilid bees were calculated and the following values were obtained: Shannon Weaver diversity index (2.18), Menhinick diversity index (0.80) with effective number of species (8.84). The results show the diverse population of Megachilid bees in Chhattisgarh. The highest relative abundance was found of *Lithurgus* sp. 1 (47% of total population) followed by *M. lanata* (12.82 %) but the distribution of *Lithurgus* sp. 1 was confined to one area (Semariya) in a horticulture field and could not be collected from any other site even after multiple attempts. However, *M. lanata* was found in many survey locations and was found to be the most common species in Chhattisgarh region. Amongst four genera collected, *Megachile* was found to be the predominant genus in Chhattisgarh (Fig. 1).

Table 2. List of Megachilid bee species collected from Chhattisgarh

Species	Specimens examined	Relative abundance (%)
Megachile lanata Fabricius	15 ♀, 5 ♂	12.82
Megachile bicolor Fabricius	4♀, 4♂	5.12
Megachile anthracina Smith	2♀, 8♂	6.41
Megachile carbonaria Smith	4♀, 2♂	3.84
Megachile hera Bingham	2♀, 4♂	3.84
Megachile vigilans Smith	10♀, 4♂	8.97
Coelioxys fuscipennis Smith	6♀	3.84
Euaspis carbonaria Smith	2♀, 4♂	3.84
Lithurgus sp. 1	2♀, 60♂	47.43
Lithurgus sp. 2	2♀	2.56

Details of species recorded from Central India

Brief diagnosis with key identifying characters of all species are as follows:

***Megachile* (*Pseudomegachile*) *lanata* Fabricius, 1775** (Figs 2A &2B)

Female ♀

Body black, antennae with black scape and pedicel, flagellum dark brown, legs black, tegulae orange. Body length 20.94 mm, large bee with testaceous pubescence. Dense fulvous pubescence on thorax; scutellum rounded and wing flavohyaline.

Male ♂

Body black, body length 18.65 mm, smaller than female; face with dense fulvous red pubescence; Mesosoma: completely covered with dense fulvous pubescence. Metasoma: T1 and T2 covered with red fulvous dense pubescence; T2-T5 with transverse white apical bands of pubescence. Genitalia: inner surface of gonostylus with fringe of plumose bristles; bare gonocoxite; slightly dilated penis valve apically.

Distribution

India: Chhattisgarh (recorded during the present survey as well as by Minz *et al.,* 2020), Jammu (Abrol *et al.,* 2017), Karnataka (Amala and Shivalingaswamy, 2018), Tamil Nadu (Kannagi *et al*., 2016), Uttarakhand (Kunjwal *et al*., 2016), Himachal Pradesh, Haryana, Punjab, Gujarat, Rajasthan (Gupta, 1993), Jammu, Kerala, Maharashtra, Uttar Pradesh, Madhya Pradesh, Bihar (GBIF, 2021), West Bengal, Assam, Dadra and Nagar Haveli (Sardar *et al*., 2011).

Global: India (Magnacca *et al*., 2013), Pakistan (Akram *et al.,* 2019), Florida (Kevin *et al.,* 2019), Colombia (Gonzalez *et al*., 2019), West Indies, Ethiopian and Oriental regions (Mitchell, 1962), Hawaii (Magnacca, 2015). Africa, Caribbean, North America, Oceania, South America, Southern Asia (ITIS, 2022), Sri Lanka (Inoka *et al.,* 2014), Africa, Trinidad and Tobago, USA, Thailand, Sint Maarten (Dutch part) (GBIF, 2021).

***Megachile* (*Amegachile*) *bicolor* Fabricius, 1781** (Figs 2C &2D)

Colour: Body black with white pubescence on face and orange fulvous pubescence on metasoma, antennae black, leg black, tegulae dark brown.

Female ♀

Body length 20.26 mm, black. Head: face with dense white pubescence on frons and gena. Metasoma: T1-T5 covered with bright orange pubescence, T6 covered with dark brown suberect pubescence; pale white sternal scopa present on S2-S5, S6 sparsely covered with black small hairs.

Male ♂

Body length 15.94 mm, smaller than female, black with yellow pubescence on metasoma. Head: pale white to yellowish dense pubescence on the face, gena and hypostomal area; Metasoma: dorsal metasoma similar to female; T6 covered with fulvous red to white pubescence. Genitalia: gonostylus with sparse hairs on inner surface; brush of hairs on distal part and extended misally.

Distribution:

India: Chhattisgarh (**new record**), Jammu (Abrol *et al.,* 2017), Karnataka (Veereshkumar and Kumaranag, 2018 and Suma *et al*., 2006), Uttarakhand (Kunjwal *et al*., 2016), Tamil Nadu, Maharashtra, Madhya Pradesh,

Fig. 1. Distribution map of different genera of Megachilidae bees in Chhattisgarh

Gujrat, Bihar, Punjab, Haryana (GBIF, 2021), Uttar Pradesh (Veereshkumar *et al*., 2020), Rajasthan (Hooda & Jain, 2020).

Global: Hong Kong, China, Thailand, India (GBIF, 2020), Japan (Yasumatsu and Hirashima, 2011), Pakistan (Saeed *et al*., 2019), Southern Asia (ITIS, 2022).

***Megachile* (*Xanthosarus*) *anthracina* Smith, 1853** (Figs 2G & 2H)

Female ♀

Body length 25.40 mm, black, robust shiny bee, body entirely black, wing metallic dark fuscous. Head: black pubescence on face; clypeus coarsely punctate, bare, convex, impunctate shiny line medially. Mesosoma: mesosoma with dense black pubescence at latero-posterior margin.

Male ♂

Body length 18.88 mm, shiny, black bee with yellowish face. Head: fulvous white pubescence on face, gena and hypostomal area. Mesosoma: fulvous white pubescence on dorsolateral part of pronotum, scutum and anterior tegulae. Genitalia: gonostylus with short and long hairs on inner and distal part respectively; penis valve apically slightly dilated.

Distribution

India: Chhattisgarh (**new record**), Punjab, Tamil Nadu (GBIF, 2021), Karnataka (Syed *et al*., 2021 and Suma *et al*., 2006), Uttarakhand (Kunjwal *et al*., 2016).

Global: Southern Asia (ITIS, 2022).

***Megachile* (*Xanthosarus*) *carbonaria* Smith, 1853** (Figs 2I &2J)

Female ♀

Body entirely black, wing metallic dark fuscous. Body length 23.79 mm, similar to *M. anthracina* except smaller in size and facial pubescence mixed black and white to golden. Head: black and golden white pubescence on face. Mesosoma: black and pale white mixed pubescence at latero-anterior part; Metasoma: black hair on anterio-lateral margine of T1; T2-T5 without hair, mid basal area without punctuation.

Male ♂

Black, body length 18.51 mm, similar to *M. anthracina* except fan like long hairs absent on mid tarsal segment. Head: face, hypostomal area and gena with pale white pubescence. Mesosoma: sooty black and white pubescence on outer margin of mesosoma. Metasoma: T1-T5 bare, finely punctate, impunctate at mid-basal area, shiny black; disc of T6 with pit like depression medially. Genitalia: similar to *M. anthracina* but penis valve slightly incurved at inner surface, narrow towards tip and directed straight.

Distribution

India: Chhattisgarh (**new record**), Gujarat, Tamil Nadu (GBIF, 2021), Karnataka (Suma *et al.,* 2006).

Global: Southern Asia, Africa (ITIS, 2022), USA (GBIF, 2021) Vietnam (Ngat & Lian, 2018).

***Megachile hera* (*Eutricharaea*) Bingham, 1897** (Figs 2P&2Q)

Female ♀

Body black with white apical bands on metasoma, tegulae dark brown, black legs with white hairs, body length 12.43 mm. Head: face, gena with pale dense white pubescence; Mesosoma: black, finely punctate with pale white shiny hairs at the outer margin of mesosoma. Metasoma: T1-T5 finely punctured, with white apical hair bands and black spines laterally, T6 covered with suberect black hairs;

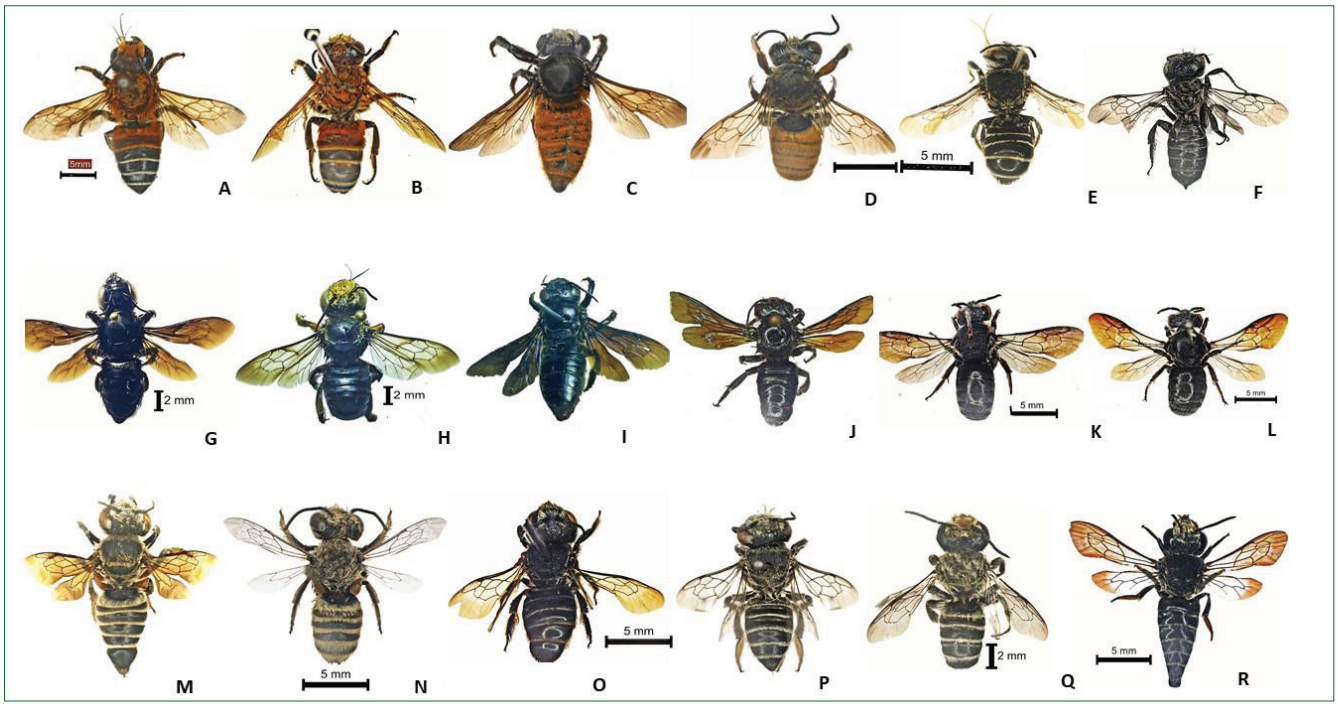

Fig. 2.(A) Female *Megachile lanata* (Fabricius) (B) Male *Megachile lanata* (Fabricius) (C) Female *Megachile bicolor* (Fabricius) (D) Male *Megachile bicolor* (Fabricius) (E) Female *Lithurgus* sp. 1 (F)Male *Lithurgus* sp. 1(G) Female *Megachile anthracina* (Smith) (H)Male *Megachile anthracina* (Smith) (I) Female *Megachile carbonaria* (Smith) (J) Male *Megachile carbonaria* (Smith) (K) Female *Euaspis carbonaria* (Smith) (L) Male *Euaspis carbonaria* (Smith) (M) Female *Megachile vigilans* (Smith) (N) Male *Megachile vigilans* (Smith) (O) Female *Lithurgus* sp. 1(P) Female *Megachile hera* (Bingham) (Q) Male *Megachile hera* (Bingham) (R) Female *Coelioxys fuscipennis* (Smith)

Male ♂

Body black, body length 11.79 mm, smaller than female, with yellowish hair on face, mesosoma and metasoma. Head: face, gena and hypostomal area with dense pale white to yellow pubescence. Mesosoma: pale white long pubescence on outer margin of mesosoma, scutum and scutellum disc finely punctate with fine sparsely distributed hairs. Metasoma: T1 with long white pubescence, T1-T4 with apical band of pale white hairs.

Distribution

India: Chhattisgarh (**new record**), Punjab (Ludhiana), Rajasthan (Alwar) (Gupta, 1993), Himachal Pradesh (Kangra, Kullu, Manali) (Suma, 2006), Karnataka (Bangalore, Mudigere, Hunsur) (Nayana, 2008; Dhanyavathi, 2009), Jammu (Abrol *et al.,* 2012).

Global: Bangladesh, China, Thailand, Malaysia, Vietnam, Chinese Taipei (Abrol *et al.,* 2012).

***Megachilevigilans* (*Eutricharaea*) Smith, 1879** (Figs 2M &2N)

Female ♀

Body black, body length 15.23 mm, mid and hind femora fulvous, white apical hair bands on dorsal metasoma. Metasoma: T1-T5 with pale white hairs band apically; T6 disc covered with suberect black pubescence.

Male ♂

Body length 11.98 mm, black bee with yellowish face and pale white hair bands on metasomal segment; similar to female except as follows: face with dense yellowish white pubescence; mandible tridentate; all the trochanter and femur fulvous in colour; T6 with 4 spines, covered with yellowish pubescence. Genitalia: gonostylus with bilobed distal end and sparse hairs; tip of the penis valves with hairs, directed straight and slightly dilated.

Distribution

India: Chhattisgarh (**new record**), Karnataka, Jammu (Shankar *et al*., 2017; Bingham, 1897).

Global: Sri Lanka (Inoka *et al*., 2014), Southern Asia (ITIS, 2022), America (Raw, 2002).

***Coelioxys* (*Liothyrapis*) *fuscipennis* Smith, 1854** (Fig 2R)

Female ♀

General description: Body length 19.7 mm, black, metasoma tapering through its length. Medio-posterior part of scutellum triangle, hanged posteriorly on metanotum with 2 lateral teeth not reaching to posterior margin of scutellum; fuscous wing, hyaline at the base; Metasoma: black, with white bands of small white hairs on T2-T5, T2-T3 with deep groove at side; T6 depressed apically with longitudinal carina, with 2 tubercle subapico-lateral and one long spine medially;

Distribution

India: Chhattisgarh **(new record**), Rajasthan (Hooda and Jain, 2020), Tamil Nadu (GBIF, 2021) Himachal Pradesh (Mandi, Kullu, Dharmshala) (Bingham, 1897), Karnataka (Shimoga) (Sanath *et al*., 2020).

Global: Sri Lanka (Inoka *et al*., 2014), Southern Asia (ITIS, 2022), India (GBIF, 2021).

***Euaspis* (*Parevaspis*) *carbonaria* Smith, 1854** (Figs 2K &2L)

Female ♀

Body black, similar to *Euaspis* edentate except S6 with distal tooth with 2 laterobasal teeth.

Male ♂

General description: body black, body length 13.18 mm, smaller than female, with white hair on face; T7 with three apical spines, median spine prominent than lateral spines. Genitalia: gonostylus bulged and slightly concave with short hairs; penis valve pointed distally, sharply raised carina between penis valve and gonostylus.

Distribution

India: Chhattisgarh (**new record**), Karnataka, Tamil Nadu, Maharashtra, Odisha, Haryana (GBIF, 2021) Maharashtra (Bombay), Gujarat (Allahabad and Ahmedabad), Punjab (Pathankot, Firozpur, Ludhiana, Faridkot, Jalandhar), Himachal Pradesh (Kangra, Manali), Karnataka, Rajasthan (Alwar, Sikar, Nagaur, Sri Ganganagar, Udaipur, Mount Abu, Pilani, Gudha), Gujarat (Veraval, Deesa, Dantiwada), (Hunsur) (Bingham, 1897; Gupta, 1993; Baker, 1995; Dhanyavathi, 2009).

Global: India, Sri Lanka (GBIF, 2021), Southern Asia (ITIS, 2022).

***Lithurgus* (*Lithurgus* s.str.) sp. 1** (Figs 2E &2F)

Body black with white shiny pubescence on face and bands of white pubescence on metasoma.

Female♀

Body length 9.36 mm, body black with white apical white pubescent bands on metasoma. Head: shiny white pubescence on face; labrum with pale white pubescence. leg black, fore and middle tibia with two rows of small tubercles and hind tibia with large tubercles; median and hind basitarsus with fulvous hairs. Metasoma: T1 covered with sparse long white hairs; T2-T5 apical margin with white fasciae, interrupted in the middle of T1.

Male ♂

Body black, body length 8.96 mm, smaller than female; similar to female but tubercles on tibia not as much developed as in female; mesosoma with pale white pubescence; T1 with long fasciae at appeal margin not interrupted in middle as female; T2-T5 with small hair bands at apex; pygidial plate present. Genitalia: much broader volsella which covered 3/4th of genitalia; narrow with slightly dilated gonostylus at the distal end, short and covered with pubescence.

***Lithurgus* (*Lithurgus* s.str.) sp. 2** (Fig 2O)

Body black with white shiny pubescence on face, yellowish pubescence on clypeus, metasomal segments with apical bands of pale white pubescence.

Female♀

Body black with white shiny pubescence on face, yellowish pubescence on clypeus, metasomal segments with apical bands of pale white pubescence, body length 10.52 mm. Head as broad as thorax, roughly punctate; Face with white pubescence, pale white pubescence on clypeus, golden yellow scopa on S2-S5 with tiny white hairs beneath scopa, S8 with 2 lateral spines.

Comments: Two different morpho-species of *Lithurgus* sp. 1 (2♀, 60♂) and *Lithurgus* sp. 2 (2♀) were collected during the surveys. As for the second species we could not collect the males hence species confirmation could not be ascertained.

DISCUSSION

The present study is the continuation of their research by the same team of authors (Sahu *et al.*, 2022), who reported the diversity of different non-*Apis* bees in the Chhattisgarh plains, where among all the bee families, Megachilidae was the least encountered family. In the present study, the diversity and abundance of Megachilid bees were further analyzed. Compared to other bees, the Megachilid bees are difficult to encounter and collect as most of these can be collected only by manual scouting in the fields through a sweep net. The collection through traps was abysmal, and only a single species of *Lithurgus* could be collected after placing

hundreds of yellow pan traps in multiple locations. In the present study, the genus *Megachile* was the most abundant Megachilid in the Chhattisgarh state, with *M. lanata* as the most dominant species. During the surveys, ten species of Megachilidae were recorded for the first time from Central India, out of which two species, *C. fuscipennis* and *E. carbonaria*, were cleptoparasitic bees. The present study revealed that *M. lanata* was the most dominant group in Chhattisgarh, and *Lithurgus* sp. 1 was highly abundant; however, it was confined only to one location. All nine species are the first records for Chhattisgarh, which comprises a significant part of Central India and a reasonably rich biodiversity hotspot.

CONCLUSION

Extensive surveys are important for the documentation of bee taxa. Regarding the pristine and rich vegetation cover and climatic diversity of Central India, the actual number of bees is expected to be much greater. Hence, more exploratory surveys followed by thorough identification are needed to document the exact faunal wealth. Based on our experience, we recommend the sweep net collection method as the most efficient method for collecting Megachilid bees.

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Thermal sensitivity of major pollinators of mango: Dipterans score high in climate resilience

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ABSTRACT: Pollination is an essential ecosystem service and climate change is a potential threat to the mutualistic interactions between plants and their pollinators. Field studies were conducted at ICAR-IIHR, Bengaluru during 2015-20 to study the effect of temperature on foraging activity of major pollinator species of a mango (Mangifera indica L.). The activity of wild honey bee, *Apis florea* (Fab.) was negatively correlated with temperature beyond 32^{o} C. while no decline was observed in case of Dipteran pollinator, *Chrysomya megacephala* (Fab.). The thermal breadth index was calculated based on density of four pollinator species foraging at different sets of prevailing temperature in the field. Species showed wide variability in their adaptability to temperature. Dipteran pollinators including *C. megacephala, Eristalinus arvorum* and *Stomorhina discolor* with higher thermal breadth index were relatively more adaptive to elevated temperature. Hence conservation of these native species is essential for climate change resilient strategies for enhancing mango production.

Keywords: Mango, pollinator, *Apis florea, Chrysomya megacephala*, thermal sensitivity, Dipterans, climate resilience, thermal breadth

INTRODUCTION

Pollination is one of the most important ecosystem services contributing to the biodiversity as well as global food security. The mutualistic interaction between plants and pollinators has evolved over centuries and been helping both natural terrestrial ecosystems as well as man-made agro-ecosystems. Animal pollinators, mainly including bees, birds and bats affect 35 per cent of the world's crop production, increasing outputs of 87 of the leading food crops worldwide (Free, 1993). In addition to factors like habitat loss, chemical intensive agriculture, invasive species etc., climate change is emerging as one of major threats to pollination services (Hegland *et al*., 2009; Reddy *et al.,* 2012). The effect of climate change on pollinators depends upon their thermal tolerance and plasticity to temperature changes. Since bees and other insect pollinators are ectothermic, the temperature of their surroundings determines their activity. Behavioural responses of pollinator insects to avoid extreme temperatures have the potential to significantly reduce pollination services. Effective crop pollination is heavily dependent on biological timing, of both the crop and its pollinators. Crops such as mangoes in tropical regions, or almonds or apples in temperate regions, have periods of mass blooming over relatively short periods, requiring a tremendous peak in pollinators. Insects and plants react differently to changed temperature, creating temporal and spatial mismatches which could be detrimental to both plants and pollinators (Abrol, 2009; Hegland, 2009).

Mango (*Mangifera indica* L.), is the most widely cultivated and economically mportant fruit crop of India. It produces both male and hermaphrodite flowers and insects play a major role in mango pollination (Mukherjee, 1997). In India, more than 20 species of insects are reported to forage on mango inflorescence. However five species *viz. Apis florea* (Fab.) (Hymenoptera:Apidae), *Chrysomya megacephala* (Fab.) and *Stomorhina discolor* (Fab.) (Diptera:Calliphoridae), *Eristalinus arvorum* (Fab.) (Dipteral:Syrphidae) and *Tetragonula iridipennis* (Smith) are the most frequent and dominant visitors significantly contributing to mango pollination (Reddy *et al.,* 2012b). The scanty productiveness of many mango varieties has been attributed by several workers to inadequate pollination. In spite of having perfect flowers, cross pollination by insects is essential to achieve adequate fruit set and there are several studies which proved the essentiality of insects in mango pollination. About 60-100% reduction in fruit set was observed when panicles were completely excluded from insect foraging (Bhatia *et al*., 1995; Singh, 1997). In the ensuing climate change scenario, there is a possibility of shifts in pollinator diversity and their foraging behavior thus ultimately affecting their ecosystem services. Studies were conducted at ICAR-Indian Institute of Horticultural Research (IIHR), Bengaluru, India on mango to understand the impact of temperature on pollinators and their foraging behaviour.

MATERIALS AND METHODS

Field studies were conducted at ICAR-IIHR, Bengaluru during 2015-20 in a mango (cv. Totapuri) orchard of about 25 year old, maintained free from insecticide spraying. Observations were recorded on the number of insect foragers of different groups visiting the blossom at weekly interval during entire flowering period. Population counts of five major species *viz.,* little bee or dwarf bee, *Apis florea* (Fab.), stingless bee, *Tetragonula iridipennis* (Smith), calliphorid flies, *Chrysomya megacephala* (Fab.) and *Stomorhina discolor* (Fab.) and syrphid, *Eristalis arvorum* (Fab.) (Fig.1) were recorded from 10 panicles (representing all directions) on each tree. Five randomly selected trees were marked and used in the study, thus making total 50 panicles for each observation week. Each panicle was visually observed for five minutes to record the visitation by different pollinators. Mean number of foragers per 10 panicles per five minutes was taken as a unit to compare foraging activity between species and at different temperature rages. The foraging activity was correlated with maximum temperature prevailing during the study period. The data were subjected to correlation and regression analysis to understand influence of temperature on the numbers of pollinators. Analyses were carried out group wise for honey bees, (*A. florea* and *T. iridipennis*) and dipterans (*C. megacephala*, *E. arvorum* and *S. discolor*). In order to quantify the thermal sensitivity, Levin's niche breadth index was used. The physical environment and resources affect the breadth of the niche of a population. Considering temperature as an independent variable of physical environment of different pollinator species, niche breadth was calculated in terms of using the below formula (Feinsinger *et al.,* 1981).

Niche Breadth (Bn) = $1/\Sigma\ p_j^2$

Where, p_j is the proportion of individuals found in or using resource state

This index is a measurement of niche breadth (Bn) of a taxon (pollinator species in present study) and ranges from 0 to 1 whereby a value of 0 indicates least and 1 indicates highest thermal breadth at which a species forages.

RESULTS AND DISCUSSION

Data on pollinator activity in relation to the corresponding temperature indicated that temperature had significantly affected the foraging activity of pollinators and the impact differed significantly between two groups i.e. bees and flies. The activity of wild honey bee, *A. florea* was negatively correlated with temperature beyond 32° C. Their numbers were maximum (0.7-0./10 panicles/5 min) at 26-30°C, which came down drastically to less than 0.1 at temperature above 32°C. The polynomial model of regression equation was fitted with R^2 value of 0.68 indicating 68% of variability in foraging activity was influenced by the temperature (Fig. 2). In contrast, no decline was observed in case of Dipteran pollinator, *C. megacephala* and was thus less vulnerable to rise in temperature as reflected in Fig. 3 where the activity had not declined even at temperatures above 32°C. In addition, the R^2 value was low (0.46) implying that foraging activity of these two species was not significantly affected with rise in temperature prevailing during flowering period.

Environmental cues controlling the phenology of bees include maximum daily temperature, number of degree days and day length. The temperature of their surroundings determines their foraging activity. Behavioural responses of bees to avoid extreme temperatures could significantly impacts pollination services. The time taken for thermoregulation at higher temperatures comes at the cost of foraging. With increase in temperatures, the efficiency of pollen removal and deposition will change and pollinators are at risk of over heating. The honey bee's capacity to accumulate energy reserves and to manage the colony's development exerts significant adaptive pressure (Willmer and Stone, 2004; Reddy *et al.,* 2012a). In a related study, Reddy *et al*. (2015) established the adverse effect of elevated temperature on the foraging activity of Indian honey bee, *A. cerana* and present findings are in line with those observations.

RESULTS AND DISCUSSION

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i. Apis florea

ii. Tetragonula iridipennis

iii. Chrysomya megacephala

iv. Eristalinus arvorum

v. Stomorhina discolor

Fig. 1. Major pollinator species of mango (I & ii : Hymenoptera ; iii, iv & v: Diptera)

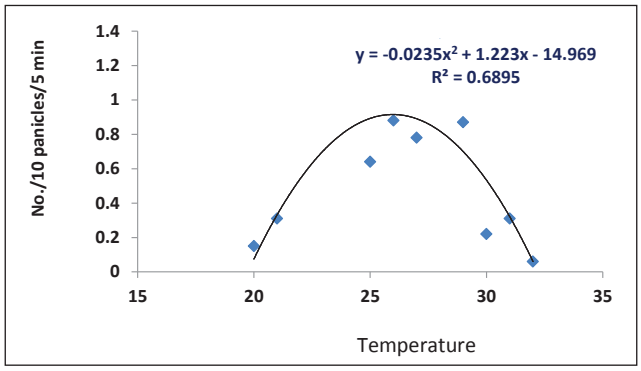

Fig. 2. Effect of temperature on foraging activity of honey bee, *A. florea*

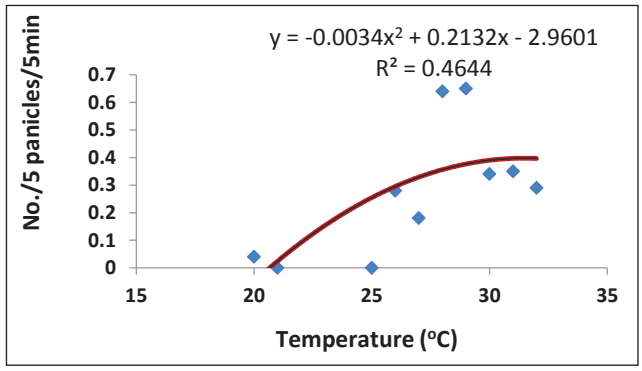

Fig. 3. Effect of temperature on foraging activity of dipteran pollinators v.z., *C. megacephala*, *E. arvorum* and *S. discolor*

Environmental cues controlling the phenology of bees include maximum daily temperature, number of degree days and day length. The temperature of their surroundings determines their foraging activity. Behavioural responses of bees to avoid extreme temperatures could significantly impacts pollination services. The time taken for thermoregulation at higher temperatures comes at the cost of foraging. With increase in temperatures, the efficiency of pollen removal and deposition will change and pollinators are at risk of over heating. The honey bee's capacity to accumulate energy reserves and to manage the colony's development exerts significant adaptive pressure (Willmer and Stone, 2004; Reddy *et al.,* 2012a). In a related study, Reddy *et al*. (2015) established the adverse effect of elevated temperature on the foraging activity of Indian honey bee, *A. cerana* and present findings are in line with those observations.

Thermal breadth index of different pollinators

The thermal breadth index was calculated based on density of four pollinator species foraging at different sets of prevailing temperature in the field. Species showed wide variability in their adaptability to temperature as evidenced through range of thermal index from lowest 0.45 in *T. iridipennis* to highest 0.64 in *C. megacephala.* The order of the thermal breadth index in descending manner was *C. megacephala* (0.64) > *S. discolor* (0.62) > *T. iridipennis* (0.54) > *A. florea* (0.45). As per Levin's index, taxon with 0 index are considered as highly specialised ones with specific niche requirement and those with 1 are generalists (Feinsinger *et al*., 1981). On these lines, pollinators with high index are capable of adjusting to wider temperature range than those with lower values. Accordingly, two dipteran pollinators with > 0.6 index are better placed than their Hymenopteran counterparts in their adaptability to enhanced temperature, an eventuality expected in the ensuing climate change scenario. Relatively lower activity of bees at higher temperature compared to flies could be due to the increased efforts needed by their colony life which demands worker bees to spend more time in regulating hive temperature. Williams *et al.* (2007) found a relationship between climatic niche and declines in British bumblebees, whereas Dormann *et al.* (2008) projected general declines in future bee species richness in Europe.

Present studies had clearly indicated that maximum temperature had significant effect on pollinator activity. Beyond 32°C, there was a decline in foraging activity of honey bees, *A. florea*. However temperature sensitivity was not uniform across species. Dipteran pollinators *viz., C. megacephala* and *S. discolor* were relatively more adaptive to temperature shifts thus making them suitable for inclusion in climate change resilient strategies for mango production. .

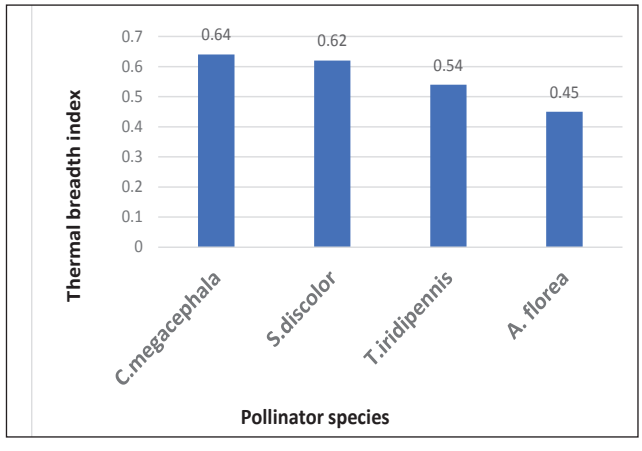

Fig. 4. Thermal breadth index of different pollinator species

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RESEARCH NOTE

First report of red palm weevil, *Rhynchophorus ferrugineus* on banana cultivar '*Asomiya Malbhog'* in Assam, India

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ABSTRACT: Red palm weevil, *Rhynchophorus ferrugineus* is a key pest of many palm species such as the oil palm, coconut, sago, and date palm. In various parts of India, yield losses of 10-25% have been recorded in palm plantations and damage to an extent of 34% from the coconut groves. Recently, this weevil has occurred as a pest of the banana cultivar "*Asomiya Malbhog*" in Assam with infestation ranging from 4-8 per cent. This is an indication of expanding host range and needs vigil to contain further spread. This article outlines the first report of red palm weevil on banana from Assam, India.

Keywords: *Rhynchophorus ferrugineus*, red palm weevil, first report, alternate host, banana

The banana cultivar '*Asomiya Malbhog*' is a locally grown popular variety of Assam, which is cultivated in traditional *bari* system of farming along with other horticultural crops. An expedition to the Lower Brahmaputra Valley Zone of Assam was initiated in search for pest complex of banana during the months of September and October, 2021. During the visit to the banana plantations of Gossainga on area (26.4371° N, 89.9767° E) of the Kokrajhar district, the incidence of Red Palm Weevil(RPW), *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae) was noticed on the banana cultivar '*Asomiya Malbhog'*. After observing it for the first time in the Lower Brahmaputra Valley Zone of Assam, extensive surveys were carried out from June to October, 2022 in the traditional banana growing hotspot areas of the Jorhat and Golaghat districts of Upper Brahmaputra Valley Zone, Darrang and Udalguri districts of North Bank Plain Zone, Naga on district of Central Brahmaputra Valley Zone and Kamrup Rural and Kokrajhar districts of Lower Brahmaputra Valley Zone. In all these areas, the cultivar '*Asomiya Malbhog'* was found to be infested by this weevil.

Both the adults and larvae of RPW were collected by cleaving the pseudostem leaf sheaths and carving up the tunnels created by the larvae from heavily infested plants and the specimens were identified following the taxonomic key of Zhang *et al*., 2003. By visual scoring, the infestation percentage of the RPW in a single banana plant on an average can be categorised between 60-80%. After examining all the locations of each zone, the RPW infestation in these areas can be estimated between 4-8% (Table 1).

The first signs of RPW infested banana plants are presence of medium sized holes and jelly like excretions on the external opening of the feeding tunnel of the pseudostem, which are viscous and the oozed out substances are yellowish in colour. The pseudostem becomes gradually hollow from inside because of the large holes made by the insatiable feeding of the larvae and the adults stay inside the tunnel. The inner contents of the infested pseudostem changes to somewhat reddish in colour compared to the healthy one, which is greenish. The infested plant releases characteristic fermented odour. The plants damaged by the weevil collapse at distal end and breaks down.

Larvae of different instars present inside the pseudostem were collected from the infested plants and brought to the Laboratory for further rearing and generating additional information. It was reared on natural diet using pseudostem of 50 cm height of the same banana cultivar as its feed. Females laid eggs by making hole in the pseudostem, which hatched in about 5-8 days. Larvae were cream coloured with a dark brown head with no legs and their sizes variesfrom2.3-2.7 cm in length. Larvae fed inside the tissue and bore their way in form of zigzag tunnels in centre of the pseudostem. The tunnels were filled with chewed fibres and frass and emanate a characteristic smell from the plant sap. Mature larvae build a pupalcase from the pseudostem fibres, and stay inside it for20-25 days while they pupate. The pupal stage varied from 9-21 days. The adults range from3.4-3.6 cm in length including the rostrum, 1.2-1.4 cm in width and weighed 1.10-1.41 g.

Table 1. Extent of infestation of *R. ferrugineus* on banana in Assam

Agroclimatic zones of Assam	Survey area	GPS Coordinates	District	Infested plants observed	Number of plants surveyed	Per cent infestation
Lower Brahmaputra Valley Zone	Gossaingaon	26.4371° N, 89.9767° E	Kokrajhar	46	580	8.0%
	Kukurmara	26.0729° N, 91.4169° E	Kamrup Rural	32	431	7.4%
Upper Brahmaputra Valley Zone	Jamuguri	26.3876° N, 93.9630° E	Golaghat	25	490	5.1%
	Charaibahi	26.6628° N, 94.1488° E	Jorhat	10	252	4.0%
Central Brahmaputra Valley Zone	Kaliabor	26.5344° N, 93.0923° E	Nagaon	17	380	4.4%
North Bank Plain Zone	Patharighat	26.4512° N, 92.1058° E	Darrang	29	465	6.2%
	Kahibari	26.7600° N, 92.1475° E	Udalguri	37	530	7.0%

Fig. 1. Heavy infestation on banana cultivar '*Asomiya Malbhog'* by *R. ferrugineus*

Fig. 2. *R .ferrugineus* weevil feeding on banana pseudostem

Red palm weevil is a native of Southern Asia and Melanesia (Malumphy and Moran, 2007) and is locally called as Asian Palm Weevil. The weevil was found attacking the palms in the Arabian peninsula and was first reported from the UAE in 1986 (Gush, 1997; Abraham *et al*., 1998). It feeds on a variety of palm species including coconut, sago, date, and oil palms. In 1891, Indian museum notes provided the earliest information on the red palm weevil (Faleiro, 2006). Lefroy (1906) identified the weevil as a destructive insect pest of coconut palm throughout India. The first record from India on the occurrence of RPW on arecanut was reported by (Dutta *et al*., 2010) from Meghalaya state. From Assam, the first record of infestation of RPW on arecanut was made by Rabha *et al*.(2013).

RPW on banana has not been documented previously from any state. This is the first record of RPW on banana from Northeast India. Early detection of the infested banana plant is crucial for the success of RPW management programme, and at this moment, it is necessary to stop the pest cycle by finding an infested pseudostem before the emergence of adults. Pheromone trapping is another potential method of surveillance.

Hence, pheromone traps loaded with effective lures and pseudostem baited kairomone traps are recommended for monitoring and mass trapping programmes in the field.

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RESEARCH NOTE

A new report of a fly, *Melanagromyza* sp. (Diptera: Agromyzidae) on carrot (*Daucus carota* L.) from India

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ABSTRACT: We describe the economic damage caused by the infestation of carrot fly, *Melanagromyza* sp. (Diptera: Agromyzidae), on tap roots resulting in inferior quality carrots with lower marketable price. The study was conducted in major carrot growing districts of Karnataka, India, where adult fly activity commenced 25-27 days after sowing (DAS) and damage by maggots was noticed around 45 DAS. Taproots of 1 to 40 days old were free from the pest attack and the feeding damage prevailed up to 60 days in the field. The report highlights that the pest is widely distributed in all surveyed locations of Karnataka. Pest incidence ranged from 0.74 to 20.77 per cent, with the highest incidence recorded from Kolar in July.

Keywords: carrot fly, taproot, damage

Carrot (*Daucus carota* L.: Apiaceae) is a popular vegetable, ranking among the top ten widely cultivated vegetables globally. The plant originated from Afghanistan and Persia and is primarily grown in temperate climates, but it is also cultivated in tropical and subtropical regions. The optimal conditions for carrot cultivation include an elevation of 1500 meters or above and sufficient irrigation, allowing for year-round growth. The taproot, which is the edible part of the carrot, is a rich source of nutrients such as carotene, thiamine, riboflavin, niacin, and vitamin C. (Holland *et al*., 1991). India produced a total of 2.13 million metric tonnes of carrots from an area of 1.18 lakh hectares. Haryana and West Bengal stand out as the top producing states of carrots in India (Anonymous, 2021a). Karnataka ranks 8th in total area and production with 4,833 hectares and 92,914 tonnes respectively (Anonymous, 2021b). Kolar and Chikkaballapur are the major carrot growing districts in Karnataka, where it is cultivated throughout the year with assured irrigation. Carrot hybrids like Taki's 999, Rado and Sayuri were predominant in these districts and their crop duration is 80-90 days.

Several insect pests have been reported on carrot *viz*., aster leafhopper, *Macrosteles quadrilineatus* (Fobes); flea beetle, *Systena blanda* (Melsheimer); carrot weevil, *Listronotus oregonensis* (LeConte); aphid, *Myzuspersicae* (Sulzer) and cutworm, *Agrotis* sp. from United States of America (Delahaut and Newenhouse, 1998); carrot aphid, *Cavariella aegopodii* (Scopoli) and *Semiaphisheraclei* (Takahashi); semilooper, *Thysanoplusia orichalcea* (Fabricius) and thrips, *Aeolothrips meridionalis* Bagnall from Jammu and Kashmir, India (Bhat and Ahangar, 2018). However, none of the studies ascertained the economic damage caused by these pests on carrot.

During our pest surveillance studies, we observed a significant economic loss of carrot in major growing areas of Karnataka due to infestation by a fly. The damage caused by the maggot of the fly led to severe injury to the taproot, resulting in the production of inferior quality carrots with lower marketable prices. To address this issue, a study was conducted to determine the current pest status of the fly in major carrot-growing areas of South India.

A series of roving surveys were conducted from December 2021 to July 2022 (Table 1) covering Kolar, Bengaluru Rural, and Chikkaballapur districts in Karnataka, as well as Krishnagiri and Nilgiris districts in Tamil Nadu. A total of 21 visits were made to these areas [Kolar (9 visits), Bengaluru Rural (3), Chikkaballapur (3), Krishnagiri (4), and Nilgiris (2)]. The team uprooted 150 carrots following a zig-zag pattern of sampling from one

Table 1. Incidence of carrot fly, *Melanagromyza* sp. in major carrot growing areas

District	Date	Location	Latitude	Longitude	Age of crop (Days)	Damage (%)
Karnataka						
Bengaluru Rural	02-01-2022	Kurubarahalli	13.327012º	77.605310º	78	0.84
	08-02-2022	Kumbalahalli	13.099595º	77.797099º	75	1.73
	22-05-2022	Muthagatti	12.691897º	77.715340º	72	12.2
Kolar	30-12-2021	Haraleri	12.989075º	77.990836º	57	1.12
	07-02-2022	Narasapura	13.148725º	78.000636º	55	0.74
	10-02-2022	Mirapanahalli	12.869137º	77.977854º	55	1.47
	25-03-2022	Turunasi	12.849614º	78.016033º	65	1.05
	28-03-2022	Kudiyanuru	12.938988º	77.958978º	64	1.48
	03-05-2022	Hosahalli	12.908325º	78.001336º	53	11.1
	20-05-2022	Hunasanahalli	12.982331º	78.167846º	63	11.2
	07-06-2022	Nagapura	12.886328º	77.979104º	82	12.15
	07-07-2022	Nanjapura	12.876184º	77.969233º	67	20.77
Chikkaballapur	01-03-2022	Hunegallu	13.492116 º	77.752719 º	80	17.88
	03-03-2022	Jeedarahalli	13.298123º	78.053325º	78	2.62
	03-03-2022	Hadigere	13.358987º	78.074939º	65	2.19
Tamil Nadu						
Krishnagiri	11-01-2022	Atturu	12.804390º	77.907100º	75	0.89
	06-02-2022	Saparapalli	12.844195º	78.051514º	77	8.18
	15-04-2022	Berigai	12.817619º	77.974007º	82	1.52
	30-06-2022	Athimugam	12.754815º	77.977165º	80	3.2
Nilgiris	30-01-2022	Fern Hill, Udakmandalam	11.394617º	76.697261º	105	0
	30-01-2022	Muthorai Palada, Udakmandalam	11.372513º	76.666689º	108	0

acre of field in each area, washing them thoroughly and examining them for damage symptoms and the different life stages of the pest. Pest incidence was calculated based on the symptoms observed and expressed as a percentage of damage.

During the survey, incidence of the carrot fly was found in all surveyed locations in Karnataka and only in Krishnagiri district of Tamil Nadu. The incidence rate varied between 0.74 to 20.77 per cent, with the highest incidence recorded in Kolar in July. Interestingly, the Nilgiris, which is a major carrot producing district in Tamil Nadu, did not report any incidence of the carrot fly during the survey. The pest responsible for the observed damage has been identified as the carrot fly, *Melanagromyza* sp. (Diptera: Agromyzidae). The adult carrot fly (Plate 1) is a small insect, measuring 2.3mm in length and 0.94mm in width, with a blue metallic

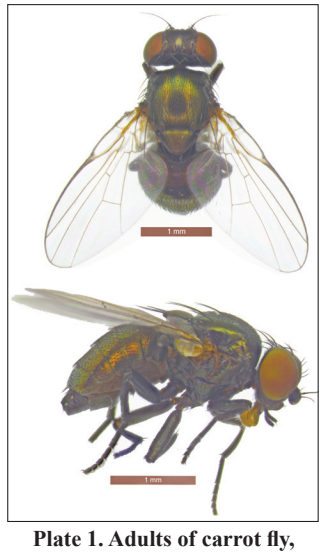

Plate 1. Adults of carrot fly, *Melanagromyza* sp.

Plate 2. Carrot damaged by maggots

shiny thorax and abdomen. Females possess a tube-like ovipositor, while males have a blunt abdomen.

The adult fly activity was commenced at 25-27 days after sowing (DAS) and peak activity recorded during 34-40 DAS. The mated females usually oviposited single egg on the stem of foliage. After hatching the early instar maggot feed through the stem and reached the taproot. The early instar maggot tunnel down the taproot resulting in production of white silvery mines on the surface of taproot, which is difficult to identify (hence, taproots were washed with water to clear off dirt). Tunneling by later instar maggot led to cracking of taproots usually at the shoulder portion. The early instar maggot moved downward, whereas the later instar maggot tunneled upward and pupated inside the mine closer to the base of carrot stem (Plate 2). The carrot fly completed one generation in one cropping period of 75 to 85 days. The taproots of developmental stage-I (1-25 days old) and II (26-40 days old) were free from carrot fly damage. Damage commenced from stage-III (41-60 days old) and prevailed till stage-V (70-90 days old). Since, carrot is a high value crop, any slight damage to taproot by maggot results in production of inferior quality carrots and drastically reduces the marketable value of the produce. The present study revealed that the pest caused an economic loss of rupees 18.30/- per kg of good quality carrots (Rupees 50/- per one kg of carrot as the market price, Anonymous, 2022). Further, our study suggested that the pest could be managed through installation of yellow sticky traps (10-12 numbers per acre) 20-25 DAS followed by application of soil insecticide at 30 and 40 DAS. Strict quarantine measures will prevent its spread to pest free areas.

The description of feeding damage and symptoms caused on carrot by the carrot fly are the first of its kind and this study marks the first report of*Melanagromyza* sp. on carrot from India.

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RESEARCH NOTE

Plant extracts for the management of two spider mite, *Tetranychus urticae* Koch on jasmine (*Jasminum sambac*)

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ABSTRACT: The efficacy of plant extracts against two spotted mite, *Tetranychus urticae* Koch was evaluated under laboratory conditions. Among different extracts tested, Wild sage, *Lantana camara* leaf extracts showed better performance recording 87.23% mortality of the two spotted mites and 85.22% reduction over untreated control.Neem seed kernel extract shows next order of efficacy presenting 82.35% and sweet flag rhizome extract with 80.58 per cent mortality with 79.57 and 77.12% reduction over control. Cashew Nut Shell Liquid (CSNL) extract showed very least efficacy against mites recording only 57.23 per cent mortality.

Keywords: Jasmine, two spotted mites, extract, plant oil, bio-efficacy, mortality, neem oil

Tetranychus urticae Koch, commonly known as red spider mite, is a polyphagous sucking pest. The mites lay their eggs and infests the adaxial side of leaves and cause profuse webbing. Feeding injury causes tiny grey or silvery spots on leaves and plant parts, known as stippling damage, where the green epidermal cells have been destroyed. Although the individual lesions are very small, attack by hundreds or thousands of spider mites can cause thousands of lesions and thus can significantly reduce the photosynthetic capability of plants (Zhang, 2003, Martinez-Ferrer *et al.,* 2006). The rapid developmental rate, short generation time, and high net reproductive rate of *T. urticae* helps them to achieve damaging population levels very quickly when growth conditions are suitable, resulting in a similar decline of host plant quality in a rapid manner. *T. urticae* is extremely polyphagous; it can feed on hundreds of plants. These include most vegetables and food crops and ornamental plants such as roses and Jasmine (Jeppson *et al.*, 1975).

Jasmine (*Jasminum sambac* L.) is one of the oldest fragrant flowers of India, grown for their decorative flowers. They are grown commercially all over the world for the milky white flowers, which are commonly used for making garlands, as a hair ornament for women and for the extraction of essential oil for perfumes. Jasmine is highly priced for their fragrant flowers, which is used for the preparation of perfumes. Recent years, yield levels of jasmine flowers are greatly influenced by pest infestation. Among the various pests, two spotted miteswere reported to be very serious and desap the crop by remaining on the under surface of the leaf causing economic loss to the growers (David, 1958).

The flowering in jasmine commences during March-April and comes to peak in May-July. The hot weather of this period is favorable for multiplication of mite population and hence the population increases quickly. Synthetic pesticides are generally used for two spotted spider mite management. However, their indiscriminate usage adversely affects non-target organisms and leads to resistance build up in pest populations and causes environmental disturbance (Schmutterer, 1990). Globally, spider mites have developed resistance to more than 93 acaricides in more than 105 countries (Whalon *et al.,* 2012). Awareness of these environmental risks has kindled interest in finding alternative pest control methods and products that are as effective as synthetics. In this context plant products and biopesticides are being explored extensively as a feasible alternative to synthetics in protecting cultivated crops from pests (Onnkum, 2012; Praveen *et al.,* 2012; Syahputra, 2013). Natural products are an excellent alternative to synthetic pesticides as a means to reduce negative impacts to human health and the environment. Keeping this in view, laboratory studies were conducted to evaluate the bioefficacy of plant extracts (Table 1) against two spotted spider mite at Department of Entomology, Agricultural college and Research Institute, Madurai, India, during October-November 2015.

Preparation of botanical extracts

Fresh leaf / nutshell / fruit samples of various plants

Table 1. *In-vitro* bio-assay of certain plant extracts against jasmine pests

Common name of Plant	Scientific name	Part used	Conc. (%)	Cumulative mean mortality after 144 HAT	PROC
Neem	*Azadirachtaindica* A. Juss.	Leaf	5	75.29(8.67)^{abcd}	71.40
Neem	*Azadirachtaindica* A. Juss.	Kernel	5	82.35(9.06)^{ab}	79.57
Cashew	*Anacardiumoccidentale*L.	Nut Shell	5	57.23(7.56)^{d}	50.50
Vitex	*Vitexnegundo* Lam.	Leaf	5	77.52(8.76)^{a}	73.98
Adathoda	*Adathodavesica*L.	Leaf	5	65.57(8.09)^{abcd}	60.15
Citrullus	*Citrulluscolocynthis* L.	Fruit	5	64.46(8.02)^{abcd}	58.86
Aloe	*Aloe vera* L.	Leaf	5	74.46(8.62)^{abcd}	70.44
Tulsi	*Ocimum sanctum* L.	Leaf	5	77.51(8.80)^{a}	73.97
Mint	*Menthapiperita* L.	Leaf	5	67.23(8.19)^{abc}	62.08
Coleus	*Coleus aromaticus* L.	Leaf	5	62.29(7.88)^{bcd}	56.36
Sweet Flag	*Acoruscalamus* L.	Rhizome	5	80.58(8.97)^{ab}	77.12
Custard apple	*Annona squamosa* L.	Leaf	5	62.56(7.90)^{cd}	56.66
Custard apple	*Annona squamosa* L.	Seed	5	60.57(7.88)^{cd}	54.36
Wild sage	*Lantana camara*L.	Leaf	5	87.23(9.32)^{ab}	85.22
Wild sage	*Lantana camara* L.	Flower	5	76.13(8.71)^{abc}	72.37
Chrysanthemum	*Chrysanthemum cinerarifolium*L.	Flower	5	73.08(8.53)^{abcd}	68.84
Profenophos 50 EC		-	2 ml l^{-1}	86.96(9.31)^{a}	84.91
Untreated check		-	-	5.63(2.37)^{e}	
SE	CD(0.05)			0.4293 0.8707	

NS - Non significant; Each value is the mean of three replications; Figures in parentheses are square root transformed values.
In a column, means followed by common letter (s) is / are not significantly different by LSD at P=0.05

were collected for the preparation of aqueous extract. The leaves were powdered using pestle and mortar and filtered through 80-mesh sieve. The dried powder was taken and soaked using different organic solvents *viz.,* ethanol/acetone/petroleum ether for 48 h. The extracts were evaporated till dryness in a rotary evaporator under vacuum. Each crude material obtained was weighted and re-dissolved in the same solvent (1g/10ml solvent), to give 10 per cent (W/V).

Bio-assay Method

The toxic effects of the test compounds were evaluated by leaf disc dip technique as suggested by Seigler (1947). The experiment was laid out in a completely randomized design with three replications.Plant derived aqueous solutions were prepared at different concentrations each at 100 ml and placed in a 250 ml conical flask. The leaf discs of 90 mm diameter were prepared from fresh jasmine leaves using a cork borer. The jasmine leaf discs were dipped in each concentration for 5 seconds and shade dried. Then ten adult females of *T. urticae* were transferred to each disc. The discs were then placed on moist cotton pad contained in Petri dishes and kept under controlled conditions of 25 $\pm$ 2^{0}C & 65 $\pm$ 5 % RH. The mortality was observed on 1, 2, 3, 5 and 7 days after treatment. Three replications were maintained for each treatment.

Statistical Analysis: The data were transformed to $\sqrt{x+0.5}$ and analyzed by completely randomized design. The treatment mean values of the experiment were compared using Latin Square Distribution (LSD). The corrected per cent mortality was worked out by using Abbott's correction (Abbot, 1925).

$$\text{Per cent corrected mortality} = \frac{\text{per cent test mortality} - \text{per cent control mortality}}{100 - \text{per cent control mortality}} \times 100$$

The results revealed that the superior effect of extracts in managing two spotted mite, T. *urticae* was noticed in *Lantana camara* leaf extract, showing 87.23 per cent

with 85.22 per cent reduction over control which was on par with the standard chemical check profenophos 50 EC portraying 86.96 per centmortality with 84.91 per cent reduction over control (Table 1). Neem seed kernel extract shows next order of efficacy presenting82.35 percent andsweet flag rhizome extract with 80.58 per cent mortality with 79.57 and 77.12 per cent reduction over control.The order of efficacy follows as *Vitex* leaf extract with 77.52 percent mortality, Tulsi leaf extract with 77.51 per cent, *Lantana camara* flower 76.13 per cent, Neem leaf 75.29 per cent, *Aloe vera* 74.46 per cent witnessing 73.98, 73.97, 72.37, 71.40, 70. 44 per cent reduction over control. The other investigated botanical extracts from mint leaves, Adathoda leaves, *Citrullus* leaves, Coleus leaves, custard apple leaves and fruits displayed 67.23, 65.57, 62.29, 64.46, 62.56 and 60.57 per cent mortality with 62.08, 60.15, 58.86, 56.66, 56.36, 54.36 and 50.50 per cent reduction over control.Cashew Nut Shell Liquid registered least potential recording 57.23 per cent cumulative mortality and 50.50 per cent reduction over control.

The acaricidal effect of certain plant extracts against two spotted mite revealed the superiority of *L. camara* in managing the mite species with 87.23 per cent mortality of the pest in the present study. The results are in line with previous findings of Hind *et al.,* (2019) stating that *Lantana camara* has the potential to manage two spotted spider mite, *T. urticae* in cucumber with a relative efficacy of 70.90%. Ricardo *et al.* (2019) have also mentioned the efficacy of *Lantana camara* against two spotted mites in several crops under laboratory conditions. Neem-based pesticides as a valuable tool to control the two-spotted spider mite, was reported by several researchers (Mansour and Ascher, 1983; Elena et al., 2005; Hussain and Magda, 2005). The present study presented NSKE with yet another superior extract portraying with 82.35 percent mortality with 79.57 per cent reduction over control.The commercial preparations of neem seed kernel extract, Margosan-O and Neem azal-S showed positive response in their deterrent, toxicant and growth inhibitor effect against two spotted mites (Nadia *et al.,* 2009). The efficacy of NSKE in managing two spotted mite was supported also by Hemalatha and Kurian (2009). Neem seed kernel extract NSKE (5%) recorded higher acaricidal and ovicidal action of 96.67 and 90.00 per cent, respectively (Gajalakshmi *et al*., 2020). Sweet flag, *Acorus calamus* have great potential in management of these mites. The present study revealed sweet flag rhizome extract as yet another better solution for mite management with 80.58 per cent mortality and 77.12 per cent reduction over control. In a study by Kitiya and Wanida (2021), fresh rhizomes (10%) caused 73.8% mortality and dried rhizomes caused 91.8% mortality of *T. urticae* adults and fresh rhizomes reduced egg hatch by 96.3% at 5%.

The other extracts with potential in managing *T. urticae* were *Vitex* leaf extract with 77.52 percent mortality, Tulsi leaf extract with 77.51 per cent, *Lantana camara* flower 76.13 per cent, Neem leaf 75.29 per cent, *Aloe vera* 74.46 per cent. Premalatha and Chinniah (2017) experimented the efficacy of various plant extracts on mite management and found *O. sanctum* (10%), *V. negundo* (10%) and *A. calamus* (10%) to be promising with maximum percent reduction of eggs (72.36%, 72.20% and 72.00%) and mites (73.62%, 73.41% and 73.20%) over untreated check., coupled with least mean number of eggs (8.76, 8.81 and 8.88) and mites (7.11, 7.17 and 7.23) respectively, which were statistically on par in their efficacy. The tulsi leaf extract @10 percent recorded 81.15 percent mortality in managing two spotted mites (Raghavendra *et al.*, 2017).

The present study revealed the promising role of *L. camara* leaves at 5 per cent in managing the mite pest to a margin of 87.23 per cent. The study also revealed the importance in identifying several other botanicals such as Neem seed kernel extract, *Vitex* leaf extract, Tulsi leaf, *L. camara* flower extract, neem leaf extract, *Aloe vera* leaf extract as botanical pesticide against mite species.

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RESEARCH NOTE

Efficacy of biopesticides against sucking insect pests of chilli (*Capsicum annuum* L.) and their impact on fruit yield

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ABSTRACT: Efficacy of different biopesicides was evaluated against major sucking insect pests of chilli (*Capsicum annuum* L.) under foot hills of Nagaland, India during November to May 2021-22. The overall average per cent reduction of sucking insect pest population indicated that Spinosad 45% SC (67.07%) was proved to be significantly superior to control followed by Neem seed powder pellet formulation (52.14%). Among Entomopathogenic fungi *Lecanicillium lecanii* (44.46%) was the most effective followed by *Beauveria bassiana* (42.91%) and *Metarhizium anisopliae* (40.84%). Pongamia oil (32.92%) was found to be the least effective among all the treatments. Spinosad 45% SC was found to have high cost benefit ratio (1:1.82) followed by *Lecanicillium lecanii* (1:1.75), *Beauveria bassiana* (1:1.62), Neem seed powder pellet formulation (1:1.47), *Metarhizium anisopliae* (1:1.44) and Pongamia oil (1:0.99). To ensure healthy and sustainable food production, use of chemical insecticides should be reduced and there is an increasing need to utilize biopesticides available and to develop new biopesticides with different mode of action.

Keywords: Biopesticides, Chilli, Efficacy, Entomopathogens, Sucking Pests

In India, Chilli (*Capsicum annuum* L.) is a well-known spice and vegetable crop extensively cultivated in tropical and sub-tropical regions throughout the year. Chilli is commercially cultivated for its pungent fruits. Capsaicin, the active ingredient of spice possesses several medicinal properties like antioxidant, anti-mutagenic and anti-carcinogenic effects with the ability to boost immune system (Saxena *et al.,* 2016). Chilli is infested by various insect pests from the time of planting to post harvest. Among 39 genera and 51 species of insects and mites infesting chilli crop (Kumar *et al.,* 2020), thrips (*Scirtothrips dorsalis* Hood), aphids (*Aphis gossypii* Glover) and whiteflies (*Bemisia tabaci* Genn) are the most important sucking pests which has a negative impact on chilli production. They are extremely polyphagous in nature and feed by sucking sap from leaves, tender shoots, flower buds and fruits. These pests have vast host range and short life cycle which make them difficult to manage. Kandasamy *et al.,* 1990 indicated that the yield loss due to insect pests of chilli range from 50-90 per cent.

Non-chemical insect pest management is an environmentally conscious approach to manage insect pests. It contributes to the sustainability of agricultural output and also minimizes crop production costs. In the past few decades, non-target organisms and the environment has been affected perniciously by the injudicious use of insecticides. The best suitable alternate is use of natural products such as botanicals and bio-agents. This suggests that developing an efficient non-chemical insect pest management ensures healthy food production.

The experiment was conducted in the experimental farm, Department of Entomology, School of Agricultural Sciences and Rural Development, Nagaland, India during November to May 2021-22 in randomized block design with eight treatments and each replicated thrice. The treatments are two botanical pesticides Neem seed powder pellet formulation (NSPPF) (30 g L^{-1}) and Pongamia oil (2 mL L^{-1}) and four microbial pesticides namely *Lecanicillium lecanii* (5 g L^{-1}), *Metarhizium anisopliae* (4 g L^{-1}), *Beauveria bassiana* (5 g L^{-1}) and Spinosad 45% SC (0.25 mL L^{-1}) along with Imidacloprid 17.8% SL (0.4 mL L^{-1}) as chemical check and untreated control. The seedlings of chilli variety KSP-1347 NIRMITI were transplanted to the experimental plots of 3.5 m × 2.0 m by adopting the spacing of 60 cm × 45 cm. Two sprays were given at 85, 110 days after transplantation. Before and after the biopesticides spray, population of sucking pests was taken on five randomly selected plants from each plot at three, five and seven days after treatments. The population of sucking pests

Table 1. Effect of different biopesticides on sucking pests of chilli

Treatments	Mean no. of thrips/ three leaves			Average % Reduction	Mean no. of aphids/ three leaves			Average % Reduction	Mean no. of whitefly/ three leaves			Average % Reduction	Overall Average % Reduction
	First spray	Second spray	Mean		First spray	Second spray	Mean		First spray	Second spray	Mean		
Neem seed powder pellet formulation (NSPPF)	6.96	6.69	6.83	49.58	8.01	7.86	7.93	53.05	4.13	4.62	4.38	53.78	52.14
Pongamia oil	10.13	9.96	10.05	32.73	12.58	12.69	12.64	32.68	7.11	7.87	7.49	33.36	32.92
Lecanicillium lecani	8.44	8.11	8.28	42.25	10.04	9.88	9.96	45.35	5.67	5.75	5.71	45.78	44.46
Metarhizium anisopliae	8.69	8.40	8.55	39.54	10.78	10.58	10.68	41.55	6.27	6.11	6.19	41.43	40.84
Beauveria bassiana	8.46	8.38	8.42	41.11	10.29	10.40	10.35	43.68	6.09	5.98	6.03	43.96	42.91
Spinosad 45% SC	4.60	4.56	4.58	63.95	5.13	5.49	5.31	67.32	2.55	2.73	2.64	69.93	67.07
Imidacloprid 17.8% SL	3.93	3.78	3.86	69.72	4.67	4.89	4.78	72.75	2.11	2.34	2.23	74.18	72.22
Control	14.22	14.18	14.20	0.00	17.80	18.47	18.14	0.00	11.16	11.13	11.14	0.00	0.00
C.D. (P=0.05)	0.31	0.48	-	-	0.32	0.45	-	-	0.39	0.42	-	-	-
SE(m)±	0.10	0.16	-	-	0.11	0.15	-	-	0.13	0.14	-	-	-

viz., thrips, aphids and whiteflies was counted on three leaves per plant from upper, middle and lower positions during morning hours as per the method suggested by Satpathy (1973) by using 10X magnifying lens. Matured chilli fruits were harvested and weighed to get yield data. Then the data were subjected to statistical analysis of variance (ANOVA).

Efficacy of different biopesticides was evaluated at three, five and seven days after spraying against sucking pests namely thrips, aphids and whiteflies. From the present findings, it is evident that all the treatments were statistically superior to control. The overall average per cent reduction of sucking pests (Table 1) indicated that Spinosad 45% SC was proved to be significantly superior in controlling sucking pests population with the per cent reduction of 67.07%. Neem seed powder pellet formulation (NSPPF) was moderately effective against sucking pests with the per cent reduction of 52.14%. Among Entomopathogenic fungi *Lecanicillium lecanii* (44.46%) was the most effective followed by *Beauveria bassiana* (42.91%) and *Metarhizium anisopliae* (40.84%). Pongamia oil (32.92%) was found to be the least effective among all the treatments. The chemical check Imidacloprid 17.8% SL recorded the maximum per cent reduction of 72.22 per cent.

Entomopathogenic fungi (EPF) are reported to control the pest populations by the release of spores and mycotoxins such as Beauvericin, Beauverolides and Destruxins (Gabarty *et al.,* 2014). Study of Samota *et al.* (2017) is in close proximity with the present results, who found that Spinosad and NSKE were moderately effective against thrips, followed by *B. bassiana* (34.86%) and *M. anisopliae* (33.60%) both are at par with each other. Borkakati *et al.,* (2019) revealed that the population of *Aphis gossypii*, *Scirtothrips dorsalis* and *Bemisia tabaci* were significantly reduced by Imidacloprid 17.8% SL closely followed by *Beauveria bassiana*. Harshita *et al.,* (2019) indicated that spinosad @ 0.3 mL L^{-1} was graded as the most effective treatment followed by azadirachtin @ 5 mL L^{-1} and *B. bassiana* @ 5 mL L^{-1} in reducing whitefly population. Singh and Kaur (2020) reported that EPF are the most efficient in suppressing aphid and whitefly populations on vegetable crops. Nimbalkar *et al.,* (2022) found that Neem oil @ 5 mL L^{-1} was proved very effective in management of thrips and whiteflies followed by NSKE 5%, *Verticilium lecanii* @ 4 g L^{-1} and *Metarrhizium anisopliae* @ 4 g L^{-1} respectively.

The fruit yield obtained from various treatments were statistically analyzed and presented in Table 1. All the biopesticides produced comparatively higher yield than untreated control (30.1 q ha^{-1}). Among the biopesticides, spinosad 45% SC (53.7 q ha^{-1}) recorded the highest yield followed by Neem seed powder pellet formulation (50.5 q ha^{-1}), *L. lecanii* (49.2 q ha^{-1}), *Beauveria bassiana* (46.9 q ha^{-1}), *Metarhizium anisopliae* (43.4 q ha^{-1}) and Pongamia oil (35.3 q ha^{-1}). Spinosad 45% SC was found to have high benefit cost ratio (1.82) followed by *Lecanicillium lecanii* (1.75), *Beauveria bassiana* (1.62), Neem seed powder pellet formulation (1.47), *Metarhizium anisopliae* (1.44) and Pongamia oil (0.99). The yield and cost benefit ratio of biopesticides treatment does not differ much than the chemical check, Imidacloprid 17.8% SL (56.4 q ha^{-1} and 1:2.20). Foliar spray of microbial pesticides were resulted in population reduction of sucking pests below economic injury level and had positive effects on yield compared to botanical pesticides. EPF present on rhizosphere region influences nitrogen availability thus promotes plant growth (Behie and Bidochka 2014). To ensure healthy food production, use of chemical insecticides should be reduced and there is an increasing need to utilize biopesticides available and to develop new products with different modes of action.

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