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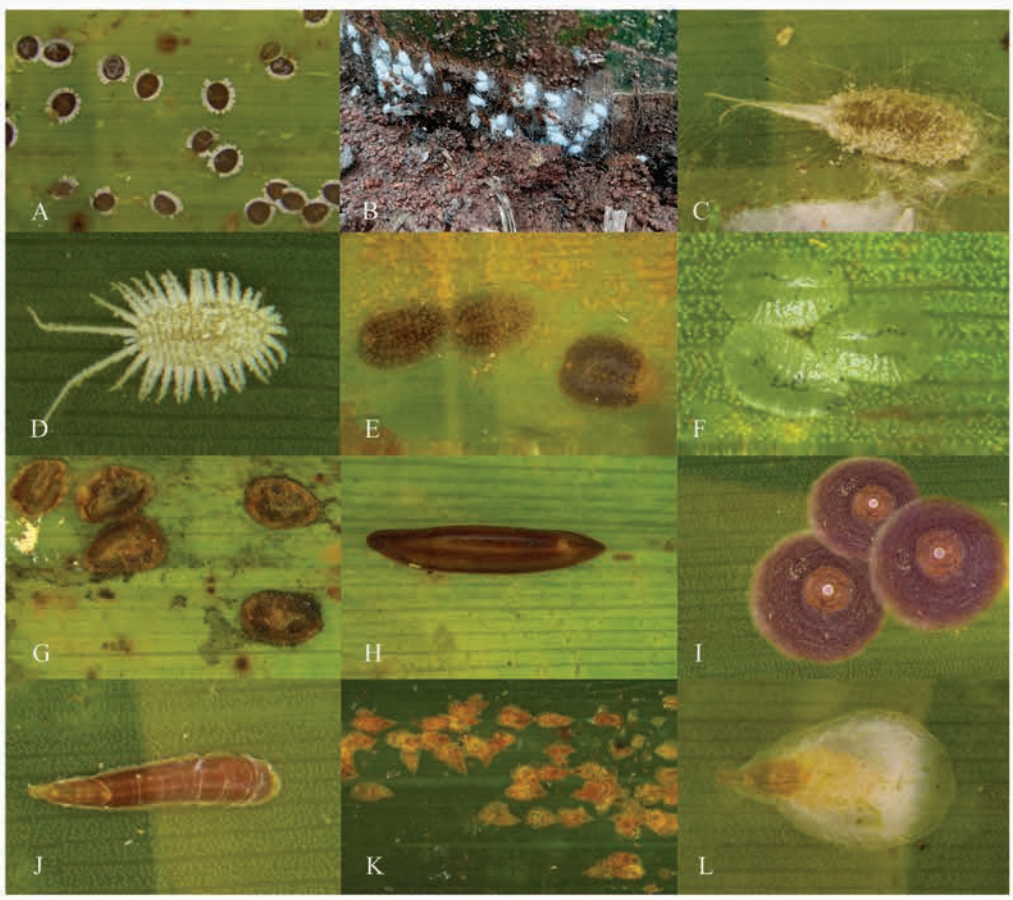

Fig. 1 Aphids and coccids occurring on arecanut- Aphididae A. *Cerataphis lataniae;* Pseudococcidae B. *Dysmicoccus brevipes,* C. *Ferrisia virgata,* D. *Pseudococcus longispinus;* Coccidae E. *Coccus hesperidum,* F. *Coccus viridis,* G. *Parasaissetia nigra,* H. *Prococcus acutissimus;* Diaspididae I. *Chrysomphalus aonidum,* J. *Lepidosaphes gloverii,* K. *Pinnaspis aspidistrae,* L. *Pseudaulacaspis cockerelli*

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EFFECT OF ECOLOGICAL ENGINEERING ON INCIDENCE OF KEY RICE PESTS

Yogesh Yele, Subhash Chander[1], Sachin S. Suroshe[1], Suresh M Nebapure[1], Arya P S[1] and Prabhulinga T[1]

ICAR-National Institute of Biotic Stress Management, Raipur 493225, Chhattisgarh, India
[1]Division of Entomology, ICAR-Indian Agricultural Research Institute, New Delhi 110012, India
*Email: yogeshyele13@gmail.com (corresponding author)

ABSTRACT

Incidence of rice pests like white backed planthopper (WBPH) *Sogatella furcifera*, leaf folder *Cnaphalocrocis medinalis*, whorl maggot *Hydrellia sasakii* and stem borers- yellow stem borer *Scirpophaga incertulas* and the pink stem borer *Sesamia inferens* were studied in ecologically engineered rice fields during kharif 2019 and 2020. The WBPH population significantly reduced in fields planted with mixture of crop and flowering plants (0.66±0.25 and 0.83±0.44 WBPH/hill) during kharif 2019 and 2020, respectively. Rice plots planted with crops and flowering plants had lowest leaf folder damage in both the seasons (0.64±0.11% and 0.54±0.35%). Similarly, whorl maggot damage in mixture of crop and flowering plants found significantly reduced than control plots in both the seasons. Reduced pest activity in ecologically engineered fields significantly increased rice yield, particularly in rice plots planted with crops and flowering plants (5.60± 0.24 and 5.27± 0.06 mt/ ha). Study revealed that planting of crop and flowering plants around the rice field increased the natural enemy activity and reduced incidence of rice pests which eventually reduced the yield losses caused by insect pests and increased the rice grain yield.

Key words: Rice, Pusa Basmati 1121, flowering plants, ecological engineering, natural enemies, population incidence, integrated pest management

Rice *Oryza sativa* L. is the world's most important staple food crop (Khush, 2004) and India has the largest cultivated area under rice. Rice production is challenged by many biotic and abiotic stresses including insect pests and diseases (Behura et al., 2011). Pest management in rice agroecosystem is heavily dependent on insecticides and partially on host-plant resistance. Indiscriminate use of insecticides has created serious imbalances. Agricultural intensification and overuse of agrochemicals has resulted in depletion of natural enemies (Matsumura et al., 2008). Ecologically sound IPM can counteract these with restoring the ecology of rice landscapes (Horgan et al., 2016). Ecological engineering is an approach with manipulation of habitats for the benefit of society and the natural environment. It mainly focuses on increasing the abundance, diversity and function of natural enemies in agricultural habitats by providing refuges and alternate or supplementary food resources (Gurr 2009; Lu et al., 2014; Lv et al., 2015; Landis et al., 2000). By planting flowers in an agroecosystem, farmers can provide resource subsidies for parasitoids, and thereby improving biological control of insect pests (Kean et al., 2003; Gurr et al., 2004). Ecological engineering is an extended and refined version of IPM and selection of appropriate flowering plants for enhancement of biological activity and conservation of natural enemies is important. These have been done in many rice growing countries. But, in India, there are not many, and hence the present study with focus on incidence of some key insect pests.

MATERIALS AND METHODS

Experiments were conducted at the ICAR-Indian Agricultural Research Institute, New Delhi during kharif 2019 and 2020 with the rice variety Pusa Basmati 1121. Healthy rice seeds were treated with fungicide and sown @ 15 kg/ ha in lines on the well-prepared nursery beds on 27th/ 29th June during kharif 2019 and 2020, respectively. All the recommended agronomic practices were followed. Plots of size 5x 4 m, 1 m apart from each other with ridges on all sides were prepared. Transplanting was done on 22nd/ 30th July in kharif 2019 and 2020, respectively. Two seedlings/ hill were transplanted each at 15x 20 cm plant and row spacing, respectively. Ridges were prepared surrounding all the plots and gap filling was done after a week. No application of insecticide was done at any crop stage. Three field crops viz., sesamum, sunflower and soybean; and three flowering crops viz., marigold, balsam and gaillardia were selected for the study. Mix planting of crop and flowering plants and no-weeding

plots were also included as the treatment. Accordingly, the treatments were designed as; T1= Field crops (sesamum+ sunflower+ soybean); T2= Flower crops (marigold+ balsam+ gaillardia); T3= Natural weeds (no weeding); T4= Field crops+ flower crops; T5= Control. The experiments were laid out in completely randomized block design (CRBD) having five treatments with four replications. Between replicates, 1m alley was provided to facilitate irrigation, fertilizer application and recording of observations.

Seeds of field crops like sesamum, sunflower and soybean were directly sown on the bunds adjacent to respective treatments. For flower crops like marigold, balsam and gaillardia nursery was raised and were transplanted on bunds adjacent to the respective treatments. All the crop and flowering plants were also raised in the plastic pots of size of 22.5x 15 cm and were transferred around the rice plots of respective treatments. Sowing and transplanting of all the crop plants and flowering plants on bunds as well as in the pots were done in staggered manner, so that the flowering occurs for longer duration. Randomly 10 hills/ plot were selected and tagged for observations on the incidence of the white backed plant hopper *Sogatella furcifera*, whorl maggot *Hydrellia sasakii* and leaf folder *Cnaphalocrocis medinalis* at 10 days interval starting from 40 days after transplanting and till harvest. For WBPH, hoppers/ hill, including nymphs were counted; for *H. sasakii*, number of leaves infested/ hill with % calculated, and with *C. medinalis*, number of folded leaved/ hill observed and % calculated; and for stem borers- yellow stem borer *Scirpophaga incertulas* and the pink stem borer *Sesamia inferens* it was % white ears at preharvest stage. Yield data was recorded after harvesting and expressed as mt/ ha. These data were subjected to two-way ANOVA and the significance evaluated with F-test, while the treatment means by LSD (p= 0.05).

RESULTS AND DISCUSSION

The WBPH *S. furcifera* was observed infesting early in both kharif seasons, and its incidence differed significantly between the treatments ($F=41.4$, $p<0.001$ and $F=18.54$, $p<0.001$) and weeks ($F=34.5$, $p<0.001$ and $F=68.62$, $p<0.001$); significantly less incidence was in rice plots planted with flowering plants. In case of *C. medinalis*, damage was seen early in the season and significantly differed between the treatments ($F=45.591$, $p<0.001$ and $F=82.19$, $p<0.001$) and weeks ($F=2.6$, $p=0.0026$ and $F=63.2$, $p<0.001$) in both the seasons. Rice plots surrounded with crops and flowering plants exhibited least incidence (0.64±0.11 and 0.54±0.35); also, the plots planted with crop plants and flowering plants alone, suffered less damage. In case of *H. sasakii* damage was more prominent during vegetative stage at 41 and 44 DAT (36th SMW); it was observed more in kharif 2019 than that of 2020, with significantly less incidence when flowering plants alone and mixture of crop and flowering plants were in the plots. Two species of stem borers were observed during vegetative and reproductive stage, of which the dominant one was *S. incertulas* and other one was *S. inferens*, with insignificant incidence during vegetative stage. Preharvest white ears were recorded in all the treatments and % white ears were calculated. It was observed that their incidence was <economic threshold level (ETL) in all the treatments including control ($F=3.9$, $p=0.028$ and $F=8.3$, $p<0.001$); however, less white ears were observed in plots planted with crops, flowers and crops+ flowers. Yield differed significantly between the treatments in kharif 2020 ($F=25.2$, $p<0.001$), and not so during kharif 2019 ($F=3.7$, $p=0.033$), with significantly higher yield being with plots planted with crops+ flowers during kharif 2019 (5.60± 0.24 mt/ ha) and kharif 2020 (5.27± 0.06 mt/ ha) (Table 1).

The IPM as an approach has shown great potential for reducing the dependence on chemical control methods (Pretty et al., 1998; Atanassov et al., 2002). It involves integrating diverse tactics, including cultural, biological, and chemical control (Dent, 1991). Intensification of agriculture has reduced the farmland biodiversity and reduced the number of flowering plants and weeds, which natural enemies depend on for the food and nectar (Lu et al., 2014). Ecological engineering has great potential in rice IPM which involves the identification of optimal forms of botanical diversity which promote the natural enemies, but very little information available on the optimal fauna and flora to be employed for this cause. Earlier attempts in the field of ecological engineering studies found reduced pest population in main crop after planting flowering crops around the main field (Yu et al., 2001; Gurr et al., 2011; Liu et al., 2014; Zhu et al., 2015; Chen et al., 2016; Kong et al., 2016). Maintaining grasses and weeds around the rice fields, planting of sesame on bunds as a source of nectar, intercropping zizania in some fields, planting vetiver grass on roadsides and along irrigation canals and releases of *Trichogramma* spp. simultaneously had been reported to lower the pest activity in the rice fields (Chen et al., 2016; Zhu et al., 2015; Zhu et al., 2017).

Table 1. Incidence of key insect pests in rice and yield of rice (kharif 2019, 2020)

S. furcifera

Treatments	Incidence*								
	Kharif 2019					Kharif 2020			
	36 SMW	37 SMW	39 SMW	40 SMW	Mean± SE	36 SMW	38 SMW	39 SMW	Mean± SE
T1 Crops (sesamum+sunflower+soybean)	0.25± 0.15 (1.11± 0.07)	1.20± 0.31 (1.47± 0.11)	1.63± 0.13 (1.62± 0.04)	0.15± 0.09 (1.07± 0.04)	0.81± 0.36 (1.32± 0.14)^{c}	0.28± 0.05 (1.13± 0.02)	1.88± 0.16 (1.69± 0.05)	0.78± 0.38 (1.31± 0.14)	0.98± 0.47 (1.38± 0.17)^{b}
T2 Flowers (marigold+balsam+ gaillardia)	0.90± 0.24 (1.37± 0.08)	1.28± 0.18 (1.51± 0.06)	1.35± 0.34 (1.52± 0.11)	0.08± 0.05 (1.04± 0.02)	0.90± 0.29 (1.36± 0.11)^{c}	0.40± 0.15 (1.18± 0.06)	1.63± 0.17 (1.62± 0.05)	0.90± 0.32 (1.36± 0.11)	0.98± 0.36 (1.39± 0.13)^{b}
T3 Natural weeds	0.83± 0.34 (1.34± 0.12)	1.03± 0.21 (1.42± 0.07)	1.28± 0.14 (1.51± 0.05)	1.13± 0.28 (1.45± 0.10)	1.06± 0.09 (1.43± 0.04)^{b}	0.20± 0.09 (1.09± 0.04)	1.70± 0.45 (1.63± 0.13)	0.63± 0.13 (1.27± 0.05)	0.84± 0.45 (1.33± 0.16)^{b}
T4 Crops+Flowers	0.40± 0.18 (1.18± 0.08)	0.98± 0.18 (1.40± 0.07)	1.15± 0.13 (1.46± 0.04)	0.10± 0.06 (1.05± 0.03)	0.66± 0.25 (1.27± 0.10)^{d}	0.33± 0.13 (1.15± 0.06)	1.70± 0.41 (1.63± 0.13)	0.45± 0.31 (1.19± 0.12)	0.83± 0.44 (1.32± 0.16)^{b}
T5 Control	1.88± 0.11 (1.70± 0.03)	3.70± 0.22 (2.17± 0.05)	2.30± 0.16 (1.82± 0.05)	1.53± 0.13 (1.59± 0.04)	2.35± 0.48 (1.82± 0.13)^{a}	1.23± 0.10 (1.49± 0.03)	3.50± 0.20 (2.12± 0.05)	1.78± 0.11 (1.67± 0.03)	2.17± 0.69 (1.76± 0.19)^{a}
Mean± SE	0.85± 0.28 (1.34± 0.10)^{b}	1.64± 0.52 (1.59± 0.15)^{a}	1.54± 0.21 (1.59± 0.06)^{a}	0.60± 0.31 (1.24± 0.12)^{c}		0.48± 0.18 (1.20± 0.07)^{c}	2.08± 0.35 (1.73± 0.10)^{a}	0.90± 0.23 (1.35± 0.08)^{b}	

C. medinalis

Treatment	Damage (%)*											
	Kharif 2019							Kharif 2020				
	36 SMW	37 SMW	39 SMW	40 SMW	42 SMW	43 SMW	Mean± SE	36 SMW	38 SMW	39 SMW	41 SMW	Mean± SE
T1 Crops (sesamum+ sunflower+ soybean)	0.05± 0.05	0.61± 0.28	1.53± 0.30	0.93± 0.24	1.02± 0.18	0.84± 0.30	0.83± 0.19^{b}	0.34± 0.17	1.76± 0.19	0.58± 0.16	0.11± 0.11	0.69± 0.36b
T2 Flowers (marigold+ balsam+gaillardia)	0.09± 0.05	0.70± 0.09	1.21± 0.57	0.93± 0.51	0.72± 0.23	0.71± 0.21	0.72± 0.15^{b}	0.12± 0.07	1.26± 0.24	0.41± 0.08	0.09± 0.05	0.47± 0.27^{c}
T3 Natural weeds	1.87± 0.27	1.25± 0.34	0.86± 0.14	0.57± 0.06	0.71± 0.09	0.70± 0.13	0.99± 0.19^{b}	0.83± 0.12	2.03± 0.41	0.49± 0.26	0.54± 0.30	0.97± 0.36^{b}
T4 Crops+flowers	0.23± 0.09	0.56± 0.11	0.70± 0.12	0.97± 0.30	0.96± 0.33	0.45± 0.23	0.64± 0.11^{c}	0.22± 0.16	1.61± 0.28	0.23± 0.10	0.10± 0.10	0.54± 0.35^{c}
T5 Control	2.27± 0.23	2.35± 0.13	2.19± 0.51	3.09± 0.35	3.11± 0.54	1.73± 0.30	2.45± 0.22^{a}	2.08± 0.33	4.48± 0.29	2.77± 0.30	1.92± 0.22	2.81± 0.58^{a}
Mean± SE	0.90± 0.48^{b}	1.09± 0.33^{a}	1.23± 0.26^{a}	1.23± 0.45^{a}	1.30± 0.45^{a}	0.89± 0.21^{b}		0.71± 0.36^{c}	2.23± 0.57^{a}	0.90± 0.47^{b}	0.55± 0.35^{c}	

(contd.)

(contd. Table 1)

H. sasakii

Treatments	Damage (%)*										
	Kharif 2019						Kharif 2020				
	36 SMW	37 SMW	39 SMW	40 SMW	42 SMW	Mean± SE	36 SMW	38 SMW	39 SMW	41 SMW	Mean± SE
T1 Crops (sesamum+ sunflower+ soybean)	7.35± 0.66	6.08± 0.60	6.90± 1.02	5.40± 1.40	1.40± 0.18	5.42± 1.06^{b}	9.00± 0.55	3.50± 0.52	2.55± 0.17	0.00± 0.00	3.76± 1.90^{c}
T2 Flowers (marigold+ Balsam+ gaillardia)	8.90± 0.82	6.50± 0.94	6.58± 1.28	4.15± 0.48	1.53± 0.26	5.52± 1.24^{b}	9.38± 0.44	3.65± 0.60	2.68± 0.49	0.10± 0.10	3.95± 1.96^{c}
T3 Natural weeds	10.88± 1.27	5.18± 0.58	7.13± 0.98	4.95± 0.84	1.73± 0.36	5.97± 1.50^{b}	10.78± 1.43	4.40± 0.52	2.88± 0.55	0.15± 0.15	4.55± 2.25^{b}
T4 Crops+flowers	4.80± 0.47	5.48± 0.91	6.88± 0.78	6.35± 0.74	1.58± 0.19	5.00± 0.93^{b}	10.53± 0.65	3.20± 0.67	3.75± 0.64	0.00± 0.00	4.37± 2.21^{b}
T5 Control	10.83± 0.97	6.15± 0.48	8.85± 0.62	7.78± 0.55	3.75± 0.46	7.47± 1.20^{a}	12.65± 1.23	7.80± 1.00	6.00± 0.87	2.08± 0.30	7.13± 2.19^{a}
Mean± SE	8.56± 1.14^{a}	5.88± 0.24^{c}	7.27± 0.41^{b}	5.72± 0.63^{c}	1.99± 0.44^{d}		10.47± 0.64^{a}	4.51± 0.84^{b}	3.57± 0.64^{c}	0.47± 0.40^{d}	

T. incertulas and S. inferens incidence and yield

Treatment	White ears (%)		Yield (mt/ ha)	
	Kharif 2019	Kharif 2020	Kharif 2019	Kharif 2020
T1 Crops (sesamum+ sunflower+soybean)	0.9± 0.08^{c}	0.8± 0.05^{bc}	4.52± 0.24^{b}	4.71± 0.07^{c}
T2 Flowers (marigold+balsam+ gaillardia)	1.1± 0.1^{b}	0.9± 0.1^{bc}	4.80± 0.55^{a}	4.97± 0.05^{b}
T3 Natural weeds	1.5± 0.1^{ab}	1.2± 0.1^{b}	4.12± 0.31^{bc}	4.44± 0.1^{d}
T4 Crops+Flowers	1.1± 0.1^{b}	0.6± 0.03^{c}	5.60± 0.24^{a}	5.27± 0.06^{a}
T5 Control	1.8± 0.2^{a}	1.7± 0.2^{a}	3.99± 0.20^{c}	4.27± 0.06^{d}
F- value	3.9	8.3	3.7	25.2
LSD	0.5	0.4	1.0	0.2
p- value	0.028	<0.001	0.033	<0.001

Kharif 2019
Treatment, F = (41.4), LSD = (0.09), p<0.001
Week, F = (34.5), LSD = (0.08), p<0.001
Interaction (treatment × week), F = (3.8), LSD = (0.19), p<0.001
WBPH counts with same superscripts do not differ significantly.
*Mean of ten replications.
Data in parentheses *SQRT (X + 1)* transformed values

Kharif 2020
Treatment, F = (18.5), LSD = (0.12), p<0.001
Week, F = (68.6), LSD = (0.09), p<0.001
Interaction (treatment × week), F = (0.5), LSD = (NA), p=0.855
WBPH counts with same superscripts do not differ significantly.
*Mean of ten replications.
Data in parentheses *SQRT (X + 1)* transformed values

Kharif 2019
Treatment, F = (45.5), LSD = (0.31), p<0.001
Week, F = (2.6), LSD = (0.34), p=0.026
Interaction (treatment × week), F = (2.6), LSD = (0.76), p<0.001
Leaf folder damage % with same superscripts do not differ significantly.
*Mean of ten replications.

Kharif 2020
Treatment, F = (82.19), LSD = (0.30), p<0.001
Week, F = (63.22), LSD = (0.27), p<0.001
Interaction (treatment × week), F = (1.65), LSD = (NA), p=0.100
Leaf folder damage % with same superscripts do not differ significantly.
*Mean of ten replications.

Kharif 2019
Treatment, F = (8.51), LSD = (0.92), p<0.001
Week, F = (56.70), LSD = (0.92), p<0.001
Interaction (treatment × week), F = (2.82), LSD = (2.06), p<0.001
Whorl maggot damage % with same superscripts do not differ significantly.
*Mean of ten replications.

Kharif 2020
Treatment, F = (21.6), LSD = (0.83), p<0.001
Week, F = (253.1), LSD = (0.74), p<0.001
Interaction (treatment × week), F = (1.0), LSD = (NA), p=0.458
Whorl maggot damage % with same superscripts do not differ significantly.
*Mean of ten replications.

Egg parasitoids of planthoppers like *Oligosita* and *Anagrus* from common grassy flora near the ridge increased, while the population of planthoppers was reduced significantly with ecological engineering techniques (Zhu et al. 2015). The numbers of egg parasitoids, invertebrate predators, vertebrate predators like frogs and numbers of aquatic predators such as Odonata (damselflies) and Tetragnathidae were significantly higher than those in the control fields (Chen et al. 2016; Kong et al. 2016; Zhu et al. 2017). The application of ecological engineering technology has kept rice pest populations at low levels. Zhu et al (2014) proposed that presence of flowering plants like *Tagetes erecta, Trida procumbens, Emilia sonchifolia* and *Sesamum indicum* around the rice reduces the planthoppers, and increased the abundance of natural enemies like mirid bug. Planting of flowering plants like sesamum, tagetes, sunflower etc. on rice field bund and along the roadsides has been recommended for improving biological control and sustainable management of rice insect pests (Lu and Guo, 2015). Planting of sesamum around the rice fields has been a widely accepted. Egg parasitoids such as *Anagrus optabilis* and *A. nilaparvatae* are known to be significantly attracted by volatile compounds from sesamum flowers and leaves. It has also been reported that the, sesamum flowers also enhances the longevity of egg parasitoids for lepidopterous pests like pink stem borers, spotted stem borers and leaf folders and does not support these pests (Zhu et al., 2012; 2015).

Laboratory screening experiments proved that volatiles of *S. indicum*, *Impatiens balsamena*, *E. sonchifolia*, *Hibiscus coccineus T. procumbens* and *H. esulentus* attract and enhance the performance of *Anagrus* spp. (Zhu et al., 2013). Of these, *S. indicum*, *E. sonchifolia*, and *I. balsamena* were also attractive to *A. nilaparvatae*, and *S. indicum* flowers specifically enhance the life span of *A. nilaparvatae* and *A. optabilis*. Horgan et al (2016) reported lower leafhopper and WBPH abundance in the rice fields planted with string bean strips. In another study, banker plant system consisted of planting a grass species, *Leersia sayanuka*, adjacent to rice fields. BPH population densities were significantly lower in rice fields with banker plant system (Zheng et al., 2017). Chandrasekar et al. (2017) recommended the use weed strips of *E. colonum* (L.) and *E. crusgalli* in rice ecosystem to enhance the availability of mirid bugs. Rice bunds were increasingly recognized as near crop habitats that can be used for planting trap crops and other flowering plants for attraction and conservation of natural enemies. Present study on ecological engineering in rice revealed that planting of crops plants such as sesamum, sunflower and soybean and flowering crops such as marigold, balsam and gaillardia on the bunds around the main rice fields attract and enhance natural enemies.

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DIVERSITY AND DIAGNOSTICS OF STERNORRHYNCHAN INSECT PESTS INFESTING ARECANUT

Vinod Kumar Dubey, Kalleshwaraswamy C M*, Sunil Joshi[1] and Shivanna B K

Department of Agricultural Entomology, College of Agriculture,
University of Agricultural and Horticultural Science, Shivamogga 577204, Karnataka, India
[1]ICAR-National Bureau of Agricultural Insect Resources, Bengaluru 560024, Karnataka, India
Email: kalleshwaraswamycm@uahs.edu.in (corresponding author)

ABSTRACT

Investigations were carried out in major arecanut growing districts of Karnataka during 2019-2020 to know the species composition of sternorrhynchan pests viz., mealybugs, scales and aphids. A total of 14 species of sternorrhynchan sucking insect pests were recorded in the arecanut growing districts. These belong to five families viz., Coccidae Stephens, Diaspididae Maskell, Pseudococcidae (Heymons) and Aphididae (Buckton). Among these, Coccidae was the species rich. *Prococcus acutissimus* (Green) was the most predominant species followed by *Pseudococcus longispinus* (Targioni Tozzetti), *Ceroplastes* sp. nr. *rusci* (L.), *Chrysomphalus aonidum* (L.), *Parasaissetia nigra* (Neitner), *Coccus viridis* (Green), *Coccus hesperidum* L., *Pseudaulacaspis cockerelli* (Cooley), *Pinnaspis aspidistrae* (Signoret), *Lepidosaphes gloveri* (Packard), *Ferrisia virgata* (Cockerell), *Dysmicoccus brevipes* (Cockerell) and *Cerataphis lataniae* (Boisduval). Diagnostics of these with descriptions of taxonomic characters and a key to genera is also provided herein.

Key words: Arecanut, aphids, Karnataka, mealybugs, scales, taxonomic key

Arecanut palm, *Areca catechu* L. is one of the important commercial plantation crops in India. The economic produce of the arecanut fruit is called betel nut or supari, which is used in various social and religious ceremonies in India. Arecanut is having some medicinal uses against leukoderma, leprosy, cough, fits, worms, anemia and obesity. The cultivation is concentrated in the southwestern and northeastern region up to an elevation of 1000m above mean sea level. In the world, arecanut palm cultivation is majorly restricted to south Asian countries like India, Pakistan, Sri Lanka, Malaysia, Philippines and Japan. In India, arecanut is extensively grown in different states like Karnataka, Kerala, Assam and West Bengal. The contribution of arecanut in total area of cultivation and production from Karnataka, Kerala and Assam accounted is around 83% (Ramappa, 2013). Among the districts of the Karnataka state, Shivamogga stands first in both area (21.06%) and production (21.30%) followed by Davanagere, Dakshina Kannada, Tumkur, Chikkamagaluru and Chitradurga. These districts together account 83.63% of the total area and 82.10% of the total production in the state (Anon, 2018).

Arecanut is infested by many species of insect and non-insect pests in its young and old stage. These pests attack nuts, inflorescence, causing direct losses to leaves, stem, nuts and roots, causing indirect losses (Daniel and Kumar, 1976). Among these, root grub *Leucopholis lepidophora* Blanchard (Scarabaeidae: Coleoptera), spindle bug *Carvalhoia arecae* Miller and China (Miridae: Heteroptera), inflorescence caterpillar *Tirathaba mundella* Walker (Pyralidae: Lepidoptera) and mite *Raoiella indica* Hirst (Acarina: Tenuipalpidae) are important in causing economic damage (Nair and Menon, 1963; Kalleshwaraswamy et al., 2015). Sucking pests are less explored and taxonomically well known among the insect pests of arecanut. Scales, mealybugs and aphids are important with possibilities of becoming severe pests. These insects suck the sap from the leaves, inflorescence and nuts and reduce the photosynthetic rate. In case of severe infestation, it interferes pollination, affect normal growth and yield (Ramappa, 2013). To understand the diversity of these sternorrhynchan insect pests infesting arecanut in Karnataka, a study was undertaken. Their diagnostics is also provided giving morphological descriptions and a key for easy identification.

MATERIALS AND METHODS

Study conducted to know the species composition of coccids and aphids in different arecanut growing districts included surveys of arecanut plantations in

the four agroclimatic zones of Karnataka, viz., coastal zone, central dry zone, southern transition zone and hilly zones. In each of these, 20 selected gardens covering different talukas were surveyed at monthly intervals. In each garden, presence or absence of the pest was recorded, and live insects collected with a fine camel hair brush were immersed in 70% ethyl alcohol. The infested plant samples were brought to the laboratory in polythene bags (16x 22 cm) or in a small plastic container. These samples were kept under cool condition and sorted out using a compound microscope (Carl Zeiss). The specimens were preserved in vials (5 ml) containing 70% ethyl alcohol, with representative samples subjected to permanent slide mounting. Sirisena et al. (2013) was followed with little modification for these and slides of scales, mealybugs and aphids were prepared. Identification of the specimens was made from these- mealybugs were identified up to species level by using taxonomic keys as given by Williams (2004) for scales key by Zimmerman (1948) and for aphids (Joshi, 2005**)**. The observation on the presence of these pests was made on the plant parts like stem, roots, inflorescence, nuts and leaflets. A list of species of sternorrhynchan insect pests, their identification characters and distribution were recorded. Live aphid and coccid photos were captured using Vivo 11 Pro mobile mounted on Olympus BX 51 microscope and microphotographs of slide mounted females and their important diagnostic characters were captured with a Nikon DS–Vi1 camera mounted on this microscope. All the figures were generated using Adobe Photoshop CS2. Diagnostic characters of each species have been given as legends in all the figures. Live and mounted female photographs of *C*. sp nr. *rusci* could not be included, as the specimens were damaged and could not be processed properly; also the live photographs of *A. destructor* as sound specimens suitable for good photographs were not available.

RESULTS AND DISCUSSION

In the present study, 14 species of sternorrhynchan insect pests were observed from major arecanut growing zones of Karnataka viz., southern transitional zone (14), hilly zone (5), coastal zone (3) and central dry zone (3) (Table 1). These included one species of aphid (Aphididae), three species of mealybugs (Pseudococcidae), five species each of soft scales (Coccidae) and armoured scales (Diaspididae). They belong to four families viz., Coccidae [*Ceroplastes* sp. nr. *rusci* L., *Parasaissetia nigra* (Neitner), *Prococcus acutissimus* (Green), *Coccus viridis* (Green), *Coccus hesperidum* L.]; Diaspididae [*Chrysomphalus aonidum* (L.), *Pseudaulacaspis cockerelli* (Cooley), *Pinnaspis aspidistrae* (Signoret), *Lepidosaphes gloverii* (Packard), *Aspidiotus destructor* Signoret]; Pseudococcidae (*Ferrisia virgata* (Cockerell) *Pseudococcus longispinus* (Targioni Tozzetti), *Dysmicoccus brevipes* (Cockerell); and Aphididae (*Cerataphis lataniae* (Boisduval).

Diversity and incidence: Among all the four zones, the highest number of insect species was recorded in the southern transitional zone (14) followed by the hilly zone (5), coastal zone (3) and central dry zone (3). Among the scales, five species each of soft scales and armoured scales were recorded in four different zones selected for the study. *P. acutissimus* was

Table 1. Species composition of sternorrhynchan insect pests in arecanut

Sl. No.	Species	Coastal zone	Central dry zone	Southern transition zone	Hilly zone
1	*Coccus viridis* (Green)	-	-	+	-
2	*Prococcus acutissimus* (Green)	+	+	+	+
3	*Ceroplastes* sp. nr. *rusci* (L.)	+	-	+	+
4	*Parasaissetia nigra* (Neitner)	-	-	+	-
5	*Coccus hesperidum* (L.)	-	-	+	-
6	*Chrysomphalus aonidum* (L.)	-	-	+	+
7	*Lepidosaphes gloverii* (Packard)	-	-	+	+
8	*Pseudaulacaspis cockerelli* (Cooley)	-	-	+	-
9	*Pinnaspis aspidistrae* (Signoret)	-	-	+	-
10	*Aspidiotus destructor* Signoret,	-	-	+	-
11	*Pseudococcus longispinus* (Targioni Tozzetti)	+	+	+	+
12	*Ferrisia virgata* (Cockerell)	-	-	+	-
13	*Dysmicoccus brevipes* (Cockerell)	-	-	+	-
14	*Cerataphis lataniae* (Boisduval)	-	-	+	-
Total		3	3	14	5

+ = Present; - = Absent

distributed in all the four zones surveyed. This was followed by *C.* sp.nr. *rusci* was distributed in all the four zones except the central dry zone. The remaining three species of soft scales recorded were *P. nigra*, *C. viridis* and *C. hesperidum*. Among armoured scales, *C. aonidum* and *L. gloverii* were distributed only in the southern transitional zone and hilly zone. Whereas, the other three species of diaspidids were *P. cockerelli*, *P. aspidistrae* and *A. destructor* were recorded only in the southern transitional zone. Among the three species of mealybugs, *P. longispinus* was the most predominant species of mealybugs distributed in all the four zones surveyed. While the other two species of mealybugs namely, *F. virgata* and *D. brevipes* were distributed only in the southern transitional zone. One species of aphid, *C. lataniae* was recorded in southern transitional zone (Table 1; Fig. 1).

Diagnostic keys: The surveys have documented 14 species of sternorrhynchan insect pests. The diagnostic keys for these are given below with relevant illustrations.

Key to the families

1. Siphunculi and cauda present..... Aphididae (Buckton) (Fig. 2)
   Siphunculi and cauda absent.....2
2. Labium three segmented, anal plate and anal cleft absent, ostiole present, cerarii present and legs present.....Pseudococcidae (Heymons) (Fig. 3)
   Labium one segmented, anal cleft and anal plates may present or absent, cerarii absent, legs may be present or absent.....3
3. Anal plate and anal cleft absent, pygidium present, legs absent.....Diaspididae Maskell (Fig. 10)
   Anal plate and anal cleft present, pygidium absent, legs present.....Coccidae Stephens (Fig. 6)

Fig. 1. Aphids and coccids occurring on arecanut- Aphididae A. *Cerataphis lataniae*; Pseudococcidae B. *Dysmicoccus brevipes*, C. *Ferrisia virgata*, D. *Pseudococcus longispinus*; Coccidae E. *Coccus hesperidum*, F. *Coccus viridis*, G. *Parasaissetia nigra*, H. *Prococcus acutissimus*; Diaspididae I. *Chrysomphalus aonidum*, J. *Lepidosaphes gloverii*, K. *Pinnaspis aspidistrae*, L. *Pseudaulacaspis cockerelli*

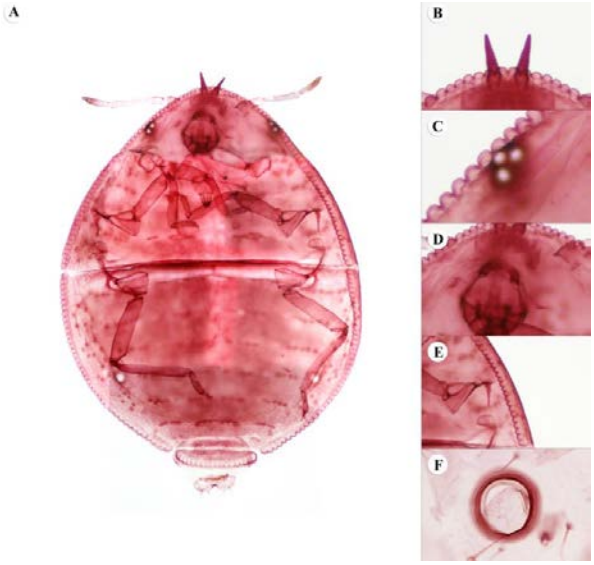

Fig. 2. Diagnostic characters of *Cerataphis lataniae* (Boisduval): A. Dorsoventrally flattened, almost circular body, B. Head with a pair of forwardly directed frontal horns, C. Eyes three faceted, D. Underside of head without dagger-like hairs but with only fine hairs, E. Crenulate body margin due to a continuous row of wax glands, F. Pore like siphunculus

Key to the genera

Pseudococcidae

1. Cerarii 1 to 3 pairs, circulus always present..... *Ferrisia* (Cockerell) (Fig. 4)
   Cerarii more than three pairs, Circulus may present or absent.....2
2. Body mainly oval, number of cerarii is 12 to17 pairs, circulus may be present or absent, antennae 7 to 8 segmented, 2 pairs auxiliary setae and conical setae present in the sclerotized area, anterior ostioles always present, discoidal pores larger than the trilocular pores.....*Pseudococcus* Westwood (Fig. 5)
   Body elongated to oval, cerarii 6 to 17 pairs, antennae 6 to 8 segmented, conical setae 2 to 8 with auxiliary setae, translucent pores may present or absent.....*Dysmicoccus* Ferris (Fig. 3)

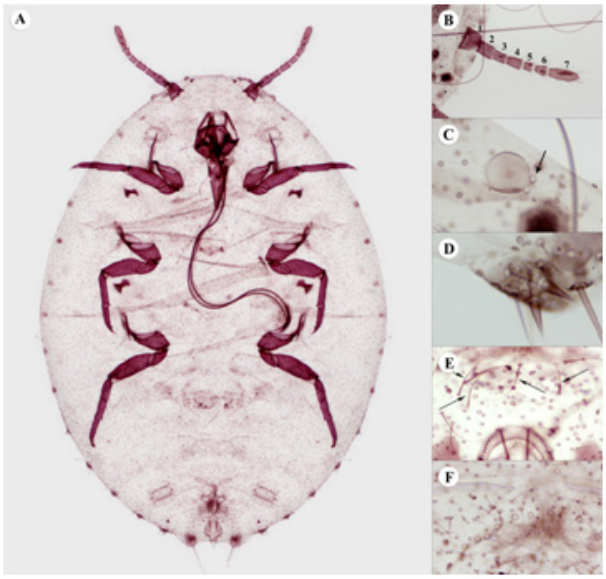

Fig. 3. Diagnostic characters of *Dysmicoccus brevipes* (Cockerell): A. Broadly oval body with 17 pairs of cerarii, B. Antenna 7 or 8 segmented, C. One or two discoidal pores present adjacent to each eye, D. Anal lobe cerarii with two conical setae and 6-7 auxiliary setae, E. Dorsal setae on abdominal segment VIII anterior to anal ring, longer than other dorsal setae, F. Multilocular disc pores present around vulva and abdominal segment VI-VII

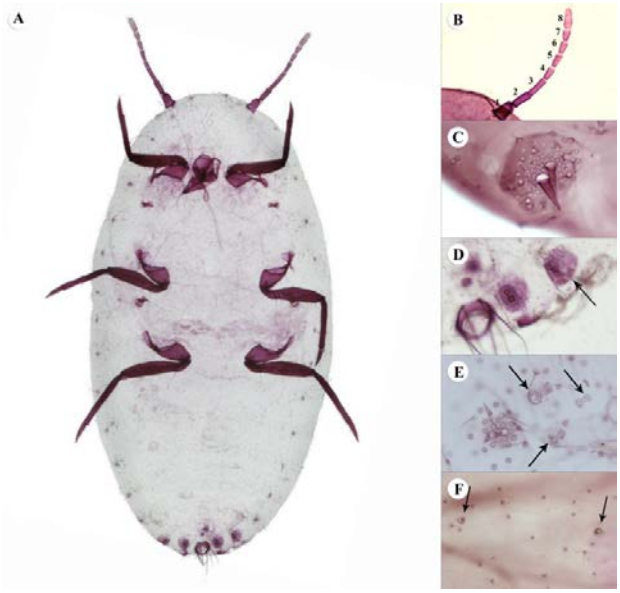

Fig. 5. Diagnostic characters of *Pseudococcus longispinus* (Targioni Tozzetti): A. Body broadly oval and membranous, B. Antenna eight segmented, C. Anal lobe cerarii with two conical setae and 3-4 auxiliary setae, D. Penultimate cerarii as large as anal ring, E. Oral collar tubular ducts of three sizes present, F. Oral rim tubular ducts present adjacent to all cerarii on dorsum

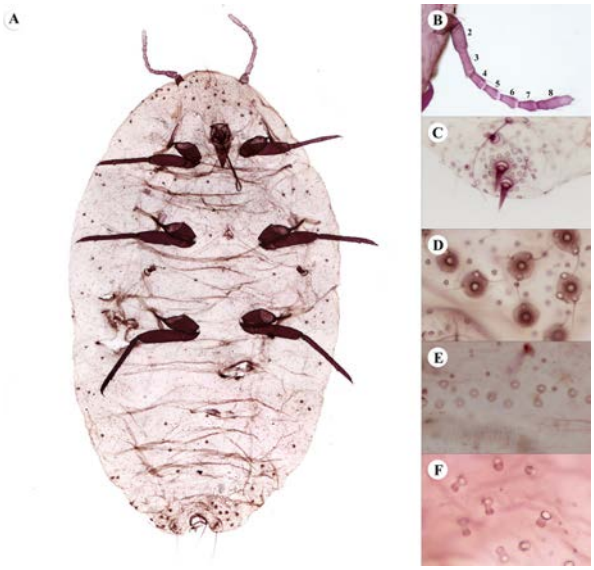

Fig. 4. Diagnostic characters of *Ferrisia virgata* (Cockerell): A. Body elongate oval with tapering abdomen having only one pair of anal lobe cerarii, B. Antenna eight segmented, C. Anal lobe cerarii with two or three conical setae and one or two auxiliary setae, D. Dorsal ducts each with rim larger than multilocular pore, containing setae situated within border of rim, E. Multilocular pores present posterior to vulva and abdominal segment VI and VII, F. Oral collar tubular ducts present across abdominal segment V and on margin on posterior abdominal segments

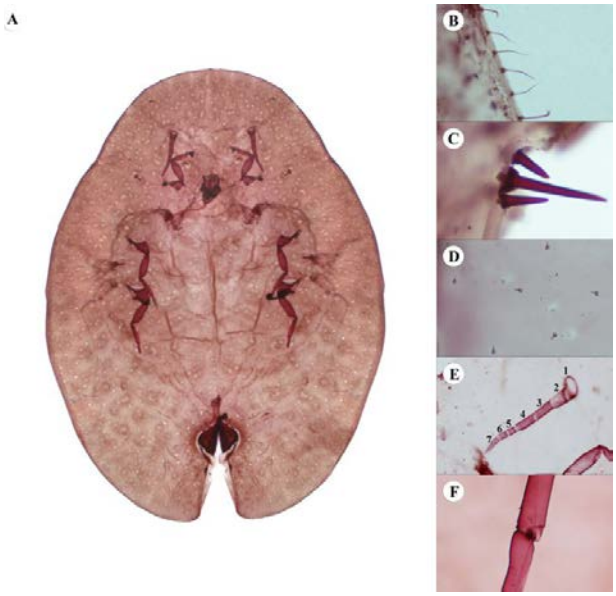

Fig. 6. Diagnostic characters of *Coccus hesperidum* (L.): A. Derm with small dispersed clear areas; B. Marginal setae slightly enlarged, usually weakly fimbriate, occasionally simple; C. Spiracular setae easily differentiated from other marginal setae, middle seta conspicuously longer than lateral setae; D. Dorsal setae enlarged, apically acute or slightly rounded, not capitate; E. Antenna seven segmented; F. Tibio tarsal sclerosis present

Coccidae

1. Stigmatic setae tubular like.....*Ceroplastes* Gray (Fig. 7)
   Stigmatic setae setose.....2
2. Ventral tubular ducts in the form of band on submarginal rea.....*Parasaissetia* Takahashi (Fig. 8)
   Ventral tubular ducts not as above; present on abdomen between the leg.....3
3. Legs and antenna reduced.....
   Prococcus Linnaeus (Fig. 9)
   Legs and antenna well developed.....
   Coccus Linnaeus (Fig. 6, 7)

Diaspididae

1. Body shape oval.....2
   Body elongate.....3
2. Paraphyses frequently present anterior to lobe 3; the paraphyses as long as or longer than lobe; fourth lobe represented by a series of low swellings.....
   Chrysomphalus Asmead (Fig. 11)
   Small paraphyses arising from the bases of the median to third lobe; fourth lobe not in the least developed.....*Aspidiotus* Bouche (Fig. 10)

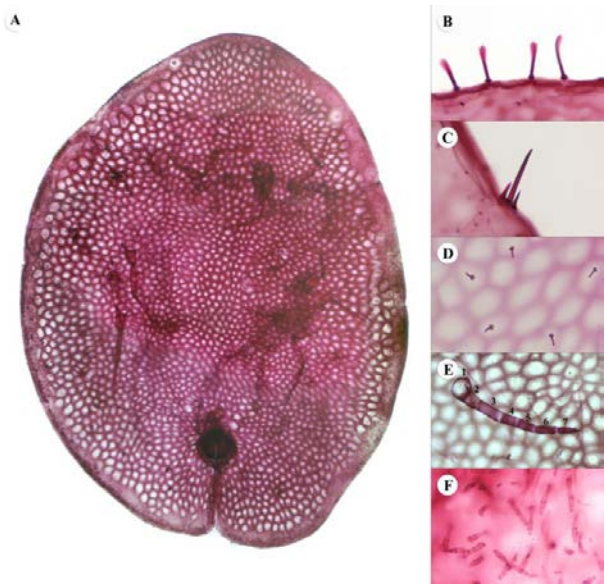

Fig. 8. Diagnostic characters of *Parasaissetia nigra* (Neitner): A. Body oval to almost circular, derm with reticulate pattern on dorsum; B. Marginal setae fimbriate; C. Stigmatic setae differentiated from other marginal setae, middle seta conspicuously longer than lateral setae; D. Dorsal setae often slightly capitate; E. Antenna seven segmented; F. Ventral tubular ducts present in the form of marginal band

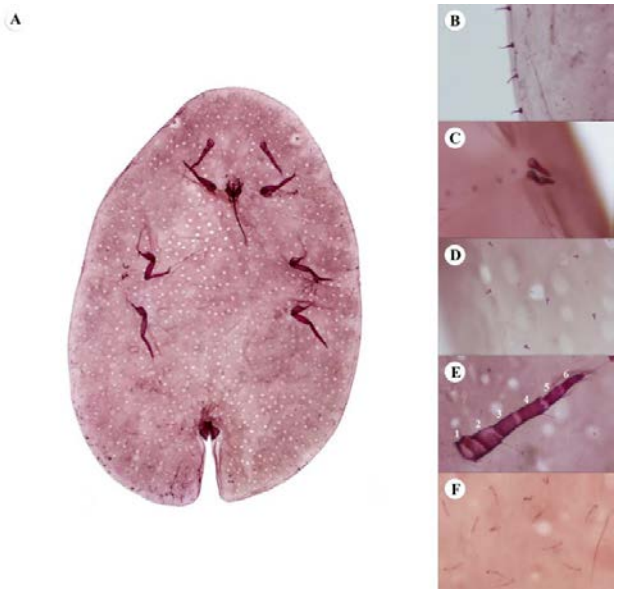

Fig. 7. Diagnostic characters of *Coccus viridis* (Green): A. Derm of older females with scattered clear areas; B. Marginal setae slightly enlarged, strongly fimbriate; C. Stigmatic setae can be differentiated from other marginal setae, middle seta slightly longer than lateral setae; D. Dorsal setae enlarged, apically clavate or rounded; E. Antenna six segmented; F. Ventral tubular ducts present between hind and middle leg

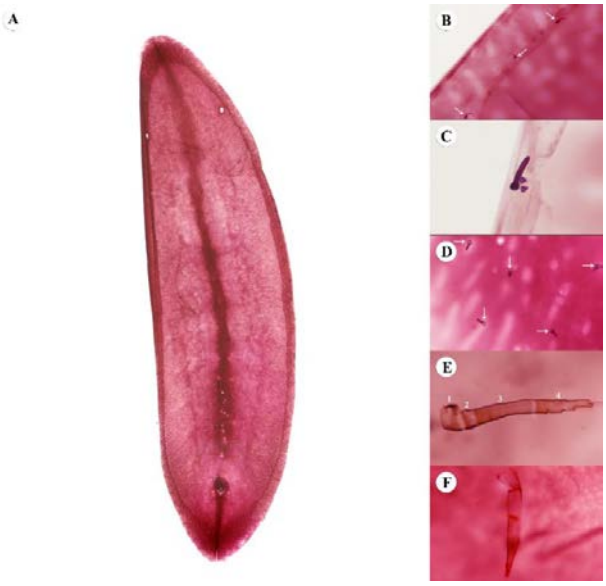

Fig. 9. Diagnostic characters of *Prococcus acutissimus* (Green): A. Body elongate, acutely pointed at both ends; B. Marginal setae short, slender, apices rounded; C. Stigmatic setae differentiated from other marginal setae, middle seta longer than lateral setae; D. Dorsal setae variable, usually spine like, with bluntly pointed to rounded apices; E. Antenna reduced, four segmented; F. Legs reduced, without tibiotarsal sclerosis

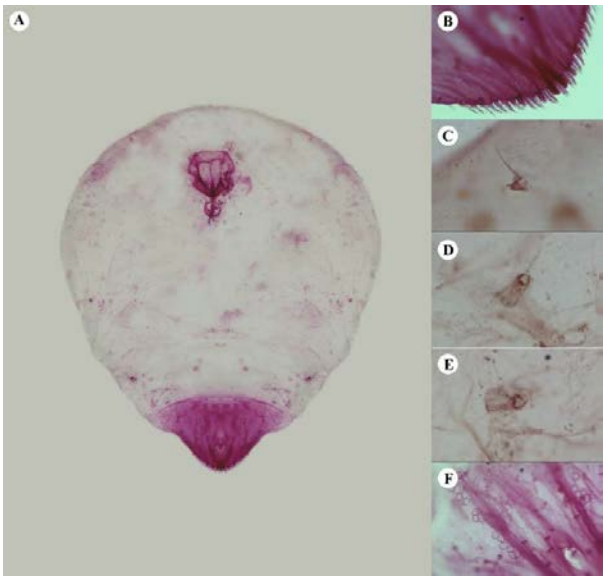

Fig. 10. Diagnostic characters of *Aspidiotus destructor* Signoret: A. Female with well-developed three pairs of lobes, paraphyses could not be seen; B. Pygidial margin showing well developed lobes and fimbriate plates; C. Stub like antenna with single seta; D. Anterior spiracle without spiracular pores; E. Posterior spiracle without spiracular pores; F. Perivulvar pores in four groups with 13-18 pores on each side

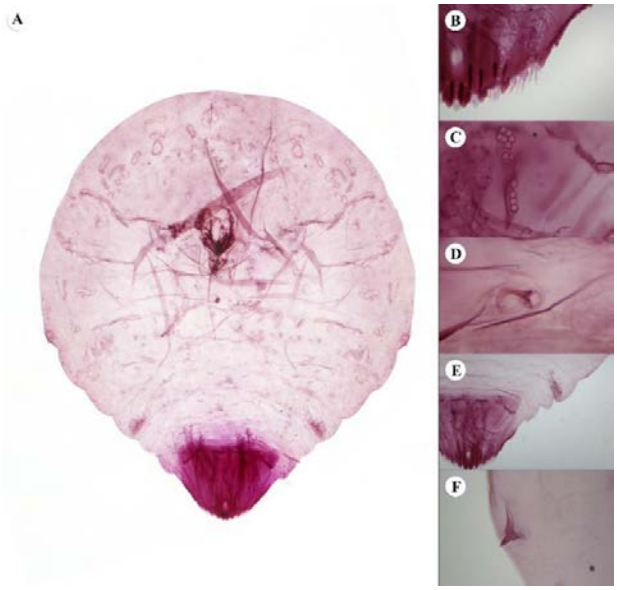

Fig. 11. Diagnostic characters of *Chrysomphalus aonidum* (L.): A. Female with well-developed three pairs of lobes, fourth pair represented by sclerotized points, paraphyses could be seen clearly; B. Pygidial margin showing well developed lobes, paraphyses and fimbriate plates; C. Perivulvar pores in four or five groups with 9-13 pores on each side; D. Spiracle without perispiracular pores; E. Prepygidial macroducts in one cluster on dorsal side of segment 2 composed of 9-27 ducts; F. spine like eye on margin

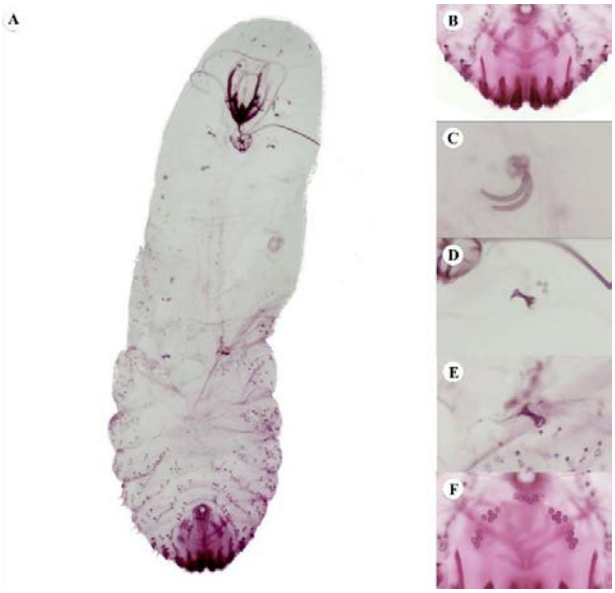

Fig. 12. Diagnostic characters of *Lepidosaphes gloverii* (Packard): A. Female elongate with two pairs of definite lobes; B. Pygidium with well-defined lobes and thin thin paraphyses like sclerotization; C. Antenna with two or four conspicuous curved setae; D. Anterior spiracle with 2-4 perispiracular pores; E. Posterior spiracle without perispiracular pores; F. Perivulvar pores in 4 or 5 indistict groups with 10-15 pores on each side

3. Pygidium with paraphyses, median lobes singly arranged, larger and always present..... *Pseudaulacaspis* MacGillivray (Fig. 14)
   Pygidium with median lobes present in pairs 4

4. Median lobes of pygidium fully or partially merged, median notch absent on pygidium..... *Pinnaspis* Cockerell (Fig. 13)
   Median lobes of pygidium present separately, median notch ..... presentt *Lepidosaphes* Shimer (Fig. 12)

Key to species of *Coccus*

1. Ventral multilocular disc pores restricted up to anal cleft; below anal plates few only present, ventral tubular ducts are absent, marginal setae are small but not fimbriate.....*C. hesperidum* L. (Fig. 6)
   Ventral multilocular disc pores not restricted up to anal plates, ventral tubular ducts present in the central region of thorax, marginal setae short and strongly fimbriate.....*C. viridis* (Green) (Fig. 7)

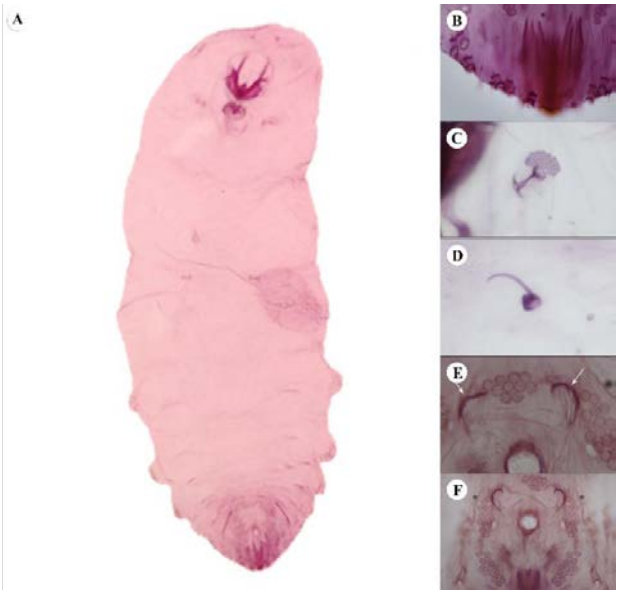

Fig. 13. Diagnostic characters of *Pinnaspis aspidistrae* (Signoret): A. Female elongate with two pairs of definite lobes; B. Pygidium showing six macroducts on each side; C. Anterior spiracle with 7-34 perispiracular pores; D. Antenna with one conspicuous seta; E. Preanal sclerosis represented by light sclerotized patch; F. Perivulvar pores in 5 groups with 29-59 pores

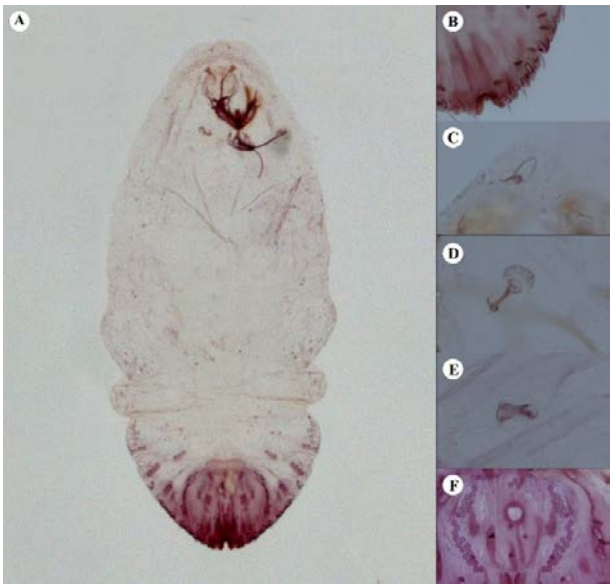

Fig. 14. Diagnostic characters of *Pseudaulacaspis cockerelli* (Cooley): A. Female elongate with two to three pairs of well-developed lobes; B. Pygidium showing five macroducts on each side; C. Antenna with one conspicuous curved seta; D. Anterior spiracle with 7-13 perispiracular pores; E. Posterior spiracle without perispiracular pores; F. Perivulvar pores in 5 groups with 35-47 pores

This study on the species composition of the sternorrhynchan insect pests of arecanut in major arecanut growing districts of Karnataka is a maiden attempt in India. Among the sternorrhynchan pests in arecanut, the most predominant insect pests were scales which includes both soft scales and armoured scales. This was followed by mealybugs and aphid. Among the soft scale species recorded, the most prevalent species was *P. acutissimus* followed by *C.* sp.nr. *rusci C. viridis*, *C. hesperidum* and *P. nigra*. Among the armoured scales, the most prevalent species recorded was *C. aonidum* and the least prevalent species was *P. aspidistrae*. Among the mealybugs, the most dominant species recorded was *P. longispinus* and the least was *D. brevipes*. Only one species of aphids, *C. lataniae* was recorded.

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MOLECULAR CHARACTERIZATION OF WHITEFLY *BEMISIA TABACI* (GENN.) AND DEVELOPMENT OF IPM MODULE AGAINST CHILI LEAF CURL COMPLEX

Ghosal Abhijit*, Das K[1] and Kundu P

Sasya Shyamala Krishi Vigyan Kendra, Ramakrishna Mission Vivekananda Educational and Research Institute, Arapanch, Sonarpur, Kolkata 700150, West Bengal, India
[1]IRDM Faculty Centre, Ramakrishna Mission Vivekananda Educational and Research Institute, Narendrapur, Kolkata 700103, West Bengal, India
*Email: ghosalabhijit87@gmail.com

ABSTRACT

Molecular identification/ characterization of *Bemisia tabaci* (Genn.) collected across five agroecological zones of West Bengal, India revealed that it resembles genetic group Q. Seed treatment with thiamethoxam 70WS 3 g/ kg seed incorporated with seedling treatment with acetamiprid 20SP @ 1g/ l, seedling rising under insect proof net and border netting with insect proof net showed efficacy with reducing the occurrence and dispersal of thrips *Scirtothrips dorsalis* Hood, mite *Polyphagotersonemus latus* and whiteflies *B. tabaci;* while their least incidence was observed with IPM module (integration of seed treatment, seedling treatment, seedling raising under insect proof net, border netting technology, installation of yellow sticky trap and need based spot application of spiromesifen and diafenthiuron), with 92.97, 82.68 and 72.97% reduction, respectively; and 98.56% reduction of chilli leaf curl virus (CLCV) incidence could be obtained through IPM with maximum yield of green chili (1.66 t/ ha). Panchagavya, dasaparni and bhramvastra appeared as potent biopesticides in reducing the CLCV causative agents.

Key words: Chilli, CLCV, IPM, *Scirtothrips dorsalis*, *Polyphagotersonemus latus*, *Bemisia tabaci* Q genetic group, seed/ seedling treatment, insect proof net, norder netting, yellow sticky trap, spiromesifen, diafenthiuron, yield

Among the five domesticated cultivars of chili peppers, *Capsicum annum* is the most popular vegetable or spice native of Peru and Mexico. Chili crop is affected by biotic and abiotic factors of which losses due to insect pests and diseases are serious. It is often infested by a group of sucking and chewing insect pests of which thrips, yellow mites, whiteflies and borers are predominant (Hosmani, 1993). Many viral diseases also infect this crop and induce mild to severe mosaic, yellow mosaic, mosaic mottle, leaf curl, leaf roll, and bushy stunt and necrosis symptoms. Out of which chili leaf curl virus is considered as severe one. The yield losses range from 50-90% due to insect pests of chili (Kumar, 1995). Kandaswamy et al. (1990) estimated 50% yield losses solely due to thrips *Scirtothrips dorsalis* Hood. For the last decade wide spread of whitefly, *Bemisia tabaci* (Genn.), development of its different genetic groups with a high potency of virus transmission (Gemini/ begomovirus) are posing serious threat. In India, Senanayake et al. (2007) reported first time chili leaf curl virus on chili. Recently the crop has been suffering from heavy infestation of leaf curl virus vectored by *B. tabaci*; consequently, CLCV is becoming the major constraint (Senanayake et al., 2007). The genus *Bemisia* contains 37 species and is thought to have originated from Asia (Mound and Halsey 1978).

Bemisia tabaci, being possibly of Indian origin (Fishpool and Burban, 1994), was described under numerous names before its morphological variability was recognized. Originally, three distinct groups of *B. tabaci* were identified by comparing their mitochondrial 16S ribosomal subunits: New World; India/ Sudan; and remaining Old World (Frohlich and Brown, 1994). It has been accepted through mitochondrial cytochrome oxidase 1 (mtCO1) gene comparison that the *B. tabaci* is divided into 11 genetic groups instead of considering as one complex species and the genus *Bemisia* is divided into 34 morphologically indistinguishable species. (Dinsdale et al., 2010; Boykin and De Barro, 2014). The first reported genetic group B known as Middle East-Asia Minor 1 species (MEAM1) evolved in 1980s (Brown et al., 1995b), whereas several other 'genetic groups' (up to S) have now been described (Brown et al., 1995b; Boykin and De Barro, 2014). A distinctive, non-specific esterase banding pattern is also helpful in identification (Brown et al., 1995a) but is not foolproof still can be utilized as basic screening of the genetic

groups (Byrne et al., 1995). It has been found that the Mediterranean species (Q genetic group) coexisted with the MEAM1 and over recent years, exposure to extensive insecticide applications and within areas of intensive agriculture exhibits a high level of resistance (Dennehy et al., 2010). Tejaswini, Bullet and locally selected high yielding varieties like Iret and Sonirag are the main cultivars widely grown in the South 24 parganas district of West Bengal, showing moderate to highly susceptible to CLCV. To mitigate the problem faced by the farmers, who are accustomed to spray the crop on daily basis aggravating the problem day by day, development of an ecology based IPM packages is necessary and hence this study.

MATERIALS AND METHODS

Field experiments were conducted in the Instructional Farm of Sasya Shaymala Krishi Vigyan Kendra situated at Arapanch, Sonarpur, West Bengal, India (22º4 N, 88.2ºE). The experiments were laid in randomized block design (RBD) during pre-kharif of 2017 and 2018 with four treatment modules. These comprises- T_1 (IPM): Seed treatment with thiamethoxam + seedling raised under insect proof net + seedling dipped in acetamiprid + border cover with insect proof net + installation of yellow sticky trap @18/ ha + need based application of spiromesifen at 30 DAT @ 1.25ml/ l and diafenthiuron @ 1.5gm/ l after seven days; T_2 (organic practices): seed bed treatment with *Trichoderma* enriched cow dung+ application of panchagavya (cow dung: cow urine: milk: curd: ghee =5:3:2:2:1, ripe banana and coconut water was mixed to enrich the culture) at 30 DAT @ 5% and seven days after dasaparni spray (fermented product of *Azadirachta indica, Carica papaya, Ficus hispida, Annona reticulata, Psidium guajava, Datura* sp., *Calotropis* sp. and *Clerodendrum viscosum* leaves each 1 kg, mixed with 2 kg cow dung and cow urine; incubated for 30 days) @ 100ml/ l; T_3 (chemical management): rotational spray of flonicamid at 30 DAT @ 0.4g/ l and spiromesifen @1.25ml/ l after seven days; T_4 (integration of inorganic and organic amendments): seedling treatment with thiamethoxam+ application of bhramvastra (paste of one kg each leaves of *A. indica, Datura* sp., *Calotropis* sp., *A. reticulata, P. guajava*: cow urine: cow dung: chili paste: allium paste: 10:5:0.25:0.25) at 30 DAT @ 25ml/ l and need based spot application of diafenthiuron after seven days @1.5g/ l along with untreated check. Each treatment was replicated four times and randomized, with crop raised with recommended package of practices in 3x 3 m^2 plots at a spacing of 50x 50 cm.

Counts of *S. dorsalis, P. latus, B. tabaci* were done from three randomly selected leaves (upper, middle and lower)/ plant from five randomly selected plants/ plot before and after spray (very next day, third day and seventh day after spray). Observation was taken during early morning hours. Thrips incidence was counted using hand lens (10x); whitefly by eye observation whereas, mite was enumerated with a microscope (Magnus stereozoom); and % disease incidence of chili leaf curl virus was enumerated 3 and 7 days after spraying. The collected data on incidence were subjected to ANOVA after square root transformation, whereas in case of CLCV, % incidence was subjected to angular transformation. The treatment means were compared following the design of RBD (p=0.05) (Gomez and Gomez, 1984). Corrected efficacy % was calculated using Abbott's formula as on before spraying data (Abbott, 1925) and the post treatment data was corrected using Henderson-Tilton's formula (Henderson and Tilton, 1955). The data were subjected to analysis using IBM SPSS statistics 21.

Adult *B. tabaci* samples were collected from five agroclimatic zones of West Bengal (Kalimpong, Nadia, Guskara, Danga, Narendrapur, Sonarpur, Baruipur, Diamond Harbour, Kakdwip, Namkhana, Patharpratima) in 70% ethanol and carried in ice bucket. The locations selected covered costal saline ecosystem. The samples after morphological analysis were stored at -20ºC (Blue Star). Screening of the collected sample was done using microsatellite site "Bem 23 analysis: "Bem-23 F" (5'CGGAGC TTGCGCC TTA GTC) and "Bem-23-R" (5'CGGCT TTATCA TAGCTCT CGT) illustrated by Bel-Kadhi et al. (2008); 5g of chilli sample was taken in a 50 ml centrifuge tube and 10 ml (ethyl acetate: cyclohexane) mixture was added and subjected to vortex for 2 min. After that adding 5 gm of activated Na_2SO_4, the sample was again vortexed for 3 min. Then the sample was centrifuged for 15 min at 10,000 rpm and then 5 ml supernatant liquid was taken in 10 ml centrifuge tube. Afterwards 25 mg each of florisil and PSA was added to it and vortexed for 2 min and the sample was again centrifuged for 10 min at 5000 rpm. Then 3 ml supernatant liquid was collected from it and evaporated to dryness in N_2 evaporator at 25°C. The residue was then reconstituted in 3 ml of ethyl acetate. The sample was then filtered through 0.2µ membrane filter and taken for final analysis in GC/MS [Varian (Walnut Creek, CA) Saturn 2200 mass spectrometer coupled to a Model 3800 gas chromatograph. The mass spectrometer was used single ion scan (SIS) mode with electron impact (EI) ionization].

Table 1. Efficacy of IPM modules *S. dorsalis*

Treatments	Mean incidence/ 3 leaves							Mean	% reduction over control	Mean reduction (%) after spraying							Mean
	Before spray	After first spray			After second spray					Before spray	After I spray			After II spray			
		1 Day	3 Days	7 Days	1 Day	3 Days	7 Days				1 Day	3 Days	7 Days	1 Day	3 Days	7 Days	
T_1	5.33	2.75	2.33	1.33	0.67	0.33	0.67	1.92	92.97	76.57	48.68	57.59	79.23	49.25	78.59	61.4	64.47
	(2.31)	(1.66)	(1.53)	(1.15)	(0.82)	(0.57)	(0.82)										
T_2	19.50	12.67	9.05	11.67	9.87	7.67	6.67	11.01	59.61	14.29	35.37	54.98	50.18	14.8	43.28	56.21	38.44
	(4.42)	(3.56)	(3.01)	(3.42)	(3.14)	(2.77)	(2.58)										
T_3	21.75	8.33	4.67	5.05	2.33	0.67	0.33	6.16	77.40	4.4	61.9	79.17	80.67	53.52	88.55	94.99	66.17
	(4.66)	(2.89)	(2.16)	(2.25)	(1.53)	(0.82)	(0.57)										
T_4	8.25	7.66	3.09	6.98	4.67	5.25	6.67	6.08	77.70	63.74	7.64	63.66	29.57	32.6	35.09	26.78	37.01
	(2.87)	(2.77)	(1.76)	(2.64)	(2.16)	(2.29)	(2.58)										
T_5	22.75	22.87	23.45	27.33	27.13	31.67	35.67	27.27									
	(4.77)	(4.78)	(4.84)	(5.23)	(5.21)	(5.63)	(5.97)		-								
SEm (±)	0.51	0.48	0.29	0.34	0.27	0.19	0.33	-	-								
CD (0.5)	1.62	1.46	0.89	1.12	0.81	0.62	1.07	-	-								

*Figure in parentheses square root transformed value

Table 2. Efficacy of IPM modules on *B. tabaci*

Treatments	Mean incidence/ 3 leaves							Mean	% reduction over control	Mean reduction (%) after spray							Mean
	Before spray	After first spray			After second spray					Before spray	After I spray			After II spray			
		1 Day	3 Days	7 Days	1 Day	3 Days	7 Days				1 Day	3 Days	7 Days	1 Day	3 Days	7 Days	
T_1	2.33	1.33	1.67	1.33	0.33	0.67	0.33	1.14	92.82	78.76	41.31	36.85	60.04	79.78	60.27	82.68	62.81
	(1.53)	(1.15)	(1.29)	(1.15)	(0.57)	(0.82)	(0.57)										
T_2	12.67	9.33	6.87	7.33	3.67	3.87	4.33	6.87	56.81	+15.50	24.29	52.22	59.50	59.20	58.36	58.77	42.41
	(3.56)	(3.05)	(2.62)	(2.71)	(1.92)	(1.97)	(2.08)										
T_3	11.88	5.57	1.87	2.00	1.97	0.87	1.07	3.60	77.33	+8.30	51.80	86.13	88.21	19.74	62.27	62.66	51.79
	(3.45)	(2.36)	(1.37)	(1.41)	(1.40)	(0.93)	(1.03)										
T_4	6.01	2.43	2.33	4.87	3.88	2.33	1.87	3.39	78.69	45.21	58.43	65.84	43.27	35.08	62.27	73.20	54.76
	(2.45)	(1.56)	(1.53)	(2.21)	(1.97)	(1.53)	(1.37)										
T_5	10.97	10.67	12.45	15.67	19.23	19.87	22.45	-	-								
	(3.31)	(3.27)	(3.53)	(3.96)	(4.39)	(4.46)	(4.74)										
SEm(±)	0.67	0.44	0.33	0.38	0.29	0.21	0.19	-	-								
CD (0.5)	2.03	1.33	1.07	1.19	0.91	0.70	0.49	-	-								

*Figure in parenthesessquare root transformed value; + denotes more insects than control

Table 3. Efficacy of IPM modules on *P. latus*

Treatments	Mean incidence/ 3 leaves							Mean	% reduction over control	Mean reduction (%) after spray							Mean
	Before spray	After first spray			After second spray					Before spray	After I spray			After II spray			
		1 Day	3 Days	7 Days	1 Day	3 Days	7 Days				1 Day	3 Days	7 Days	1 Day	3 Days	7 Days	
T_1	6.45 (2.54)	3.33 (1.82)	2.67 (1.63)	1.33 (1.15)	0.33 (0.57)	0.67 (0.82)	1.30 (1.14)	2.30	72.97	45.66	48.93	63.14	84.38	75.84	52.87	20.64	55.92
T_2	13.27 (3.64)	8.25 (2.87)	6.33 (2.52)	5.44 (2.33)	2.33 (1.53)	2.87 (1.69)	3.90 (1.97)	6.06	28.76	+11.79	38.50	57.52	68.95	58.29	50.64	41.79	43.41
T_3	12.67 (3.56)	11.33 (3.37)	12.00 (3.46)	12.33 (3.51)	1.67 (1.29)	0.67 (0.82)	1.33 (1.15)	7.43	12.61	+6.74	11.54	15.66	26.28	86.81	94.92	91.24	45.67
T_4	12.33 (3.51)	7.67 (2.77)	6.00 2.45	5.87 2.42	2.67 1.63	3.33 (1.82)	3.67 (1.92)	5.93	30.18	+3.88	38.47	56.67	63.94	55.70	46.93	49.24	43.87
T_5	11.87 (3.93)	12.00 (3.42)	13.33 (3.27)	15.67 (3.37)	16.09 (1.83	16.75 (1.82)	19.30 (1.92)	15.00	-								
SEm(±)	0.99	0.22	0.34	0.37	0.22	0.31	0.42	-	-								
CD (0.5)	NS	0.69	1.08	1.20	0.73	0.97	1.29	-	-								

*Figure in parentheses square root transformed value; *'+' denotes insects more than control

Table 4. Efficacy of IPM modules on chili leaf curl virus incidence and yield

Treatments	CLCV disease incidence (%)					Mean	% overall Reduction over control	Disease reduction/ increase (%) after spray				Mean	% disease reduction over untreated check				Mean	Yield (t/ ha)	Increased yield over control (%)
	Before spray	After first spray		After second spray				After I spray		After II spray			After I spray		After II spray				
		3 Days	7 Days	3 Days	7 Days			3 Days	7 Days	3 Days	7 Days		3 Days	7 Days	3 Days	7 Days			
T_1	0.00	0.00	0.00	0.00	2.33 (8.72)	0.47	98.56	-	-	-	2.33	0.58	100.00	100.00	100.00	95.63	98.91	1.66	71.13
T_2	18.67 (25.55)	19.33 (26.06)	23.42 (28.93)	23.42 (28.93)	25.25 (30.13)	22.02	31.74	3.54	25.44	0.00	7.81	9.20	13.90	28.31	40.45	52.65	33.83	1.19	22.68
T_3	9.45 (17.85)	14.87 (22.63)	16.33 (23.81)	17.50 (24.73)	18.00 (25.1)	15.23	52.78	57.35	72.80	7.16	2.86	35.05	33.76	50.02	55.50	66.25	51.38	1.38	42.26
T_4	10.33 (18.72)	13.33 (21.39)	14.45 (22.30)	15.90 (23.50)	17.20 (24.50)	14.24	55.85	29.04	39.88	10.03	8.18	21.78	40.62	55.77	59.57	67.75	55.93	1.49	53.60
T_5	13.50 (21.56)	22.45 (28.25)	32.67 (34.82)	39.33 (38..82)	53.33 (46.89)	32.26	-	66.30	142.00	20.39	35.60	66.07						0.97	-
SEm(±)	1.02	0.90	1.16	1.09	1.59	-	-												
CD (0.5)	3.21	2.81	3.42	3.33	4.92														

*Figure in parentheses angular transformed value

RESULTS AND DISCUSSION

The effect of IPM treatment modules on *S. dorsalis*, *P. latus* and *B. tabaci* and CLCV incidence show that seed treatment with thiamethoxam 70WS @ 3 g/ kg seed incorporated with seedling treatment with acetamiprid 20SP @ 1g/ l and seedling raising under insect proof net showed significant superiority. Border netting with insect proof net has showed significant impact in reducing their dispersal. Against thrips *S. dorsalis*, before spray incidence showed significant variation (5.33 to 22.75/ 3 leaves, and the least incidence was in IPM (5.33/ 3 leaves), which may be correlated with the effect of seed treatment, seedling treatment and raising seedling under insect proof net; overall mean was observed to be the least from IPM plots (T_1) (1.92/ 3 leaves) with 92.97% reduction over control. This is closely followed by integration of inorganic and organic amendments (T_4) (77.70% reduction), chemical management (T_3) (77.40% reduction) and organic practices (T_2) (59.61% reduction) (Table 1). As regards *B. tabaci*, all the treatments showed efficacy; on seven days after first spray IPM treated plot showed the least incidence (1.33/ 3 leaves) with 60.04% reduction; seven days after second spray showed that need based spot application of insecticides was effective (0.33/ 3 leaves- 82.68% reduction) in T_1; overall only 1.14 whiteflies/ 3 leaves was observed from IPM. (Table 2). With *P. latus* significant decrease in incidence was observed with treatments- one day after first application least incidence was observed with T_1 (3.33/ 3 leaves), and 7 days after first spray 84.38% reduction was observed; likewise second spray with T_1 (0.33/ 3 leaves- 75.84% reduction) was the best, and overall it led to 72.97% reduction of mite population over control in respect of mean population was recorded by T_1 reduction (Table 3). The CLCV incidence was nil in the IPM plot initially, but with 18.67% in T_2 followed by control plot (13.5%).

Border netting technology with insect proof net prevents the dispersal of whiteflies, whereas installation of yellow sticky trap within the netted plot allows attracting those whiteflies entered somehow within the netted plot as reflected in the present data; 98.56% reduction of CLCV over control was recorded in T_1 followed by T_4 (55.85%), T_3 (52.78%) and T_2 (31.74%), as against 66.07% in control; only 0.58% incidence was observed in T_1. Maximum yield of green chili (1.66 t/ ha) with 71.13% increase was obtained with T_1 followed by T_4 (1.49 q/ ha), T_3 (1.38 t/ ha) and T_2 (1.19 t/ ha) (Table 4). Thus, IPM treatment comprising of seed treatment with thiamethoxam 70WS 3 g/ kg seed, seedling treatment with acetamiprid 20SP @ 1g/ l, seedling raising under insect proof net, installation of yellow sticky trap and need based spot application of spiromesifen 240SC and diafenthiuron 50WP was observed to be the best in managing the CLCV and its causative agents. The pesticides used were observed for their residues and results revealed only small or moderate amounts (below the instrumental LOQ range) (Fig. 1).

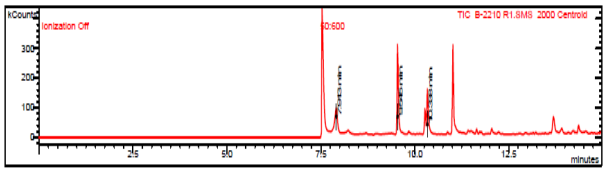

Fig. 1. Residue analysis performed by GC/ MS

Neonicotinoids as seed treatment are effective against sap feeders as observed in this study. Agreeing with the results of Kannan et al. (2004); imidacloprid @ 5 g/ kg of seeds was more effective against *B. tabaci* up to 40 days after sowing. Thiamethoxam exhibits systemic action and provides excellent control of sap feeders (Maienfisch et al., 2001). Spiromesifen is a potent insecticide/ acaricide in cotton and tomato (Ghosal and Chatterjee, 2018). The present results on acetamiprid and spiromesifen against CLCV causative agents agrees with those of Kontsedalov et al. (2009) on thrips; and spiromesifen was found safe to predatory mites, coccinellid beetles, spiders (Varghese and Mathew, 2013). Diafenthiuron was found to be efficient against chili thrips and whiteflies. Ishaaya et al. (1993) observed that diafenthiuron was effective against B. tabaci, on cotton. Vanisree et al. (2017) Chakrabarti and Sarkar (2014) and Dennehy et al. (2010) also revealed similar results. Fig. 2 shows the isolated DNA of samples collected from eleven locations of West Bengal resulted the same banding patterns of 410 bp using Bem 23 primer pairs. These observations corroborate with those of Bel-Kahdi et al. (2008) and Mukherjee et al. (2016) that bands produced at 410 bp

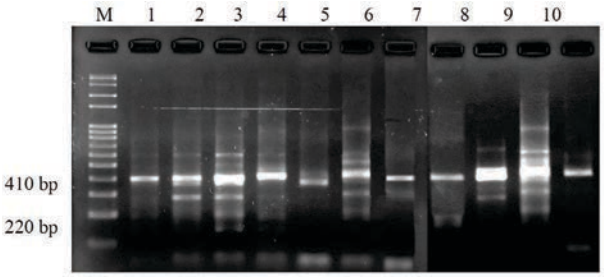

Fig. 2. Gel electrophoresis of RAPD: RAPD profile of 1= Baruipur2; 2= Narendrapur6; 3= Namkhana6; 4= Patharpratima7; 5= Kakdwip5; 6= Diamond Harbour4; 7= Arapanch2; 8= Guskara2; 9= Kalimpong1; 10= Nadia3; 11= Danga9 in respect of M= 100bp plus DNA marker

is characteristic of the genetic group Q, and 41 distinct populations including 24 genetic groups are known (Perring, 2001). Previously, it has been reported that RAPD primers (Bem-23 microsatellite marker) such as Bem 23F and Bem 23R, can easily differentiate the two genetic groups B and Q of *B. tabaci* (McKenzie et al., 2009). Genetic variability in *B. tabaci* has been studied using mtCOI and ITS1 marker genes (Boykin et al., 2007; Dinsdale et al., 2010).

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SOME DETAILS ON THE BIOLOGY OF LEAF BEETLE *SASTROIDES BESUCHETI* MEDVEDEV OCCURRING ON WILD NUTMEG

Gavas Ragesh*, Tom Cherian[1], Nagaraju D K[1], Milu Mathew[1] and Pushpalatha P B

*ICAR-AICRP on Fruits, Banana Research Station, Kerala Agricultural University, Kannara (P.O), Thrissur 680652, Kerala, India
[1]Directorate of Plant Protection, Quarantine and Storage, Block A, First Floor, Kendriya Bhavan, Kakkanad, Kochi 682037, Kerala, India
*Email: gavas.ragesh@kau.in (corresponding author)

ABSTRACT

This study provides some preliminary details on the biology of the leaf beetle *Sastroides besucheti* Medvedev (Coleoptera: Chrysomelidae: Galerucinae) occurring on wild nutmeg *Myristica malabarica* Lam. with damage symptoms. Banana (cv. Jnalipoovan) as a host observed now for the adults is also explained.

Key words: Chrysomelidae, leaf beetle, new record, outbreak, *Sastroides besucheti*, wild nutmeg, *Myristica malabarica*, banana, *Myristica fragrans*, Idukki district, biology

Genus *Myristica* belonging to the primitive family Myristicaceae (Order: Magnoliales) is a pantropical tree group that includes 172 species (Plants of the World Online, 2021). Among the *Myristica* spp., *Myristica fragrans* Houtt and *M. malabarica* Lam. are commercially important; the former as an introduced crop exploited fully for its commercial products viz., nutmeg and mace (Thangaselvabai et al., 2011), *Myristica malabarica* is an economically important native tree spice endemic to Southern Western Ghats from Konkan southward (Jose and Chandrasekhara Pillai, 2016), and famous for its large yellow arils.

Commonly known as Malabar nutmeg, rampatri, Bombay mace or kaatuhjathi (Chelladurai and Ramalingam, 2017), *M. malabarica* is one of the characteristic species in Myristica swamps, and its fruits are extensively exploited for its aril locally (Jose and Chandrasekhara Pillai, 2016). It is a large perennial tree (15-25 m tall) found in evergreen forests up to 800 m in the swamp and lowland forest habitats in the Western Ghats (Chelladurai and Ramalingam, 2017), most frequently in evergreen and semi-evergreen forests (Nagaraju et al., 2013). This tree has large greyish black trunks, with flowering and fruiting season being from February through August (Chelladurai and Ramalingam, 2017). This tree is economically important for its wild nutmeg and mace, used for both medicinal and industrial purposes. It is also used as a hardy rootstock for grafting the commercial nutmeg i.e *M. fragrans* (Mathew and Joseph, 1982). It is traditionally used for its anti-ulcer, sedatives hypnotics, antimicrobial, nematicidal and anti-inflammatory properties (Chelladurai and Ramalingam, 2017).

There are scant reports on pests of *M. malabarica.* But 19 species of insects are known to infest its congener *M. fragrans* in Asia and the Pacific (Reddy, 1977). Of these, nine insect species have been recorded as pests in India, most of which are bugs (Prathapan and Balan, 2016). Prathapan and Balan (2016) reported *Sastroides besucheti* Medvedev as a pest of *M. fragrans* from Idukki district of Kerala. It was observed that the eggs are laid in the soil and the larva is a soil dweller that feeds on the roots, as being common with members of Galerucinae. Not much work has been done on this sporadic pest of *Myristica* other than its description based on 15 specimens collected (on 4th November, 1972) at Periyar in Idukki District, India, by Medvedev (1999) and its record as a pest of *M. fragrans* (Prathapan and Balan, 2016).

The present study was carried out in the Idukki district to explore the outbreaks of gregarious beetles on wild nutmeg and banana, based on the information shared by the local Agriculture Department. The dearth of information on the pests of wild *Myristica* spp. along with the inclusion of wild nutmeg *M. malabarica* in the IUCN Red List (IUCN, 2000), and the occurrence of the adult beetle on banana, led to urgent surveys. The observations made during these surveys and the occurrence of *S. besucheti* are explained herein along with preliminary observations on its biology.

MATERIALS AND METHODS

During June-July 2021, outbreaks of leaf beetles were observed infesting wild nutmeg and banana in Kamakshy (9.82°N, 77.0274°E) and on wild nutmeg in Chinnakanal (10.04°N, 77.18°E) Panchayats of Idukki District, Kerala. Repeated surveys were carried out and infested areas were scouted to evaluate the infestation, nature of damage, feeding preference, oviposition, eggs and other lifestages focused on *S. besucheti*. Observations on the habitus were made with a Canon EOS 700D camera with a 100 mm macrolens or with OPPO mobile camera with the macrolens option enabled.

Under laboratory conditions, its biology was observed. Fresh twigs of wild nutmeg from the field on which egg masses, grubs and adults found were collected. These were placed in large containers lined with thick layer of moist filter paper at the bottom to maintain humidity and freshness of the leaves. To ensure freshness, the cut end of twigs were wrapped with moist cotton. Adult beetles which were flying around the wild nutmeg branches were collected, using insect net, transferred into large containers lined with moist filter paper, tagged and brought to the Entomology laboratory, Banana Research Station, Kannara, Thrissur, Kerala. A portion of these specimens were preserved in 70% ethanol as voucher specimens.

Egg masses found under the leaves were kept along with the leaf portion in transparent, circular, insect breeding dishes with net on top (90x 40 mm) and lined with thick layer of moist filter paper to record the egg period. Only freshly laid egg masses, confirmed by the greenness of scrapped foliage from the areas near the oviposition sites, which were covered by female beetles were used. For rearing grubs and adults, transparent plastic containers of 25 x 23 and 40 x 22 cm size were used, respectively, which were again lined with moist filter paper. For the final instar grubs, soil was provided to facilitate pupation. To ensure supply of fresh leaves, wild nutmeg seedlings were procured and maintained. Different lifestages of the beetle collected were also reared in insect cages provided with wild nutmeg plants as food. The containers and cages were maintained at 25$\pm$ 2^{0}C and 70-80% RH. The various lifestages were observed in samples of ca. 20 adults, 10 egg masses, and 20 grubs and pupae each.

RESULTS AND DISCUSSION

The leaf beetles collected from the field were identified as *Sastroides besucheti* Medvedev (Coleoptera: Chrysomelidae: Galerucinae). Adult beetles measured 7-9 mm long, with pale yellow body and bluish black eyes. The antenna consisted of eleven antennomeres with apical ones slightly dark and elytra clothed with short, golden setaes. Females were slightly larger than males (Fig. 1).

A total of 34 wild nutmeg trees (32 no. in a 15 acre farmers' plot and 2 no. in nearby 8 acres farmers' plot) of 30 years old were found affected by *S. besucheti* in Kamakshy Panchayat; whereas around 8 trees were affected in Chinnakanal Panchayat. These plots were mixed plantations of wild nutmeg, nutmeg, jackfruit, mango, garcinia, clove, cardamom, black pepper etc. along with some other large trees retained for shade. Large number of adult beetles were found to feed on wild nutmeg (*M. malabarica*) causing severe damage to foliage. They were found in groups of 7-18/ leaf and fed on both sides by scrapping the green matter, especially the abaxial side, leaving distinctive scars (Fig. 2). These scars initially gave a burning appearance to the foliage (Fig. 3), which later dried off and fell to the ground near the trees. Heavy feeding by the adults also lead to total drying up of young branches and trees appeared dried up (Fig. 4). During the initial surveys, with examination of the affected foliage, the presence of eggs and grubs were confirmed, but no pupae was observed. Adults when disturbed flew around the branches and after a few minutes settled down. Vegetation other than wild nutmeg in farmers' plantations were observed for feeding. Only on the leaves of banana (cv. Jnalipoovan), few beetles (3-5) were found feeding. These plants were around 4 m away from the base of a very large wild nutmeg tree which harboured maximum number of beetles. These adults were observed scrapping banana leaves leaving white window pane patches (Fig. 5). These banana plants (12 no.) when searched for the presence of grubs did not yield any.

Large numbers of mating pairs of the beetle were often observed in the field (Fig. 6). Females sometimes resort to feeding while mating. Eggs are laid in masses on the abaxial surface near the midrib of leaves. In *M. malabarica*, these egg masses were covered with the green matter scrapped from the leaf as could be seen near the oviposition sites (Fig. 7). Egg masses consisted of 18-23 eggs. Eggs were oval, yellowish orange and measured 1 mm. Few females were seen laying eggs singly on banana leaves and covering it with excreta (Fig. 8).

First instar grubs were gregarious, 1-2 mm long, with yellowish body, serrated body margins and sparse hairs

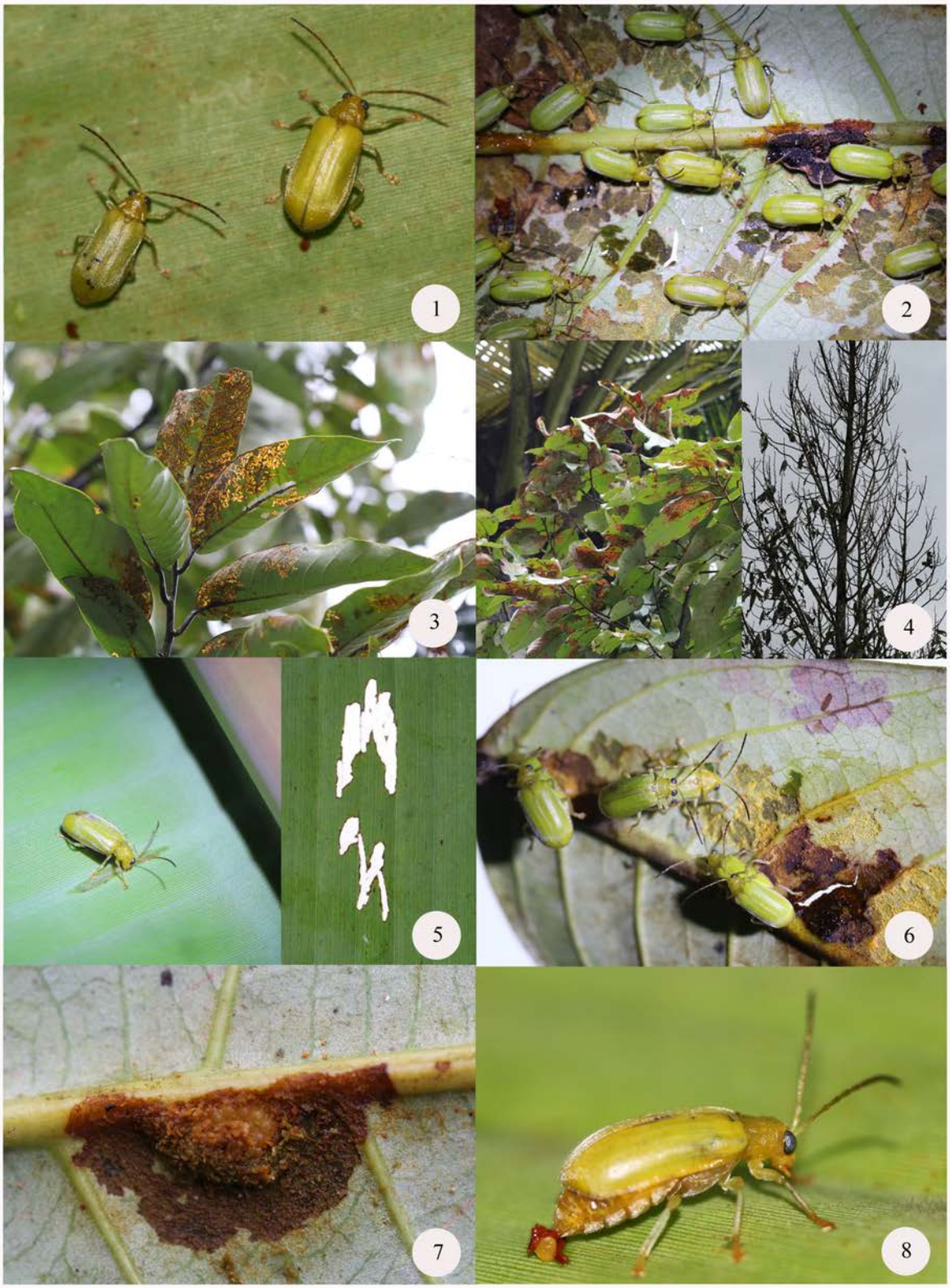

Fig. 1-8. *Sastroides besucheti*: 1. A pair of adults; 2. adults on wild nutmeg; 3-4. Damage symptoms on wild nutmeg; 5. on banana; 6. mating pairs; 7. eggs mass on abaxial side of leaf; 8. Egg laying in banana.

Fig. 9-16. *Sastroides besucheti* larvae, pupae, newely emerged adults: 9. First instar; 10. Final instar on wild nutmeg; 11. Excretal threads produced by grubs; 12. Characteristic zigzag feeding patterns; 13. Tunnelling in soil by the last instar; 14. Pupation chamber and pupae; 15. Adult emergence; 16. Newly emerged adult.

distributed all over (Fig. 9). The grubs feed voraciously and scrap the leaf surface. Final instar grubs are >1 cm long and are dark greenish yellow (Fig. 10). Grub stages have plump body with wrinkles and black head capsule. These grubs have only thoraxic legs, with a sticky peg like structure in the last abdominal segment. The grubs produced copious amount of excreta while feeding, which were retained as long strings (Fig. 11); these are many times as long as the grub, perhaps as a defence mechanism. The feeding grubs made characteristic zigzag patterns on the leaves (Fig. 12). Presence of all lifestages (except pupae), including 1st and final instar grubs simultaneously points to the likelyhood of overlapping generations. It was observed that ready to pupate final instar grubs migrated to the base of the trees. Also, some grubs were noticed to fall to the ground to reach the soil under the tree canopy for pupation. The grubs excavated 1-3 cm top soil under the host tree canopy in the field to enter pupal stage in an earth chamber or under a fallen leaf and turned into an exarate pupa. At the end of the pupal period, translucent yellow adults emerged out, which became active after sometime.

Life history of *S. besucheti* on wild nutmeg (*M. malabarica*) was observed with 20 adults, 10 egg masses, and 20 grubs and pupae each in the laboratory (25± 2^{0}C and 70-80% RH). Some details observed are based on the reared individuals (Fig.13-16). Adult longevity lasts 13.8± 0.58 (7-16) days; egg stage for 6.8± 0.23 (6-9) days on moistened leaves; larval stage lasts for 18.1± 0.37 (16-21) days and there were four instars; pupal stage lasted for 7.6± 0.4 (6-11) days.

Association of beetles, especially chrysomelids with *Myristicaceae* is mostly known as assisting pollination referred to as cantharophily (Armstrong and Irvine, 1989; Bernhardt, 2000). There are very few records among Myristicaceae (e.g., genera *Virola* and *Knema*) as host plants of leaf beetles. *Sceloenopla lutena* Staines and *S. nigropicta* Staines (Cassidinae: Hispini) (Staines, 2011) and *Laselva triplehorni* Furth (Galerucinae: Alticini) (Furth, 2007) are known with *Virola koschnyi* as their host plant. *Notosacantha calligera* Spaeth (Cassidinae: Cassidini) is observed with *Knema* sp. as its host (Borowiec et al., 2013).

The genus *Sastroides* was described by Jacoby (1884) from Sumatra with *Sastroides bimaculata* Jacoby as its type species. Records of *Sastroides* from India and neighbouring countries include: *Sastroides nigriceps* Kimoto (North India), *Sastroides parvula* Jacoby (Myanmar)-Kimoto, 2004; *Sastroides dohertyi* (Sri Lanka, Myanmar); *Sastroides rugicollis* Kimoto (Sri Lanka)-Kimoto, 2003; and *Sastroides besucheti* Medvedev (Kerala, India)-Medvedev, 1999.

Sastroides besucheti seems to prefer *Myristica* sp. (Myristicaceae) as food plant as evident from the present study. Earlier record only shows *M. fragrans* as its adult host. The present study documents *M. malabarica*, as its larval and adult food. This study also describes its outbreak after a gap of five years in the Idukki district with *M. malabarica* as its most preferred host for both grubs and adults. Banana (*Musa* spp.) as a probable alternate host at least in the adult stage has also been brought out. The biology evaluated under laboratory conditions confirm that eggs are laid on leaves, larval stages are spent on the foliage, and pupation takes place in soil. These results are significant, considering the economic importance of *M. malabarica* and its threatened status.

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AVIFAUNAL DIVERSITY IN WHEAT CROP: A CASE STUDY OF BATHINDA DISTRICT OF PUNJAB

Navjot Kaur* and H K Sidhu

Department of Zoology, Desh Bhagat University, Mandi Gobindgarh 147301, Punjab, India
*Email: navjotsandhu.pau@gmail.com (corresponding author)

ABSTRACT

Ornithological studies confirmed that 83 species belonging to 16 orders were present in and around the wheat fields from preparatory tillage to ripening stage at village Ruldu Singh Wala, Katar Singh Wala and Bir Talab. The diversity analyses revealed a richness index of 77, 58 and 55, respectively. Rose-ringed parakeet was the most abundant at all the locations (10.53, 25.51 and 21.30%, respectively) followed by blue rock pigeon (7.57, 14.19 and 10.80). Passeriformes (46.99%) was the most dominant order followed by Cicioniiformes (12.05%) and Charadriiformes (8.43%). Insectivorous guild (39 species, 46.99%) was the dominating guild followed by omnivorous (19 species, 22.89%) and carnivorous guild (12 species, 14.46%). Species number increased from early (preparatory tillage and sowing) to late (seedling and ripening) stages. Thus, it is observed that wheat crop acts a major habitat for birds.

Key words: Agriculture, wheat, avifauna, diversity, abundance, dominance, guild, insects, seedling, ripening, rose ringed parakeet, pigeon, Passeriformes

Agroecosystems are managed by humans in terms of species composition. In Punjab, agricultural habitat determines the presence of various faunal groups namely insect, reptile, bird and mammal. Agroecosystems provide food to the birds and birds bring about seed dispersal, cross pollination and pest control (Dhindsa and Saini, 1994). Wheat is an important and prominent crop in Punjab. Insect and rodent pests damage the crop at various stages and farmers use various pesticides to control the pests. These chemicals have adverse effects on human health and have resulted in weakened immune system, endocrine disruption and even death of birds. This calls for an alternate measure for pest control. Various species of birds are natural enemies of these pests and acts as biocontrol agents. Hence, they need to be maintained to optimal limits in agroecosystem. The presence of birds as plant pollinators and seed dispersers indicates a healthy ecosystem (Ramchandra, 2013). But change in agricultural practices, deforestation, habitat destruction and fragmentation reduce their number (Mazumder, 2014). To counteract the decline in avian diversity, it is crucial to recognize habitats that are hotspots. Hence, the present study with an objective to study wheat crop as a habitat for birds by exploring their diversity and abundance. The activities of birds at various stages of the crop were recorded to study the role of birds.

MATERIALS AND METHODS

The present study was conducted in Bathinda District of Punjab at three locations namely village Ruldu Singh Wala (I), Village Katar Singh Wala (II) and Village Bir Talab (III) for one year from May 2019 to April 2020. Weekly visits were conducted in selected locations between 6:00 am to 8:00 am to record avian species visiting the wheat crop. Birds visiting in and around the wheat fields were observed with binoculars and photographs were taken by digital camera. Any other relevant information was noted, and identification was done by visual observation and by comparing the photographs with universal accepted handbooks and field guides such as- Guide to the Birds of the Indian Subcontinent (Grimmet et al., 2011); and The book of Indian birds (Ali, 2002). Species richness, abundance as well as feeding habits was observed and recorded at different crop stages namely preparatory tillage, sowing, seedling and ripening stage.

RESULTS AND DISCUSSION

The presence of various bird communities recorded in wheat agroecosystem along with their feeding guilds at different locations in Bathinda district of Punjab is given in Table 1. The species diversity/ abundance analyses confirmed that 83 species belonging to 16 orders, with species richness being maximum at

Table 1. Bird diversity and abundance at different stages of wheat crop (Bathinda district, Punjab)

S.No.	Common name	Scientific name	Feeding habits	Location I Ruldu Singh Wala				Location II Katar Singh Wala				Location III Bir Talab			
				Early		Late		Early		Late		Early		Late	
				PT	SW	SD	RP	PT	SW	SD	RP	PT	SW	SD	RP
1.	Alexandrine parakeet	*Psittacula eupatria* (L., 1766)	F	-	0.58	-	-	-	-	-	0.07	3.88	1.45	-	0.05
2.	Ashy prinia	*Prinia socialis* (Sykes, 1832)	I	0.93	1.08	1.81	0.72	-	0.09	-	-	-	0.36	-	0.65
3.	Asian koel	*Eudynamys Scolopacea* (L., 1758)	O	-	-	0.20	0.38	-	-	-	0.33	-	0.12	-	0.15
4.	Bank myna	*Acridotheres ginginianus* (Latham, 1790)	I	-	0.17	-	0.21	-	-	-	0.13	1.94	0.24	-	1.10
5.	Bay backed shrike	*Acridotheres ginginianus* (Valenciennes, 1826)	I	-	-	-	0.13								
6.	Black crowned night Heron	*Lanius schach* (L., 1758)	I	-	-	0.40	0.26								
7.	Black drongo	*Dicrurus adsimilis* (Vieillot, 1817)	I	-	0.33	1.01	1.19	1.10	1.11	2.10	1.67	0.97	1.09	2.65	1.35
8.	Black froncolin	*Francolinus Francolinus* (L., 1766)	O	-	0.50	0.81	0.51	-	0.09	0.84	0.80	-	0.36	-	0.55
9.	Black ibis	*Pseudibis papillosa* (Temminck, 1824)	O	2.78	0.25	1.01	1.45	1.10	0.43	2.10	2.40	2.91	1.21	2.65	2.10
10.	Black kite	*Milvus migrans* (Boddaert, 1783)	C	-	0.08	-	0.09	-	-	-	0.20	-	0.12	-	0.05
11.	Black winged stilt	*Himantopus himantopus* (L., 1758)	MG	0.93	8.24	13.31	4.13	-	0.26	-	0.33	1.94	2.53	15.93	5.90
12.	Blue rock pigeon	*Columba livia* (J.F. Gmelin, 1789)	G	12.04	8.74	5.04	4.47	13.19	15.09	16.81	11.69	10.68	13.27	13.72	5.55
13.	Blue throat	*Erithacus svecicus* (L., 1758)	I	1.85	0.25	1.01	1.32	1.10	0.69	-	1.54	-	0.60	-	0.65
14.	Blyth's reed warbler	*Acrocephalus dumetorum* (Blyth, 1849)	I	-	0.17	1.21	0.13								
15.	Brown headed barbet	*Megalaima Zeylanica* (J F Gmelin, 1788)	F									-	-	-	0.20
16.	Brahminy starling	*Sturnus pagodarum* (J F Gmelin, 1789)	O	-	-	-	0.13								
17.	Cattle egret	*Bubulcus ibis* (L., 1758)	I	4.63	12.90	2.22	9.50	7.69	6.69	6.72	3.47	14.56	13.39	7.96	3.95
18.	Common babbler	*Turdoides caudatus* (Dumont, 1823)	O	-	-	-	0.34					-	-	-	0.05
19.	Common crow	*Corvus splendens* (Vieillot, 1817)	O	-	0.33	0.60	2.00	4.40	0.94	2.52	10.49	1.94	0.60	5.31	10.31
20.	Common green shank	*Tringa nebularia* (Gunnerus, 1767)	C					-	-	-	0.13				
21.	Common hoopoe	*Upupa epops* (L., 1758)	O	1.85	0.42	0.81	0.34					-	0.36	0.44	0.05
22.	Common moorhen	*Gallinula chloropus* (L., 1766)	O	8.33	5.16	3.23	2.00								
23.	Common myna	*Acridotheres tristis* (L., 1766)	O	4.63	6.32	4.84	6.94	9.89	5.32	11.76	9.75	4.85	6.63	9.73	10.11
24.	Common redshank	*Tringa nebularia* (L., 1758)	I	-	0.67	-	0.13								
25.	Common rose-Finch	*Carpodacus erythrinus* (Pallas. 1770)	MG	-	-	-	0.17								
26.	Common sandpiper	*Actitis hypoleucos* (L., 1758)	I	-	0.67	-	0.13					-	0.12	-	-
27.	Common starling	*Sturnus vulgaris* (L., 1758)	MG	-	0.08	-	1.49								

(contd.)

28.	Common stone chat	*Saxicola torquata* (Pallas, 1773)	I	-	0.42	0.40	1.06	-	0.17	-	5.41	-	-	0.88	0.25
29.	Common tailorbird	*Orthotomus sutorius* (Pennant, 1769)	I	-	-	0.81	0.38								
30.	Eurasian collared dove	*Streptopelia decaocto* (Frivaldszky, 1838)	G	1.85	2.16	3.63	2.51	4.40	11.23	7.14	2.34	-	2.17	0.44	1.65
31.	Great cormorant	*Phalacrocorax Carbo* (L., 1758)	C	-	0.25	0.81	0.04								
32.	Greater coucal	*Centropus sinensis* (Stephens, 1815)	O	-	0.33	-	0.43	-	0.09	-	0.33	-	-	0.44	0.30
33.	Grey heron	*Ardea cinerea* (L., 1758)	C	-	0.33	-	0.26								
34.	Grey francolin	*Francolinus pondicerianus* (J.F. Gmelin, 1789)	O	-	-	-	0.09	-	-	-	0.53	-	-	2.21	0.30
35.	Grey goshawk	*Accipiter novaehollamdiae* (Gmelin, 1788)	C									-	-	-	0.05
36.	Grey wagtail	*Motacilla cinerea* (Tunstall, 1771)	I	-	0.25	-	-								
37.	House sparrow	*Passer domesticus* (L., 1758)	O	1.85	2.91	2.62	4.64	-	0.34	2.52	0.80	-	0.24	0.88	0.50
38.	Indian treepie	*Dendrocitta Vagabunda* (L., 1790)	O	-	0.33	0.40	0.72	1.10	0.17	1.26	0.33	-	0.12	0.88	0.55
39.	Indian chat	*Cercomela fusca* (Blyth, 1851)	I	-	0.42	-	1.28	3.30	0.60	3.36	0.94	-	1.45	2.21	1.30
40.	Indian cuckoo	*Cuculus micropterus* (Gould, 1838)	I	-	-	-	0.09	-	-	-	0.20	-	-	-	0.25
41.	Indian grey Hornbill	*Ocyceros birostris* (Scopoli, 1786)	O	-	0.17	0.20	0.77	-	-	0.42	1.00	-	0.24	1.33	0.95
42.	Indian robin	*Saxicoloides fulicata* (L., 1766)	I	-	-	-	0.26	-	-	-	0.13				
43.	Indian roller	*Coracias benghalensis* (L., 1758)	I	0.93	0.08	0.60	0.51	2.20	2.06	4.62	1.87	0.97	0.60	2.21	0.90
44.	Indian shikra	*Accipiter badius* (J.F. Gmelin, 1788)	C	-	0.08	0.81	0.17	1.10	0.26	0.84	0.20	-	0.36	0.88	0.10
45.	Issabelline shrike	*Lanius isabellinus* (Hemprich & Ehrenberg,1833)	I	-	0.08	-	-								
46.	Indian swallow	*Hirundo rustica* (L., 1758)	I	-	0.17	-	-	-	0.43	-	-	12.62	9.17	-	1.80
47.	Jungle babbler	*Turdoides striatus* (Dumont, 1823)	I	4.63	5.24	5.44	5.75	-	1.63	5.88	3.74	-	2.65	4.42	4.40
48.	Large grey babbler	*Turdoides malcolmi* (Sykes, 1832)	O	-	-	-	0.34	9.89	1.46	-	0.94				
49.	Large pied wagtail	*Motacilla maderaspatensis* (J.F. Gmelin, 1789)	I	0.93	0.83	1.01	0.04	-	0.09	0.84	-	-	0.48	0.44	0.15
50.	Laughing dove	*Streptopelia senegalensis* (L., 1766)	G	1.85	1.08	0.60	1.32	-	0.26	-	0.07	-	-	0.88	0.40
51.	Lesser golden backed woodpecker	*Dinopium benghallense* (L., 1758)	I	-	-	0.20	0.04					-	-	0.44	0.05
52.	Little cormorant	*Phalacrocorax niger* (Vieillot, 1817)	I	-	0.17	0.20	0.21								
53.	Little egret	*Egretta garzetta* (L., 1766)	O	-	-	-	0.17								
54.	Long tailed shrike	*Lanius schach* (L., 1758)	I	0.93	0.25	0.20	0.17	-	0.09	0.84	0.33				
55.	Median fgret	*Mesophoyx intermedia* (Wagler, 1829)	I	-	-	-	0.17								
56.	Oriental honey buzzard	*Pernis ptilorhynchus* (Temminck, 1821)	I	-	0.08	-	-					-	0.12	-	-
57.	Oriental Magpie Robin	*Copsychus saularis* (L., 1758)	I	-	0.08	-	0.09								
58.	Oriental Tree Pipet	*Anthus hodgsoni* (Richmond, 1907)	I	3.70	1.75	-	-	1.10	0.60	-	0.33	1.94	0.97	-	0.35
59.	Oriental White Ibis	*Threskiornis melanocephalus* (Latham, 1790)	C	-	0.08	-	0.30								

(contd.)

(contd. Table 1)

60.	Paddyfield warbler	*Acrocephalus Agricola* (Jerdon, 1845)	I	-	0.33	1.01	0.09	-	0.86	-	0.47	0.97	0.97	3.98	0.35
61.	Pied bushchat	*Saxicola caprata* (L., 1766)	I	-	0.17	0.20	0.34	-	0.26	-	-				
62.	Pied kingfisher	*Ceryle rudis* (L., 1758)	C	0.93	0.67	0.60	0.64								
63.	Plain prinia	*Prinia inornata* (Sykes, 1832)	I	2.78	3.33	7.86	1.83	-	2.23	1.26	0.13	-	0.36	2.21	-
64.	Pond heron	*Ardeola grayii* (Sykes, 1832)	C	1.85	1.83	3.23	2.26	2.20	0.69	-	0.53	-	0.24	-	0.40
65.	Purple sunbird	*Nectarinia asiatica* (Latham, 1790)	N	-	-	-	2.81	1.10	0.17	-	1.74	-	-	-	0.85
66.	Red breasted flycatcher	*Ficedula parva* (Bechstein, 1792)	I	-	0.17	-	-								
67.	Red vented bulbul	*Pycnonotus cafer* (L., 1766)	O	-	0.42	3.23	2.56	2.20	1.03	2.52	1.54	-	0.48	-	0.30
68.	Red wattled lapwing	*Vanellus indicus* (Boddaert, 1783)	I	6.48	8.40	5.04	5.49	5.49	3.34	10.92	6.61	3.88	6.15	8.41	4.40
69.	Rose ringed parakeet	*Psittacula krameri* (Scopoli, 1769)	F	8.33	11.23	12.50	10.05	25.27	40.31	13.03	23.45	33.98	28.35	-	22.86
70.	Rosy starling	*Sternus roseus* (L., 1758)	I									-	-	-	4.25
71.	Singing bush-lark	*Mirafra cantillans* (Blyth, 1845)	I									-	-	-	0.05
72.	Small bee eater	*Merops orientalis* (Latham, 1801)	I	-	-	-	4.13	-	-	-	0.73	-	-	-	5.15
73.	Spot billed duck	*Anas poecilorhyncha* (Horsfield, 1816)	I	-	0.17	1.21	0.51					-	-	6.64	2.85
74.	Spotted munia	*Lonchura punctulata* (L., 1758)	MG	-	0.17	-	0.38								
75.	Spotted owlet	*Athene brama* (Temminck, 1821)	C	-	0.08	-	0.72	-	0.09	0.42	0.27	-	-	0.44	0.05
76.	Stone curlew	*Burhinus oedicnemus* (L., 1758)	MG	-	-	-	0.09					-	-	-	0.10
77.	White breasted water Hen	*Amaurornis phoenicurus* (Pennant, 1769)	O	5.56	4.08	2.22	1.53	1.10	-	-	0.33	-	0.36	0.44	0.55
78.	White eared bulbul	*Pycnonotus leucotis* (Gould, 1836)	O	-	1.25	5.04	3.11	-	-	0.84	-				
79.	White throated kingfisher	*Halcyon smyrnensis* (L., 1758)	C	1.85	1.66	2.22	1.41	-	0.60	0.42	0.73	0.97	1.33	0.88	0.50
80.	White wagtail	*Motacilla alba* (L., 1758)	I	-	0.58	0.20	-	-	0.09	-	-	0.97	0.48	-	-
81.	Wire tailed swallow	*Hirundo smithii* (Leach, 1818)	I	16.67	0.83	-	0.13	-	0.09	-	-	-	0.24	-	-
82.	Yellow legged green pigeon	*Treron phoenicoptera* (Latham, 1790)	F	0.93	0.17	-	1.96	1.10	0.09	-	0.94				
83.	Yellow wattled lapwing	*Vanellus malabaricus* (Boddaert, 1783)	I									-	-	-	0.30

PT- Preparatory tillage stage; SW- Sowing stage; SD- Seedling stage; RP- Ripening stage; I-Insectivorous; F- Frugivorous; C- Carnivorous; O- Omnivorous; MG- Multiple guild; G- Granivorous; N-Nectarivorous

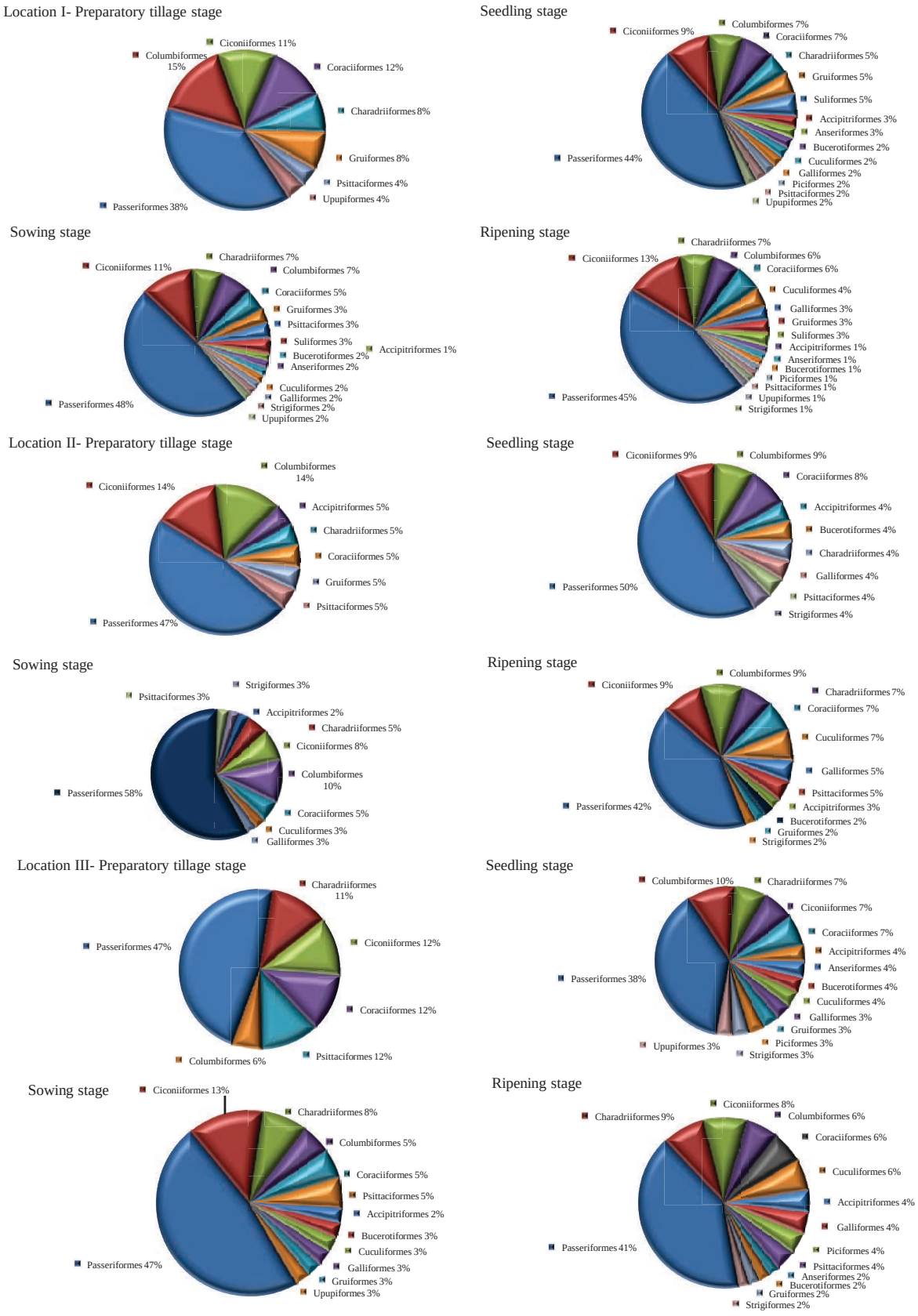

Fig. 1. Abundance of bird orders at various stages of wheat (location-I, II & III)

location I (77); rose-ringed parakeet was found to be the most abundant species (10.53, 25.51 and 21.30%, respectively) followed by blue rock pigeon (7.57, 14.19 and 10.80%, respectively). The third most abundant species was cattle egret at location I (7.31%) and location III (9.97%) and common myna at location II (9.18%). Passeriformes (46.99%) formed the most dominant order. Similar observations were recorded on the avifauna of Sonanadi Wildlife sanctuary, Uttarakhand (Kumar, 2021). It was followed by Cicioniiformes (12.05%), Charadriiformes (8.43%), Coraciiformes (4.82%) and Columbiformes (4.82%), with similar being observed at all the studied locations. Relative abundance at four stages of wheat crop viz., preparatory, sowing, seedling and ripening stages revealed that during preparatory stage, wire tailed swallow was the most dominant (16.67%) at location I; rose-ringed parakeet at location II (25.27%) and location III (33.98%). During sowing stage at location I, cattle egret (12.90%) was the most abundant, and rose-ringed parakeet at location II (40.31%, and location III (28.35%). Seedling stage revealed the maximum abundance of black winged stilt at location I (13.31%) and location III (15.93%); at location II, blue rock pigeon was the most dominant (16.81%). During the ripening stage, rose-ringed parakeet was the most abundant at all the locations (Fig. 1).

The present study revealed various avian species during various crop stages in wheat. The orders found in abundance and feeding guilds were similar to earlier studies done at Ludhiana (Kler, 2009). Species number increased from early (preparatory tillage and sowing stage) to late (seedling and ripening) stages. This is because more complex vegetation provides more food resources, better cover and protection against predators. Agricultural crops are better habitats due to more food availability (Hafner et al., 1986). Insectivorous guild formed the most dominant guild (39 species, 46.99% abundance) followed by omnivorous (19 species, 22.89% abundance) and carnivorous guild (12 species, 14.46% abundance). Similar trend for feeding guild was observed at all the stages of wheat at the studied locations. Avian predators of rabi crops feeding on larvae exposed during field ploughing include cattle egret, common crow and common myna (Shah and Garg, 1988). Insects are the primary invertebrates present in agroecosystems; hence form the major part of diet of insectivorous species. Common crow was seen feeding on insects and sown wheat seeds. Pied crested cuckoo was found to feed on dragonflies and other insects. Indian chat, black drongo, white wagtail, bay-backed shrike, black drongo and red-wattled lapwing were observed to feed exclusively on insects and soil invertebrates. Species richness of insectivorous bird community is dependent on food availability (both for adults and nestling). Role of insectivorous bird community in wheat agroecosystem should be considered to manage the arthropods and insect pests (Rey Benayas et al., 2017). Disparity in the diversity and abundance of the insectivorous bird communities at different locations is dependent on the availability and density of perching trees, availability of suitable nesting sites, and vegetation structure surrounding the study area (Rajashekara and Venkatesha, 2014).

Agricultural habitats have higher productivity (Dhindsa and Saini, 1994) and habitat breadth (Tscharntke et al., 2008). Wheat forms a major cropping system and acts a major habitat for bird species (Borad and Parasharya, 2018). Bird diversity and richness is dependent upon many variables. Habitat cover is directly influencing the survival of a species. Habitat heterogeneity also determines the occurrence and abundance (Pennington and Blair, 2011). Due to the presence of high diversity of plants and perennial multi-strata designs in the orchard systems, more habitats and resources are available for birds (Simon et al., 2010; Boller et al., 2004). Agriculture intensification have resulted in indirect negative impacts on the bird diversity i.e. reduction in nesting sites, bird mortality by farming operations and after harvesting, predation rate increases (Altaf et al., 2018).

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EFFECT OF FARMING SYSTEMS ON DIVERSITY AND SEASONAL ABUNDANCE OF INSECT PESTS AND THEIR NATURAL ENEMIES IN CAULIFLOWER

Abdul Wakil Barakzai*, Rajeshwar Singh Chandel, Prem Lal Sharma, Subhash Chander Verma, Maneesh Pal Singh and Panma Yankit

Department of Entomology, Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan 173230, Himachal Pradesh, India
*Email: abdulwakilbb@gmail.com (corresponding author)

ABSTRACT

A study was conducted on effect of two farming systems namely zero budget natural farming (ZBNF) and conventional farming (CF) on diversity and seasonal abundance of insect pests of cauliflower and their natural enemies during 2018-19 and 2019-20. Studies revealed that ZBNF system harboured less pest diversity and attracted more natural enemies as compared to the CF system. Natural enemy activity and % parasitisation were maximum in ZBNF system as compared to CF system. The results indicate that indigenous ZBNF formulations and intercropping have a positive effect on the population of natural enemies and repelled the insect pests much better as compared to CF system.

Key words: Zero budget natural farming, conventional farming, insect pests, natural enemies, cauliflower, repellency, parasitisation, natural enemy activity

Cauliflower *Brassica oleracae* var. *botrytis* L., is one of the common vegetables, and introduced in India in 1822 from England (Chatterjee et al., 1986). It is currently grown throughout the country. Cauliflower is attacked by various insect pests (Gaikwad et al., 2018; Raja et al., 2014). A large number of insecticides have been recommended and used to control these. These insecticides have their own harmful effects, including their negative impacts on natural enemies. Agroecosystem is not self-regulated as compared to others due to monocropping, and extra efforts are required to control the pests. Natural enemies play an effective role in IPM (Mandal and Patnaik, 2008). Intercropping, organic amendments generally harbour more natural enemies. Farming systems have great impact on insect pests and natural enemies, and organic practices increase the natural enemies (Gallo and Pekar, 1999). Such comparisons are necessary, as agroecosystems are with increased pest diversity and reduced natural enemies (Yadav 1989; Meena et al., 2002). The effect of organic farming system on natural enemies is required to be brought out and there are many studies. Recently a new system of farming called as zero budget natural farming (ZBNF) has been practiced. However, the studies on the impact of this system on the diversity and abundance of insect pests and their natural enemies are lacking. Natural enemies play key role in insect pest control (Liu et al., 2000). Hence, the current study to study the effects of ZBNF in comparison to conventional farming (CF) in cauliflower.

MATERIALS AND METHODS

The study was carried out at the experimental farms of Dr Y S Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh (1300 masl). Cauliflower (PSBK-1) was raised following standard package of practices for ZBNF and CF separately. In ZBNF, the main crop was intercropped with pea (P89), coriander (local selection) and mustard (trap crop). In CF cauliflower was raised as a sole crop, with plot size of 9x 4.5 m. For fertilization and pest management, indigenous plant and cow dung-urine based formulations were used. Jeevamrit, Ghanjeevamrit and Beejamrit were used as fertilizers, while Darekastra @ 500 l ha^{-1}, Bramhastra @ 3% and Agniastra @ 3% were used for pest management in ZBNF (Palekar, 2016). In CF system crop was raised following all the standard package of practices recommended by the University. The fertilizers used were urea @ 300 kg, SSP @ 675 kg and MOP @ 85kg/ha. The pests and diseases were controlled by need based applications of Captan (75%WP), malathion (50%EC) and imidacloprid (17.8%SL).

The diversity and seasonal abundance of insect pests were monitored at weekly intervals from nursery stage to final harvest. The data on the number of species

of pests and their natural enemies and the density of each species were observed. The population density of aphids, whitefly, caterpillars and beetles were counted on plant basis from 50 randomly selected plants in each case. The natural enemies viz. coccinellids and syrphid flies' density were observed by directly counting the beetles and maggots/ plant; in case of parasitized aphids, the parasitized ones were collected from 50 randomly selected plants and kept in the laboratory for emergence of adult parasitoids. The parasitized larvae of diamond back moth and cabbage butterfly were collected from sampling plants and kept in the laboratory for the emergence of parasitoids. The diversity of insect pests and natural enemies were analysed through Simpson Index (Simpson, 1949) and Shannon- Wiener Index (Shannon, 1948). For evaluating the seasonal abundance, weekly data collected were statistically analysed using t-Test by OP-STAT software (Sheoran et al., 1998).

RESULTS AND DISCUSSION

Diversity of insect pests and natural enemies: During 2018-19, six species of insect pests (under 6 genera and families each) were observed on cauliflower crop under ZBNF and CF systems. The pests include: the cabbage aphid *Brevicoryne brassicae* (L.); flea beetle *Phyllotreta* sp; greenhouse whitefly *Trialeurodes vaporariorum* (Westsood); diamond back moth *Plutella xylostella* (L.); cabbage head borer *Hellula undalis* (F.) and cabbage butterfly *Pieris brassicae* (L.). During 2019-20, in ZBNF system the diversity and species composition remained the same as that of previous year. In CF system, in addition to the above insect pests cabbage semilooper *Thysanoplusia orichalcea* (F.) was observed. As regards natural enemies, seven species were found associated with insect pests under ZBNF system. Out of these, five were predators and two parasitoids. Among predators, two coccinellids i.e. *Coccinella septempunctata* (L.) and *Hippodamia variegata* (Goeze); and three syrphids i.e. *Episyrphus balteatus* (De Geer), *Eupeodes frequens* (Matsumura) and *Metasyrphus confrator* (Wiedemann) were observed. The parasitoids observed were *Diaeretiella rapae* (Mc'Intosh) parasitizing the cabbage aphid, and *Diadegma semiclausam* (Hellen) parasitizing the larvae of *P. xylostella*.

During 2019-20 in ZBNF system, eight species of natural enemies were observed, all the species observed in the previous year were found along with the parasitoid *Cotesia glomerata* (L.) parasitizing the larvae of butterfly. In cauliflower grown under the conventional farming system, six species of natural enemies were observed during both the years of study. Five of them were predators and one was parasitoid. Among the five predators, two coccinellids i.e. *C. septempunctata* and *H. variegata*; and three syrphids i.e. *E. balteatus*, *E. frequens* and *M. confrator* were observed. The parasitoid observed was *D. rapae* parasitizing the cabbage aphid. The insect pest diversity indices revealed that CF based cauliflower ecosystem was more diverse than ZBNF system, while, the natural enemies' diversity indices revealed that ZBNF based system was more diverse (Table 1). This is possibly because of higher crop diversity and non-application of insecticides in the ZBNF system.

Seasonal abundance: The cabbage aphid appeared during the last week of October, 2018 (44th standard week (SW)- 2.74± 0.30 and 4.18± 0.40 aphids plant^{-1} in ZBNF and CF systems, respectively during 2018-19; and reached peak incidence of 23.40± 4.00 and 27.74± 5.09 aphids plant^{-1}) during 6th and 5th SW in ZBNF and CF systems, respectively. In 2019-20, the aphids appeared @2.04± 0.38 and 4.04± 0.66 aphids plant^{-1} in ZBNF and CF systems, during the last week of October, 2019 (44th SW), and peaked to 18.88± 3.94 and 28.38± 4.94 aphids plant^{-1} during 6th and 5th SW in ZBNF and CF systems, respectively (Fig.1A). The

Table 1. Diversity indices of insect pests and their natural enemies in cauliflower under ZBNF and CF systems (2018-19, 2019-20)

Diversity indices	Insect-pests				Natural enemies			
	2018-19		2019-20		2018-19		2019-20	
	Farming systems		Farming systems		Farming systems		Farming systems	
	ZBNF	CF	ZBNF	CF	ZBNF	CF	ZBNF	CF
Simpson index	0.78	0.68	0.74	0.64	0.51	0.54	0.47	0.50
Shannon index (H)	0.73	0.99	0.82	1.06	1.23	0.78	1.38	0.83
H_{max}	1.79	1.79	1.79	1.94	1.38	1.10	1.60	1.10
Evenness (J)	0.41	0.55	0.46	0.55	0.89	0.71	0.86	0.75
Dominance (D)	0.59	0.45	0.54	0.45	0.11	0.29	0.14	0.25

flea beetle appeared during the last week of October, 2018 (44th standard week) @0.14± 0.05 and 0.30± 0.07 beetles plant^{-1} in ZBNF and CF systems, and reached peak of 0.28± 0.08 and 0.60± 0.12 beetle plant^{-1} during the 50th SW in ZBNF and CF systems, respectively; during the second year, the incidence appeared during the last week of October, 2019 (44th SW) @ 0.10± 0.04 and 0.26± 0.06 beetle plant^{-1} in ZBNF and CF systems respectively; these reached the peak in the second week of December, 2019 (50th SW) @ 0.24± 0.07 and 0.58± 0.13 beetles plant^{-1} in ZBNF and CF systems, respectively (Fig.1B).

Whitefly infestation started on 47th SW in ZBNF and CF systems, with the peak reaching in 52nd SW (0.58± 0.16 and 1.28± 0.28 whiteflies plant^{-1}) in ZBNF and CF systems, respectively in 2018-19; in 2019-20, the incidence appeared during the third week of November, 2019 (47th SW) and reached the peak in the last week of December, 2019 (52th SW) (Fig.1C). During 2018-19. Diamond back moth (DBM) started on 1st SW in ZBNF and CF systems, and reached peak in the third week of February, 2019 (8th SW) @0.96± 0.16 larvae plant^{-1} in ZBNF system, and 1.40± 0.18 larvae plant^{-1} in CF system; during 2nd year, the incidence started during

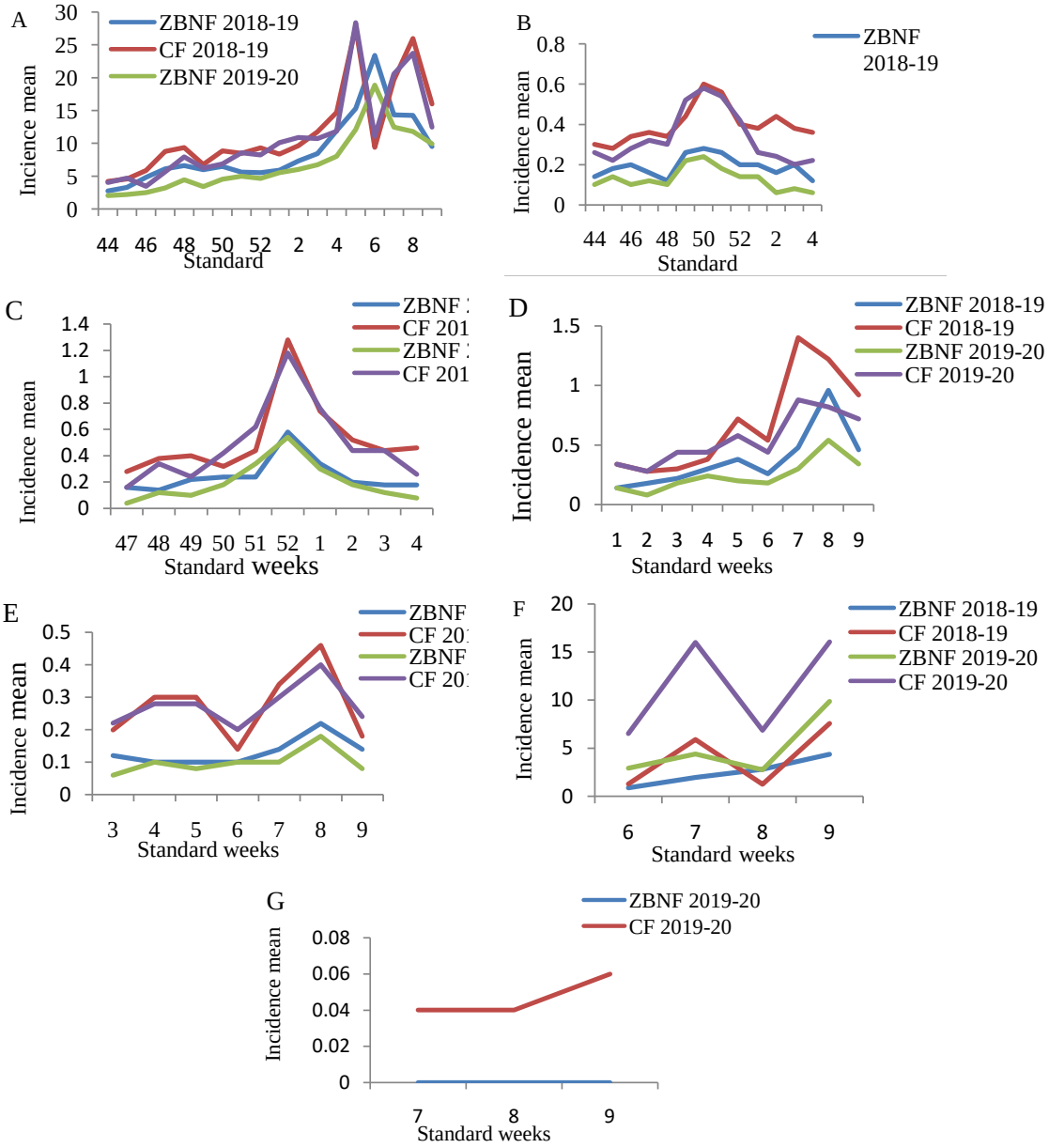

Fig. 1. Seasonal abundance of insect-pests of cauliflower under ZBNF and CF systems during 2018-19 and 2019-20

the first week of January, 2020 (1st SW) and reached the peak of 0.54± 0.10 larvae plant^{-1} in ZBNF system, during the third week of February, 2020 (8th SW); while, in CF system, peak was at 0.88± 0.16 larvae plant^{-1}) in the second week of February, 2020 (7th SW) (Fig.1D). Likewise, cabbage head borer started infesting the crop during 3rd SW in both the systems in both the seasons with peak incidence being during the 8th SW (Fig.1E). Cabbage butterfly infestation started in the first week of February, 2019 and 2020 i.e. 6th SW, with its larval counts reaching the peak in the fourth week of February, 2019 and 2020 (9th SW- 6.52± 2.37 and 16.00± 3.97 larvae plant^{-1} in ZBNF and CF systems, 2019; and 6.86± 2.15 and 16.06± 3.94 larvae plant^{-1} in 2020, respectively (Fig.1F). Cabbage semilooper was recorded only in CF system and infestation started on 7th SW, with peak incidence recorded on 9th SW during second year (Fig.1G). In case of natural enemies *D. rapae* parasitization was observed on 44th and 46th standard weeks in of ZBNF and CF systems during 2018-19 and its peak incidence (1.28± 0.35 and 1.94± 0.39 mummified aphids plant^{-1}) were recorded on 5th and 6th SW in CF and ZBNF systems. During 2019-20 the peak incidence of 1.60± 0.33 and 2.26± 0.47 mummified aphids plant^{-1} was observed on 5th and 6th SW in CF and ZBNF systems, respectively.

The maximum parasitization (13.56 and 4.61%) was observed on 1st and 5th SW, 2019 in ZBNF and CF systems, respectively. During 2019-20 peak parasitisation (22.22 and 6.40%) was observed on 52nd and 46th SW in ZBNF and CF systems, respectively (Fig. 2A). Activity of coccinellids started (0.10± 0.04 and 0.08± 0.04 beetles plant^{-1}) on 46th and 47th SW during 2018-19, and 0.16± 0.06 and 0.08± 0.04 beetles plant^{-1} during 2019-20, in ZBNF and CF systems. Peak occurrence of coccinellids (0.58± 0.12 and 0.28± 0.09 beetles plant^{-1}) was observed during 6th and 7th SW in 2018-19, and (0.86± 0.17 and 0.42± 0.11 beetles plant^{-1}) during 2019-20, in ZBNF and CF systems (Fig. 2B). Syrphids appeared during 50th and 51st SW in ZBNF and CF systems during both seasons with maximum counts observed on 8th SW (Fig. 2C); *D. semiclausam* appeared on 5th SW in ZBNF, while it was not observed in CF system during both seasons- maximum was on 9th SW in ZBNF system in both seasons (Fig. 2D). Similarly, parasitic wasp, *C. glomerata* was seen only in ZBNF system during 2019-20 and this occurred during 8th SW with peak being in 9th standard week (Fig. 2E).

In ZBNF system organic amendment and intercropping had an impact on natural enemies and use of intercrop also repelled certain insect pests up to a remarkable level. Sharma et al. (2020) also observed similar insect pests in their study from cauliflower, revealing 14 species of insect pests, of which seven are similar as in this study. Rana (2019) also reported these pests from the cruciferous ecosystem from Himachal Pradesh and revealed a better impact of ZBNF than CF system. Current study recovered all insect pests reported by Rana (2019) except green peach aphid *Myzus persicae* (Sulzer). Similar results were obtained by Mishra et al. (2018) where cabbage aphids (*B. brassicae*) appeared from 35th to 47th SW in cauliflower ecosystem. Mandal and Patnaik (2008) also observed insects of cole crops with peak incidence of *B. brassicae* during January and February. Patra et al. (2013) documented the seasonal abundance of DBM during late February to early March, which is in accordance with the present results. Singh et al. (2015) reported DBM from the 2nd SW and peak in 8th SW. Embaby (2015) observed similar incidence of *B. brassicae* and DBM. Dewanda and Khan (2016) also found DBM on cauliflower during the first week of September which gradually increased and reached its peak during first week of November. Similar results were reported by Meena and Singh (2012) on DBM that it appeared 35 days after transplanting of cabbage with peak in the last week of January. Das et al. (2017) studied the effect of temperature (ºC) on species richness of whitefly in mustard- incidence was very low at 20 November, 2015, which gradually reached the peak in 19 March, 2016.

Khan and Talukder (2017) studied the influence of weather factors on the abundance and population dynamics of *P. brassicae* on cabbage- and found that larval incidence ranged from 0.58 to1.98 larvae/ plant with peak on 5th February. Sharma et al. (2020) found *C. septempunctata* was the most abundant predator of aphids in cauliflower with relative proportion of 74.55 and 52.98% and the parasitization of *P. xyllostella* by *D. semiclausam* was 28.94 and 30.77%; they also found that *C. glomerata* was the most abundant parasitoid of the larva of *P. brassicae* and *P. rapae* (42.43 and 57.58% during 2017 and 2018, respectively) which is quite similar to present results; and 10 predators and 4 parasitoids were observed in contrast to 5 predators and 3 parasitoids in the present study. The incidence of *P. brassicae* observed now is similar to that reported by Dwivedi et al. (2015). Jakhar and Singh (2018) observed the occurrence of coccinellids in cauliflower with *C. septempunctata* as the most dominant. Gaikwad et al. (2018) studied the insect pests and natural enemies of cauliflower during 2017 and reported the incidence of *B. brassicae, P. xylostella* and *H. undalis*. In addition, they

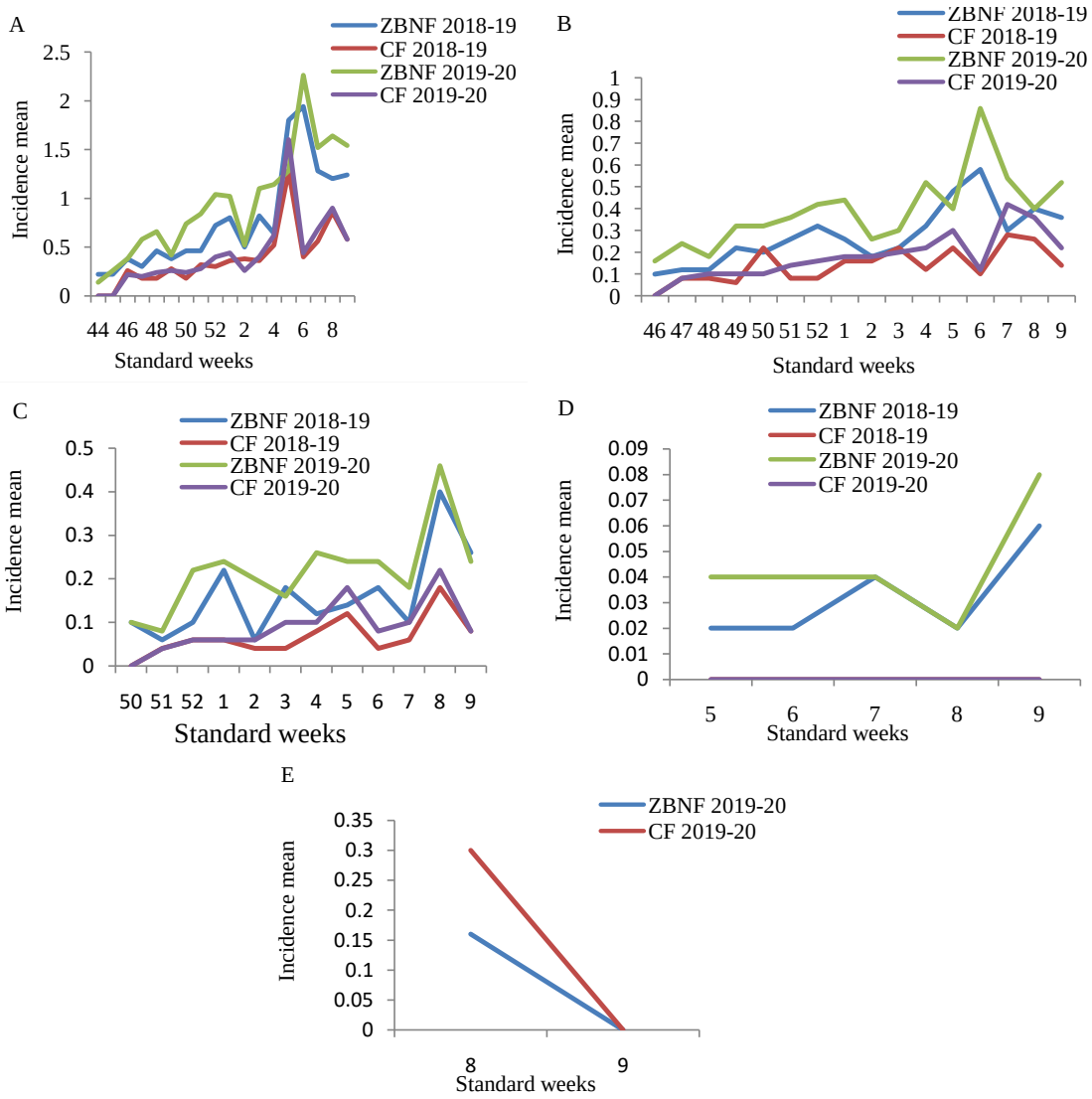

Fig. 2. Seasonal abundance of natural enemies of insect pests of cauliflower under ZBNF and CF systems (2018-19, 2019-20)

recorded the occurrence of syrphid flies and mummified aphids. Evidences and results of current study provide a platform to conclude that ZBNF is a better farming system than CF system as it not only repels the pests, but conserves the natural enemies and improves the crop ecosystem.

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COMPARATIVE BIOLOGY OF THREE COCCINELLID PREDATORS ON COWPEA APHID *APHIS CRACCIVORA*

Ipsita Mishra, Subhalaxmi Roy* and B K Mishra

Department of Entomology, Odisha University of Agriculture and Technology,
Bhubaneswar 751003, Odisha, India
*Email: subhalaxmiroy54@gmail.com (corresponding author)

ABSTRACT

Laboratory experiment was conducted to study the biology of coccinellid predators from agroecosystems of Odisha. About 17 species were identified, the most important being *Coccinella septempunctata, Coccinella transversalis* and *Cheilomenes sexmaculata* predating on aphids infesting cowpea. The biology of these when evaluated indicated that *C. septempunctata* was the largest, and *C. sexmaculata* the smallest; grubs of all the three are susceptible to the rising temperature. The total developmental period was maximum during January and the least during May for all species. Total larval period was 11.9± 2.34, 12.1± 6.19 and 12.6± 0.01 days in January and 8.2± 0.07, 7.00± 0.01 and 7.9± 0.06 during May with *C. septempunctata*, *C. transversalis* and *C. sexmaculata*, respectively; developmental periods for these were observed to be 22.4± 0.67, 20.2± 1.46 and 17.4± 0.82 days during January, and 15.2± 0.01, 11.5± 0.39 and 12.3± 0.61 days during May, respectively. Prepupae and pupae were the least affected by the fluctuations in temperature.

Key words: *Cocinella septempunctata, C.transversalis, Cheilomenes .sexmaculata*, life stages, size, duration, larval period, developmental period, mortality, morphometrics, temperature

Insect pests have always been a threat to agriculture, and various chemicals are applied against these. Due to the intensive and indiscriminate use of pesticides, there are many hazards to humans. Hence, there is a need for ecofriendly, safe and cheap control methods. This can only be achieved by IPM ensuring environmental safety (Solangi, 2004). Ladybird beetles are important agents in biological control in pests of many economically important crops (Obrycki and Kring, 1998). They are predators in both adult and larval phases, presenting an intense search for food and predatory capacity (Vandenberg, 2002). Aphids are one of the most injurious insect pests which suck the cell sap affecting crop yield (Fondren et al., 2004), as these affect the general vigour of plant (Dixon and Kindlmann, 1998). Coccinellids are very effective predators of homopteran pests, and predate upon sucking pests like aphids, jassids, thrips, scales, mealy bugs, planthoppers and whiteflies besides other insect eggs and neonate larvae. The present study evaluates the biology of three coccinellids and their predation on aphids under laboratory conditions.

MATERIALS AND METHODS

In order to assess the relative abundance of various predaceous coccinellids in Bhubaneswar, a regular field survey of crop fields was conducted at the Central Research Station, OUAT, Bhubaneswar from September, 2014 to March, 2015. The beetles collected were reared in the laboratory for maintaining their culture. Stock culture of *Aphis craccivora* was maintained on cowpea raised in earthen pots. Adults of *Coccinella septempunctata* L., *C. transversalis* F. and *Cheilomenes sexmaculata* F., the predominant species around Bhubaneswar collected from the field were and reared on aphid infested cowpea seedlings in the laboratory @ 10 beetles/ jar and were observed for presence of both males and females. It was ensured that at least 50% females were present in each jar. Five mated females were released in the jar containing aphid infested cowpea seedlings for egg laying. Next day, the beetles were removed to separate jars and the previous jars were examined for eggs. Eggs were usually laid on under surface of leaves and sometimes on inner wall of the jars. Eggs were removed carefully along with the leaves and were kept in petridishes for hatching and development of the grubs. For pupation, paper pieces were provided in each of the jars. After emergence of adults, the beetles were placed separately in other jars, containing aphid infested seedlings and thus, cultures were maintained.

Biology of the three species was studied during January, March, May, July, September and November, 2015. Ten freshly laid eggs of each were separated out

and kept in petridishes (10 cmx 1.5 cm) for hatching and further rearing. Three replications were maintained for each species. The early instar grubs were provided with early instar nymphs of *A. craccivora* on cowpea twigs. Each grub was provided with sufficient number of aphids every 24 hr, after removing it to a new petridish, so that there was no dearth of food. Observations were made on the duration of instars. This procedure was followed till all the grubs pupated. Developmental period of stages and measurement of egg and larval instars were also observed. Ten prepupa of were separated in petridishes. Three replications were maintained. Prepupal and pupal periods and their measurements were also observed. Ten freshly emerged adult mating pairs of each species were removed from the stock culture and were reared individually in petridishes on *A craccivora.* Fresh cowpea twigs were provided for egg laying. Eggs laid were counted on daily basis, replicated thrice times. Observations on fecundity, longevity of females and male beetles and their measurements were also made. In case of natural death of any individual in the experimental stages, the same was replaced with an individual of the same age simultaneously maintained in the stock culture. Observations on morphometrics of life stages were also made. Data obtained were statistically analysed by descriptive method as suggested by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Among the coccinellids, *C. septempunctata*, *C. transversalis* and *Chilomenes sexmaculata* were observed in large numbers (Table 1). The life stages of *C. septempunctata* were the largest as observed from their egg and other life stages. While length and breadth of *C. sepempunctata* eggs were 1.2± 0.17 mm and 0.49± 0.00 mm respectively it was 1.05± 0.01 mm and 0.46± 0.07 mm eggs were spindle shaped with both ends evenly rounded; for *C. transversalis* and 0.61± 0.01 and 0.03± 0.00 mm, eggs were cigar shaped for *C. sexmaculata* respectively. Similarly, all the larval stages of *C. septempunctata* were found to be larger. The fourth instar grubs of *C. septempunctata* measured 6.7± 0.61 in length and 3.4± 0.02 mm in breadth whereas the same for *C. transversalis* were 6.12± 0.17 mm and 2.5± 0.08 mm and *C. sexmaculata* were 3.9± 0.07 mm and 1.8± 0.06 mm, respectively. Similarly the pupae of *C. septempunctata* were 4.5± 0.43 mm in length and 4.2± 0.39 mm in breadth as compared to 5.31± 0.42 mm length and 3.41± 0.08 mm in breadth of *C.transversalis* and 3.7± 0.11 mm length and 2.4± 0.06 mm breadth of *C. sexmaculata*. Adult male of *C. septempunctata* were 4.8± 0.67 mm in length and 4.5± 0.42 mm in breadth. *C. transversalis* male were 4.5± 0.31 mm in length and 4.0± 0.06 mm in breadth. The measurements for *C. sexmaculata* male were 3.8± 0.11 mm in length and 3.1± 0.09 mm in breadth. The female of *C. septempunctata* measured about 5.2± 0.13 mm in length and 5.1± 0.64 mm in breadth whereas *C. transversalis* male was 4.9± 0.17 mm in length and 4.8± 0.17 mm in breath and that of *C. sexmaculata* 3.7± 0.37 mm in length and 3.3± 0.43 mm in breadth, respectively (Table 2). Tank and Korat (2007) observed the biological parameters of *C. sexmaculata* similar to the present ones, and Ullah et al. (2012) also got similar observations on the morphometrics of *C. transversalis* and *M. sexmaculata.*

Duration of lifestages were studied during different months (January, March, May, July, September and November) representing different environmental conditions of the year, the corresponding temperatures being 21.7, 28.5, 37.2, 30.1, 28.1 and 27.6^{o}C. Among the coccinellids *C. septempunctata* had the longest developmental period followed by *C. transversalis* and *C. sexmaculata.* It was observed that during the cooler months of January and November, the lifestages are prolonged and in the warmer months of March and May the life stages shorter. In January, when the mean temperature was 21.7^{O}C, the total developmental period, i.e., from egg to adult stage, took 22.4± 0.67 days in *C. septempunctata*, whereas, it took 20.2± 1.46 and 17.4± 0.82 days in case of *C. transversalis* and *C. sexmaculata*, respectively. When temperature increased in May (mean 32.7^{o}C) the total developmental periods were 15.2± 0.01, 11.5± 0.39 and 12.3± 0.61 days, respectively. When temperature increased in September, the developmental periods increased to 16.7± 0.64, 16.2± 0.41 and 14.7± 0.64 days. Adult longevity also exhibited the same trend (Table 3). In their study on the biology of *C. septempunctata*. Rauf et al. (2013) reported that with increasing temperature, developmental duration decreases significantly. The fecundity indicated the same trend, more eggs being laid in cooler months of November and January and less eggs being laid in warmer months of March and May. It was also observed that *C. septempunctata* laid more eggs; and more eggs were viable in the cooler months; eggs of *C. septempunctata* were more viable as compared to *C. transveralis* and *C. sexmaculata*. Wang et al. (2013) observed that egg hatchability and fecundity of *C. sexmaculata* are more at 30^{o}C in China. Krengel et al. (2012) on *C. septempunctata* feeding on the grain aphid *Sitobion avenae* found that compared

Table 1. Predaceous coccinellids observed in Bhubaneswar (September 2014- March 2015)

Crop	Month	*Adults/ 10 plants				
		C. septempunctata	*C. transversalis*	*C. sexmaculata*	*B. suturalis*	*S. coccivora*
Okra	Feb.	1.6	0.6	0.3	1.3	0.3
	Mar.	1.2	0.8	0.7	0.4	0.1
	April	1.3	0.9	0.8	0.3	0.4
	May	0.4	0.1	0.3	1.2	0.8
	June	1.0	0.3	0.7	0.5	0.7
	July	1.3	0.2	0.9	0.6	1.0
	Aug.	1.5	1.3	1.1	0.7	0.9
Green gram	Sept.	2.4	1.3	2.9	1.6	0.9
	Oct.	2.2	2.5	1.9	1.8	1.3
	Nov.	2.3	1.8	2.2	0.3	0.2
	Dec.	0.3	1.7	1.6	1.0	0.9
	Jan.	1.5	1.3	1.2	1.8	0.7
	Feb.	1.2	0.9	2.5	1.9	0.4
	Mar.	1.7	0.7	2.7	0.2	1.3
Cowpea	Sept.	2.2	1.5	1.2	1.0	0.7
	Oct.	1.3	1.2	1.1	0.8	0.4
	Nov.	1.7	1.1	0.7	0.5	0.3
	Dec.	1.8	0.9	0.5	0.9	0.6
Groundnut	Sept.	1.4	1.7	0.7	0.3	0.8
	Oct.	1.3	1.5	1.3	0.4	0.3
	Nov.	1.9	1.2	1.1	0.7	0.5
	Dec.	1.7	1.1	0.8	0.5	0.9
	Jan.	1.2	1.8	0.9	1.1	0.6
	Feb.	1.0	1.4	1.1	1.0	1.2
	Mar.	1.1	1.2	0.7	1.2	0.7
Mustard	Nov.	2.3	2.1	2.0	0.8	0.9
	Dec.	3.1	2.7	1.7	1.6	2.0
	Jan.	4.8	2.2	1.2	0.5	1.3
	Feb.	3.2	1.6	0.6	0.2	0.3
	Mar.	3.9	2.3	1.3	0.0	0.8
Cabbage	Dec.	5.0	3.6	2.0	1.3	1.5
	Jan.	4.3	4.2	2.7	1.5	1.3
	Feb.	3.3	2.3	2.1	0.9	2.1
	Mar.	2.7	1.9	1.6	1.3	0.8

Table 2. Morphometrics of life stages of aphidophagous coccinellids (n=10)

Developmental stages	*Measurements (mm) (Mean ± S.E.)					
	C. septempunctata		*C. transversalis*		*C. sexmaculata*	
	Length	Breadth	Length	Breadth	Length	Breadth
Egg	1.2± 0.17	0.49± 0.00	1.05± 0.01	0.46± 0.07	0.61± 0.01	0.03± 0.00
I instar grub	1.69± 0.21	0.6± 0.02	2.45± 0.00	0.75± 0.01	1.1± 0.03	0.7± 0.01
II instar grub	3.48± 0.11	0.82± 0.01	3.45± 0.01	1.05± 0.03	2.2± 0.01	0.6± 0.02
III instar grub	5.9± 0.13	2.5± 0.14	5.71± 0.01	1.45± 0.14	2.9± 0.04	1.3± 0.01
IV instar grub	6.7± 0.61	3.4± 0.21	6.12± 0.17	2.5± 0.08	3.9± 0.07	1.8± 0.06
Pupa	4.5± 0.43	4.2± 0.39	4.31± 0.42	3.41± 0.08	3.9± 0.6	2.4± 0.06
Adult male	4.8± 0.67	4.5± 0.42	4.5± 0.31	4.0± 0.06	3.8± 0.11	3.1± 0.09
Adult female	5.2± 0.13	5,1± 0.64	4.9± 0.17	4.8± 0.17	3.7± 0.37	3.3± 0.43

Table 3. Duration of lifestages of *C. septempunctata* , *C. transversalis and C. sexmaculata* on *A. craccivora*

Stages of development	*C. septempunctata* *Developmental period in days (Mean± S.E.)						*C. transversalis* *Developmental period in days (Mean± S.E.)						*C. sexmaculata* *Developmental period in days (Mean± S.E.)					
	January	March	May	July	Sept-ember	Nov-ember	January	March	May	July	Sept-ember	Nov-ember	January	March	May	July	Sept-ember	Nov-ember
Egg	5.5± 0.13	4.9± 0.37	2.1± 0.13	3.1± 0.19	2.7± 0.31	3.2± 0.53	2.9± 0.71	2.0± 0.00	1.8± 0.03	2.1± 0.11	1.9± 0.17	2.4± 0.13	3.1± 0.27	2.4± 0.13	1.2± 0.01	2.0± 0.17	2.2± 0.04	2.6± 0.29
Grub																		
I instar	2.3± 0.11	1.8± 0.01	1.2± 0.01	2.6± 0.06	2.7± 0.32	2.1± 0.31	2.1± 0.37	2.9± 0.07	1.2± 0.01	2.0± 0.00	2.7± 0.01	2.8± 0.00	2.9± 0.46	2.7± 0.01	1.6± 0.16	2.7± 0.06	2.4± 0.12	2.8± 0.11
II instar	2.0± 0.00	1.8± 0.03	1.1± 0.02	2.5± 0.02	1.6± 0.07	2.0± 0.00	2.5± 0.14	2.8± 0.62	1.2± 0.29	2.4± 0.19	2.8± 0.00	2.6± 0.43	2.4± 0.41	2.1± 0.16	1.8± 0.01	2.3± 0.01	2.8± 0.00	2.3± 0.13
III instar	3.6± 0.31	3.1± 0.03	3.0± 0.01	3.9± 0.43	1.9± 0.04	3.4± 0.19	3.2± 0.91	3.1± 0.04	2.2± 0.01	3.2± 0.04	3.8± 0.07	2.7± 0.01	3.7± 0.11	2.5± 0.64	2.4± 0.14	2.7± 0.17	2.7± 0.11	2.9± 0.01
IV instar	3.7± 0.41	3.2± 0.17	3.9± 0.00	2.4± 0.19	3.0± 0.00	3.6± 0.04	4.2± 0.13	3.8± 0.13	3.1± 0.03	3.7± 0.01	3.0± 0.00	3.8± 0.11	3.5± 0.17	2.7± 0.11	1.8± 0.16	2.9± 0.11	2.1± 0.01	3.2± 0.11
Total larval period	11.9± 2.34	10.8± 0.94	8.2± 0.07	11.9± 1.36	10.6± 0.32	11.0± 0.00	12.1± 0.19	13.2± 0.22	7.0± 0.01	11.5± 0.07	13.0± 0.00	13.7± 0.67	12.6± 0.01	10.9± 0.67	7.9± 0.06	11.2± 0.61	10.8± 0.06	11.9± 0.12
Prepupa	1.9± 0.01	1.4± 0.06	1.0± 0.00	1.7± 0.03	1.3± 0.23	1.2± 0.07	2.5± 0.41	2.1± 0.19	1.5± 0.11	1.4± 0.13	1.0± 0.00	1.6± 0.62	1.2± 0.02	1.0± 0.00	1.0± 0.00	1.1± 0.01	1.0± 0.00	1.1± 0.01
Pupa	6.2± 1.37	4.7± 0.03	3.8± 0.01	4.9± 0.09	4.3± 0.31	3.1± 0.98	3.3± 0.93	2.3± 0.17	2.4± 0.16	2.5± 0.32	1.1± 0.39	2.6± 0.17	2.2± 0.34	2.8± 0.43	2.1± 0.01	3.1± 0.11	2.4± 0.03	3.2± 0.03
Total Development	22.4± 0.67	20.1± 0.21	15.2± 0.01	17.3± 0.09	16.7± 0.64	17.5± 0.34	20.2± 1.46	18.2± 0.17	11.5± 0.39	15.8± 0.74	16.2± 0.41	17.1± 0.83	17.4± 0.82	16.1± 0.24	12.3± 0.61	15.3± 0.32	14.7± 0.64	16.8± 0.32
Adult male	38.2± 2.91	35.2± 0.91	26.3± 0.43	36.4± 1.43	34.8± 0.09	37.3± 1.86	19.2± 3.47	16.3± 0.37	16.8± 0.64	17.2± 0.11	16.1± 0.31	17.4± 0.99	17.6± 0.42	15.8± 0.17	13.6± 0.14	16.2± 0.51	15.6± 0.62	16.8± 0.61
Adult female	44.2± 1.9	40.2± 3.2	32.7± 0.07	41.9± 0.97	39.9± 0.87	43.4± 2.7	35.7± 0.14	28.4± 0.13	22.0± 0.00	30.0± 0.00	20.2± 0.61	32.9± 1.67	22.4± 0.91	19.8± 0.31	19.0± 0.00	18.0± 0.00	19.4± 0.37	21.3± 0.07

to the normal temperatures, elevated temperatures resulted in significant decrease of the lifestages. The adult beetles lived for more days in cooler months. Balikai et al. (2000), Sukla and Jadav (2014) observed similar life history in coccinellids.

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STINGLESS BEE *TETRAGONULA IRIDIPENNIS* AND HONEY BEE *APIS CERANA* POLLINATION IN CUCUMBER

Avinash Chauhan* and H K Singh

Department of Entomology, School of Agricultural Sciences and Rural Development
Nagaland University, Medziphema 797106, Nagaland, India
*Email: avi_shimla@hotmail.com (corresponding author)

ABSTRACT

Pollination in cucumber (*Cucumis sativus* L.) was studied using stingless bees, *Tetragonula iridipennis* Smith and honey bee, *Apis cerana* F. Data on the resource partitioning revealed the foraging activity of pollinators. Pollination efficiency index was observed to be maximum with *A. cerana* (24) followed by *T. iridipennis* (14), and significantly maximum fruit set (81.66 and 78.97%) was obtained with their pollination. An increase of 87.48% in fruit set, 46.47% in healthy fruits and 275.23% in seed numbers was noticed, with longer (17.85 and 17.22 cm) and heavier (0.415 and 0.411 kg) fruits in the *A. cerana* and *T. iridipennis* pollinated plots. Maximum number of healthy fruits was achieved with bee pollination as compared to open pollination and control, and *A. cerana* showed more mortality as compared to *T. iridipennis*.

Key words: *Tetragonula iridipennis*, *Apis cerana*, cucumber, pollination index, pollination impact, fruit set, fruit size, healthy fruits, seed number, seed weight

Honey bees, stingless bees and bumble bees are important pollinators often used for meeting the pollination requirements in different crops (Chauhan et al., 2013; Free, 1993; Mussen and Thorpe, 1995). The effectiveness of pollinator is ascertained by its pollination efficiency index (P.E.I.) (Chauhan et al., 2019) and most efficient pollinator carries and deposits plenty of pollen on stigmas as it moves from flower to flower (Kearns and Inuoye, 1997; Spears, 1983; Inouye and Pyke, 1988; Stubbs and Drummond, 1999; Dag and Kammer, 2001). All the cucurbit vegetables require pollinators for fruit set (Roubik, 1995). Cucumber is cultivated in all states of India, from temperate to tropical regions, and it is widely grown in all North Eastern states. The varieties grown are mainly monoecious and require pollination for better fruit yield and quality (Santos et al., 2008). Honey bees (*A. mellifera* and *A. cerana*) are used for managed pollination of crops in open conditions. These, when utilized under protected conditions, the results are not promising due to inability to orient in a small space and susceptibility to high temperatures sometimes resulting in loss of bee colonies. The stingless bees on the other hand have short flight range, easily orient on flowers under high temperature and do not sting workers. Recent studies have revealed that stingless bees are effective alternatives to honey bees for the pollination of many greenhouse crops. Keeping in view the enhanced use of stingless bees in pollination of different crops, present study evaluates the pollination potential of *T. iridipennis* in cucumber under protected conditions.

MATERIALS AND METHODS

The experiment was carried out on cucumber at the Experimental farm, AICRP Honey Bees and Pollinators, Department of Entomology, School of Agricultural Sciences and Rural Development (25.75961°N, 93.853698°E). All agronomical practices were done as per good agricultural practices with the crop sown in the last week of February 2019 at a spacing of 60 x 90 cm. The crop germinated and came to bloom in the first week of April, 2019. After that, two colonies of stingless bee, *T. iridipennis* were shifted in the caged plots at 5% flowering. Similarly, one colony of *A. cerana* having six frames was added to the other treatment. In control, the crop was not exposed to any pollination service. Resource partitioning (relative abundance) and foraging activity of stingless bees, honey bees and other pollinators (xylocopa, solitary bees, flies, beetles) was observed under open field conditions from early morning hours (0500 hr) till late evening (1700 hr) at 2 hr interval for ten days consecutively. The foraging activity (foraging rate/ speed and loose pollen grains) were observed as per the method adopted by Chauhan and Thakur (2014). Pollination Efficiency Index was worked out for each pollinator, using the formula given by Bohart and Nye (1960). To know the impact of different pollination treatments, the female flowers/ vine

were precounted. Ten plants from each treatment viz., stingless bee pollinated, *A. cerana* pollinated, control and open pollinated were selected and tagged randomly. The fruit set on these plants were then recorded and total yield was calculated on fruit set basis. The % healthy fruits and deformed fruits were computes from the data on fruit set. Ten representative fruit samples from each treatment were taken for calculating the fruit length, diameter, fruit weight, seed number/ fruit, weight of 1000 seeds. All these parameters were measured with the scale, digital Vernier caliper and digital weighing balance. Increase in production and quality parameters was also calculated along with decrease in deformed fruits.

RESULTS AND DISCUSSION

The main visitors of cucumber flowers were *A. cerana*, *A. dorsata*, *A. florea*, *T. iridipennis*, *T. laeviceps*, *Lophotrigona canifrons*, *Lepidotrigona ventralis*, *Halictus semiaerinus*, *Xylocopa tenuiscapa*, *Amagiella zonata*, *Megachile umbripennis* and *M. lanata* (Table 1). Honey bees are known as frequent visitors of cucumber flowers besides halictids and Xylocopinae (Thakur and Rana, 2008; Santos et al., 2008; Samoskorn et al., 2010; Chauhan and Thakur, 2014; Sawatthum et al., 2017). Grewal and Sidhu (1978) reported *A. florea, A. mellifera, A. dorsata* and *Bombus* sp. as main insect visitors of cucurbit crops. A total of 24 insect visitors were reported by Sajjanar et al. (2004) in cucumber with hymenopterans as major visitors. In ash gourd stingless bees and honey bees were the predominant pollinators in Nagaland (Chauhan et al., 2019). Resource partitioning studies revealed stingless and honey bees, and other pollinators like halictids, xylocopa bees, flies, beetles and butterflies as the major beneficiaries from cucumber pollen and nectar. All these insect visitors share the resources (pollen and nectar) for their development. Similar observations had been made by McGregor (1976); Kauffeld et al. (1978); Cervancia and Bergonia (1991); Stanghellini et al. (1997); Sajjanar et al. (2004); Hanh et al. (2014); Azmi et al. (2015); Sawatthum et al. (2017). These reveal that bees are the most frequent and beneficial visitors sharing the rewards with other insects from cucumber flowers (Table 1, 2).

Table 1. Insect visitors of cucumber flowers under open conditions

S. No.	Species visiting	N/ P/ N&P	Frequency of Occurrence
1	*Apis cerana*	N&P	M.F.V.*
2	*Apis dorsata*	N&P	M.F.V.*
3	*Apis florea*	N&P	F.V.
4	*Tetragonula iridipennis*	N&P	M.F.V.*
5	*Lophotrigona canifrons*	N&P	M.F.V.*
6	*Lepidotrigona ventralis*	N&P	F.V.
7	*Tetragonula laviceps*	N&P	M.F.V.*
8	*Episyrphus balteatus*	N	F.V.
9	*Mylabris pustulata*	P	F.V.
10	*Raphidopalpa foveicolis*	P	F.V.
11	*Halictus semiaerinus*	N&P	F.V.
12	*Musca sp.*	EFE	L.F.V.
13	*Xylocopa tenuiscapa*	N&P	M.F.V.
14	*Megachile lanata*	N&P	F.V.
15	*Megachile umbripennis*	N&P	F.V.
16	*Icaria guttatipennis*	N	F.V.
17	*Monomorium indicum*	N	M.F.V.
18	*Amagiella zonata*	N&P	M.F.V.

N- Nectar, P- Pollen, EFE- Extra flower exudation, MFV- Most frequent visitor, LFV- Less frequent visitor, FV- Frequent visitor

The activity of pollinators was more in the morning from 0500- 1100 hr which decreased in the noon. The relative abundance of *A. cerana* (11.58 bees/ 5 min) and *T. iridipennis* (10.92 bees/ 5 min) was found statistically at par in comparison to each other irrespective of time. The relative abundance of pollinators in morning time revealed higher nectar and pollen availability between 0700-1000 hr. Maximum activity of pollinators in ash gourd was between 0800-1000 hr (Chauhan et al., 2019), and in cucumber at 1000-1200 hr (Kishan et al., 2017). Similarly, Roopa (2002) observed the major peak of pollen and nectar foragers between 1000 to 1200 hr. Danaraddi (2007) observed the peak activity of *T. iridipennis* at 1000-1200 hr. The activities of stingless bee, *Scaptotrigona aff. deplis* and *Nannotrigona testaceicornis* was more on cucumber flowers in Brazil (Santos et al., 2008). Similarly, Singh and Chauhan (2020) observed stingless bees as the important pollinators of cucumber, and maximum activity of *T. iridipennis* was observed during morning and evening time in Kerala (Devanesan et al., 2002). However, it was observed that maximum numbers of flowers for pollen were visited in the morning time (Fidalgo and Kleinert, 2007). Foraging activity disclosed that honey bees have more pollination efficiency index (24.00) as compared to stingless bees (14.00) and other pollinators (3.00) (Table 2).

Significantly maximum fruit set (81.66 and 78.97%) was obtained with *A. cerana* and *T. iridipennis*) pollinated plots which is at par to each other, followed by open pollinated crop (72.00%) and pollinator excluded crop (42.12%), signifying the role of pollination in cucumber. Amano (2005) obtained maximum fruit set in cucumber using stingless bees, and it was found that honey bees are less efficient. Similarly, weight (0.415 and 0.411 kg) of fruits was observed significantly at par in the honey bee stingless bee pollination; and this is higher as compared to weight (0.386 kg) of fruits obtained in open pollination conditions and in control pollination (0.262 kg). The fruit

Table 2. Activity and pollination efficiency of pollinators in cucumber

Time (h)	Honey bees				Stingless bees				Other pollinators			
	*Relative abundance	Foraging rate	Foraging speed	Loose pollen grains	Relative abundance	Foraging rate	Foraging speed	Loose pollen grains	Relative abundance	Foraging rate	Foraging speed	Loose Pollen grains
0500	9.66 (3.11)	7.25	4.33		10.50 (3.24)	8.25	5.66		2.08 (1.44)	4.66	9.91	
0700	16.33 (4.04)	8.41	4.55		16.14 (4.02)	9.50	5.66		4.18 (2.04)	7.00	9.00	
0900	17.54 (4.19)	7.66	5.11		16.58 (4.07)	8.33	4.58		7.22 (2.69)	6.16	7.08	
1100	13.42 (3.66)	6.00	4.11		11.74 (3.43)	5.91	4.41		7.81 (2.79)	3.50	5.58	
1300	12.18 (3.49)	5.33	4.00	1720± 43	11.46 (3.39)	6.08	3.25	1290± 68	4.33 (2.08)	4.83	7.33	465± 71
1500	9.21 (3.03)	5.91	3.44		8.62 (2.94)	6.16	5.00		2.00 (1.41)	4.41	7.91	
1700	2.72 (1.65)	2.66	2.22		1.41 (1.19)	3.00	1.75		1.11 (1.05)	1.58	3.25	
Mean	11.58 (3.40)	6.17	3.97		10.92 (3.30)	6.75	4.33		4.10 (2.03)	4.59	7.15	
CD (p=0.05)	0.45	0.23	0.051		0.45	0.23	0.051		0.45	0.23	0.051	
Pollination Efficiency Index			24				14				3	

*Relative abundance= number of foragers/ 5 min/ m^2; Foraging rate= Number of flowers visited/ 5 min; Foraging speed= time spent/ flower (in seconds)

Table 3. Impact of modes of pollination on fruit quality and production in cucumber

Treatment	Fruit set (%)	Fruit diameter (cm)	Fruit weight (kg)	Fruit length (cm)	Healthy fruit (%)	Deformed fruits (%)	Number of seeds/ fruit	Weight of 1000 seeds (g)
**_Apis cerana_ pollination	81.66	10.11	0.415	17.85	81.12	18.88	402	32.08
*_Tetragonula iridipennis_ pollination	78.97	9.82	0.411	17.22	87.21	12.49	394	32.42
Open pollination	72.00	9.14	0.386	15.43	72.40	27.60	371	27.54
Pollinator exclusion (control)	42.12	6.64	0.262	8.68	59.54	40.46	105	16.64
CD (p=0.05)	4.54	1.12	0.29	0.95	6.66	2.61	6.94	0.18

* Stingless bee **honey bee

length was also found to follow the same trend. Azmi et al. (2017) in Malaysia and Tej et al. (2017) reported more fruit set, fruit length and fruit diameter in crop pollinated by stingless bees. Similar results were reported by Nicodemo et al. (2013) in cucumber crop pollinated by stingless bees. It is also observed that quality of fruits is increased by pollination using stingless bees (Heard, 1999). Singh and Chauhan (2020) also reported stingless bees as important pollinators of cucurbits. Similar results were reported in sweet pepper (Cruz et al., 2005) and in cucumber (Santos et al., 2008); stingless bee pollination gave significantly more healthy fruits (87.21%) and less deformed fruits (12.49%) were obtained followed by honey bee pollination (81.12 and 18.88%) and open pollination (72.40 and 27.60%). Significantly more deformed fruits (40.46%) were observed from pollination excluded plots (Table 3). Chauhan et al. (2019) reported less deformed fruits in stingless bee pollinated ash gourd. Likewise, Hodges and Baxendale (1991) reported less deformed fruits in bee pollinated cucumber vines and observed more deformed fruits otherwise. Chauhan and Thakur (2014) also reported less crooked fruits in cucumber when pollinated by bumble bees under protected conditions. Chauhan et al. (2019) observed better quality ash gourd fruits with healthy fruits when pollinated by stingless bees as compared to honey bees.

Significantly maximum seeds were produced in plots pollinated by honey bees (402) as compared to those by stingless bee (394) and open pollination (371). In contrast, seed weight of 1000 seeds was significantly more (32.42 g) in stingless bee pollinated crop (Table 3). Similar results were obtained in ash gourd (Chauhan et al., 2019), in green pepper (Santos et al., 2008), in chilli (Azmi et al., 2016), in tomatoes (Sarto et al., 2005) and in cucumber (Santos, 2004; Azmi et al., 2017) with stingless bee pollination under protected conditions. Impact of stingless bee pollination over control revealed an increase of 87.48% in fruit set, 46.47% in healthy fruits, 98.38, 47.89 and 56.87% in fruit length, diameter and weight. Reduction in deformed fruits (69.13 %) was also observed in stingless bee pollinated plants. The seeds number increased by 275.23% and an increase of 94.83% was reported on introduction of stingless bees as a pollinator of cucumber crop. Similarly, Azmi et al. (2017) reported with stingless bee pollination, the fruits were heavier and longer in cucumber. However, no significant differences were observed in seed weight. Likewise, in Australia, Occhiuzzi (2000) reported 11% increase in fruit weight and 34% in number of seeds/ fruit when sweet pepper was pollinated by *Trigona carbonaria* under greenhouse conditions. Viana et al. (2014) also observed more fruit and seed production in honey bee plus stingless bee pollinated apple crop. Similarly, Nunes-Silva et al. (2013) reported *M. fasciculata* as an efficient pollinator of eggplants which increased the fruit set by 29.50% in Brazil. Similarly, Rajasri et al. (2012) observed increased seed yield in sunflower with stingless bee pollination, and honey bee revealed more mortality (13%) as compared to stingless bees (5.1%). Thus, for effective pollination of cucumber under caged conditions *T. iridipennis* is more suitable than *A. cerana*. This is because, initially for acclimatization, *A. cerana* worker mortality was observed while in *T. iridipennis,* the mortality was very less. However, under open conditions, both pollinators can effectively pollinate the crop.

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DETERRENT ACTIVITY OF NATURAL PRODUCTS ON TWO SPOTTED SPIDER MITE *TETRANYCHUS URTICAE* KOCH

Sudeshna Thakur[1] and A K Sood*

CSK Himachal Pradesh Agriculture University, Palampur, 176062, Himachal Pradesh, India
[1]Email: thakursudeshna@gmail.com (corresponding author)

ABSTRACT

The feeding inhibition and oviposition deterrent activity of natural products were evaluated under laboratory conditions against *Tetranychus urticae* Koch. Mite feeding specks in the treatments varied from 61.3 to 428 at concentrations ranging from 0.625 to 40%. *Darekastra* and fermented buttermilk outperformed others to result in reduced number of feeding specks with increase in concentration. The feeding inhibition index for all the products was negative suggesting that these have varied level of inhibition. Cow urine, *Darekastra,* fermented buttermilk and *Tamarlassi* were found to effectively reduce the oviposition by mite. The oviposition deterrence index exhibited both attractiveness and repellent activity of natural products. Cow urine, *Darekastra* and fermented buttermilk proved as potent acaricides against *T. urticae* under both the deterrence parameters.

Key words: *Tetranychus urticae*, natural products, parthenocarpic cucumber, bioassay, feeding specks, deterrence, cow urine, *Darekastra*, fermented butter milk, *Jeevamrit*, *Panchgavya*, *Tamarlassi*, vermiwash

Approximately 1,305 valid described species of two spotted spider mites have been recorded and among them 10% are the phytophagous (Ivana et al., 2018; Santamaria et al., 2020). Amongst these, *Tetranychus urticae* Koch has worldwide distribution feeding upon >1200 plant species and is known to infest agricultural, horticultural and ornamental crops (Migeon and Dorkeld, 2019; Mitra et al., 2020). In Himachal Pradesh, *T. urticae* has been recognized as a major pest of greenhouse crops especially cucumber (Ghongade and Sood, 2019). At present, management of *T. urticae* is mainly based upon intensive use of acaricides which has threatened the environment health and has increased risk to human health too. An alternative approach to chemical pesticides is the use of natural products (derived from cow byproducts).

Natural products have proved effective against *T. urticae* both under laboratory and field conditions such as *Darekastra* comprising *Melia* leaves (Carpinella et al., 2003; Su et al., 2011), vermicompost extract (Edwards et al., 2010; Arancon et al., 2007), *Tamarlassi* (Thakur and Sood, 2019) etc. Most of these have two components, cow urine and cow dung, both of which are effective against the insect pests (Karkar et al., 2014). *Melia azedarach* has excellent insecticidal activity, repellence, feeding inhibition as well as growth regulatory activities (Sharma et al., 2014) which are attributed to the limonoids (meliarachins A-K), steroids, triterpenoids in *M. azedarach* (Wang et al., 2020). Vermiwash is composed of growth regulating compounds such as auxins, micronutrients, macronutrients, actinomycetes but is also known to exhibit acaricidal activity (Aghamohammadi et al., 2016). The advantage of using these relies on their cheapness, and poor farmers can afford. Also, no harmful residues are present since these are biodegradable, pose no health hazards to humans and non-target organisms and hold toxicity against major pests of greenhouse crop (Saleem et al., 2019). The present study focused on the evaluation of deterrent activity of these products against *T. urticae*. This study will validate the acaricidal property of natural products by screening them on two major parameters i.e., feeding inhibition and oviposition deterrence.

MATERIALS AND METHODS

Seven natural products namely; cow urine (fermented 15 days old from Indian cow), *Darekastra* (5 kg *Melia azedarach* leaves, 5 l cow urine, 2 kg cow dung, 100 l water), fermented butter milk (prepared from milk cultured for several days), *Jeevamrit* (1 kg cow dung, 1 l cow urine, 200 g jaggery, 200 g gram flour, 100 g local fertile soil, 20 l water), *Panchgavya* (5 kg fresh cow dung, 3 l cow urine, 2 l cow milk, 2 l curd, 1 kg desi ghee), *Tamarlassi* (fermenting butter milk in copper pot for minimum 15 days) and vermiwash (3 kg cow dung, 2 kg biomass, 200-300 adult earthworms layered into pitcher pot with water source. Earth worm secretion collected at bottom in a container

was evaluated for feeding and oviposition deterrence against *T. urticae* under laboratory conditions in the Department of Entomology, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur during 2016-17. These products were prepared freshly. *Tetranychus urticae* was cultured on French bean, *Phaseolus vulgaris* potted plants kept in insectary (25± 1^0C, 70± 5% RH and 16 hr photoperiod -16 L: 8D). Adults were allowed to oviposit for 24 hr and thereafter removed. Eggs were reared till adult emergence to get uniform age samples. The leaf disc bioassay method elaborated by Erdogan et al. (2012) was used. Leaf discs of 3.5 cm dia were excised from French bean apical leaves. Excised discs were dipped into concentrations of natural products (prepared by serial dilution) for 30 sec. These were air dried and placed onto wet sponge in abaxial position. Control was also set up by dipping leaf discs into water. Treated leaf discs were placed under controlled conditions (25±1^0C and 70± 5% RH).

Feeding inhibition offered by natural products was evaluated in terms of number of feeding specks. Adult females (n=10) released onto treated and untreated leaf discs were allowed to feed for 24 hr and removed thereafter. Numbers of white speck were counted under stereozoom miniscope. Reduction in feeding was calculated taking into account number of feeding specks in treatment and control. Feeding inhibition index was worked out using the equation:

$$\text{Feeding inhibition index} = \frac{\text{Number of feeding specks in treatment} - \text{Number of feeding specks in control}}{\text{Number of feeding specks in treatment} + \text{Number of feeding specks in control}} \times 100$$

Values of index vary from +100 (very attractive) to -100 (complete deterrence). Oviposition deterrent activity of natural products was evaluated in terms of number of eggs laid by *T. urticae* up to 96 hr of exposure duration (HED) on to treated leaf surface. Female mites (n=10) were released on treated and untreated leaf discs. Change in oviposition was calculated taking into account number of eggs in control and treatment. Oviposition deterrence index (ODI) was calculated as per Hang et al. (1982).

$$\text{Oviposition deterrence index} = \frac{\text{Number of eggs laid in treatment} - \text{Number of eggs laid in control)}}{\text{Number of eggs laid in treatment} + \text{Number of eggs laid in control}} \times 100$$

The value of index varies from +100 (very attractive) to -100 (complete deterrence). Experimental data was subjected to statistical analysis as per Gomez and Gomez (1984). Square root transformation was used for normalising data. Transformed data were subjected to factorial ANOVA in CPCS programme. Least significant difference test (LSD) was used to determine significance of data.

RESULTS AND DISCUSSION

Data pertaining on number of feeding specks produced on the leaf discs treated with varying concentrations of natural products was found to be significant (Table 1). Number of feeding specks varied significantly (p=0.05) for two products; cow urine and *Darekastra* at all the concentrations and were also least of all the products evaluated. Leaf discs treated with *Darekastra* and fermented buttermilk exhibited reduction in number of feeding specks with increase in concentration; values being significant only for *Darekastra*. An opposite trend was observed in for leaf discs treated with *Panchgavya* and *Tamarlassi* where feeding specks increased with increase in concentration. However, treatments did not differ significantly among each other. The remaining products such as cow urine, *Jeevamrit* and vermiwash did not show any definite trend in reduction of feeding specks with in concentration. The number of feeding specks in untreated check (UTC) remained significantly higher for all the treatments.

Reduction in mite feeding was found to be significant for cow urine, *Darekastra*, *Panchgavya* and vermiwash (Fig. 1). For cow urine treated leaf discs, reduction in feeding varied from 4.80 to 56.30%. However, no definitive trend was noticed but the reduction was highest under 10 and 20% concentration. *Darekastra* and fermented buttermilk treated leaf discs resulted in increased feeding reduction with concentration i.e., 53.71 to 91.24% and 15.76 to 26.14%, respectively, with maximum reduction being at 20%. However, *Panchgvaya* and *Tamarlassi* showed an opposite trend i.e decrease in feeding reduction varying from 71.73 to 23.03% and 58.79 to 48.03%, respectively; with increase in concentration. *Jeevamrit* and vermiwash exhibited in no definite trend in feeding reduction. The feeding inhibition index was found to be negative for all the evaluated natural products namely; cow urine (-2.48 to -39.22), *Darekastra* (-36.77 to -83.93), fermented buttermilk (-8.56 to -15.03), *Jeevamrit* (-19.44 to -29.57), *Panchgavya* (-13.33 to -56.05), *Tamarlassi*

Table 1. Feeding inhibition and oviposition inhibition by natural products on *T. urticae* adult females

Concen-tration (%)	No. of feeding specks produced on leaf disc after 24 hr of exposure duration (HED)							% change (- /+) in oviposition after 96 HED compared to untreated check						
	Cow urine	*Darekastra*	Fermented butter milk	*Jeevamrit*	*Panchgavya*	*Tamarlassi*	Vermiwash	Cow urine	*Darekastra*	Fermented butter milk	*Jeevamrit*	*Panchgavya*	*Tamarlassi*	Vermiwash
0.625	-*	-	-	-	-	146.6± 2.40 (12.1)[a]	-	- *	-	-	-	-	-34.05± 3.29 (35.64)[a]	-
1.25	315.3± 7.42 (17.7)[c]	245.0 + 2.89 (15.6)[e]	370.6± 11.84 (19.2)[b]	200.3± 5.49 (14.1)[bc]	-	150.0± 5.77 (12.2)[a]	-	-32.22± 3.48 (34.51)[a]	-19.01± 0.94 (25.83)[a]	-22.70± 3.30 (28.33)[a]	-12.31± 1.76 (20.45)[a]	-	-43.61± 3.83 (41.9)[b]	-
2.50	356.6± 9.61 (18.9)[cd]	214.0± 6.93 (14.6)[d]	350.0± 7.64 (18.7)[ab]	207.6± 4.33 (14.4)[bc]	157.6± 5.36 (12.5)[a]	175.0± 2.89 (13.2)[b]	250.0± 52.17 (15.8)[a]	-30.92± 5.45 (33.61)[a]	38.46± 4.70 (38.25)[b]	-26.70± 2.62 (31.04)[a]	-14.82± 1.84 (22.56)[a]	+3.96± 3.12 (9.64)[a]	-44.12± 2.85 (41.59)[b]	-8.28± 1.19 (16.63)[a]
5.00	379.3± 1.45 (19.5)[d]	174.3± 13.86 (13.2)[c]	347.0± 14.22 (18.6)[ab]	177.0± 4.36 (13.3)[a]	240.0 + 10 (15.5)[b]	185.0± 2.89 (13.6)[b]	351.3 + 53.99 (18.7)[bc]	-35.72± 0.78 (36.69)[a]	-39.30± 2.97 (38.78)[b]	-44.80± 2.46 (41.99)[b]	-22.06± 1.52 (27.98)[b]	+9.56± 5.24 (16.68)[a]	-48.94± 3.46 (44.38)[b]	-16.33± 1.03 (23.81)[b]
10.00	254.0± 42.25 (15.7)[b]	61.3± 1.86 (7.9)[b]	335.0± 14.43 (18.3)[ab]	191.3 + 4.67 (13.8)[ab]	272.3± 2.85 (16.5)[b]	185.0± 2.89 (13.6)[b]	375.3± 37.53 (19.4)[c]	-53.99± 6.87 (47.32)[b]	-39.60± 2.24 (38.97)[b]	-47.87 + 3.97 (43.76)[b]	-24.45± 1.34 (29.60)[b]	+53.36± 10.84 (46.93)[b]	-51.83± 3.50 (46.03)[b]	-18.58± 1.69 (25.48)[b]
20.00	174.0± 5.29 (13.2)[a]	46.3± 2.73 (6.8)[a]	325.0± 8.66 (18.1)[a]	219.6± 8.21 (14.8)[c]	409.0± 5.77 (20.2)[c]	-	337.6± 20.53 (18.4)[bc]	-54.42± 2.88 (47.53)[b]	-44.65± 3.54 (41.90)[b]	-50.85± 3.43 (45.47)[b]	-33.60± 4.34 (35.32)[c]	+46.82± 7.42 (43.12)[b]	-	-35.78± 2.99 (36.69)[c]
40.00	-	-	-	-	428.0± 32.62 (20.6)[c]	-	330.0± 40.41 (18.1)[b]	-	-	-	-	+56.89± 5.49 (48.99)[b]	-	-38.17± 2.84 (38.12)[c]
Untreated check	398.6 + 5.93 (19.9)[d]	530.0± 11.55 (23.1)[f]	440.0± 5.77 (21.0)[c]	325.6± 15.88 (18.1)[d]	559.6± 17.03 (23.6)[d]	356.0± 3.46 (18.8)[c]	433.0± 14.43 (20.8)[d]	- *	-	-	-	-	-34.05± 3.29 (35.64)[a]	-
CD (p=0.05)	(1.7)	(0.8)	(0.9)	(0.7)	(1.2)	(0.4)	(1.2)	(8.33)	(5.80)	(6.15)	(5.14)	(15.17)	(6.23)	(4.41)

Figures in parentheses $\sqrt{(x+1)}$ transformed values; *Concentration not evaluated; Figures in parentheses arc sine transformed values; No. of eggs laid by RSM adult females in UTC varied from 93 to 150; -ve : Reduction; +ve : Increase

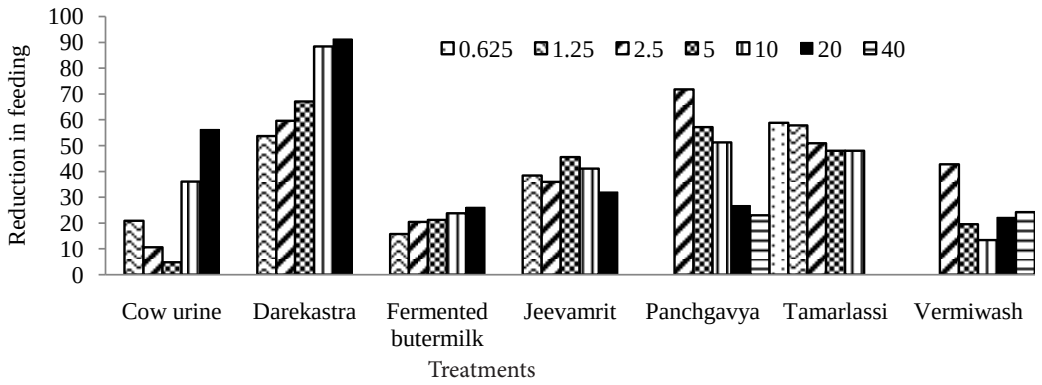

Fig. 1. Reduction in feeding of *T. urticae* adults due to natural products

(-31.61 to -41.66) and vermiwash (-7.14 to -26.79) which depicts that all the products offered varying degree of feeding inhibition. However, *Darekastra* proved to be highly effective and fermented buttermilk proved to be the least effective.

The feeding inhibition property of *Darekastra* can be attributed to the presence of components of *Melia* which are pesticidal in nature. The chinaberry tree *Melia azedarach* is prevalant in Himachal Pradesh and is known to contain triterpenoids (like meliacarpins) and limonoids (meliartenin) which act as antifeedant, repellent and growth regulator against insect herbivores (El-Wakeil, 2013). The mode of action of *M. azedarach* as suggested by Breuer et al. (2003) is that it acts upon NADPH-cytochrome c reductase and cholinesterase in insects. Also, the limonoids and triterpenoids compounds are known to induce apoptosis/ programmed cell death (Akihisa et al., 2013). Exposure to *Darekastra* treated leaves results in inappropriate feeding of insect resulting into increased mortality. Hammad et al. (2017) recorded *T. urticae* mortality of 45 and 34% when exposed to leaf and fruit aqueous extract of *M. azedarach*, respectively. About 70% mortality of *T. urticae* eggs, nymphs and adults was recorded at 72 hr of treatment (Mwandila et al., 2013).

Oviposition deterrence activity of natural products against *T. urticae* presented as % change in oviposition was found significant (p=0.05) for all treatments (Table 1). However, treatments did not differ significantly from each other. The negative values represent reduction in oviposition while positive indicates increase. Change in oviposition was found negative for products viz. cow urine, *Darekastra*, fermented buttermilk, *Jeevamrit*, *Tamarlassi* and vermiwash which depict their efficacy in reducing the egg laying capacity of *T. urticae*. Reduction in oviposition ranged from 30 to 60% but cow urine, *Darekastra*, fermented buttermilk and *Tamarlassi* led to maximum reduction. *Panchgavya* resulted in positive values ranging from +3.96 to +56.89% depicting it as an oviposition inducer. Thus, cow urine, *Darekastra*, fermented buttermilk and *Tamarlassi* outperformed others to reduce oviposition. Oviposition deterrence index ranged- for cow urine (-25.46 to +3.17), *Darekastra* (-4.10 to +19.70), *Panchgavya* (-27.45 to +23.61), vermiwash (-8.19 to +13.88) exhibiting both attractiveness and deterrence activity. Cow urine exhibited deterrence at maximum concentration (10%), *Darekastra* and vermiwash were the least attractive and *Panchgavya* exhibited attractiveness to mites at maximum concentration. Fermented buttermilk (-7.01 to -28.89), *Jeevamrit* (-1.28 to -16.80) and *Tamarlassi* (-22.27 to -34.97) offered oviposition deterrence at all the concentrations.

Cow urine is known to be effective against insect pests. The oviposition deterrence of cow urine is not known but insecticidal activity against Bihar hairy caterpillar *Spilarctia oblique* sprayed @10% (Geetanjaly and Tiwari, 2014), *Spodoptera litura* @20% (Naik and Tiwari, 2018), sorghum shoot fly, *Atherigona soccata* @5% (Mudigoudra et al., 2009) is documented. *Darekastra* also possess the oviposition deterrence that can be attributed to its composition and mode of action of *M. azedarach.* Reduction of > 50% in oviposition activity and an increased premature period of *T. urticae* were recorded by Ashrafju et al. (2014). Outcomes of our study will act as reference for the oviposition deterrent activity of fermented buttermilk, *Tamarlassi* and vermiwash against *T. urticae* as this has not been documented earlier.

For both the parameters (feeding inhibition and oviposition deterrence, *Panchgavya* exhibited opposite trend i.e. treated leaf discs resulted in more feeding specks and induced egg laying by *T. urticae*. The possible reason is that *Panchgavya* is used as nutrient

rich soil amendment containing higher quantity of macro and micronutrients like zinc, copper, manganese resulting into good soil health, increased microflora, plant growth, improved seed germination when used for seed treatment (Jain et al., 2013) and hence did not offer deterrence to the spider mite adults. This study clearly concludes that *Darekastra* offered excellent feeding inhibition against *T. urticae* but at the same time it resulted in oviposition deterrence along with cow urine and fermented buttermilk.

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POTENTIAL OF POLYMER MATRIX IN DELIVERY OF LEMON GRASS *CYMBOPOGON CITRATUS* STAPF ESSENTIAL OIL AGAINST HOUSE FLY *MUSCA DOMESTICA* L.

Senthoorraja R[1#], Subaharan K[#*], Deepak Kumar Patel[2], Vppalayam Shanmugam Pragadheesh[3, 4], Basavarajappa S[1] and N Bakthavatsalam

ICAR-National Bureau of Agricultural Insect Resources, H A Farm Post, Bellary Road, Hebbal, Bengaluru 560024, Karnataka, India
[1]Department of Studies in Zoology, University of Mysore, Mysore 570006, India
[2]CPMU, Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore 560064, India
[3]National Centre for Biological Sciences- TIFR, Bengaluru 560065, India
[4]CSIR- Central Institute of Medicinal and Aromatic Plants, Regional Centre, Bengaluru 560065, India
[#]Both the authors contributed equally to the work
*Email: Kesavan.Subaharan@icar.gov.in (corresponding author)

ABSTRACT

House fly *Musca domestica* L. is a pest of humans, poultry, and livestock across the world. Dependence on chemical insecticides to contain the flies provided varying results and their continued use has led to development of insecticide resistance. Bioactive compounds in plants are an alternative source to manage *M. domestica.* Lemon grass, *Cymbopogon citratus* Stapf essential oil caused fumigant toxicity to eggs (LC_{50} 1.299 mg/dm^3) and adults (16.56 mg/ dm^3). The *C. citratus* EO caused larval repellence. Polyvinylpyrrolidone when used as polymer matrix to load *C. citratus* at 1:1, 1:2, and 1:3 caused toxicity to flies for a longer period as compared to use of EO alone. The EO loaded in polymer matrix had a slower dissipation, EO+ PVP polymer mixed at 1:3 retained over 80% of EO after 72 hr when exposed to 60ºC. EO, whilst EO alone without a dispenser dissipated in 3 hr. The biological effect of *C. citratus* EO on *M. domestica* can be enhanced for a longer period if loaded into a polymer matrix and this would be an effective strategy to manage *M. domestica.*

Key words: *Cymbopogon citratus*, essential oil, fumigant toxicity, *Musca domestica*, polyvinyl pyrrolidone, polymer matrix, slow delivery, repellence activity, ovicidal toxicity, GC-MS

The house fly *Musca domestica* (L.), is a pest of medical and veterinary importance (Wang et al., 2019) transmitting pathogens that cause enteric diarrheal diseases (Chauhan et al., 2016; EL Zayyat et al., 2015). Indiscriminate use of chemical insecticide to manage flies leads to development of insecticide resistance, ill effects on non-target organisms and environmental contamination (Prado, 2003; Pavela et al., 2009). Biopesticides derived from plant parts are an alternative, as they are effective on target pests and safe to natural enemies, pollinators (Liu et al., 2000) and fit into the IPM measures (Koul et al., 2008). Derivatives from natural products termed as green pesticides (Benelli et al., 2019) include essential oils (EOs) that possess desirable qualities as a good pest control method (Benelli and Beier, 2017; Chellappandian et al., 2018). Essential oils are widely used as flavours and fragrances (Bakkali et al., 2008), antimicrobials (Dorman and Deans, 2000) and as pest control agents (Isman and Machial, 2006). EOs in addition to being a good candidate as insecticides also prevent the insects from developing insecticide resistance due to their complex mixtures of monoterpenes, sesquiterpene, hydrocarbons and their oxygenated derivatives (alcohol, aldehyde, and ketones) (Saad et al., 2013; Isman, 2017).

Essential oil derived from *Cymbopogon citratus* Stapf. (Oyedele et al., 2002) is widely used as flavour, fragrance and in aromatherapy (Shah et al., 2011). The major constituents of *Cymbopogon* spp. EOs are citral, geranial, citronellol, citronellal, geranyl acetate, geranyl formate and piperitone (Bhatnagar, 2018; Devi et al., 2020). Sinthusiri and Soonwera (2013) reported cidal and repellent properties of *C. citratus* against *M. domestica. C. citratus* EO alone or in combination with other oils was toxic to mosquitoes and house fly *M. domestica* L. (Sritabutra et al., 2011). The complex mixture in essential oils makes them an ideal candidate to mitigate the development of insecticide resistance (Feng and Isman, 1995). Essential oils are proven to have desirable

biological effect on insects, but the hurdle in field level use its quick physical loss due to evaporation (Isman, 2006; Koul et al., 2008) and chemical breakdown due to photo degradation and hydrolysis. This gap can be addressed by using a matrix that could prevent the loss of compounds. The plasticizers and stabilizers from polymers have been utilised in development of controlled release pesticide polymer formulations (Flemming et al., 2000; Roy et al., 2014: Ravindran et al., 2019b). Combining the essential oil and its constituents with polymeric matrix resulted in better spatio temporal release (Koul et al., 2018). The present study attempts to establish the fumigant toxic effect of *C. citratus* EO to eggs and adults and repellence to larvae of *M. domestica*. The efficacy of EO loaded in polymer matrix and its dissipation pattern are also discussed.

MATERIALS AND METHODS

The essential oil from *C. citratus* leaves (500 gm) was extracted by hydro-distillation for 8 h. The shade dried leaves were powdered and loaded into a round bottom flask with 500 ml of distilled water. The flask was placed over a heating mantle and the contents in the flask were raised to 100 ºC. The essential oil collected in the receiver tube and the aqueous portion was separated from oil using a separating funnel. It was passed over anhydrous sodium sulphate to remove the moisture trace and stored at 4 ºC until use. The *C. citratus*, EO was characterized using GC-MS as suggested by Ravindran et al. (2019a). Attenuated total reflection Fourier-transform infrared spectroscopy (ATR-FT-IR) was utilized for the identification of the functional groups present in polymer matrices. Perkin Elmer Premium HATR instrument with Germanium (Ge) crystal was used to acquire the FT-IR spectra. All the samples were dried prior to measurements. Lemon grass oil, Polyvinylpyrrolidone (PVP) and their physical mixture were placed over the sample plate. The IR spectra were obtained over a wave number region of 4000-400 cm^{-1} at room temperature. Functional groups possessed by each individual ingredient should be identical in their blend/mixture which confirms their compatibility.

The dissipation of EO loaded in PVP polymer matrix was assessed by loading 500 mg of EO along with 500 µl dichloromethane in Eppendorf tubes containing 500, 1000 and 1500 mg of PVP so as to achieve EO + polymer mix of 1:1, 1:2 and 1:3 ratio. The setup was placed on a heating platform maintained at 60ºC. Care was taken to check if there were temperature fluctuations. The entire setup was placed under fume hood and the weight loss of the contents in the tube was recorded by gravimetric method using a precision balance (Shimadzu) at 0.5, 1, 2, 3, 4, 6, 12, 18, 24, 36, 48, 60 and 72 hr after start of the assay. Three replicates were maintained for each concentration. The *M. domestica* were reared by the method suggested by Senthoorraja et al. (2020). The life stages of the flies collected from the rearing chamber were used in experiments.

The fumigant toxicity to *M. domestica* was done as suggested by Kumar et al. (2012). Briefly, 100 freshly laid *M. domestica* eggs were placed on a moist filter placed in a polypropylene container. The *C. citratus* EO was loaded on to 2x 2 cm filter paper at a concentration ranging from 0.3 - 36.61 mg/ l to assess ovicidal effect and concentration ranging from 7.32- 58.58 mg/ l to assess adult fumigant toxicity. The cap (with the filter paper) of the container was tightly sealed and placed in an incubator at 25± 2ºC and RH 65 ± 5%. Five replicates were maintained for each treatment. DDVP was used as positive control and acetone treated filter paper was maintained as negative control. Observations were made 3hrs after the start of the experiment to assess mortality of adults. The flies that ceased to move its appendages on a gentle prick with the pin were considered dead. In case of eggs exposed to EO and DDVP the per cent hatchability after 48 hrs were recorded to assess the ovicidal effect. Mortality if any in control was subjected abbot's correction prior to calculating the probit.

The toxicity of EO loaded in polymer matrix was assessed by mixing the EO (8 mg) with polymer Polyvinyl pyrrolidone at 1:1, 1:2 and 1:3 ratio (w/w basis). The constituents were mixed with 100 µl dichloromethane in an Eppendorf tube. This was mixture was then transferred to filter paper (2x 2 cm) and dried in fume hood for 10 min to facilitate the drying of the solvent from EO + polymer mix prior to use. These filter sheets loaded with the analyte and polymer were placed in the inner lid of the sample container as mentioned in previous section of fumigant toxicity. Batch of *M. domestica* eggs and adults were exposed to EO + polymer mix sheet 1 and 3 days after loading. Mortality of adults were recorded after 24 hr and the ovicidal effect after 48 hr. Filter paper loaded with EO alone (8mg) was used as positive control. In addition, the PVP treated filter and solvent treated paper were maintained as negative control.

The larval repellence to *C. citratus* EO was assessed by the method followed by Sinthusiri and Soonwera (2014). Insect breeding dishes (9x 4.5 cm) (Tarsons) base was divided to two halves and larval diet (2 g) treated with *C. citratus* oil at varied concentrations was

placed in one half and diet treated with acetone was maintained as control. Neem oil treated diet was used as positive control. The III[rd] instar larvae, 20 numbers per replicate, were released in the midline. The number of larvae in treated and untreated diet was recorded after 30 min to calculate the repellence. Five replications were maintained for each concentration.

The repellency percent was calculated by using the formula: Repellency %= (NC−NT)/(NC+NT) x 100; here, NC represents no. of larvae at control region and for NT, no. of larvae at treated region. Fumigant toxicity of eggs and adults was subjected to probit analysis to calculate the dose response and Chi-square values. The effect of EO loaded in polymer matrix was subjected to one-way ANOVA and post hoc test to compare the means.

RESULTS AND DISCUSSION

The major components present in *C. citratus* EO were citronellol (64.73%), geraniol (10.51%), linalool (5.24%), phenyl ethyl alcohol (4.82%), isopulegol acetate (2.91%), neryl acetate (1.10%), citronellal and 1,8 cineole (1.08%), limonene (1.00%), lavandulyl acetate (0.44%), and menthone (0.34%). The ATR-IR spectrum of PVP revealed the absorption band located around 1644 cm^{-1} and it can be ascribed to the stretching vibration of the C=O bond in the pyrrolidone group. In addition, the CH stretching modes can be assigned at 2944 cm^{-1}. The peak at 1415 cm^{-1} corresponds to the CH deformation modes from the CH_2 group. The peak at 3435 cm^{-1} is due to the O-H stretching. The absorption bands at 1263 cm^{-1} is due to the C–N stretching vibration from the pyrrolidone structure. The absorption bands of amines at around 3400–3500 cm^{-1} were not observed because PVP is a bi-substituted amide.

The physical mixture of the lemon grass oil and PVP gave a sharp peak in the ATR spectrum at 2932 cm^{-1} and 2857 cm^{-1} for –CH stretching due to the presence of alkane group in the structure. The Peak at 1420 cm^{-1} is due to C–H scissoring for the mono-substituted alkane group. A sharp peak at was observed 1058 cm^{-1} for strong C-O stretching which indicates alkyl aryl ether in the structure (Fig. 1). A strong C=O stretching at 1657 cm^{-1} might be a confirmatory peak for the ester group that corresponds to lemon grass oil. The peak at 1284 cm^{-1} was observed for the CN stretching due to the presence of an imine/oxime group. The physical mixture showed intact characteristic peaks of lemon grass oil and PVP, thereby indicating no particular interactions of the herbal oils with any excipient in the physical mixture.

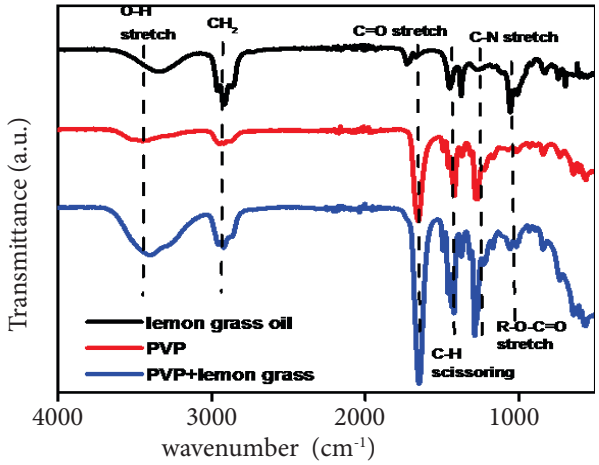


Fig. 1. FTIR spectra of EO, PVP and EO + PVP mix

ATR-IR spectrum of C. citratus EO oil exhibited a characteristic peak at 1710 cm−1 for the C=O stretching due to α, β-unsaturated ester. The broad peak at 3331 cm-1 is due to O-H stretching, sharp Peak at 2902 cm-1 and 2854 cm−1 is due to CH2 stretching, the sharp peak at 1441 cm−1, 1374 cm−1 is due to the C=C stretching. A peak at 1050 cm−1 for the R-O-C=O is observed.

Dissipation pattern of *C. citratus* loaded in PVP polymer matrix: *C. citratus* EO used as such without a carrier dissipates quickly as compared to EO loaded in a PVP polymer dispenser. More than 50 per cent of EO dissipated within 3 hrs from start of the run. The EO entrapped in PVP delivery matrix irrespective of the ratio in which they were blend caused controlled release of essential oil loaded in polymer matrix when exposed to temperature at 60 °C. Among the blends, EO + PVP polymer mixed at 1:3 was more effective in retaining over 80 % of EO even after 72 hr followed by 1:2 and 1:1 mix (Fig. 2). Higher quantum of PVP polymer in 1:3 ratio would have facilitated better cross linking of polymer with EO. This results in controlled release which would in turn facilitate in keeping its efficacy over a longer period

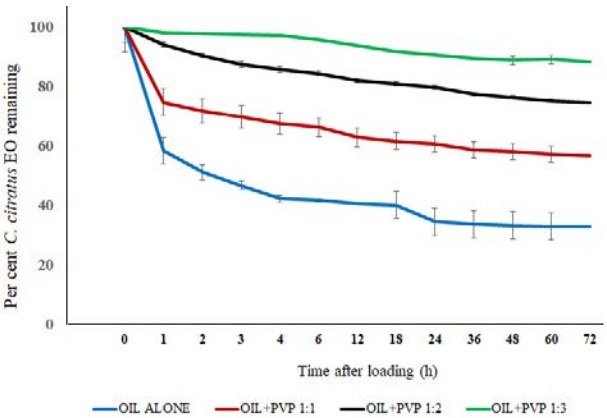


Fig. 2. Dissipation pattern of essential oil entrapped in PVP matrix

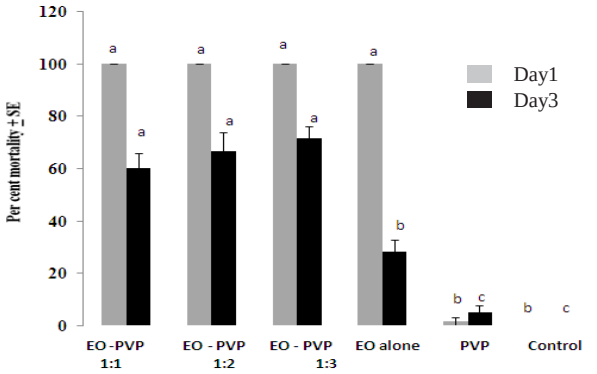
of time as compared to EO exposed as such without a delivery matrix. The dissipation pattern revealed that EO entrapped in PVP polymer matrix offers an appropriate dispensing mechanism for controlled delivery. Sweet basil oil and citridora oil loaded in poly vinyl alcohol sheets dissipated slowly as compared oil exposed as such without a dispenser (Ravindran et al., 2019a, b).

Fumigant toxicity: The quantum of *C. citratus* EO required to cause toxicity to adults (LC_{50} 16.56 mg/dm^3) was higher than to *M. domestica* eggs with LC_{50} at 1.299 mg/dm^3. The synthetic insecticide DDVP was highly toxic than *C. citratus* EO to both eggs and adults (Table 1). There are no earlier reports on fumigant toxicity of *C. citratus* EO on *M. domestica* eggs. Topical application of *C. citratus* caused less than 5% hatching inhibition (Sinthusiri and Soonwera, 2014). Pushpanathan et al. (2006) reported that *C. citratus* oil had ovicidal effect on *A. aegypti* and *C. quinquefasciatus*. A major constituent in *C. citratus* oil citral caused 96% inhibition of egg hatching in housefly (Rice and Coats, 1994). Targeting the non-motile stage like eggs is an easy method to eradicate the flies in poultry and livestock facilities.

These results on fumigant toxicity to adult *M. domestica* agree with those of fumigant toxicity of *C. citratus* to *M. domestica* (Kumar et al., 2012). Geraniol and 1,8 cineole present in *C. citratus* cause mortality of houseflies by inhibition effect of neuronal receptors with the symptoms ranging from hyperactivity, loss of balance and mortality (Chellappandian et al., 2018; Pavela, 2015; Pavela and Benelli, 2016). In our studies we observed that adults exposed to *C. citratus* EO caused uncoordinated movements and jitters prior to their death. The fumigant toxicity of *C. citratus* may be due to presence of 1, 8-cineole that is reported to be toxic to respiratory and digestive systems of adult mosquitoes (Pujiarti and Fentiyanti, 2017). The impact of *C. citratus* EO on intersegmental membranes of *M. domestica* and *An. stephesi* larvae was reported earlier (Chauhan et al., 2016; Mishra et al., 2017).

Though the chemical insecticide DDVP was effective against the biostages of flies (egg and adults) at an extremely low concentration as compared to *C. citratus*, they are highly toxic to non-targets and the applicators. Toxicity of EO loaded in PVP polymer matrix was assessed. Though *C. citratus* EO caused fumigant toxicity to eggs and adult of *M. domestica* there exists a hurdle in its use. EO when applied on surface is subjected physical and chemical degradation that reduces its field efficacy over a period. To tide over this gap, *C. citratus* EO was mixed with Polyvinyl pyrrolidone (PVP) polymer at 1:1,1:2 and 1:3 ratio and was compared with essential oil applied as such without any carrier. Exposure of eggs to filter paper treated with EO (LD_{90}) polymer mix showed that all the treatments on day 1 after exposure (essential oil alone and the EO polymer mix at various ratios) caused 100 per cent mortality. On day 3, the EO polymer mix at 1:3 caused higher mortality of eggs but was on par with other blends in causing ovicidal activity. EO when used without a carrier caused less than 40% egg mortality on day 3 which may be due to degradation of EO (Fig. 3). Similar trend was observed when EO polymer mix was used to assess the fumigant toxicity to adults. All the combination of EO+ PVP mix and EO alone caused 100% mortality on day 1. On day 3 all the EO Polymer mix at 1:1, 1:2 and 1:3 caused over 70% adult mortality, whilst the EO used without a carrier caused a lowest mortality of less than 40% (Fig. 4). PVP alone and control did not cause significant mortality of eggs and adults.

Larval repellence: Larval repellence on food treated



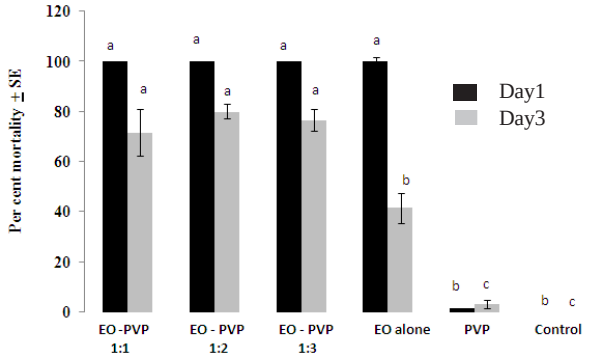
Means followed by same alphabet in a bar of given colour do not differ significantly by DMRT $p < 0.05$.

Fig. 3. EO + PVP mix toxicity on *M. domestica* eggs

Table 1. Fumigant toxicity of *C. citratus* against *M. domestica*

Bio stage	Treatment	LC_{50} (mg/ dm^3)	95% CI	LC_{90} (mg/ dm^3)	95% CI	df	Chi-square
Egg	*C. citratus* EO	1.299	0.810–1.891	13.23	8.354–25.281	5	8.64
	DDVP	0.215	0193 – 0.236	0.454	0.404 – 0.531	8	10.403
Adult	*C. citratus* EO	16.56	11.68-21.66	43.69	31.75-79.23	3	7.9644
	DDVP	0.125	0.094-0.157	0.36	0.27-0.56	6	6.143

CI- Confidence Interval; Df – Degree of freedom; p=0.05



Means followed by same alphabet in a bar of given colour do not differ significantly by DMRT $p < 0.05$

Fig. 4. EO + PVP mix toxicity on *M. domestica* adults

with *C. citratus* EO and neem oil revealed that EO at 0.5% caused maximum repellence of 74% but it was on par with EO at 0.3%. Across the doses tested EO caused higher repellence % as compared to neem oil tested at same dose. Both EO and neem at 0.3 and 0.5% caused more than 45% larval repellence (Fig. 5); *C. citratus* oil at 10% caused 87.93% oviposition repellency in house fly adults (Sinthusiri and Sonowera, 2014); *C. citratus* caused moderate repellence to house fly adults at 0.01µl/ cm^3. Kumar et al. (2012) reported substantial house fly repellency of mentha oil (RC84, 61.0 µg/ cm^2) followed by eucalyptus (RC84, 214.5 µg/ cm^2) and lemongrass (RC84, 289.2 µg/ cm^2) against house fly. The present study observed 74% repellency at 0.5% concentration in house fly at larval stage. It indicates lemon grass to be the strong repellent and it can be formulated as promising repellent for house fly management. Lemongrass oil is considered safer for human health than chemical insecticides and this oil has been traditionally used as tonic and carminative medicine in Thailand (Sinthusiri and Soonwera, 2013), and used to repel mosquitoes in jungle regions of Bolivian Amazon (Nerio et al., 2010). Magierowicz et al. (2020) reported that *C. citratus* oil

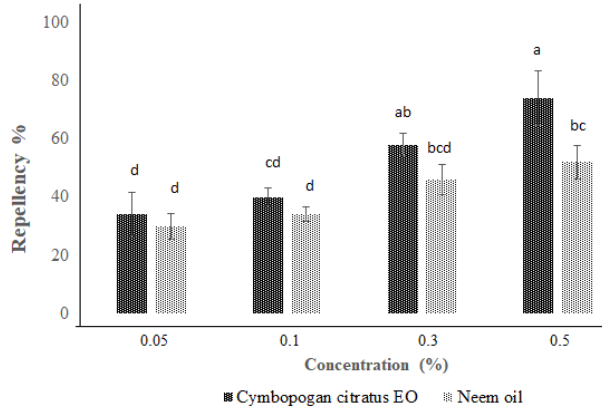


Fig. 5. Larval repellency of *C. citratus* on *M. domestica*

was non-effective as repellent on *Acrobasis advenella* (Zinck.), but from the current study it shows 74% repellent against house fly larva.

Citral and 1,8-cineole are major components of *Cymbopogon citratus* (lemongrass) which was responsible for the insecticidal activities against house fly have been reported in earlier studies (Kumar et al., 2012). The direct impact of essential oils and their components on mortality, secondary impacts are important in the development of fertility, repellency and anti-feedancy, as well. Lethal doses of citrus oils, applied to mature house flies, reduced the number of eggs delivered in a ratio of 50% per single female. In addition, repellency the secondary impacts may play a role in reduction of insect population (Pavela et al., 2009). *Cympopogon citratus* EO is an effective alternative to chemical insecticides in *M. domestica* management as it possesses fumigant toxicity, larval repellency and are safe to non-targets and environment. The pitfall in use of essential oil is its quick degradation. Loading them in a polymer matrix aided to overcome the problem as they caused sustained release of *C. citratus* EO. The polymer matrix loaded with EO is an ecofriendly technology for house fly management and can be adopted with ease.

ACKNOWLEDGEMENTS

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ECOFRIENDLY MANAGEMENT OF RUGOSE SPIRALLING WHITEFLY *ALEURODICUS RUGIOPERCULATUS* MARTIN INFESTING COCONUT

M Alagar*, V Sivakumar, S Praneetha, K Chinnadurai, A Josephrajkumar[1] and H P Maheswarappa[2]

Coconut Research Station, Tamil Nadu Agricultural University,
Aliyarnagar 642101, Tamil Nadu, India
[1]ICAR-Central Plantation Crops Research Institute, Regional Station,
Kayamkulam 690533, Kerala, India
[2]ICAR-Central Plantation Crops Research Institute, Kasaragod 671124, Kerala, India
*Email: siaamalagar@gmail.com (corresponding author)

ABSTRACT

Studies were conducted on the incidence, intensity of infestation, infestation grade index and natural enemy complex of rugose spiralling whitefly (RSW) *Aleurodicus rugioperculatus* Martin infesting coconut palms so as to evolve ecofriendly IPM. RSW incidence was at peak in June 2018 (38.3%), subsequently declined in December 2018 (20.5%), but later attained peak again in March 2019 (47.5%). The pest intensity also showed increasing trend from January 2018 to June 2019. The mean intensity of infestation and infestation grade index were 29.5% and 1.5 (medium), respectively in 2018-2019. The incidence and intensity significantly reduced from 75.5 to 37.7% and 85.7 to 42.9%, respectively on palms treated with ecofriendly IPM practices in 2018-19. Nut yield and net return were also found more in synergy with maximum parasitism (78.5%) by the aphelinid parasitoid *Encarsia guadeloupae* Viggiani observed on palms treated with ecofriendly IPM practices.

Key words: Coconut, *Aleurodicus rugioperculatus*, seasonal incidence, intensity, infestation grade index, IPM, biological pest suppression, *Encarsia guadeloupae*, parasitism, ecofriendly IPM

Rugose Spiralling Whitefly (RSW) *Aleurodicus rugioperculatus* Martin (Hemiptera: Aleyrodidae), first described from Belize (Martin, 2004) is a polyphagous, small, sap sucking, phloem feeder belonging to the order Hemiptera. The nymphs and adult whiteflies feed from the under surface of the palm leaflets by inserting the pointed stylets. This pest is considered serious by its extensive feeding habit that led to the excretion of abundant honey dew which subsequently gets deposited on the upper surface of the leaves down beneath and also on other under storey crops. In case of severe attack, egg spirals could be located on leaf, petiole as well as on tender coconuts. Honey dew excrement, being sweet and watery, attracts ants and develop sooty mould rapidly, which disrupts the normal leaf physiology and exacerbates its invasive potential. This exotic whitefly pest was reported from Miami-Dade County, Florida, in March 2009 (Stocks and Hodges, 2012). In India, this pest was reported from different locations of Coimbatore district, Tamil Nadu and Palakkad district, Kerala during July-August 2016 on coconut (Sundararaj and Selvaraj, 2017; Srinivasan et al., 2016; Selvaraj et al., 2016) and also from other parts of the country (Chalapathi Rao et al., 2018; Chandrika Mohan et al, 2016; 2017). RSW feeds on a broad range of host plants including palms, woody ornamentals and fruit trees (Mannion, 2010; Elango and Jeyarajan Nelson, 2019; Alagar et al., 2020). The present study focuses on evolving measures for its ecofriendly IPM through assessment of pest intensity, infestation grade index and natural enemy complex.

MATERIALS AND METHODS

The study was done during 2018-19 and 2019-20 at the Coconut Research Station, Aliyarnagar (10.49201^{0}N, 76.9033^{0}E), Tamil Nadu Agricultural University, Tamil Nadu, India. The observations were made at monthly intervals in the three gardens having 15 years old Chowghat Orange Dwarf (COD) and Kenthali Dwarf (KTD) palms. Five palms were randomly selected in each garden and incidence and intensity of damage were assessed through counts of eggs, nymphs and adults; infestation grade index; and occurrence of predators and parasitism by *Encarsia guadeloupae* Viggiani (Hymenoptera: Aphelinidae). The infestation was observed as % of leaves infested, and the intensity

assessed from four infested leaves/ fronds/ palm from outer/ middle whorl representing four directions (No. of leaflets infested/ fronds/ total leaflets/ frond x 100). Five leaflets from the observed leaf samples were brought to laboratory for the assessment of life stages of pest and natural enemies (20 leaflets/ palm and total of 100 leaflets/ plot). The infestation grade index was recorded with grading index methodology developed by Srinivasan et al. (2016) as follows: Adults nil, no sooty mould - Grade 0, Category Nil, Infestation grade index (IGI) 0.0; < 10 adults/ leaflet with sooty mould in 5- 6 lowermost fronds- Grade 1, Category low, IGI -0.01 to 1.0; 10-20 adults/ leaflet with sooty mould in 10-12 fronds- Grade 1, Category medium, IGI-1.01 to 2.0; >20 adults/ leaflet; sooty mould encrustation in >12 fronds- Grade 3, Category- high, IGI- 2.01 to 3.0. A minimum of 20 palms were randomly selected in a garden in diagonal fashion and categorized. Infestation grade index was arrived as given below to categorize the gardens as low/ medium/ highly infested.

$$IGI = \frac{\text{(No. of palms under Scale 0 x 0) + (No. of palms under Scale 1 x 1) +…. + (No. of palms under Scale 3 x 3)}}{\text{Total no. of palms observed}}$$

Surveys were conducted to assess the natural enemies complex and IGI at the Coconut Research Station, Aliyarnagar and nearby 20 villages viz., Kottur, Malayandipattinam, Angalakurichi, Puliyankandi, Pongaliyur, Kaliayapuram Sangampalayam, Aval Chinnampalayam, Pil Chinnampalayam, Somandurai chittur, Thenchittur, Ramanamuthali pudur, Manchanayaganur, Duraiyurmedu, Kammalapatti, Sungam, Pethanayanur, Sethumadai, Odaiyakulam and Devipattinam. The collected coconut leaf samples were observed under the microscope and the parasitized nymphs and exit holes on the pupae were counted. Infested leaflets collected were kept in the laboratory for the emergence of the parasitoid. The circular exit holes of parasitoid emergence were counted under stereozoom microscope to assess the rate of parasitism. The parasitised nymphs were black whereas, the unparasitised nymphs were pale yellow, and % parasitism was worked out.

Ecofriendly IPM practices formulated under AICRP (Palm) cell, ICAR- Central Plantation Crops Research Institute (CPCRI), Kasaragod, Kerala were evaluated on selected 50 palms of 15 years old COD variety which is relatively more susceptible to RSW. Fifty palms were maintained as untreated control. The treatments include: installation of light traps @ 5/ ha, fixing yellow sticky trap sheets @ 25/ ha, spraying three rounds of 0.5% neem oil at 15 days interval on the under surface of leaves, three rounds of jet water spray at 10 days interval about 15 days after spraying of neem oil and stapling of leaflets containing, *E. guadeloupae* parasitised puparia on palm leaflets. In control palms, all cultural operations were followed except for imposition of treatments. The RSW incidence (%), intensity, IGI, number of eggs, nymphs, adult, predators, parasitism by *E. guadeloupae* before and after IPM measures were recorded. Student't' test was used for analyzing the data.

RESULTS AND DISCUSSION

The results showed that the RSW incidence declined after the receipt of south west monsoon showers and it was at its least (20.5%) in December 2018; however it reached a peak (47.5%) during March 2019; intensity of infestation and the IGI also decreased after the onset of monsoon. Maximum parasitism by *E. guadeloupae* was observed in December 2018 (70.5%); between April 2019 and March 2020, incidence was at its peak (60.2%) in June 2019, and after initiation of monsoon, it declined (20.3%) in November 2019, and reached a peak (45.5%) during June 2019, which subsequently declined to 22.7% in December 2019. Maximum parasitism by *E. guadeloupae* (84.6%) was observed in December 2019 (Table 1).

Surveys on the natural enemy complex in the infested coconut gardens at Pollachi, Tamil Nadu revealed the occurrence of predators *Jauravia pallidula* Motschulsky (Coccinellidae: Coleoptera) and *Pseudomallada astur* (Banks) (Chrysopidae: Neuroptera) and the aphelinid parasitoid *E. guadeloupae* as well established ones. Parasitism by *E. guadeloupae* ranged from 40.4 to 82.5%, with a maximum (82.5%) at the Coconut Research Station, Aliyarnagar. Predators like *Chrysoperla zastrowi sillemi* (Esben- Petersen), *Mallada boninensis* (Navas), *Chilocorus nigrita* (F.), *Coccinella transversalis* (F.), *Menochilus sexmaculatus* (F.), *Propylea dissecta* (Mulsant), *Scymnus nubilis* (Mulsant), *Scymnus saciformis* (Mots.) and *Oecophylla smaragdina,* (F.) were also observed in the infested gardens at Pollachi North, and South and Anaimalai taluks of Coimbatore district. Similar results were reported from Kerala and Andhra Pradesh (Josephrajkumar et al., 2016; Shanas et al., 2016; Krishnarao and Chalapathi Rao, 2019). The aphelinid parasitoid *E. guadeloupae* and the chrysopid predator *P. astur* were the predominant natural enemies. The

Table 1. Seasonal incidence of RSW and its natural enemies in coconut (2018-19 & 2019-20)

Months	Incidence of RSW (%)	Intensity of RSW (%)	Infestation grade index	Live colony/ four leaflets/ palm			Predators/ four leaflets/ palm	Parasitisation by *E. guadeloupae* (%)
				Eggs	Nymphs	Adult		
2018-19								
June 2018	38.3	50.7	1.3	50.2	26.5	12.2	0.2	25.7
July 2018	32.2	40.7	0.9	42.5	38.7	10.5	0.5	35.5
August 2018	29.2	28.5	0.8	27.2	52.5	7.2	0.5	23.5
September 2018	25.7	24.8	0.8	8.3	3.4	4.5	0.7	50.8
October 2018	24.4	23.5	1.0	40.5	32.5	6.5	0.9	60.3
November 2018	21.5	25.3	1.2	27.2	52.5	7.2	0.5	52.8
December 2018	20.5	20.8	1.3	42.5	38.7	10.5	-	70.5
January 2019	32.5	20.7	2.4	50.2	26.5	12.2	0.5	48.8
February 2019	41.8	25.5	2.5	42.5	54.5	15.8	0.7	69.5
March 2019	47.5	34.9	2.7	37.8	48.5	20.5	0.4	60.5
Mean ± SE	31.3± 2.7	29.5± 2.9	1.5± 0.2	36.9± 3.8	37.4± 4.8	10.7±1.4	0.5± 0.1	49.9± 5.0
2019-20								
April, 2019	50.5	35.8	1.2	40.2	21.2	9.8	0.2	30.8
May, 2019	55.7	40.5	1.5	34.0	31.0	8.4	0.6	42.6
June, 2019	60.2	45.5	1.4	21.8	42.0	5.8	0.6	28.2
July, 2019	50.8	40.2	1.0	6.6	2.7	3.6	0.8	61.0
August, 2019	48.3	37.4	0.8	32.4	26.0	5.2	1.1	72.4
September, 2019	32.5	33.2	0.8	21.8	42.0	5.8	0.6	63.4
October, 2019	25.2	28.5	1.0	34.0	31.0	8.4	0.8	42.6
November, 2019	20.3	25.2	0.8	21.8	42.0	5.8	0.2	30.8
December, 2019	21.4	22.7	0.5	34.0	31.0	8.4	0.6	84.6
January 2020	22.5	25.2	0.7	34.0	38.5	18.5	0.8	70.5
February 2020	28.7	30.2	1.5	35.2	48.7	25.7	0.5	65.2
March 2020	35.3	33.4	2.0	35.2	60.7	38.4	0.6	42.5
Mean± SE	37.6±4.0	33.2± 1.9	1.1± 0.1	29.3± 2.6	34.7± 4.1	12.0± 2.9	0.6± 0.1	52.9± 5.2

*Mean of three trials, Mean ± standard error

ecofriendly IPM measures adopted during 2018-19 revealed that the RSW incidence significantly reduced from 75.5 to 37.7%, with intensity reducing from 85.7 to 42.9% on treated palms; in the untreated control palms, it increased from 64.2 to 80.2% and 80.5 to 95.5%, respectively. Similarly, the live colonies of eggs, nymphs and adults also significantly reduced. All the parameters except IGI and occurrence of predators significantly differed as compared to natural control in the post treatment observations.

Similar decreasing trend of incidence and intensity was observed during 2019-20 as well, and with IPM practices it was significantly reduced from 56.6 to 28.3%, with intensity of 64.3 to 32.2% and the IGI also significantly reduced from 1.7 (medium) to 0.8 (low). The IGI was observed to be subdued in control plots owing to the reduced treatmental disturbances, which subsequently enhanced the parasitic potential of *E. guadeloupae* marginally up to 56.6% (Table 2). The natural control as exhibited in control plots led to declining incidence, intensity and IGI even in comparison to the IPM practiced plots. Comparison between intensity of infestation and parasitism by *E. guadeloupae* revealed that the intensity reduced from 85.7 to 42.9% in treated palms compared to control palms (in which it increased from 80.5 to 95.5%. The parasitism by *E. guadeloupae* also increased from 43.2 to 70.2% in the IPM practiced plots, whereas it increased marginally from 50.5 to 61.5% in control plots. During 2019-20, the intensity of infestation reduced from 64.3 to 32.3% in the IPM practiced plots compared to control plots, and parasitism by *E. guadeloupae* increased from 32.4 to 78.5% (IPM plots) and 37.9 to 56.6% (control plots). This indicated faster reduction in intensity of infestation also coupled with enhancement in parasitic potential by *E, guadeloupae* when IPM is practiced. These results indicate that the palms that received ecofriendly IPM practices along with parasitism by *E. guadeloupae* suppressed the RSW infestation to a significant level. These results are in accordance with the research outcome emerged from Kerala and

Table 2. Efficacy of ecofriendly IPM against RSW and yield/ economics in in coconut (2018-19 & 2019-20)

Treatments	2018-19															
	Pre-treatment								Post-treatment							
	Incidence (%)	Intensity (%)	Live colony			Infestation Grade Index	Predators (No./ Palm)	Parasitisation (%)	Incidence (%)	Intensity (%)	Live colony			Infestation Grade Index	Predators (No./ Palm)	Parasitisation (%)
			Egg	Nymph	Adult						Egg	Nymph	Adult			
T1-Eco friendly pest management	75.5	85.7	22.5	30.2	12.4	2.2	0.8	43.2	37.7	42.9	11.3	15.1	6.2	1.1	0.4	70.2
T2-Natural control	64.2	80.5	25.5	32.5	10.1	2.5	0.5	50.5	80.2	95.5	31.9	40.6	12.7	2.5	0.6	61.5
Significance (p= 0.1)	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	*	*	*	*	*	*	N.S.	N.S	*
't' value	0.6	0.1	0.7	0.2	0.004	0.2	0.3	6.2	6.2	4.5	0.001	2.3	0.1	1.3	0..5	6.5
2019-20																
T1-Eco friendly pest management	56.6	64.3	16.9	22.7	9.3	1.7	0.6	32.4	28.3	32.2	8.5	11.3	4.7	0.8	0.3	78.5
T2-Natural control	48.2	60.4	19.1	24.4	7.6	1.9	0.4	37.9	60.2	71.6	23.9	30.5	9.5	1.0	0.5	56.6
Significance (p= 0.1)	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	*	*	*	*	*	*	N.S.	N.S	*
't' value	0.6	0.1	0.7	0.2	0.004	0.2	0.3	6.2	6.2	4.5	0.001	2.3	0.1	1.3	0..5	6.5

Treatments/ year	Pretreatment					Post-treatment				
	Yield (No. of nuts/ha)	Cost of Cultivation (Rs/ ha)	Gross return (Rs/ ha)	Net return (Rs/ ha)	BC ratio	Yield (No. of nuts/ha)	Cost of Cultivation (Rs/ ha)	Gross return (Rs/ ha)	Net return (Rs/ ha)	BC ratio
2018-19										
Ecofriendly IPM	10,726	65,245	1,44,801	79,556	1:2.2	12,975	71,245	1,75,163	1,03,918	1: 2.5
Natural control	11,245	67,152	1,51,808	84,656	1:2.3	10,726	67,542	1,44,801	77,259	1:2.1
2019-20										
Ecofriendly IPM	12,975	71,245	1,75,163	1,03,918	1: 2.5	15,916	71,245	2,14,866	1,43,621	1:3.0
Natural control	10,726	67,542	1,44,801	77,259	1:2.1	10,726	65,124	1,44,801	79,677	1:2.2

Andhra Pradesh (Josephrajkumar et al., 2016; Shanas et al., 2016; Krishnarao and Chalapathi Rao, 2019). Enhancement in nut yield and better economics was realized from ecofriendly IPM, and the benefit cost ratio was 1:2.2 before treatment increased to 1:2.5 and 1:3.0 after the treatment during 2018-19 and 2019-20, respectively. In control plots it was 1:2.3 at the start of the experiment, which got slightly reduced to 1:2.1 during 2018-19 and 1:2.2 during 2019-20 (Table 2).

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REPELLENCY OF PLANT ESSENTIAL OILS TO KEY COLEOPTERAN STORED GRAIN INSECTS OF RICE

Naveenkumar B Patil*, Basana Gowda G, Totan Adak, Guru Pirasanna Pandi G, Mahendiran Annamalai, P C Rath and Mayabini Jena

Crop Protection Division, ICAR-National Rice Research Institute, Cuttack 753006, Odisha, India
*Email: patil2850@gmail.com (corresponding author)

ABSTRACT

Laboratory studies were conducted to assess the repellant effects of three essential oils from plants viz., orange, eucalyptus and cinnamon oils against four major coleopteran stored grain insect pests of rice viz., *Sitophilus oryzae, Oryzaephilus surinamensis, Rhyzopertha dominica,* and *Tribolium castaneum.* The % repellency (PR) and index of repellency (RI) were observed to range from 10 to 100% and 0.00 to 0.90, respectively. Eucalyptus oil @ 5% showed maximum repellent action against *Tribolium castaneum,* registering PR and RI values of 93.33 (F=0.921), 100 (F=1.66), 100 (F=3.772) and 0.07, 0.00 and 0.00, respectively at 3, 6 and 12 hrs after treatment and were found significantly superior over rest of the treatments. Chemical profiling of tested oils through GCMS showed presence of 2- 3 chemical constituents amounting to >90 % of total composition of oil. The results highlight the repellency effects of the essential oils and indicate that these can be ecofriendly ones for the post-harvest protection of rice.

Key words: Orange, eucalyptus, cinnamon oils, *Sitophilus oryzae*, *Oryzaephilus surinamensis*, *Rhyzopertha dominica*, *Tribolium castaneum*, rice, index of repellency, % repellency, GCMS

In India, stored product insect pests in cereals, pulses and oilseeds cause severe post-harvest losses in the range of 3.9-6.0%, 4.3-6.1% and 2.8-10.1%, respectively (Dhingra, 2016). Amongst these pests, the most important and common are the coleopterans attacking stored rice and their products, viz., *Sitophilus oryzae* L., *Oryzaephilus surinamensis* (L.), *Rhyzopertha dominica* (F.) and *Tribolium castaneum* (Herbst). Management of these depends mostly on the use of fumigants and persistent insecticides. Although effective fumigants like phosphine or methyl bromide (only quarantine treatment) are available to manage stored grain insect pests, but substantial increase in awareness of their ill effects viz., toxicity to non-targets, pesticide residues and environmental pollution is noticed in recent days (Benhalima et al., 2004; Collins et al., 2005; Haririmoghadam et al., 2011). Aromatic essential oils of plant origin are promising alternative to insecticides in protecting the post-harvest produce and are traditionally been used to kill or repel stored-grain insects (Isman, 2006). These are better alternative to conventional insecticides due to their low mammalian toxicity and high volatility (Shaaya et al., 1997; Li and Zou, 2001). Basically, these are volatile in nature; their secondary metabolites are characterized by a strong aroma and having density lower than water (Bakkali et al., 2008). It has been well established that products of biological origin are reported to have useful insecticidal compounds against insect pests (Arthur, 1996). Recently, these essential oils have been recognised as pesticides (Isman et al., 2011). Essential oils are considered insecticides because they are selectively bioactive, have little or no harmful effects on non-target organisms and environment (Dong et al., 2004; Kestenholz et al., 2007; Regnault et al., 2012). In this study, repellent activity of three plant essential oils viz., orange (*Citrus sinensis* L.), eucalyptus (*Eucalyptus obliqua* L'Her) and cinnamon (*Cinnamomum verum*) oils are evaluated against stored grain insect pests of rice viz., *S. oryzae, T. castaneum, O. surinamensis* and *R. dominica* under laboratory conditions.

MATERIALS AND METHODS

The samples of *S. oryzae, T. castaneum R. dominica* and *O. surinamensis* were collected from rice storage godown of ICAR- National Rice Research Institute (NRRI), Cuttack and were maintained in the Grain Entomology laboratory (28± 2°C; 65± 5% RH). Initially, 50 pairs of freshly emerged adults were placed in a jar containing rice grains (0.5 kg). The open end of jars were covered with muslin cloth and allowed for 7 days for mating and oviposition. Then parental stocks were removed and the left over content of each jar (freshly laid eggs and rice grains) were allowed for further

multiplication and insects were collected and reused for subculturing. The subsequent progenies (adults) were used for bioassays. For the bioassay, commercially available eucalyptus, orange and cinnamon oils were obtained from commercial suppliers (NICE Chemicals Private Limited, India). For chemical characterization, the tested plant essential oils (2 µl) were dissolved in Hexane (HPLC grade) and were analyzed using GC-MS (Jeol GC mate) system following Thanigaivel et al. (2017). The molecular weight/ formula and structure of the compounds of test materials were ascertained by interpretation on mass spectrum of GC-MS using the database of the National Institute of Standards and Technology (NIST).

'Area preference method' in a completely randomized design was used to assess the repellent effects of essential oils (Obeng- Ofori et al., 1998) during 2017-2018. Preparation of test solutions (@ 1, 2 and 5 %) was done by dissolving essential oils in acetone (AR grade). Half cut filter paper (diameter 9.0 cm, Whatman No.1) was dipped in 1.0 ml of the respective test oil while, remaining half was dipped in 1.0 ml acetone which served as control. Both halves were allowed for solvent evaporation. All treatment and control halves were attached together on 9 cm glass petridishes using adhesive tape from bottom of filter paper. Three replicates were maintained for each concentration of oil. Test insects (20 No) were released at the centre of each filter paper disc and were then covered and sealed using para films. Petridishes were kept under dark at 26^0C and 65± 5%RH. The number of adults on the treated and untreated sides were counted at 3, 6, 12 and 24 hr after treatment, with the experiment repeated twice. Effectiveness of plant essential oil was evaluated by Percent Repellency (PR) and Repellency Index (RI) using the formula PR (%) = [(Nc − Nt)/ (Nc + Nt)]x 100 (where, Nc- no. of insects in untreated side, Nt- no. of insects in treated side as per Nerio et al., 2009). Ranges of PR values and their categories used are: 0-0.1%: Class 0; 0.1-20%: Class I; 20.1-40%: Class II; 40.1-60%: Class III; 60.1-80%: Class IV; 80.1-100%: Class V (Tapondjou et al., 2005). Repellency index was calculated by using RI= 2G/ (G+P) as per Mazzonetto (2002), wherein G= number of insects in treated side and P= number of insects in untreated side. RI values ranges from 0 to 1 and inversely related with PR values.

RESULTS AND DISCUSSION

The constituents detected in the study from eucalyptus, cinnamon and orange oils are shown in Table 1. These reveal that the major compounds of eucalyptus oil were eucalyptol (64.80%), α-pinene (11.17%), β-pinene (8.19%), γ-terpinene (5.91%), α-phellandrene (3.88%), terpinen-4-ol (0.72%), α-terpineol (1.01) and 4-carene (0.51%); beside these, carvacrol, α-terpinene, 1-epi-alpha-gurjunene, aromandendrene, alloaromadendrene, α-farnesene, γ-gurjunene, γ-eudesmol and β-eudesmol were observed. Cinnamon oil resulted in eugenol (82.68%) as the major constituent; in addition, caryophyllene (4.60%), safrole (2.19%), trans-isoeugenol (1.82%), caryophyllene oxide (0.88%), humulene (0.56%), linalool (0.51%) were the other major constituents. Orange oil had D-limonene (83.35%) as the major constituent and cis-limonene oxide (3.31%), trans-2-caren-4-ol (2.08%), tricyclo [4.1.0.0(2,7)] heptanes (0.84%), chrysanthenone (0.73%) and β-myrcene (0.59%) were the other constituents.

The present study reveals that the repellent activity of the essential oils depends on the insect pest and time after treatment, with concentration dependent repellant activity noticed with all the four pests evaluated. Toxicity of eucalyptus oil to coleopteran stored product pests had been attributed to metabolic compounds such as terpenoids and phenolic compounds (Lee et al., 2004; Tapondjou et al., 2005), and its toxicity to lepidopteran agricultural pests is known (Isman, 2006). Numerous plant species had been reported to have repellency properties, contact and fumigant toxicity (Golob et al., 1999). Important constituents of *Cymbopogon* spp., *Ocimum* spp. and *Eucalyptus* spp., and repellent activity of essential oils on insects had been reviewed by Nerio et al. (2010). Essential oils and many other plant extracts are known to possess repellent, insecticidal and ovicidal activities against various stored product insects (Ahmed et al. 1980; Hill and Schoonhoven, 1981; Jilani and Saxena, 1990; Desmarchelier, 1994; Papachristos and Stamopoulos, 2002) and was due to presence of monoterpenoids (Tong and Coats, 2010, Waliwitiya et al., 2005). Due to the high volatile nature of oils these are known to possess repellent and fumigant activities that have pest management significance (Koul, 2004; Konstantopoulu et al., 1992). The present results of chemical profiling of essential oils through GC MS showed presence of 2- 3 chemical constituents amounting to >90 % of total composition of oil which is responsible for repellent activity.

Bioassay against stored grain insect pests revealed increased repellency with concentration of evalauted

Table 1. Chemical constituents of oils used and their relative composition

Cinnamon oil			Eucalyptus oil			Orange oil		
Compound	Retention time	% area	Compound	Retention time	% area	Compound	Retention time	% area
Benzaldehyde	3.29	0.03	α-Pinene	3.08	11.17	α-Pinene	3.05	0.33
o-Cymene	3.95	0.15	β-Pinene	3.51	8.19	β-Myrcene	3.54	0.59
Linalool	4.81	0.51	α-Phellandrene	3.76	3.88	D-Limonene	4.08	83.35
4-Carene	6.03	0.24	Eucalyptol	4.11	64.80	α-Ocimene	4.83	0.27
cis-p-Mentha-2,8-dien-1-ol	6.20	0.01	γ-Terpinene	4.43	5.91	cis-Limonene oxide	5.33	3.31
3-Phenylpropanol	6.53	0.06	4-Carene	4.73	0.51	1,1,2-trimethyl-Cyclopropane	5.86	0.29
Chavicol	6.79	0.10	Terpinen-4-ol	5.89	0.72	Tricyclo[4.1.0.0(2,7)] heptane	6.17	0.84
Safrole	7.33	2.19	α-Terpineol	6.06	1.01	trans-2-Caren-4-ol	6.42	2.08
Cinnamyl alcohol	7.81	0.06	Carvacrol	7.41	0.06	(-)-Carvone	7.12	0.20
Eugenol	8.48	82.68	2,4-dimethyl-1,3-Cyclopentanedione	7.68	0.21	5-ethylidene-1-methyl-Cycloheptene	7.54	0.66
Caryophyllene	9.18	4.60	α-Terpinene	8.09	0.30	2,5,5-trimethyl-1,3,6-Heptatriene	7.72	0.50
Humulene	9.57	0.56	1-Epi-alpha-gurjunene	8.94	0.50	Chrysanthenone	8.25	0.73
β-Patchoulene	10.03	0.11	Aromandendrene	9.33	0.43	8-oxo-cis-Ocimene	8.45	0.35
trans-Isoeugenol	10.33	1.82	Alloaromadendrene	9.59	0.17	Caryophyllene oxide	11.09	0.06
Caryophyllene oxide	11.13	0.88	α-Farnesene	10.71	0.08	Santolina triene	12.27	0.08
α-Farnesene	11.91	0.24	γ-Gurjunene	11.09	0.23	Eicosane	17.99	0.06
Coniferol	12.73	0.15	γ-eudesmol	11.61	0.22			
Benzyl Benzoate	13.11	3.78	β-eudesmol	11.85	0.48			
Total	-	98.17	Total	-	98.87	Total	-	93.7

Concentration (%): % of concentrations based on peak area integration.

oils. Repellency Index and percent repellency values ranged from 0.00 to 0.90 and 10 to 100 (Table 2). Against *S. oryzae*, eucalyptus oil @ 5% concentration exhibited significantly higher PR 83.33% (F=4.282) and RI value of 0.17 when tested at 3 hr after treatment; cinnamon oil @ 5% concentration found on par with eucalyptus oil @ 5% with same PR and RI values; at 6, 12 and 24 hrs after treatment, cinnamon oil @ 5% exhibited significantly higher repellency with PR values of 96.67 (F=10.68), 90.00 (F=3.857), and 86.67 (F=3.25) and RI of 0.03, 0.10 and 0.13, respectively. A repellent action of eucalyptus oil against stored grain pests is known earlier. Extracts of eucalyptus leaf prepared in different solvents are known to possess repellent action against *S. oryzae* adults (Lee et al., 2004); similarly repellent potential of leaves of six vegetables species against adults of *S. zeamais* was observed by Procópio et al. (2003) and they reported only leaves of *E. citriodora* (PI = -0.81) and *Capsicum frutescens* (PI= -0.17) have shown the repellency based on Preference Index (PI).

Similarly, against *T. castaneum* eucalyptus oil @ 5% showed maximum repellent action with PR and RI values of 93.33 (F=0.921), 100 (F=1.66), 100 (F=3.772) and 0.07, 0.00 and 0.00 at 3, 6 and 12 hr after treatment, and were found significantly superior; at 12 hr after treatment orange oil @ 5% had shown repellant action on par with eucalyptus oil @ 5% with PR value of 98.33 and RI value of 0.03; and after 24 hr after treatment orange oil @ 5% exhibited significantly superior repellency (F=20.26) with PR and RI values 100 and 0.00, respectively. Against *R. dominica*, at all time intervals, eucalyptus oil @ 5% has shown maximum repellency; at 3 and 6 hr after treatment, the said oil exhibited repellent action with PR value of 86.67 (F=3.87), 83.33 (F=2.60) and RI value of 0.13, 0.17 and found significantly superior; at 12 hr after treatment, eucalyptus oil @ 2% having PR value of 80.00 (F=10.99) and RI value of 0.20 was found on par with eucalyptus oil @ 5% having PR value of 83.33 RI value of 0.17; same eucalyptus oil @ 2% having PR value of 76.67 (F=12.56) and RI value of 0.23 was found on par with eucalyptus oil @ 5% with PR value of 83.33 (F=12.56) and RI value of 0.17 and orange oil @ 5% having PR value of 83.33 (F=12.56)

Table 2. Repellant activity of plant essential oils against major stored grain pests of rice

S. No.	Treatments	3 HAT				6 HAT				12 HAT				24 HAT			
		Adult individuals (%)		PR (%)	RI	Adult individuals (%)		PR (%)	RI	Adult individuals (%)		PR (%)	RI	Adult individuals (%)		PR (%)	RI
		UT	T			UT	T			UT	T			UT	T		
							Sitophilus oryzae										
1	Eucalyptus oil @ 1 %	78.33	21.67	56.67^{de}	0.43	76.67	23.33	53.33^{e}	0.47	78.33	21.67	56.67^{c}	0.43	71.67	28.33	43.33^{d}	0.57
2	Eucalyptus oil @ 2 %	85.00	15.00	70.00^{bc}	0.30	83.33	16.67	66.67^{d}	0.33	81.67	18.33	63.33^{c}	0.37	78.33	21.67	56.67^{c}	0.43
3	Eucalyptus oil @ 5 %	91.67	8.33	83.33^{a}	0.17	91.67	8.33	83.33^{b}	0.17	90.00	10.00	80.00^{b}	0.20	90.00	10.00	80.00^{ab}	0.20
4	Cinnamon oil @ 1 %	80.00	20.00	60.00^{de}	0.40	86.67	13.33	73.33^{c}	0.27	88.33	11.67	76.67^{b}	0.23	81.67	18.33	63.33^{c}	0.37
5	Cinnamon oil @ 2%	88.33	11.67	76.67^{ab}	0.23	93.33	6.67	86.67^{b}	0.13	91.67	8.33	83.33^{ab}	0.17	88.33	11.67	76.67^{b}	0.23
6	Cinnamon oil @ 5%	91.67	8.33	83.33^{a}	0.17	98.33	1.67	96.67^{a}	0.03	95.00	5.00	90.00^{a}	0.10	93.33	6.67	86.67^{a}	0.13
7	Orange oil @ 1%	65.00	35.00	30.00^{f}	0.70	66.67	33.33	33.33^{g}	0.67	65.00	35.00	30.00^{e}	0.70	73.33	26.67	46.67^{d}	0.53
8	Orange oil @ 2%	76.67	23.33	53.33^{e}	0.47	73.33	26.67	46.67^{f}	0.53	71.67	28.33	43.33^{d}	0.57	80.00	20.00	60.00^{c}	0.40
9	Orange oil @ 5%	81.67	18.33	63.33^{cd}	0.37	76.67	23.33	53.33^{e}	0.47	88.33	11.67	76.67^{b}	0.23	91.67	8.33	83.33^{ab}	0.17
SEm±		4.08		8.16	-	3.19		6.38	-	5.09		10.18	-	4.44		8.89	-
CD= 0.01		16.62		33.24	-	12.99		25.98	-	20.73		41.45	-	18.09		36.18	-
							Tribolium castaneum										
1	Eucalyptus oil @ 1 %	86.67	13.33	73.33^{bc}	0.27	88.33	11.67	76.67^{de}	0.23	88.33	11.67	76.67^{c}	0.23	86.67	13.33	73.33^{d}	0.27
2	Eucalyptus oil @ 2 %	90.00	10.00	80.00^{b}	0.20	93.33	6.67	86.67^{bc}	0.13	91.67	8.33	83.33^{b}	0.17	93.33	6.67	86.67^{c}	0.13
3	Eucalyptus oil @ 5 %	96.67	3.33	93.33^{a}	0.07	100.00	0.00	100.00^{a}	0.00	100.00	0.00	100.00^{a}	0.00	98.33	1.67	96.67^{ab}	0.03
4	Cinnamon oil @ 1 %	76.67	23.33	53.33^{f}	0.47	86.67	13.33	73.33^{e}	0.27	88.33	11.67	76.67^{c}	0.23	96.67	3.33	93.33^{b}	0.07
5	Cinnamon oil @ 2%	81.67	18.33	63.33^{de}	0.37	90.00	10.00	80.00^{cde}	0.20	93.33	6.67	86.67^{b}	0.13	98.33	1.67	96.67^{ab}	0.03
6	Cinnamon oil @ 5%	86.67	13.33	73.33^{bc}	0.27	91.67	8.33	83.33^{cd}	0.17	98.33	1.67	96.67^{a}	0.03	100.00	0.00	100.00^{a}	0.00
7	Orange oil @ 1%	78.33	21.67	56.67^{ef}	0.43	81.67	18.33	63.33^{f}	0.37	80.00	20.00	60.00^{d}	0.40	91.67	8.33	83.33^{c}	0.17
8	Orange oil @ 2%	81.67	18.33	63.33^{de}	0.37	93.33	6.67	86.67^{bc}	0.13	91.67	8.33	83.33^{b}	0.17	96.67	3.33	93.33^{b}	0.07
9	Orange oil @ 5%	85.00	15.00	70.00^{cd}	0.30	96.67	3.33	93.33^{ab}	0.07	98.33	1.67	96.67^{a}	0.03	100.00	0.00	100.00^{a}	0.00
SEm ±		6.41		12.81	-	4.23		8.46	-	3.24		6.48	-	2.94		5.88	-
CD= 0.01		26.08		52.16	-	17.22		34.44	-	13.19		26.37	-	11.97		23.93	-
							Rhyzopertha dominica										
1	Eucalyptus oil @ 1 %	81.67	18.33	63.33^{c}	0.37	86.67	13.33	73.33^{b}	0.27	81.67	18.33	63.33^{b}	0.37	76.67	23.33	53.33^{c}	0.47
2	Eucalyptus oil @ 2 %	88.33	11.67	76.67^{b}	0.23	88.33	11.67	76.67^{ab}	0.23	90.00	10.00	80.00^{a}	0.20	88.33	11.67	76.67^{a}	0.23
3	Eucalyptus oil @ 5 %	93.33	6.67	86.67^{a}	0.13	91.67	8.33	83.33^{a}	0.17	91.67	8.33	83.33^{a}	0.17	91.67	8.33	83.33^{a}	0.17
4	Cinnamon oil @ 1 %	73.33	26.67	46.67^{de}	0.53	78.33	21.67	56.67^{c}	0.43	60.00	40.00	20.00^{f}	0.80	58.33	41.67	16.67^{e}	0.83
5	Cinnamon oil @ 2%	75.00	25.00	50.00^{de}	0.50	80.00	20.00	60.00^{c}	0.40	63.33	36.67	26.67^{e}	0.73	60.00	40.00	20.00^{e}	0.80
6	Cinnamon oil @ 5%	76.67	23.33	53.33^{d}	0.47	86.67	13.33	73.33^{b}	0.27	66.67	33.33	33.33^{d}	0.67	68.33	31.67	36.67^{d}	0.63
7	Orange oil @ 1%	71.67	28.33	43.33^{e}	0.57	68.33	31.67	36.67^{e}	0.63	75.00	25.00	50.00^{c}	0.50	76.67	23.33	53.33^{c}	0.47
8	Orange oil @ 2%	80.00	20.00	60.00^{c}	0.40	73.33	26.67	46.67^{d}	0.53	81.67	18.33	63.33^{b}	0.37	85.00	15.00	70.00^{b}	0.30
9	Orange oil @ 5%	86.67	13.33	73.33b	0.27	88.33	11.67	76.67^{ab}	0.23	88.33	11.67	76.67^{a}	0.23	91.67	8.33	83.33^{a}	0.17
SEm ±		3.77		7.54	-	4.87		9.75	-	3.60		7.20	-	3.64		7.29	-
CD= 0.01		15.34		30.67	-	19.84		39.69	-	14.66		29.31	-	14.83		29.66	-
							Oryzaephilus surinamensis										
1	Eucalyptus oil @ 1 %	66.67	33.33	33.33^{d}	0.67	63.33	36.67	26.67^{de}	0.73	61.67	38.33	23.33^{cd}	0.77	56.67	43.33	13.33^{d}	0.87
2	Eucalyptus oil @ 2 %	71.67	28.33	43.33^{c}	0.57	66.67	33.33	33.33^{bcd}	0.67	68.33	31.67	36.67^{ab}	0.63	65.00	35.00	30.00^{bc}	0.70
3	Eucalyptus oil @ 5 %	80.00	20.00	60.00^{b}	0.40	68.33	31.67	36.67^{bc}	0.63	71.67	28.33	43.33^{a}	0.57	68.33	31.67	36.67^{ab}	0.63
4	Cinnamon oil @ 1 %	63.33	36.67	26.67^{d}	0.73	61.67	38.33	23.33^{e}	0.77	58.33	41.67	16.67^{de}	0.83	61.67	38.33	23.33^{c}	0.77
5	Cinnamon oil @ 2%	65.00	35.00	30.00^{d}	0.70	70.00	30.00	40.00^{b}	0.60	65.00	35.00	30.00^{bc}	0.70	65.00	35.00	30.00^{bc}	0.70
6	Cinnamon oil @ 5%	71.67	28.33	43.33^{c}	0.57	81.67	18.33	63.33^{a}	0.37	70.00	30.00	40.00^{a}	0.60	70.00	30.00	40.00^{a}	0.60
7	Orange oil @ 1%	78.33	21.67	56.67^{b}	0.43	65.00	35.00	30.00^{cde}	0.70	55.00	45.00	10.00^{e}	0.90	56.67	43.33	13.33^{d}	0.87
8	Orange oil @ 2%	81.67	18.33	63.33^{b}	0.37	70.00	30.00	40.00^{b}	0.60	58.33	41.67	16.67^{de}	0.83	61.67	38.33	23.33^{c}	0.77
9	Orange oil @ 5%	86.67	13.33	73.33^{a}	0.27	85.00	15.00	70.00^{a}	0.30	61.67	38.33	23.33^{cd}	0.77	68.33	31.67	36.67^{ab}	0.63
SEm ±		5.30		10.60	-	5.24		10.48	-	5.44		10.89	-	6.74		13.47	-
CD= 0.01		21.57		43.15	-	21.33		42.67	-	22.16		44.32	-	27.42		54.84	-

PR - % Repellency; RI- Repellence index; HAT- hr after treatment; UT- Untreated area; T- Treated area

and RI value of 0.17. All the evaluated oils at different concentrations against *O. surinamensis* did not exhibit significant differences.

Thus, the present results reveal the excellent repellency exhibited by eucalyptus oil @ 5% against *T. castaneum* and *R. dominica*. These results are in line with those of earlier ones- viz., Olivero-Verbal et al. (2010) with *T. castaneum* observed that *Eucalyptus citriodora* is a good repellent. Essential oils of *E. kingsmillii* and *E. salmonophloia* tested at four concentrations against female adults of *Tetranychus urticae* Koch indicated that repellency index was neutral at 9 and 17%, whereas, at 23 and 29% it stands as repellent (Haririmoghadam et al., 2011). The essential oil of *E. dundasii* and *E. astringens* against *O. surinamensis* show a more repellent effect corroborating the present results (Khemira et al., 2012). Study of Salvadores et al. (2007) indicated that clove oil was the best repellent against *R. dominica, S. oryzae* and *T. castaneum*. Strong repellent and deterrent activity against *T. castaneum* was observed with the leaf extract of *Ocimum viride* (Owsu, 2001); fumigant and repellent effects of oil of *Ocimum gratissimum* and its constituents as a better alternatives to synthetic fumigants against *T. cactaneum, S. oryzae, R. dominica, O. surinamensis* and *Callosobruchus chinensis* (Ogendo et al., 2008). Insecticidal and repellent properties of *C. citrinus* against *C. maculatus* were described by Zandi- Sohani et al. (2013) and repellent effects of essential oils of *E. citriodora, Lippia origanoides, Tagetes lucida* against *S. zeamais* are known earlier (Nerio et al., 2009); also, repellency against *T. castaneum* with *Piper retrofractum* oil had been documented (Tripathi et al., 2000). Wild species of 21 botanical families screened by Pascual-Villalobos (1999) revealed that the family Compositae reveals maximum repellency against *T. castaneum*; likewise, antifeedant and repellent properties of *Cyperus articulatus* against *T. castaneum* are known (Abubakar et al., 2000).

Thus, the current study revealed repellent activity of the essential oils against key stored grain insect pests. Traditionally plant based products have been used to kill or repel stored grain insects since time immemorial, hence the evaluated essential oils could be better alternative to conventional insecticides.

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VOLATILE PROFILES AS AFFECTED BY RICE BROWN PLANT HOPPER AND YELLOW STEM BORER IN RICE LAND RACES

S J Reuolin, N Muthukrishnan[1]*, M Paramasivam, R P Soundararajan[2], K S Subramanian and N Maragatham

Tamil Nadu Agricultural University, Coimbatore, 641003
[1]Agricultural College and Research Institute, Vazhavachanur, Thiruvannamalai 606753
[2]Horticultural College and Research Institute for Women, Navalur Kuttapattu, Trichy 620027
*Email: nmkrish@tnau.ac.in (corresponding author)

ABSTRACT

Rice (*Oryza sativa* L.,) plants release a complex profile of volatile organic compounds. Present study investigates the differences in volatile compounds from four rice landraces viz., Karuthakar, Norungan, Thavala Kanan and Varappu Kudaichan each under four conditions like healthy, mechanically damaged, and the ones infested by the brown plant hopper *Nilaparvata lugens* Stal and yellow stem borer *Scirpophaga incertulas* (Wlk.). The volatiles were collected using air entrainment method and characterized by the GCMS. Statistical analysis tools like clustering, principal component analysis and partial least square discriminant analysis were applied. Clear differences among the treatments were observed and certain volatile compound groups like terpenoids (squalene), unsaturated fatty acids (n-hexadecanoic, tetradecanoic and pentadecanoic acids), alkanes (heptacosane, tetracosane) were found. The statistical test of Partial Least Square Discriminant Analysis was found to be satisfactory in determining the compounds responsible for variations in treatments.

Key words: Rice landraces, *Nilaparvata lugens*, *Scirpophaga incertulas*, secondary metabolites, herbivore induced plant volatiles, terpenoids, fatty acids, esters, GCMS, Clustering analysis, multivariate analysis

Plants communicate to the environment by releasing certain organic volatile compounds. These act as chemical signals for tritrophic interaction. Healthy plants maintain a baseline level of volatile metabolites which tend to differ from those that are mechanically damaged or infested by pests (Pare and Tumilson, 1999). This phenomenon makes the field of chemical ecology more interesting as it gives a better insight into the compounds playing role in tritrophic interaction. Apart from these, it is quite noteworthy to observe a quantitative and qualitative difference in volatiles among the varieties of a plant (Krips et al., 2001; Hoballah et al., 2002). This might be the reason behind the varietal difference in attraction of insect pests and natural enemies. So, it creates a need in the exploration of volatile profiles between varieties of plant. Even though there are some studies on the difference in the HIPV's among the plant varieties, very little is known like that of Lou et al. (2006), focused on the variations in the induced volatiles between rice varieties. There is practically no work on the variations in the traditional rice landraces. Since landraces are rich in the diverse gene pool, characterizing their volatile profiles under both herbivore induced and controlled conditions is essential. This has been attempted in the present study. The multivariate data analysis has now become a powerful tool in data analysis to estimate the interactions and the data obtained in this study have been subjected to such analyses.

MATERIALS AND METHODS

Popular and stress tolerant rice landraces- Karuthakar (K), Norungan (N), Thavala Kanan (T) and Varappu Kudaichan (V) were used and their seeds were obtained from the bank of plant genetic resources, TNAU. The seeds were soaked in the water for 24 hr and then incubated in dark condition before sowing. The pre-germinated seeds were sown in clay pots kept in cages. After 14 days, the seedlings were transplanted in separate clay pots (12cm dia x 10 cm height) @ 2 seedlings/ pot and watered daily. Urea was applied 15 days after transplanting @ 0.3 g/ pot. The pots were then placed in netted cages to maintain healthy seedlings free from the attack of insects. Plants were used for experiment at 35 to 45 days after transplanting. Mechanically damaged plants were obtained by individually damaging the plants with needle at the lower and upper portion of the rice stems each with approximately 200 pricks to

simulate the feeding behaviour of brown plant hopper (BPH) *Nilaparvata lugens* (Stal).

Nymphs and adults of BPH were collected from the Tamil Nadu Agricultural University rice fields and released into the cages where TN1 (susceptible) potted plants were maintained. The BPH was allowed to multiply and then their nymphs were selected for the experiment. Three second/ third instar nymphs/ seedling were allowed to feed after starving for 2 hr. Similarly, rice yellow stem borer (YSB) *Scirpophaga incertulas* (Walker) females were collected from the field and released into the cages with TN1 variety for oviposition. The eggs were allowed to hatch and the 1st instar larvae were collected using the camel hair brush and released on to the 35 to 45-days old Karuthakar, Norungan, Thavala Kanan and Varappu Kudaichan seedlings. Each tiller was released with five to six larvae, and these used. Two replications were maintained for each, with a total of 16 treatments used in volatile collection.

Plant volatile collection was made using the air entrainment method. The volatile collection system basically consists of a vertically placed cylindrical glass tube (62 cm height, 6 cm internal dia). The bottom part of the cylinder was left open in order to fit the plant inside. The top of the cylinder has two raised ports (2 cm height x 0.8 cm internal dia) of which air was passed through one port and the plant volatile was collected through the other. Aquarium pump (Champion, CX-0088) was used to provide air @ 1.0 l/ min. purified and humidified air was passed by the means of activated charcoal and humidifier. The purified air after passing through the plant was pulled (0.8 l/ min) through a super Q-absorbent trap (volatile collection trap) in order to collect the volatiles. The bottom of the cylinder around the base of the plant was covered with aluminium foil to prevent the contamination of soil volatiles. The entire system was sealed air tight. Volatile collection was carried out for 24 hr and the collected volatiles were extracted from the collection trap with 700 µl of hexane in GC vials before stored at -20°C until further use.

The Clarus SQ 8C Gas Chromatography- Mass Spectrometer instrument was set as follows: Injector port temperature set to 220°C, Interface temperature as 250°C, and source kept at 220°C. The oven temperature programmed as available, 75°C for 2 min, 150°C @ 10°C/ min, up to 250°C @ 10°C/ min. Split ratio set as 1:12. The DB-5 MS capillary standard non- polar column was used. Helium was used as the carrier gas at 1 ml/ min. The MS data system has inbuilt libraries for searching and matching the spectrum. Interpretation of mass spectrum of GC-MS was done using the database of National Institute of Standard and Technology (NIST14). The spectrum of the known component was compared with the spectrum of the known components stored in the inbuilt library. The raw data of peak areas of volatile compounds were tested for normality and proceeded with the non-parametric Kruskal-Wallis test. Heat map analysis was performed using the package "d3.heatmap". K means clustering was done using the "stats" package and kmeans function. The number of clusters for kmeans clustering is found by silhouette method. Hierarchical clustering analysis using ward method was done. In order to reduce the dimensionality of the multivariate data, Principal Component Analysis (PCA) was performed using the prcromp function with the data centered and scaled before analysis. Partial Least Square Discriminant Analysis (PLS-DA) was done using "mixOmics package". All the statistical analysis was performed using the R statistical software (R version 4.0).

RESULTS AND DISCUSSION

Among the headspace volatiles released by the rice landraces Karuthakar, Norungan, Thavala Kanan and Varappu Kudaichan (healthy, mechanically damaged, BPH infested and YSB infested), 45 volatile organic compounds (VOC's) were identified (Table 1). These 45 volatile compounds were selected from the total observed compounds based on their repeated occurrence in replications. Nineteen compounds were found to be significantly different ($p<0.05$) among the treatments.

Heat map analysis as given in Fig. 1 provides the distribution of important volatiles among the sixteen treatments. Similar colour in the heatmap indicates the similar level of compound- darker the colour, higher is the concentration, and lightest blue colour indicates those undetected compounds. The results reveals qualitative and quantitative differences among the 45 volatile compounds. *K* means clustering yielded two clusters by silhouette method (Fig. 3) whereas hierarchical clustering resulted in three clusters (Fig. 2). The size of the clusters are 4 (all the treatments of Varappu Kudaichan) and 12 (Fig. 4). In hierarchical clustering, all the four treatments of Varappu Kudaichan were grouped under a cluster like *k*-means clustering. Compared to *k* means clustering hierarchical clustering was more consisted with those of PCA and PLSDA. Both the clustering analysis performed in the present study had separated the treatments of Varappu Kudaichan into

Table 1. Volatile compounds (head space) obtained from the rice landraces

S. No.	Compound	Karuthakar (mean relative peak area ± Std. error)				Norungan (mean relative peak area ± Std. error)				Thavala kanan (mean relative peak area ± Std. error)				Varappu Kudaichan (mean relative peak area ± Std. error)				P value
		KH	KMD	KBPH	KYSB	NH	NMD	NBPH	NYSB	TH	TMD	TBPH	TYSB	VH	VMD	VBPH	VYSB	
1.	(1S,14S)-Bicyclo (12.10.0)-3,6,9,12,15,18,21,24-octaoxatetracosane	0	0	0	3.41± 1.31	0	3.47± 2.96	0	0	0	0	0	0	0	0	0	0	0.0926
2.	(2S,2'S)-2,2'-Bis (1,4,7,10,13-penta oxacyclopentadecane)	1.24± 1.05	0.71± 0.31	0	2.54± 1.20	2.14± 0.01	1.53± 0.02	0	0.49± 0.01	0	0	0	0.95± 0.05	0	0	0	0	0.1493
3.	1,2-Diamino-2-methylpropane	0	0	0.87± 0.02	0	0	0.29± 0.01	0.84± 0.04	0	0.32± 0.06	0	1.11± 0.01	0.45± 0.01	0	0	0	0	0.0227*
4.	1,4,7,10,13,16,19-Heptaoxa-2-cyclo heneicosanone	5.04± 0.48	10.34± 5.04	0	1.57± 0.98	0.77± 0.50	0.59± 0.04	0	0.85± 0.08	0	1.76± 0.01	0	0.72± 0.12	0	0	0	0	0.0229*
5.	17-Pentatriacontene	0	0	0	0	0.61± 0.01	0.36± 0.01	0	0	0	0	0	0.46± 0.03	0	0	0.42± .0.01	0	0.0563
6.	1-Hexadecanol, 2-methyl-	0	0.10± 0.01	0	0	0	0	0	0	0	0	0	0.36± 0.04	0	0	0	0	0.0382*
7.	1-Penten-3-ol	0	0	0	0	0	0	0	0	0.27± 0.01	0	0	0.36± 0.01	0	0	0	0	0.0561
8.	2,2,4-Trimethyl-3-(3,8,12,16-tetramethyl heptadeca-3,7,11,15-tetraenyl)-cyclohexanol	0	0	0.99± 0.01	0	0	0	0.75± 0.01	5.98± 0.51	0.38± .02	0	0	1.45± 0.01	4.19± 0.23	1.82± 0.17	0.51± 0.04	3.40± 0.18	0.0944
9.	2-Aminocyano-acetamide	0	0	0	0	0	0	0	0	0.24± 0.02	0	0	0.37± 0.01	0	0	0	0	0.0382*
10.	2-Decanol	0	0	0.91± 0.05	0	0	0	0	0	0	0	1.27± 0.03	0.30± 0.05	0	0	0	0	0.1053
11.	2-Ethyl-oxetane	0	0	1.56± 0.01	0	0	0	0	0	0.26± 0.01	0.41± 0.01	0	0	0	0	0	0	0.0793
12.	2-Ketobutyric acid	0	0	1.02± 0.01	0	0	0	1.07± 0.44	0	0	0	0.63± 0.03	0.31± 0.01	0	0	0	0	0.0518
13.	2-Myristynoyl pantetheine	0	0.36± 0.01	0	0.56± 0.06	0.65± 0.01	0	0	0.32± 0.01	0.69± 0.01	0.39± 0.01	0	0	0	0.25± 0.01	0.38± 0.03	0	0.0782
14.	2-Nonadecanone 2,4-dinitrophenyl hydrazine	0	0	0	0	0	0	0	0	0	0	0	0.44± 0.12	0.41± 0.08	0	0	0	0.0926

(contd.)

S. No.	Compound	Karuthakar (mean relative peak area ± Std. error)				Norungan (mean relative peak area ± Std. error)				Thavala kanan (mean relative peak area ± Std. error)				Varappu Kudaichan (mean relative peak area ± Std. error)				P value
		KH	KMD	KBPH	KYSB	NH	NMD	NBPH	NYSB	TH	TMD	TBPH	TYSB	VH	VMD	VBPH	VYSB	
15.	3',8,8'-Trimethoxy-3-piperidyl-2,2'-bi naphthalene -1,1',4,4'-tetrone	1.27± 0.35	0	0	1.67± 0.11	1.95± 0.01	0	0	0	0	0.23± 0.01	0	0.26± 0.01	0	0	0	0	0.2504
16.	3-Hydroxy-2-butanone (Acetoin)	0	0	1.29± 0.07	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0088*
17.	3-tert-Butylsulfanyl-3-fluoro-2-trifluoro methyl acrylicacid methyl ester	0	0	0	0	0	0	0	0	0.27± 0.01	0.27± 0.01	0	0	0	0	0	0	0.0561
18.	à-D-Glucofuranose, 6-O-(trimethylsilyl)-, cyclic 1	0	0	0	0	0	0	0	0.31± 0.01	0	0.57± 0.02	0	0	0	0	0	0	0.0561
19.	Azetidine	0	0	2.03± 1.24	0	0	0	0	0.25± 0.01	0	0.24± 0.04	1.39± 0.01	0.24± 0.02	0	0	0	0	0.0474*
20.	Borinic acid, diethyl-	0	0	1.10± 0.30	0	0	0	0	0	0	0	1.23± 0.01	0.34± 0.01	0	0	0	0	0.0210*
21.	Butoxyacetic acid	0	0	0.83± 0.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0088*
22.	Dasycarpidan-1-methanol, acetate (ester)	0	0	0	0	0.36± 0.01	0.18± 0.01	0	0	0	0.54± 0.01	0	0	0	0	0.58± 0.03	0	0.04472*
23.	Diisooctyl phthalate	0	0	0	0	5.20± 0.14	1.83± 0.01	1.26± 0.01	8.58± 0.03	0.77± 0.51	0	1.18± 0.20	3.74± 2.43	4.38± 0.02	0	4.78± 0.13	5.13± 0.04	0.1388
24.	Dodecanoic acid	0	0	1.45± 0.01	0	0	0	0	0	0.30± 0.01	0	2.15± 0.01	0	0	0	0	0	0.0793
25.	Heptacosane	0	0	0	0	0	0	0.65± 0.26	0	0	0	0	0	0	0	0	0	0.0088*
26.	Heptaethylene glycol	1.46± 0.98	0	0	0	0.69± 0.35	2.25± 0.01	0	0.40± 0.01	0	0	0	0	0	0	0	0	0.0577
27.	Heptaethylene glycol monododecyl ether	0	0	0	2.29± 1.34	0	0	1.28± 0.03	0.91± 0.01	0	20.78± 0.02	0	0	0	0	0	0	0.1755
28.	Hexacosane	0	0	1.44± 0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4514
29.	Methane, isocyanato-	0	0	1.08± 0.01	0	0	0.36± 0.01	0	0	0	0	0.68± 0.02	0.28± 0.01	0	0	0	0	0.0362*
30.	Methyl 21-methyldocosanoate	0.28± 0.11	0	0	0	0	0	0	0	0	0	2.35± 0.21	0	0	0	0	0	0.0088*

(contd.)

(Table 1 contd.)

S. No.	Compound	Karuthakar (mean relative peak area ± Std. error)				Norungan (mean relative peak area ± Std. error)				Thavala kanan (mean relative peak area ± Std. error)				Varappu Kudaichan (mean relative peak area ± Std. error)				P value
		KH	KMD	KBPH	KYSB	NH	NMD	NBPH	NYSB	TH	TMD	TBPH	TYSB	VH	VMD	VBPH	VYSB	
31.	n-Hexadecanoic acid	0.25± 0.10	0	0	0.31± 0.07	0.28± 0.02	0.50± 0.01	0.58± 0.02	0.69± 0.13	0.52± 0.08	1.21± 0.01	0	0.51± 0.13	3.58± 0.38	2.63± 0.03	5.26± 0.13	4.95± 0.26	0.03995*
32.	Nonanal	0.56± 0.01	0	1.21± 0.18	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4904
33.	octacosane	0	0	0	0.84± 0.27	0	0	0	0	0	0	0	0	0	0	0	0	0.0088*
34.	Octadecanal, 2-bromo-	0.22± 0.03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0088*
35.	Octadecane	1.28± 0.01	0	0	0	0	0	0.43± 0.05	0	0	0	0	0	0	0	0	0	0.0561
36.	Octadecane, 3-ethyl-5-(2-ethylbutyl)-	0.48± 0.22	0.27± 0.01	0	0.86± 0.06	0.68± 0.01	0.59± 0.22	0.45± 0.01	0.48± 0.01	0.34± 0.06	0	0	0.25± 0.01	0	0.74± 0.23	0.87± 0.10	0.44± 0.03	0.1547
37.	Octaethylene glycol monododecyl ether	0.13± 0.01	0.25± 0.01	0	2.22± 0.12	0	0	0.88± 0.01	0.58± 0.03	0.60± 0.12	0.85± 0.03	0	0	0	0	0	0	0.0985
38.	Pentacosane	0	0	6.05± 5.01	2.07± 1.83	0.27± 0.03	0	0	0	0	1.21± 0.01	0	0.50± 0.02	0	0	0	0	0.2579
39.	Pentadecanoic acid	0	0	0	0	0	0	0.32± 0.01	0	0	1.75± 0.03	0	0.75± 0.03	0.61± 0.02	0.42± 0.04	0.58± 0.02	0.63± 0.04	0.0810
40.	Pentane, 2,2,3,4-tetramethyl-	0	0	0.85± 0.13	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0088*
41.	Pentane, 3-methyl-	0	0	1.22± 0.25	0	0	0	0	0	0	0.25± 0.01	0	0	0	0	0	0	0.0382*
42.	Squalene	0	0	0	0	0	0	0	0	0	0	0	0	6.74± 4.44	7.45± 1.95	4.30± 0.07	10.55± 0.33	0.0102*
43.	Tetracosane	0	0	0	3.49± 0.98	0	0	0.36± 0.01	0	28.88± 0.13	0	0	0	0	0	0	0	0.1053
44.	Tetradecanoic acid	0	0	0	0	0	0	0	0	0	0	0	0	2.49± 0.01	1.62± 0.06	2.42± 0.03	3.11± 0.09	0.0088*
45.	Tetratetracontane	0	0	0	0	0	0.31± 0.07	4.40± 0.10	0	0	0	0	0	0	0	0	0	0.0561

*Indicates the significant p value of the non-parametric Kruskal Wallis test; Healthy (H), Mechanically damaged (MD), *N.lugens* infested (BPH) and *S. incertulas* infested (YSB)

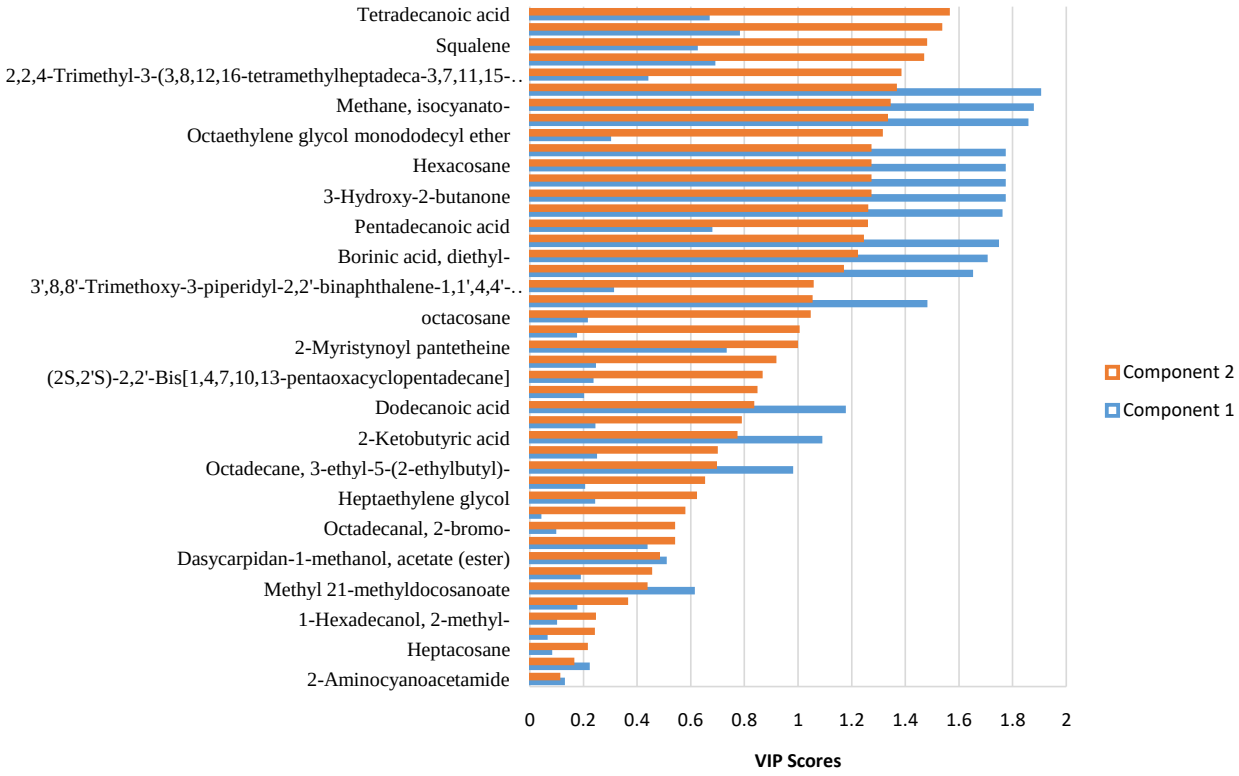
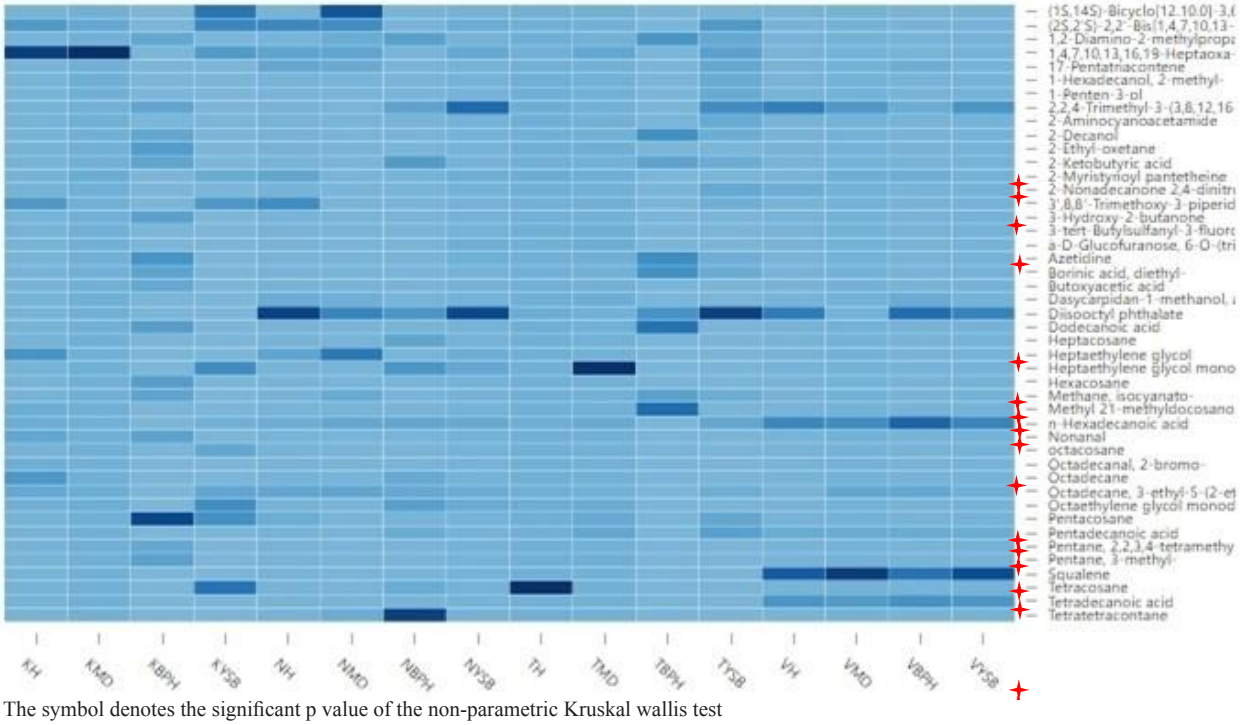


Fig. 1 (Supplementary). Variable Importance Projection scores of the Components 1 and 2 for the volatile compounds



The symbol denotes the significant p value of the non-parametric Kruskal wallis test

Fig. 1. Heatmap of VOCs emitted from treatments of rice landraces- Karuthakar, Norungan, Thavala Kanan and Varappu Kudaichan

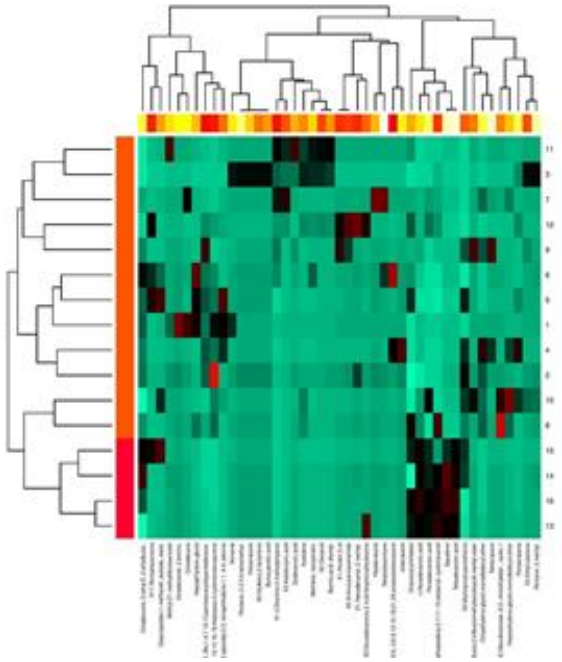


Fig. 2. *K* means clustering heat map

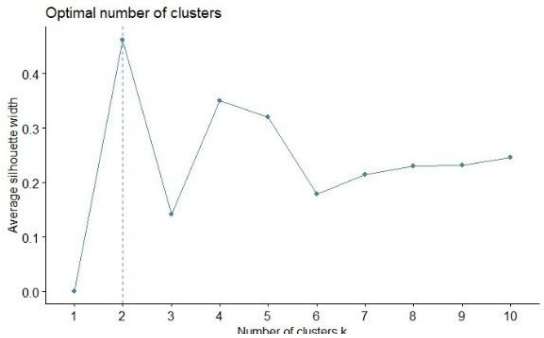


Fig. 3. Clusters selection – silhouette method

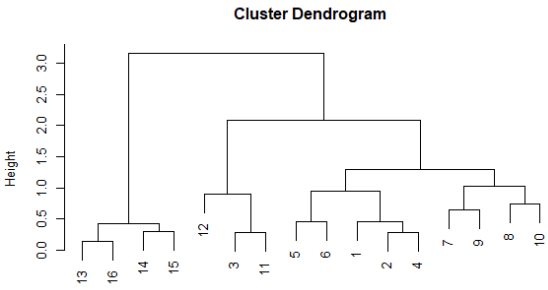


Fig. 4. Hierarchical clustering – ward method

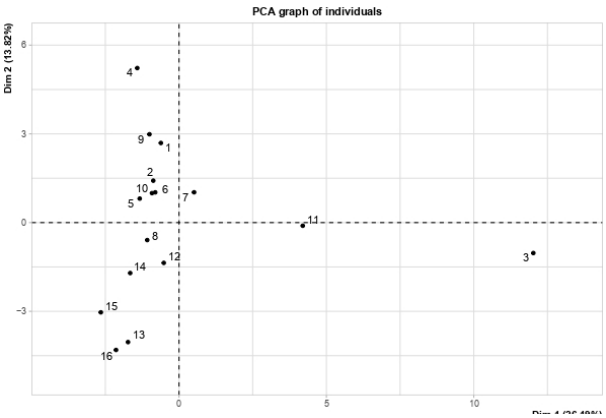


Fig. 5. PCA Score plot (1-16 indicates treatment orders)

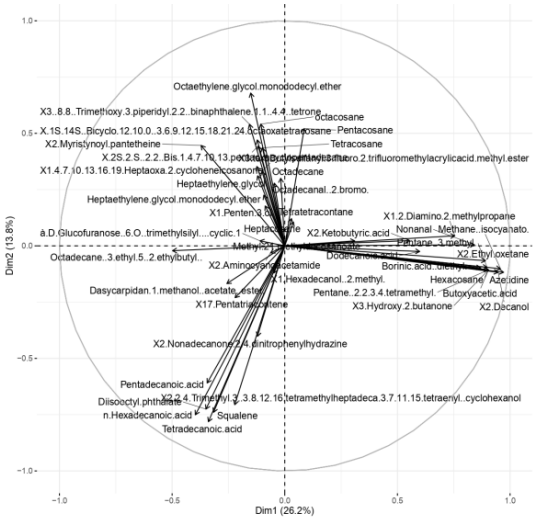


Fig. 6. Loadings plot of variables

separate cluster. This might be due to the influential role of compounds like disooctyl phthalate, n-hexadecanoic and pentadecanoic acids, squalene and tetradecanoic acid. This was also verified from the loadings plot of PCA and PLSDA. Clustering analysis also indicated the uniqueness in the volatile profiles released by each insect species irrespective of the varietal differences. Similar results had been earlier reported (Chen et al., 2020; Hoballah et al., 2002).

Principal Component Analysis was applied to the 45 volatile compounds to determine whether the samples belonging to different treatments of rice landraces can be separated based on their quantitative or qualitative differences in the emitted volatile profile. PC 1 and PC 2 explained approximately 26.19% and 13.82% of the total variation, respectively which accounts to totally of 40.01%. In Fig. 5, the treatments were represented as the matrix of scores according to the principal components. The numbers in the score plot denote the order of treatment groups as mentioned in the Table 1. Overall, from the results of PCA score plot (Fig. 5), it is evident that except Varappu Kudaichan, the landraces were found clustered according to their treatment similarities like the results of clustering analysis. Fig. 6 shows the volatile compounds responsible for the position of particular treatment in the score plot. Their project values on each principal component show how much weight they have on that principal component. For instance, treatment groups like VYSB,

VMD, VBPH, VH, TYSB and NYSB which is on the negative side of the PC1 and PC2 are strongly influenced by the compounds like 2,2,4-Trimethyl-3-(3,8,12,16-tetramethyl heptadeca-3,7,11,15-tetraenyl)-cyclohexanol), n-hexadecanoic acid, squalene and tetradecanoic acid. These compounds were also found to be highly correlated among themselves as these vectors lie close to each other with less angle between them. Similarly, certain compounds lie close the PC1 and other compounds to the PC2. These three groups of compounds were found to be at 90° between each group indicating that they are negatively correlated with each group.

Partial Least Squares Discriminant analysis, was applied to make an even better separation between the treatments of landraces. The 45 volatile compounds were designated as the X-matrix, while the Y matrix consisted of the details of the sixteen treatments. Figure 5 explains 26% and 14% variance of X variate (volatile compounds). Clear differentiation among the rice landrace treatments was observed as given in Fig. 7. Like PCA, the treatments like VH, VMD, VYSB, VBPH, TYSB and NYSB were grouped together. The treatments KBPH and TBPH are far from these groups and lie on the negative side. On the upper side of the plot, treatments like NH, NMD, NBPH, KMD, TMD, KH and TH are together like cluster whereas the treatment KYSB were far from these treatments. Compounds like 8 (2,2,4-Trimethyl-3-(3,8,12,16-tetramethyl heptadeca-3,7,11,15-tetraenyl)-cyclohexanol), 31 (n-hexadecanoic acid), 39 (pentadecanoic acid), 42 (squalene) and 44 (tetradecanoic acid) were found to lie on the correlation circle of the landrace Varappu Kudaichan (Fig. 8). Among the 45 volatile compounds observed, 25 were found to have VIP scores above 1. Of these, 14 volatiles have significant difference with p value ≤ 0.05, and these are considered to be highly influential ones for each treatment groups.

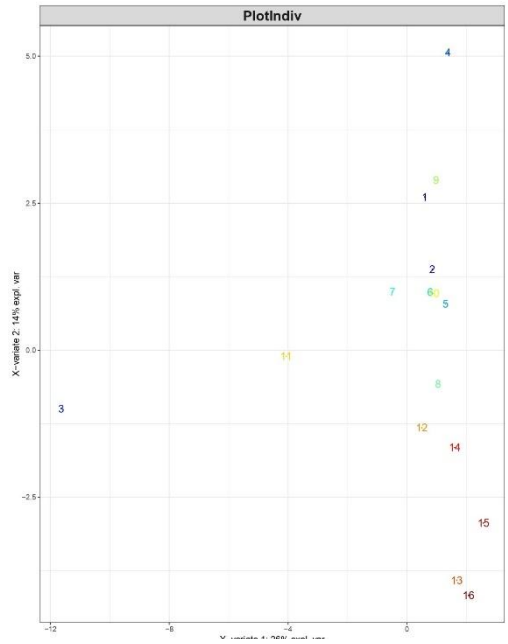


Fig. 7. PLSDA – Score plot

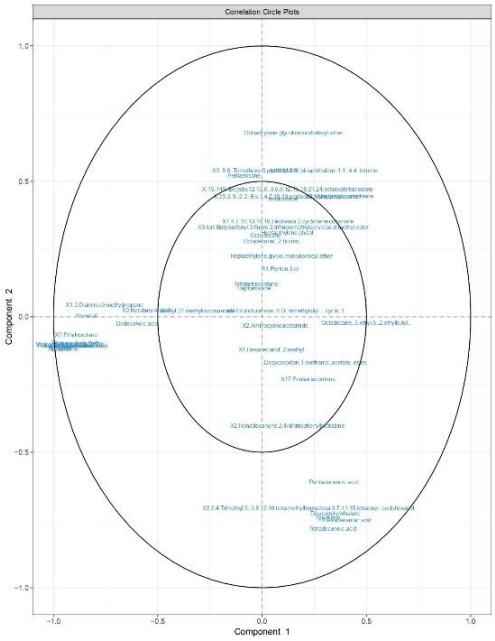


Fig. 8. PLSDA- Loadings plot

Some of the compounds reported to have significant difference in the present study are known to have influence in tritrophic interaction. The squalene which was found to influence the landrace Varappu Kudaichan is comparatively higher in the YSB and BPH infested treatments. This compound is a triterpenoid and is known to possess wound healing properties. It is also considered to be a potential compound in biological control as it attracts the natural enemies like *Chrysoperla* sp. and some parasitoids (Dutton et al., 2002; Jones et al., 2011). This might be the reason for its relatively higher amount in infested rice landrace. Compounds like n-hexadecanoic acid, pentadecanoic acid and tetradecanoic acid were also found to influence the landrace Varappu Kudaichan. These are saturated fatty acids and play important role in plants, and are known to possess oviposition deterrent activity against insects. Similarly, dodecanoic and hexadecanoic acids in *Solanum sarrachoides* were found to poorly deter the oviposition of *Tetranychus evansi*, Baker and Pritchard (Murungi et al., 2016). Compounds like octacosane and heptacosane play a role in intraguild predation

(Nakashima et al., 2006). Different multivariate analysis performed on the data provided the similarity in certain results like clustering of similar treatments from all the landraces together except Varappu Kudaichan and the volatile compounds that influence in the separation of the landrace Varappu Kudaichan from others.

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INVASION OF *ALEURODICUS RUGIOPERCULATUS* MARTIN IN ASSAM, POSING THREAT TO COCONUT GROWERS

Arup Kumar Sarma*, Shobha Dutta Deka[1] and Prasanta Kumar Das[2]

Department of Entomology; [1]Department of Statistics; [2]Department of Horticulture,
BN College of Agriculture, Assam Agricultural University, Biswanath 784176, Assam, India
*Email: arup.sarma@aau.ac.in (corresponding author)

ABSTRACT

***Aleurodicus rugioperculatus* Martin has invaded NER India in 2018 and established already in many districts of lower Assam and is alarmingly spreading to new districts owing to the inadequate domestic quarantine. The pest has been detected for the first time in Biswanath district of Lower Brahmaputra Valley Zone of Assam in May, 2019. Variation in speed of invasion has been noticed in different zones depending on the mode of dispersal of the pest. Rainfall had no impact on short-distance dispersal of the pest. However, rainfall-deficient months of 2018 and low rainfall days of 2019 had some impact on its arrival and establishment. The pest is likely to affect the coconut economy in future. Extensive survey in the NER India for assessing crop loss due to the invasion and enforcement of strict domestic quarantine in inter-state borders are the urgent need of the hour.**

Key words: Rugose spiraling whitefly, *Aleurodicus rugioperculatus*, rainfall, invasion, quarantine, coconut, NER, Assam

The North Eastern Region (NER) of India, one of the largest salients (panhandles) in the world, is known for its unique geographical location and rich biodiversity. Conservation International has upscaled the Eastern Himalaya hotspot to include all the eight states of Northeast India (https://en.wikipedia.org/wiki/Northeast_India). An entry of any invasive pest may pose a threat to this biodiversity hotspot. The state of Assam being at the centre of NER, the entry of any exotic pest to Assam may open a window to the other NE states too due to interconnected road communication. Therefore, such an invasion of pest to Assam is always a concern for entire Northeast India. In recent times, three exotic pest species have invaded the crop-ecosystem of Assam viz., Papaya mealybug (Sarma, 2013), Rugose Spiralling Whitefly (Mohan et al., 2018) and Fall Armyworm (Sarma, 2020). Till April 2017, NER India was reported to be free from RSW (Chakravarthy et al., 2017), but in August, 2018 it was observed for the first time in Assam by Mohan et al. (2018). Coconut is a major crop in India. As per the coconut production data of 2018-19, India ranks 3rd in coconut production in the world with a production of 21384.33 million nuts (Source: Coconut Development Board, India) and with an export earning of Rs. 2045.36 million (Source: DGCIS, Kolkata). Assam, being the largest producer of coconut in NER, produces 172.78 million nuts with a domestic market value of about Rs. 8639 million a year. This contributes a large share to poor and marginal farmers of the state. In this study, and effort has been to highlight the spread of Rugose Spiralling Whitefly (RSW) on coconut to new areas in the state of Assam; present status in the previously reported places; probable mode of its spread; role of rainfall on its dispersal; and prediction of its invasion in adjoining districts as well as in neighbouring state.

MATERIALS AND METHODS

The present study is based on a sample survey conducted at 45 hamlets of two districts (Nalbari and Biswanath) under two different agro-ecological zones of Assam in order to ascertain the new invasion of RSW and its establishment of previously invaded places. Field-survey was initiated in 20 villages of Biswanath district of Assam in May, 2019 based on the first infestation of *A. rugioperculatus* observed on coconut leaf. Periodic sample survey was done in two occasions (one in May-June and the other in November- December, 2019) to see the change in severity of infestation, if any, in the same village. Survey was conducted in villages of both the subdivisions of Biswanath district viz., Biswanath Chariali and Gahpur to see the establishment and dispersal of RSW. In order to ascertain the establishment of the pest, a survey was also conducted in the same five villages of Nalbari district where the first report of RSW invasion in Assam had been made by Mohan et al. (2018).

In addition, similar survey was also done in other 20 villages of Nalbari district that have not been surveyed earlier. This is to confirm the dispersal of the pest from the original place of report. In each case of surveys, 5 randomly selected farm households having coconut plants were taken into consideration in a village and infestation on coconut leaves were observed for confirmation. The specimens were collected and confirmation of the pest species was made based on the literatures of Mohan et al. (2017), and Sundararaj and Selvaraj (2017). Monthly rainfall data of 2018 (as non-occurrence year of RSW), 2019 (as occurrence year of RSW) and Normal (long term mean) are analysed here in relation to the occurrence of RSW in Biswanath district using two-way ANOVA. Line charts on monthly rainfall data and multiple bar diagram for no. of rainy days/ month are also presented for better visual interpretation. Status of deviation of rainfall from the Normal is seen for entire year (January - December) and also for the high rainfall months (March- October) of 2018 and 2019. Data on rainy days are subjected to square root transformation and t-test is performed for comparison. Necessary computation is made by using SPSS 16.0 and MS excel. Rainfall data were collected from the Agro-Meteorology Department of Biswanath College of Agriculture, Assam Agricultural University.

RESULTS AND DISCUSSION

The results of this study confirms that RSW has expanded its invasion in additional district of Assam, established well in previously reported places of the state; its dispersal took place through two different modes and showed variation in speed of invasion in different agroecological zones. It is perceived that the pest has colonized in new area in rainfall deficit months and high rainfall interrupted the long-distance dispersal of the pest. Infestation on coconut leaf by RSW was detected for the first time in Biswanath district of Assam in May, 2019. Different levels of intensity were observed during the periodic survey conducted in 20 villages of two subdivisions of the district. The severity of infestation observed in some villages during May has confirmed that pest might have invaded few months earlier, probably in very early part of 2019. It was noticed that within a short span of time it has invaded many villages. Each of the villages infested is susceptible to receive the infestation to its maximum intensity with time as reflected in increase of range of mean infestation (Table 1).

Mean incidence of immature stages ranged from 0.2- 0.8 nymphs/ inch^2 of leaflet initially in May-June, 2019 which increased to 0.7-2.1 nymphs/ inch^2 in November- December, 2019. Populations comprising of adult and immature, completely covered some leaflets of coconut palm in some highly infested villages and were also observed on the inflorescence, pedicle and exocarp. The pest is spreading to adjoining villages and is likely to invade more and more villages in near future. It is perceived that the existing agroecological conditions of the plain regions of Assam is supportive to RSW and hence, likely to affect the coconut economy of the state. The pest has established itself in an area where its first invasion was observed by Mohan et al. (2018). The pest is also dispersing to nearby areas as observed in the present survey (Table 2). Polyphagy of the pest has also been noticed in newly invaded villages. The pest has been identified on at least 118 plant species (Francis et al., 2016), which include a combination of edibles, ornamentals, palms, weeds, as well as native and invasive plant species (Stocks, 2012). The RSW can invade a new area by itself (i.e. self-perpetuating from an already invaded area) or by other mode of transport (i.e. when carried by other agent along with planting materials). Nalbari and Kamrup districts of Assam are well known for the coconut production and its planting materials are supplied regularly to rest of NER. Therefore, the pest may invade other places of NER at any point of time, since domestic quarantine mechanism is not strong in NER. The aerial distance between Coimbatore, Tamil Nadu (the 1st reported place of RSW invasion in India) and Nalbari, Assam (the 1st reported place of NER) is about 2,290 km. This distance was covered by RSW in about 23 months (690 days or 16,560 hrs.) i.e. @3.2 km/ day or @138.3 m/ hr. Biologically, RSW cannot cover this distance with such a high flight rate in continuous manner since it does not remain in active flight mode throughout the day.

Previous studies on its flight behavior have also reported that RSW was most active in flight right after the dawn and flight activity reduced between 12:00- 16:00 with a smaller peak of activity near sunset (Siavash Taravati et al., 2014). Higher flight activity in and around dawn and dusk had also been reported by Han et al. (2009) in a congeneric spiraling whitefly (*A. disperses* Russell). Therefore, the active time of dispersal from Coimbatore to Nalbari was less than 690 days at a flying speed of more than 3.2 km/day. Moreover, the varied agro-climatic conditions that prevail in the places between Coimbatore and Nalbari might have affected its normal flight rate; for instance, the average annual rainfall of the two states are- Tamil

Nadu (945 mm) and Assam (1927 mm). Therefore, it is logical to interpret that the pest has entered Assam, possibly, along with the planting materials of coconut or other host plants. Shanas et al. (2016) also made a doubt that the pest gained entry into the country through trade in ornamental plants. Notably, the pest did not reach Biswanath Chariali (BNC) at the same speed as that in between Coimbatore and Nalbari. The aerial distance between Nalbari and BNC is about 175 km; therefore, the pest should have arrived at BNC @3.2 km/ day (as assumed in case from Coimbatore to Nalbari) in 53 days, but it took about 9 months (270 days) with an average speed of just 0.7 km/ day. Moreover, the entire corridor joining the two districts is agroecologically similar in terms of floral diversity and weather. It indicates that the "dispersal along with planting materials" occurred more promptly in the former sector (i.e. Coimbatore to Nalbari) than the later (Nalbari to BNC). Nalbari is located near to the NH 37 which is more crowded with goods-carrying vehicles heading to NER from mainland India as compared to that in BNC which is located near to a relatively less crowded NH 52. RSW took about 9 months with an average speed of just 0.7 m/day in reaching BNC from Nalbari. Such a low average speed clearly indicates that the pest invaded BNC by flying (self -perpetuation), not along with the planting-material of coconut. Assuming a flight rate of 0.7 km/ day, it can be predicted that RSW may invade the other districts of North Bank Plain Zone (NBPZ) of Assam viz., Lakhimpur district in about 157 days (5.2 months) and Dhemaji district in 242 days (8.1 months) from the date invasion in BNC. The pest may reach the East Siang district of Arunachal Pradesh state in 13.3 months. The predicted period may deviate due to abiotic factors, primarily the rainfall and temperature; but, it is certain that the pest is going invade these places in near future. The Government of Arunachal Pradesh should take strict quarantine measures to prevent the entry of RSW along with planting material.

Table 1. Status of *A. rugioperculatus* on coconut- Biswanath district, Assam

Village[2]	[1]Intensity of the pest		GPS	Remarks
	May-June, 2019	November-December, 2019		
A. Subdivision : Biswanath Chariali				
Bahboriagaon	++	+++	26°43'43.1"N 93°10'38.7"E	Each of the tabulated data of infestation is based on mean of 5 samples. Samples were drawn from 5 farm-households per village to judge the average intensity of *A. rugioperculatus*. GPS of random location of the village has been mentioned here. Tabulated mean infestation range is the average of the respective lower and upper values of 20 villages surveyed in the district.
Japarijan	++	+++	26°43'22.1"N 93°11'12.4"E	
Morolgaon	++	+++	26°44'11.7"N 93°11'07.3"E	
Balipukhuri	-	++	26°44'35.8"N 93°12'00.8"E	
Bamgaon	++	+++	26°44'05.5"N 93°09'17.7"E	
Madhupur	+	+++	26°43'21.2"N 93°08'43.6"E	
Nirolabasti	-	++	26°44'02.4"N 93°11'54.3"E	
Arabari	-	++	26°43'08.4"N 93°10'17.7"E	
Garehagi	+	+++	26°42'42.2"N 93°08'44.6"E	
Bhirgaon	+	++	26°42'16.2"N 93°09'26.8"E	
Panibharal	+	++	26°41'52.6"N 93°09'08.8"E	
Na-bazar	-	++	26°40'11.8"N 93°09'36.2"E	
Da-gaon	-	++	26°41'38.4"N 93°08'41.0"E	
Gelapukhuri	-	++	26°47'34.3"N 93°13'26.0"E	
Disiripathar	-	++	26°47'05.4"N 93°12'05.9"E	
Geruabari	-	++	26°47'03.1"N 93°10'18.5"E	
Kuwari	+	+++	26°45'34.7"N 93°08'48.3"E	
Lehugaon	+	+++	26°45'31.4"N 93°09'04.7"E	
B. Subdivision: Gahpur				
Ganakdoloni	-	-	26°55'45.6"N 93°47'06.2"E	
Dholpur	-	-	26°55'23.0"N 93°47'38.0"E	
Mean infestation (nymphs/inch^2)	0.2 - 0.8	0.7 - 2.3	-	

[1]Intensity of infestation in coconut leaf as indicated: by: – (No infestation; No egg-colony/ leaflet), + (1-5 egg-colonies/ leaflet), ++ (6-10 egg-colonies/ leaflet), +++ (> 10 egg-colonies/ leaflet); [2]Villages include only those surveyed by us up to end of December, 2019; however, many more villages in Biswanath subdivision have been invaded by RSW as reported by farmers and agricultural extension workers.

Table 2. Status of *A. rugioperculatus* on coconut- Nalbari district of Assam

Year of observation	District	Village/Hamlet	Intensity[1]		GPS	Remarks
			2018	2019		
2018	Nalbari	Bijulighat*	++	+++	*Hamlets surveyed by Mohan et al., (2018) are surveyed again in 2019 to see the establishment of RSW and its present status of severity. No GPS data was assigned in the previous report.	
		Barkuriha*	++	+++		
		Madhapur*	++	+++		
		Katpuha*	++	+++		
		Tilana*	+	+++		
2019	Nalbari	Namkhala	+++		26°22'51.3"N 91°30'33.0"E	Each of the tabulated data of infestation is based on mean of 5 samples. Samples were drawn from 5 farm-households per village, but GPS of a random location of the village has been cited here
		Chatama	+++		26°23'07.5"N 91°30'44.4"E	
		Chamarkuchi	+++		26°21'57.9"N 91°30'24.1"E	
		Datara	+++		26°24'02.0"N 91°30'44.0"E	
		Dhanara	+++		26°23'57.7"N 91°30'43.4"E	
		Kundargaon	+++		26°25'03.2"N 91°30'59.5"E	
		Narpara	+++		26°24'27.6"N 91°30'28.9"E	
		Barara	+++		26°23'41.1"N 91°30'09.2"E	
		Barkhala	+++		26°22'45.7"N 91°31'14.5"E	
		Pandula	+++		26°22'48.4"N 91°30'27.2"E	
		Dhurkuchi	+++		26°23'05.9"N 91°30'32.2"E	
		Larma	+++		26°22'15.6"N 91°31'12.7"E	
		Sanekuchi	+++		26°21'57.2"N 91°30'50.8"E	
		Bangabari	+++		26°22'42.5"N 91°29'27.3"E	
		Kalag	+++		26°22'43.6"N 91°28'49.4"E	
		Deharkuchi	+++		26°21'51.8"N 91°31'12.8"E	
		Nonoi	+++		26°25'02.0"N 91°30'31.0"E	
		Nakheti	+++		26°21'19.7"N 91°29'18.0"E	
		Dingdingi	+++		26°22'01.7"N 91°29'10.9"E	
		Athghoria	+++		26°21'54.2"N 91°30'12.1"E	

[1]Intensity of infestation in coconut leaf as indicated: by: – (No infestation; No egg-colony/ leaflet), + (1-5 egg-colonies/ leaflet), ++ (6-10 egg-colonies/ leaflet), +++ (> 10 egg-colonies/ leaflet)

Monthly rainfall- based analysis shown in Table 1 reveal that even though it is reported that prolonged dry and warm conditions due to low rainfall (600 mm in 2016), high populations of RSW were observed on host plants in Pollachi, Tamil Nadu, India (Chakraborty et al., 2017), it is difficult to ascertain the extent of negative impact of rainfall in dispersal of RSW since the pest has been observed dispersing in high rainfall months in Assam. In Biswanath, Chariali subdivision, the first infestation was noticed in May, 2019 during which a rainfall of 453.6 mm (with 24 rainy days) was received; likewise, a total rainfall of 363.2 mm was received in previous three months (February-April; with 25 rainy days) and subsequently a total of 1038.9 mm (with 72 rainy days) during June - October (Table 3; Fig. 1 and 2). Factually, RSW dispersed in different villages of Biswanath Chariali subdivision during the high rainfall days itself. Moreover, the leaf geometry and hardness of leaf lamina of coconut plant might have offered a safe micro-environment for the pest on the underside of the leaf.

As depicted by Table 3 and Fig. 1 and 2, the winter months and rainfall-deficient months, particularly September and October, in previous year (2018) might have helped in arrival and initial colonization of RSW in Biswanath district from infested area of other districts. Similarly, in 2019, one non-rainy month (January) and four rainfall-deficient months might have supported in intensifying its invasion by increased colonization in already invaded villages of the district. Even though there was difference in no. of rainy days in respective months occurrence and non-occurrence years, the total amount of rainfall were statistically *at par.* Months with deficient rainfall in 2019, particularly the August and October with less no. of rainy days (6 days each), might have played a positive role in intensifying infestation. This is why the pest is still spreading as observed in the end of December, 2019 in Biswanath Chariali. High rainfall intensity and wet spell with continuous rainy days might have affected the long distance dispersal of RSW. This may be supported by the fact the even in the mid of December 2019, no invasion of RSW was noticed in villages of Gohpur subdivision of the district. Such a non-occurrence of the predicted event clearly confirms the

Table 3. Monthly rainfall and non-occurrence year vs occurrence year of RSW- Biswanath district, Assam

Month	Rainfall (mm), its intensity in different years and % deviation from normal rainfall					
	Non-occurrence year (2018)			Occurrence year (2019)		
	Intensity of rainfall	% deviation from normal	SOD	Intensity of rainfall	% deviation from normal	SOD
January	No rain	(-) 100.0	No rain	No rain	(-) 100.0	No rain
February	Moderate	(-) 18.5	Normal	Rather heavy	(+) 92.1	Excess
March	Rather heavy	(-) 20.8	Deficient	Heavy	(+) 88.4	Excess
April	Extremely heavy	(+) 47.7	Excess	Very heavy	(+) 10.0	Normal
May	Very heavy	(-) 38.9	Deficient	Extremely heavy	(+) 83.9	Excess
June	Extremely heavy	(-) 18.5	Normal	Very heavy	(-) 48.5	Deficient
July	Extremely heavy	(+) 8.6	Normal	Extremely heavy	(-) 14.0	Normal
August	Extremely heavy	(+) 12.4	Normal	Very heavy	(-) 47.8	Deficient
September	Very heavy	(-) 20.3	Deficient	Extremely heavy	(+) 43.7	Excess
October	Heavy	(-) 43.6	Deficient	Heavy	(-) 34.6	Deficient
November	Rather heavy	(+) 178.6	Excess	Moderate	(-) 47.9	Deficient
December	Moderate	(+) 121.9	Excess	Moderate	(+) 49.1	Excess
Total Rainfall during January-December		1980.8^{N} 1898.1^{A}			1980.8^{N} 1882.7^{A}	
% deviation from normal rainfall		(-) 4.2	Normal		(-) 5.0	Normal
Total Rainfall during March - October		1901.8^{N} 1794.7^{A}			1901.8^{N} 1797.7^{A}	
% deviation from normal rainfall		(-) 5.6	Normal		(-) 5.5	Normal

Normal rainfall = Mean of 30 years' rainfall data. Data superscripted with N is Normal rainfall data and that with A are actual rainfall data. SOD: Status of deviation; Intensity of rainfall is as per Indian Meteorological Department: http://imd.gov.in/section/nhac/termglossary.pdf)

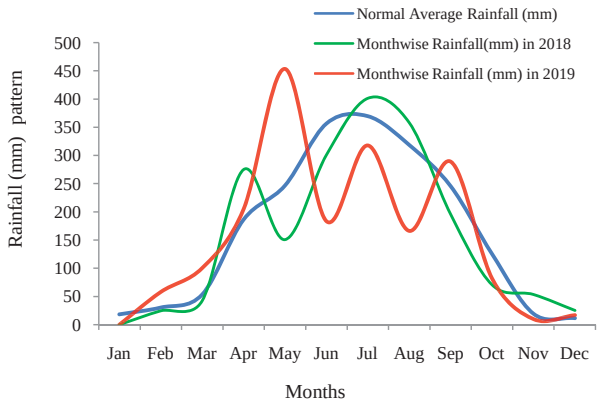

Fig. 1. Rainfall pattern- non-occurence (2018), occurence year (2019) vs Normal rainfall

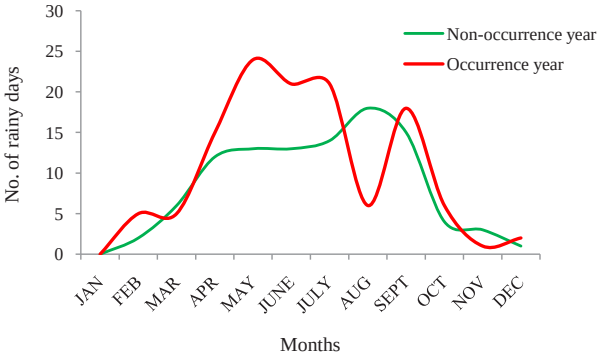

Fig. 2. No. of rainy days- non-occurence (2018) & occurence year (2019)

negative role of high rainfall in long distance dispersal of the pest. In between Biswanath Chariali and Gahpur, there are large paddy fields, big tea plantation, and low density of coconut plantation. Possibly under such a circumstance the negative impact of high rainfall in long distance dispersal of RSW acted pronouncedly and delayed the invasion in the eastern districts of NBPZ of Assam.

It is certain that the RSW has established in already invaded places of Assam and gained the potentiality to invade further any corner of NER sooner or later based on its mode of dispersal. Its invasion or colonization in a locality may vary with the local ecological parameters *viz*., prevailing meteorological factors and richness of host-plant species. However, the pest would affect the coconut economy in this region. Extensive survey in entire NER for assessing the crop loss and impose of strict domestic quarantine in interstate boarders are the prime needs of the hour.

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MORPHOLOGY OF IMMATURE STAGES AND ADULTS OF *HELICOVERPA ARMIGERA*

Snehel Chakravarty, Sabuj Ganguly, Kanchan Gangaram Padwal, Ram Keval and C P Srivastava*

Department of Entomology and Agricultural Zoology, Institute of Agricultural Sciences,
Banaras Hindu University, Varanasi 221005, India
*Email: csrivastava63@gmail.com (corresponding author)

ABSTRACT

***Helicoverpa armigera* (Hübner) is a highly polyphagous insect pest of worldwide occurrence, including India. In the present study, a detailed morphological assessment of *H. armigera* showed the following: typically dome-shaped egg with ribbed surface; larva having coriaceous skin, biordinal crochets and 11 primary setae on the prothoracic segment; pupa adecticous and obtect with prominent posterior tip cremaster; and adult forewings characterized by the presence of 7-8 black spots along the apical margin and a reniform shaped brown marking, more prominent on the underside. Adults exhibit sexual dimorphism in the colour of vestiture and forewings. The genitalic traits like the presence of usually 12 or less sets of cornuti in aedeagus, apically broadened harpe having length ranging between 4.5 to 4.9 mm and a single lobe at the base of everted vesica in males, and four distinct signa on bursa copulatrix in females, also distinguishes it from other congeneric species.**

Key words: *Helicoverpa armigera*, morphology, egg, larva, chaetotaxy, pupa, wings, sexual dimorphism, genitalia

Heliothinae is a small subfamily of noctuid moths that includes some of the major agricultural pests of worldwide importance (Mitchell and Gopurenko, 2016), of which an important one is *Helicoverpa armigera* (Hübner). This pest species has an exceptionally wide geographical distribution and host range (Gomes et al., 2018). In India, it is known to attack around 96 crops, including major cereals, legumes, oilseeds, cotton, and a wide range of horticultural crops (Srivastava and Joshi, 2011). Depending on the crop, *H. armigera* induced damage can lead to 50 to 90% yield loss, inflicting huge monetary loss (Chakravarty et al., 2019). Correct identification of the pest is an essential requisite for devising effective IPM strategies (Chakravarty et al., 2018). The external morphological characters of life stages (Ranjith and Chellappan, 2015), wing colour patterns (Ethier and Despland, 2015), and genitalia morphology (Pogue, 2004; Dias et al., 2010), have been found to be highly informative and useful for species recognition in lepidopteran insects. Though much has been published concerning general morphology, biology and behavioural aspects of *H. armigera* (King, 1994; Ali et al., 2009; Kingsolver et al., 2011; Tang et al., 2016; Queiroz-Santos et al., 2018), studies offering details on key identification features of this species from India are still limited and scattered. Recently, doubts have also been raised regarding existence of unidentified cryptic species (Gill et al., 2015) or different subspecies (Chakravarty et al., 2020) of *H. armigera* in the country, as it exhibits differential responses to various selection pressures. Thus, the present study was undertaken to provide a revised and detailed morphological characterization of all the immature stages and adults of *H. armigera* from India. The information offered here is meant to expedite the accurate identification of this pest species, as it is often confused with other congeneric species. This study will also form a basis to understand the effects of genetic and environmental factors on morphological features, and to capture its intraspecific morphological variations among geographically isolated populations.

MATERIALS AND METHODS

The larvae of *H. armigera* were collected from chickpea fields of the Agricultural Research Farm, Banaras Hindu University during February-March, 2017-2018 and were reared at the Biocontrol Laboratory, Department of Entomology and Agricultural Zoology, Banaras Hindu University, for two consecutive generations, in a digitally controlled insect rearing chamber (Instech Environmental Chamber, Instech Systems, India; 25± 1°C, 65± 5% RH and 12 hr photophase), following standard procedures as described by Chakravarty et al. (2018). All the morphological characters were analyzed from the second filial generation, and illustrations of these, along

with measurements of all stages (egg, larva, moulted head capsule, and pupa), and genitalia were made in a stereozoom microscope with an image analyzer (Leica DM1000). The larvae and adult specimens were killed with ethyl acetate before examination (Queiroz-Santos et al., 2018). The setal arrangement on the prothoracic segment of larvae was studied following Ranjith and Chellappan (2015), and compared with the illustrations of setal arrangements of *H. armigera* by Passoa (2014). The method suggested by Padwal et al. (2018) was followed with minor modifications for dissection of genitalia from both male and female moths and preparation of their slides. All the morphometric measurements are specified based on mean and standard deviation values from 50 randomly selected specimens, using a statistical package (SPSS, Version 16).

RESULTS AND DISCUSSION

Egg: The eggs were typically dome-shaped, circular in cross-section, and with the micropyle being borne on a small mound at the apex of the dome. The surface of the eggs was sculptured in the form of longitudinal ribs. These were gleaming yellowish white when freshly deposited (Fig. 1a). The colour gradually changed during the next 14 to 36 hr to a rather muddy yellow, at which time a brown subequatorial band appeared on the egg (Fig. 1b). Concurrently, or somewhat later, this band darkened. Between 48 and 72 hr after deposition, the whole egg became dark grey (Fig. 1c) as the larva matured within the chorion. The infertile eggs became dark yellow and shriveled after three to four days. Oviposition occurred singly, with female moths preferably selecting soft surfaces for laying eggs. The size varied from 0.51± 0.04 x 0.49± 0.05 mm. Egg morphology and oviposition behaviour described herein for *H. armigera* are consistent with what has previously been observed by King (1994), Deepa and Srivastava (2010), Gomez-Rolim et al. (2013) and Queiroz-Santos et al. (2018).

Larva: The larval stage had six instars, of which the first was translucent creamish white and lacked prominent markings; their head, prothoracic and supra-anal shields, thoracic legs, spiracles and setal bases were black and thereby giving them a spotted appearance (Fig. 1d), as also observed by Bhatt and Patel (2001). The larva became segmentally marked with the end of the stadium. The second instar resembled the first in appearance, but the dermal spinulation was more pronounced (Fig. 1e). In the third instar (Fig. 1f), the abdominal prolegs became fully developed on third to

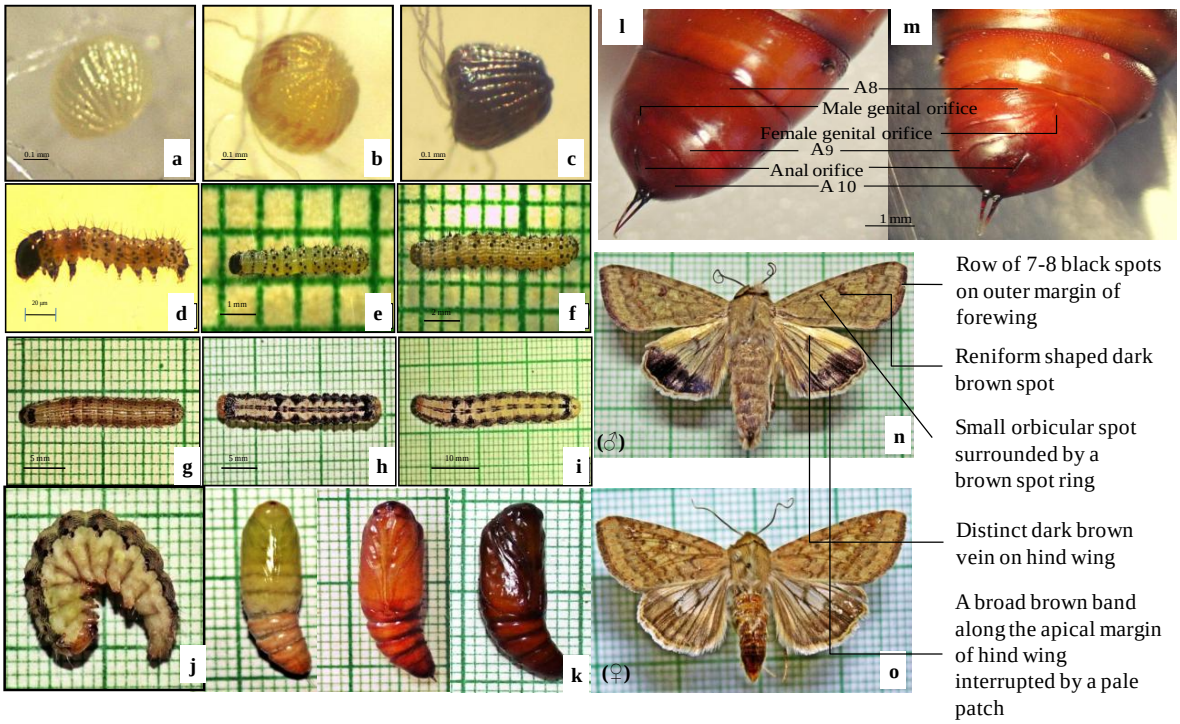

Fig. 1. Life stages of *H. armigera*, a-c: Egg; d: First instar; e: Second instar; f: Third instar; g: Fourth instar; h: Fifth instar; i: Sixth instar; j: Pre-pupa; k: Colour change in pupa; l: Posterior region of male pupa in ventral view; m: Posterior region of female pupa in ventral view; n: Male moth; o: Female moth

sixth and tenth abdominal segments, and these remained until last larval instar. In the fourth instar (Fig. 1g), the dorsal tubercles on the first abdominal segment formed a distinct "saddle-like" structure. In the penultimate (fifth) larval stadium (Fig. 1h), the two colour phases (green and brown) became distinctly evident and the general macular pattern became better defined or complex. These were also found responding to external disturbances by raising their head and thoracic segments (Chakravarty et al., 2018). The two colour-patterns observed in *H. armigera* larvae had not been reported for other species in this genus to date (Queiroz-Santos et al., 2018). In the final (sixth) instar (Fig. 1i), an abrupt change in body colour occurred. Head was pale green or orange, often with white reticules. The trunk showed a variety of shades of brown, yellow, green, and even black colouration (Chakravarty et al., 2020). The larval skin was coriaceous, and the crochets were typically biordinal. The chalazae of the first abdominal segment and spiracular rim of the eighth abdominal segment were twice the size of others (Fig. 2). The body length and width of first, second, third, fourth, fifth and sixth instar larvae was recorded as 1.68± 0.07 and 0.46± 0.04 mm, 3.94± 0.05 and 0.72± 0.04 mm, 8.65± 0.13 and 1.61± 0.06 mm, 15.40± 0.24 and 2.95± 0.05 mm, 24.52± 0.21 and 3.36± 0.07 mm, and 30.76± 0.33 and 4.72± 0.08 mm, respectively. The head capsule width of corresponding stages were 0.32± 0.03 mm, 0.48± 0.04 mm, 0.71± 0.06 mm, 1.22± 0.07 mm, 1.87± 0.11 mm, and 2.70± 0.10 mm. The present findings are in accordance with earlier reports of Deepa and Srivastava (2010), Gill et al. (2015), and Chakravarty and Srivastava (2020).

Chaetotaxy: Most of the formal keys for the identification of lepidopterans at larval stage rely heavily on chaetotaxy, particularly primary setae (Ranjith and Chellappan, 2015). In the present study,

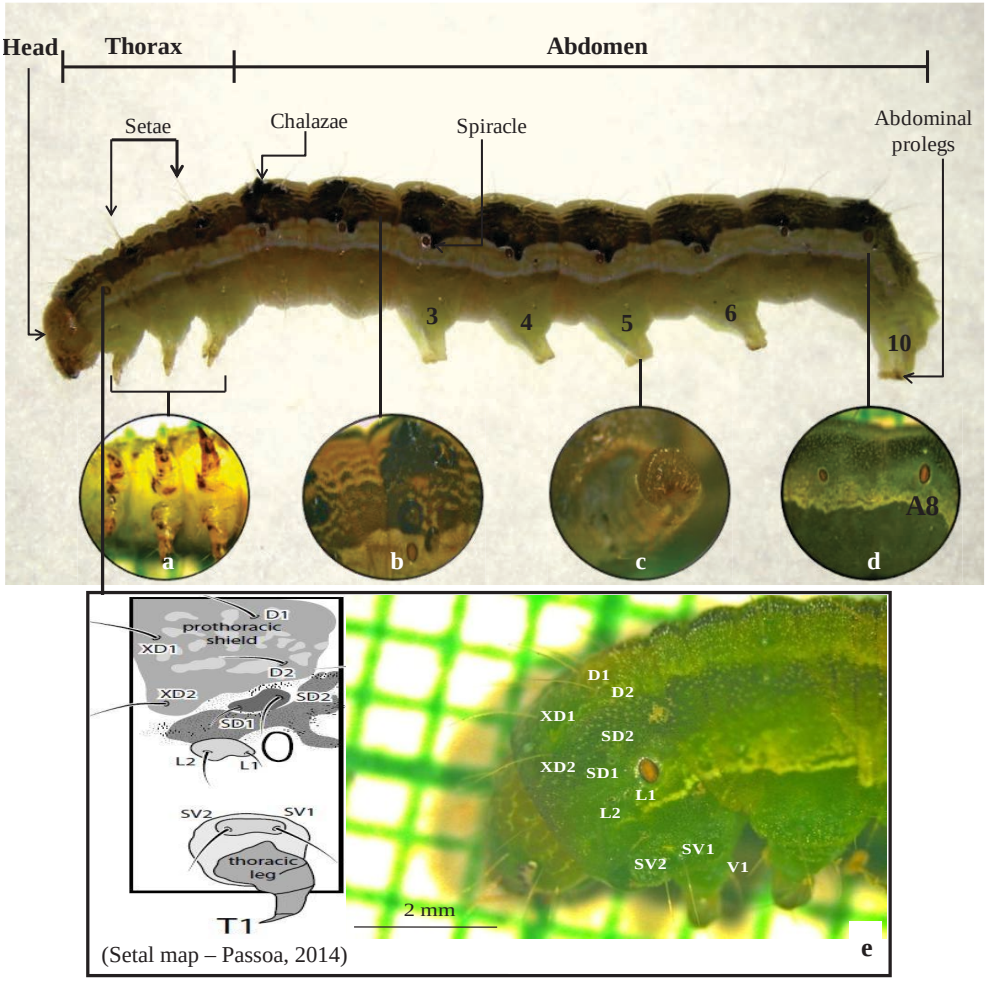

Fig. 2. Lateral view of *H. armigera* larva (sixth instar), a: Thoracic legs, b: Coriaceous skin, c: Biordinal crochets, d: Spiracular rim of the eighth abdominal segment (A8) twice the size of others; e: Setal arrangement on the prothoracic segment

11 unbranched primary setae were observed on the prothoracic segment that included two each of dorsal (D1, D2), subdorsal (SD1, SD2), lateral (L1, L2), subventral (SV1, SV2) and additional (XD1 and XD2) setae, along with one ventral seta (V1) (Fig. 2). These setae have specific names based on their positions. The additional setae exist near to the anterior margin of the pronotal plate. The dorsal setae were situated posterolateral to their respective additional setae. Both the subdorsal setae lied near the lateral margin of the pronotal plate, and the lateral setae are anterior and horizontally aligned to the prothoracic spiracle. The two subventral setae lied above coxa while, the single ventral seta was post coxal in position and most ventrally located. The same arrangement was observed in all instars. These observations are in accordance with Passoa (2014) and Ranjith and Chellappan (2015), who prepared diagnostic keys based on the above characters to distinguish *H. armigera* from related species. The position of seta on the prothoracic segment observed in the present study was also in consonance with Singh and Goel (1987) and Sri et al. (2010) who described the taxonomy of Noctuidae with special reference to immature stages.

Prepupa: The last instar larva after its complete development, did not moult but was contracted and shortened into a grub-like prepupa (Fig. 1j). Its mean length and width were 22.78± 0.25 mm and 5.50± 0.09 mm, respectively, and it had pale yellowish green or yellowish brown body, as also observed by Deepa and Srivastava (2010) and Chaudhary et al. (2016). This stage digs into the soil to pupate; a behavior described for all *Helicoverpa* spp., and could be a style to increase survival (Queiroz-Santos et al., 2018).

Pupa: The pupa was adecticous, obtect, rounded at ends, smooth textured and edges of segments well marked. Newly formed ones were yellowish green, which became mahogany brown within few hours of its formation and further darkened prior to adult emergence (Fig. 1k). The pupa measured 18.56± 0.19 x 6.42± 0.15 mm, corroborating with Ali et al. (2009) and Chaudhary et al. (2016). In ventral view, a goblet like frontoclypeus, triangular shaped hypopharynx, and lance-shaped galea, covering a significant portion of the anterior half were easily noticeable. Legs were placed along the antenna towards the galea in repose. Hind wings were placed over forewings, both ending above the anterior margin of the fifth abdominal segment. Dorsally prothorax was small and triangular; mesothorax and metathorax projecting latero-ventrally, forming the pterotheca. The abdomen had ten segments with elliptical and conspicuous spiracles, between the second and seventh segment, and reduced in the eighth one. A posterior-tip cremaster in the form of two tapering parallel spines was borne on the tenth abdominal segment terminus. An elongate anal opening scar was also located on the distal ventral area of the tenth abdominal segment. Female genital pore was located medioventrally on the eighth abdominal segment while, the male genital opening was situated on the ninth segment, surrounded by small protuberances (Fig. 1 l,m), as also observed by Gill et al. (2015) and Queiroz-Santos et al. (2018).

Adult: The adults were stout bodied moths with broad thorax. Antennae were of the filiform type, not sexually dimorphic and covered with fine hairs, an aspect also observed by Diongue et al. (2013). Male and female moths were readily distinguishable based on colouration of vestiture and forewings. In males, they were greenish brown while, female moths had orange brown to dark brown vestiture and forewings (Fig. 1n,o). The forewings of both sexes were also characterized by the presence of brown, broad, and irregular transverse bands and seven to eight black spots along the apical margin. A dark brown, reniform shaped marking was also present on the forewing of each sex, more prominent on the underside. The hind wings of both sexes were dull creamish with a broad dark brown border at the apical end, interrupted by a pale patch. Males and females also had identical venation patterns. Each of the forewings had 14 longitudinal veins (C, Sc, R_1-R_5, M_1-M_3, CuA_1, CuA_2, 2A, 3A) and four cross veins (dcs, dcm, dci, m-cu) (Fig. 3a). Hind wings with eight longitudinal veins (C, Sc + R_1, Rs, M, CuA, A) and two cross veins (dcm, dci) (Fig. 3b). Wingspan was 39.82± 0.28 mm, and the males were usually smaller than females, as also reported by Nylin and Gotthard (1998) and Brambila (2009).

Male genitalia: The various parts of male genitalia observed were uncus, harpe, corona, vinciculum, saccus, corpus genitalis, aedeagus, and cornuti (Fig. 4). Uncus was small, cylindrical and hook-like towards its tip. Vinculum was V-shaped and the paired clasping organ (harpes or valvae) articulated from its caudal margin. The length of apically broadened harpe ranged between 4.5 to 4.9 mm, which was consistent with what has previously been observed by Pogue (2004). It also had numerous rows of closely set spines anteriorly (corona). Saccus was short (0.57± 0.04 mm), bell-shaped with curved apical portion. The length of corpus genitalis was 3.28± 0.07 mm. Aedeagus was 4.46± 0.06

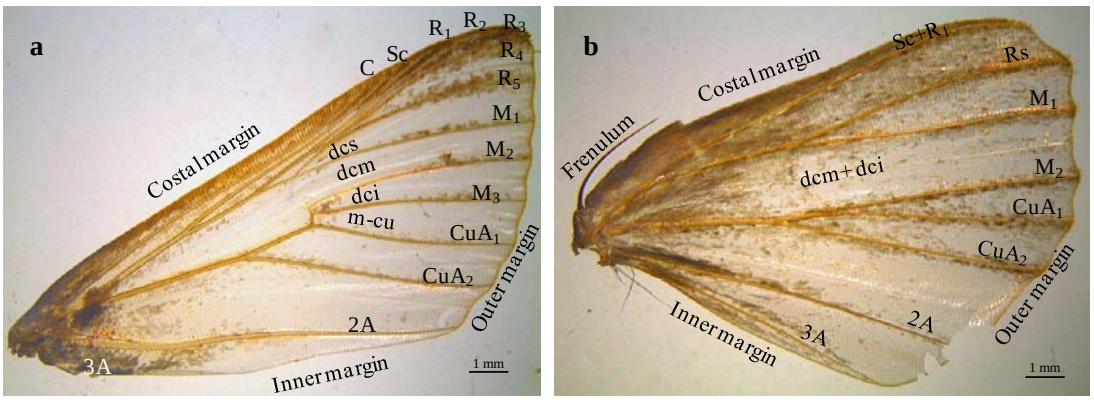

Fig. 3. Wing venation of *H. armigera*, a: Fore wing; b: Hind wing; Costa (C), Subcosta (Sc), Radius (R), Media (M), Cubitus (Cu), Anal (A), Upper discocellular (dcs), Median discocellular (dcm), Lower discocellular (dci), Medio-cubital (m-cu)

mm long, weakly sclerotized structure with usually 12 to 14, or less sets of cornuti (sclerotized spines) inside it, in accordance with Krinski and Godoy (2015). However, Brambila (2009) reported that presence of 12 or fewer sets indicating that the specimen "could be" *H. armigera*, while more than 15 sets indicates it to be "probably" *H. zea*. The long spiral tube called vesica was also partially everted out from the aedeagus, and only a single lobe or diverticula was found at its base.

Female genitalia: The various parts of female genitalia observed were ovipositor, anterior and posterior apophysis, ductus bursae, bursa copulatrix, and bursa seminalis (Fig. 4). The ovipositor consisted of two curved hairy lobes, hairs probably having sensory function. Anterolateral margin of the eighth tergum extended and formed the anterior apophysis, and the same region in ninth tergum formed the posterior apophysis. Both apophyses were narrow; the anterior one slightly curved while the posterior one was straight and slightly shorter. Bursa copulatrix and bursa seminalis were two distinct diverticula of ductus bursae, and 3.95± 0.02 mm and 6.54± 0.05 mm long, respectively. Bursa copulatrix was membranous with four distinct heavily sclerotized areas (signa) readily visible on its surface, of which, three were long and one short, structurally apposed. Bursa seminalis or spermatheca was helical, sclerotized, twice as long as bursa copulatrix, and it was attached to the bursae duct in its distal half by a sclerotized plate. The observations made herein are in agreement with Hardwick (1965), and Ranjith and Chellappan (2015).

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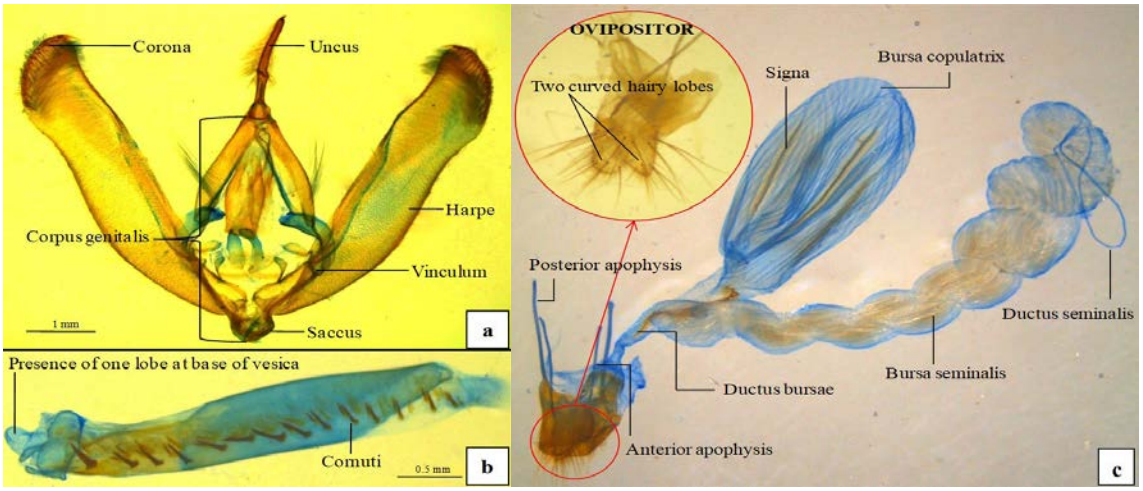

Fig. 4. Genitalia of *H. armigera*, a: Entire male genital structure excluding aedeagus; b: Aedeagus with uninflated vesica; c: Female genitalia

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EFFICACY OF INSECTICIDES AGAINST JAMUN SEED WEEVIL *CURCULIO C- ALBUM* F.

Aishwarya Hiremath*, Pooja and Ramegowda G K[1]

Department of Entomology, College of Horticulture; [1]Regional Horticultural Research and Extension Centre, UHS Campus, GKVK, Bengaluru 560065, Karnataka, India,
*Email: aishwarya23297@gmail.com (corresponding author); ORCID id- 0000-0003-3113-9841

ABSTRACT

Among seven insecticides evaluated azadirachtin 10000 ppm (1 ml/ l) was found to be the most effective against seed weevil *Curculio c-album* F., followed by deltamethrin 2.8EC (1.0 ml/ l) and malathion 50EC (2.0 ml/l). The least effective was spinosad 45SC (0.3 ml/ l) followed by cyantraniliprole 10.26OD (1.8 ml/ l). Three rounds of sprays (new flush, pre bloom and post bloom) of insecticides gave better protection when compared to single/ two sprays. Maximum healthy fruit yield (49.81 kg/ tree) was obtained with azadirachtin.

Key words: Jamun, *Curculio c-album*, insecticides, sprays, damage grades, healthy fruit yield, BCR, azadirachtin, deltamethrin, malathion, spinosad, cyantranilprole

Jamun, popularly known as "fruit of gods" as it possesses multiple health benefits. The jamun fruits and products are acknowledged for their therapeutic purposes, particularly diabetics. The seed is used in Ayurveda, Unani and Chinese medication for stomach related afflictions. So for 78 insect species from five orders viz., Hemiptera (26 spp.), Coleoptera (8 spp.), Diptera (5 spp.), Lepidoptera (34 spp.), Thysanoptera (6 spp.) are known from jamun (Rajeshkumar et al., 2010) and four mite species (Nayak, 2017) of which seed weevil *Curculio c-album* F., causing significant economic damage to seeds is important (Hiremath et al., 2021). Fletcher (1917) was in a dilemma for placing *C. c-album* as a jamun pest as it was feeding on seeds thinking seed has no economic value. Systemic studies on chemical control of seed weevil of jamun have not been done so far. There is a need for screening of safer and effective pesticides to manage seed weevil without causing the environmental damage. A field experiment was conducted to evaluate the efficacy of seven insecticides against *Curculio c-album* and the results are presented herein.

MATERIALS AND METHODS

The study site was Regional Horticulture Research and Extension Center, GKVK, Bengaluru (13° 05' N, 77° 33'E, 930 masl- Zone-5) of Karnataka. Thirteen jamun varieties/ accessions were used including Mysuru, Chinthamani, Bahadoli, No-58, K-45, No-20, AJG-85, Hoagalagere, Hadonahalli, Kallahalli, Krishnagiri, GKVK-1 and GKVK-2 planted during 2012 and Dhupdal planted during 2019. These were in a compact block at a spacing of 5 x 5 m each and a single tree served as an experimental unit. As the number of trees of single variety were not available for the experiment it was conducted with a three sets using Mysuru (8), Chinthamani (8) and Bahadoli (5) for one round of spray at fruit set (post –bloom); No.-58 (3), K-45 (3), No.-20 (3), AJG-85 (3), Hoagalagere (3), Hadonahalli (3) and Kallahalli (3) for two rounds of spray at flower bud initiation (pre-bloom) and fruit set; Dhupdal (21) for three rounds of spray at new flush, flower bud initiation and fruit set. One or two trees each of these varieties and six plants of Dhupdal were used for no spray (untreated control–UTC) following completely randomized factorial design. The chemicals evaluated include two botanicals (azadirachtin and neem oil), and two pesticides (spinosad and cyantriniliprole), two synthetic pyrethroids (lamda cyhalothrin and deltamethrin) and one OP compound (malathion). Among these, deltamethrin (1 ml/ l) and malathion (2 ml/ l) were standard checks as these were prescribed for jamun (Anonymous, 2017; Singh et al., 2009). Observations were made on fruit yield/ tree, with observations from seven to 10 pickings, which were weighed and a sample of 100 g was segregated into four damage grades (Pooja, 2019). As the damage by other seed and fruit borer complex was <10% which were not uniform, it was not considered. To know the efficacy of insecticides evaluated in monetary terms, the benefit cost ratio was worked out. Cost of the insecticides used

and other data were used for computing cost benefit ratio as per standard procedure.

RESULTS AND DISCUSSION

Results revealed that it was impossible to get healthy fruits (Grade 1) without insecticidal sprays (Table 1). The yield of Grade 2 fruits was only 1.00/ tree and that of Grade 3 fruits was 2.66 kg/ tree, while that of Grade 4 obtained without sprays was fairly high (11.94 kg/ tree). Irrespective of the damage grades and the number of sprays, azadirachtin 10000 ppm (1 ml/ l) led to maximum fruit yield (18.09 kg/ teee) which was significantly superior. The standard checks, deltamethrin 2.8EC (1.0 ml/ l) (15.24 kg) and malathion 50 EC (2.0 ml/ l) (14.37 kg) were the next best. Mean fruit yield per tree with neem oil (5 ml/ l) (11.05 kg) was on par with lambda cyhalothrin 5EC (0.5 ml/ l) (10.69 kg). Similarly, overlooking the number of sprays, the healthy fruit yields were significantly more with azadirachtin (21.21 kg/ tree) followed by deltamethrin (16.11 kg/ tree). Significantly more grade 1 fruits was obtained with three rounds of spray with azadirachtin

Table 1. Efficacy of insecticides against jamun seed weevil *C. c-album* (RHREC, Bengaluru, 2019)

Treatments (ml/ l)	No. of sprays	Yield (kg/ tree)				Total yield (kg/ tree)
		G1	G2	G3	G4	
	I	1.31	1.96	4.48	17.48	25.24
Neem oil @ 5 ml+	II	5.22	5.60	10.58	18.04	39.44
Soap @ 0.5 g	III	18.15	14.50	20.31	15.03	67.99
	Mean	6.25	5.61	9.40	15.14	
	I	5.27	7.71	8.36	7.22	28.56
Azadirachtin	II	29.77	27.77	23.88	5.90	87.32
10,000 ppm @ 1 ml	III	49.81	30.75	17.60	3.05	101.21
	Mean	21.21	16.79	13.15	6.60	
	I	0.59	1.63	2.49	15.73	20.45
Spinosad 45 SC	II	1.90	3.55	3.79	17.98	27.22
@ 0.3 ml	III	10.62	6.85	6.59	22.35	46.38
	Mean	3.28	3.31	3.83	17.10	
	I	2.50	6.07	11.69	9.76	28.06
Cyantraniliprole	II	8.59	10.33	6.16	10.71	35.79
10.26 OD @ 1.8 ml	III	10.63	13.14	11.67	10.96	46.39
	Mean	5.43	7.62	8.22	10.73	
	I	2.86	6.18	8.73	16.59	33.20
Malathion 50 EC	II	21.63	13.32	11.43	15.38	61.73
@ 2 ml (ICAR- CISH)	III	27.61	24.67	14.56	9.49	76.32
	Mean	13.02	11.31	9.44	14.25	
Lambda	I	3.78	3.94	4.70	12.06	24.48
cyhalothrin 5 EC	II	6.63	7.84	9.26	15.94	39.67
@ 0.5 ml	III	13.61	15.07	19.32	16.22	68.37
	Mean	6.00	7.05	9.08	13.54	
	I	4.37	5.61	8.75	10.59	29.32
Deltamethrin	II	24.70	18.72	12.29	11.70	67.41
2.8 EC @ 1 ml	III	35.36	26.72	18.79	5.30	86.18
(UHSB)	Mean	16.11	13.06	10.40	10.39	
UTC		0.00	1.00	2.66	11.94	15.60
	CD (p=0.05)	SE(m±)				
Treatments	0.77	0.28				
Number of sprays	0.58	0.21				
Treatments X Number of sprays	1.54	0.55				
Grades	0.58	0.21				
Treatments X Grades	1.54	0.55				
Number of sprays X Grades	1.17	0.42				
Treatments X Number of sprays X Grades	3.09	1.11				

Grade 1: Healthy with no visible signs on fruits; Grade 2: ≤10 punctures or scars (feeding/oviposition marks); Grade 3: ≥11 punctures with slight malformation and Grade 4: Unmarketable

(49.81 kg/ tree) followed by deltamethrin (35.36 kg) where the unmarketable fruit (grade 4) yields were significantly lower. One round of spray with the same chemicals gave healthy fruit (grade 1) yields of 5.27 and 4.37 kg/ tree and unmarketable (grade 4) yields of 7.22 and 10.59 kg/ tree, respectively.

Thus, for managing *C. c-album* three rounds of sprays are must, and azadirachtin 10000 ppm (1 ml/ l), deltamethrin 2.8 EC (1 ml/ l) and malathion 50 EC (2 ml/ l) were found highly effective. In a similar study against litchi fruit borer *Conopomorpha litchiella* Bradley two rounds of spray with spinosad were found superior (Pandey, 2015). The cost economics presented in Table 2 reveal that with the 13 varieties used, mean total yield (Grade 1, 2 and 3) in untreated control was 15.61 kg/ tree with net return of Rs 233.36/ tree. With malathion spray followed by deltamethrin and azadirachtin it was more and the least with spinosad followed by lamda cyhalothrin. The benefit cost ratios with one spray ranged from 11.21 (spinosad) to 74.26 (azadirachtin); with two sprays fruit yield was maximum with azadirachtin (87.32 kg/ tree), and benefit cost ratios ranged from 8.09 (spinosad) to 152.04 (azadirachtin). With three rounds of azadirachtin spray (101.21 kg/ tree) yielded highest total jamun fruits followed by delatmetrhin and malathion and was the least (46.38 kg/ tree) with spinosad followed by cyantraniliprole, and benefit cost ratios ranged from 7.37 (spinosad) to 130.41 (azadirachtin). Pandey (2015) observed that lambda cyhalothrin gave maximum yield in litchi against litchi fruit borer *C. litchiella*.

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Table 2. Benefit cost ratio of insecticides used against jamun seed weevil *C. c-album* (RHREC, Bengaluru, 2019)

Treatment (dose/l)	0 Spray			I Spray				II Spray				III Spray			
	Yield (Kg/ tree)	NR (Rs./ tree)	Yield (Kg/ tree)	Cost (Rs./ tree)	GR (Rs./ tree)	NR (Rs./ tree)	BCR	Yield (Kg/ tree)	C (Rs./ tree)	GR (Rs./ tree)	NR (Rs./ tree)	BCR	Yield (Kg/ tree)	C (Rs./ tree)	GR (Rs./ tree)	NR (Rs./ tree)	BCR
Neem oil @ 5 ml+ Soap @ 0.5 g	12.61	148.5	25.24	24.4	551.0	526.5	21.52:1	39.44	48.9	1611.0	1562.1	31.92:1	67.99	86.9	4280.5	4193.6	48.26:1
Azadirachtin 10,000 ppm @ 1 ml	13.91	228.0	28.56	22.8	1716.0	1693.2	74.26:1	87.32	45.4	6948.0	6902.6	152.04:1	101.21	68.0	8936.0	8868.0	130.41:1
Spinosad 45 SC @ 0.3 ml	16.00	242.5	20.45	40.5	346.5	306.0	7.55:1	27.22	80.8	734.5	653.7	8.09:1	46.38	121.2	2076.5	1955.3	16.14:1
cyantriniliprole 10.26 OD @ 1.8 ml	15.83	263.0	28.06	118.1	1441.5	1323.4	11.21:1	35.79	236.0	2200.0	1964.0	8.32:1	46.39	353.9	2960.5	2606.6	7.37:1
Malathion 50 EC @ 2 ml	19.65	258.0	33.20	21.6	1340.5	1318.9	61.06:1	61.73	43.0	4066.5	4023.5	93.57:1	76.32	64.4	5956.0	5891.6	91.48:1
Lambda cyhalothrin 5 EC @ 0.5 ml	14.35	287.0	24.48	18.0	1007.0	989.0	54.85:1	39.67	35.9	1910.0	1874.1	52.26:1	68.37	53.7	3834.0	3780.3	70.41:1
Deltamethrin 2.8 EC @ 1 ml	16.92	206.5	29.32	20.4	1435.5	1415.1	69.37:1	67.41	40.6	4956.5	4915.9	121.08:1	86.18	60.8	7147.5	7086.7	116.56:1

NR: Net Returns; GR: Gross Returns; BCR: Benefit Cost Ratio

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APHRODISIAC EFFECT OF *ALOE VERA* GEL SUPPLEMENTATION IN DIET OF *DROSOPHILA MELANOGASTER* MEIGEN

Usha Rani[1], Manvender Singh[1] and Krishan Kumar Selwa*

Department of Biotechnology, Deenbandhu Chotu Ram University of Science and Technology, Murthal 131039, Haryana, India
[1]Department of Biotechnology, University Institute of Engineering and Technology, Maharshi Dayanand University, Rohtak 124001, Haryana, India
*Email: krishan.kselwal@gmail.com (corresponding author)

ABSTRACT

The well-established model organism *Drosophila melanogaster* Meigen was used in the present study to ascertain the aphrodisiac property of *Aloe vera* gel supplementation in diet on it's mating behaviour and fitness parameters. The results revealed that the gel supplementation enhanced its reproductive performance. Male *Drosophila* individuals with high vigour (short mating latency period) reacted quickly in a female's presence, while a male with less vigour (a large mating latency period) responded slowly. Copulation duration was found to be negatively correlated with mating latency. Treated groups showed longer copulation duration and shorter mating latency period. Female fecundity was observed to be significantly and positively correlated with copulation duration. Increased copulation duration in *A. vera* supplement fed females revealed increased egg lying. Thus, *A. vera* gel supplemented diet enhances the reproductive fitness parameters in *D. melanogaster.*

Key words: *Drosophila melanogaster*, *Aloe vera* gel, antioxidant, aphrodisiac, copulation duration, fecundity, oxidative stress, mating latency, reproductive fitness

Plants have been considered a source of medicine in the past for centuries as they provide nutritional and therapeutic benefits from the presence of an extensive array of secondary metabolites. The plethora of herbs and spices mentioned in traditional medical systems like Ayurveda holds an extra advantage due to its time-tested formulations. Various medicinal plant extracts have been investigated for their fertility activity in animal models. Several reports present the aphrodisiac activity attributed to plants (Adimoelja, 2000; Amin et al., 1996). *Aloe vera* plant has immense ethnopharmacological importance, rich traditional history, and several pharmacological uses. Although there are many studies, only a few studies are available, which demonstrate the reproduction enhancing the potential of *Aloe vera* in different model organisms (Mehrdad and Alireza, 2014).

For most species (*Drosophila melanogaster* Meigen inclusive), two sexes (male and female) must come together or mate to achieve the task of living. *D. melanogaster* has been long time used as a model in evolutionary biology because of its advantages over other animal models, such as its ease-of-use, little space occupation, and short generation time, i.e., its life cycle is short (11-12 days) depending on environmental factors. Besides procreation, coming together has psychological, physical, and social benefits to the union. One main advantage of interest to a biologist is its characterization of life history traits (e.g., life span, fecundity, mating competitiveness). During mating, males of the arthropods transfer substances that suppress female remating propensity, increase the rate of offspring production, stimulate females physically, and weaken sperm from previous matings (Simmons 2001; Edvardsson and Canal 2006). Copulation duration in arthropods has a significant effect on the outcome of sperm competition through several mechanisms (Simmons, 2001; Barbosa, 2011). Some males prolong copulations to guard females to keep away other males from mating (Simmons 2001). These adaptive strategies were found to increase reproductive success in a competitive environment (Singh and Singh 2014). In *D. melanogaster*, mating latency is one of the parameters, which indicates the vigour of male *Drosophila* individuals. Successful mating depends on male activity and female receptivity.

Aphrodisiacs are substances that stimulate or increases sexual desire and performance. Fecundity is a measure of reproduction in *D. melanogaster*, an estimate of the number of potentially viable embryos

(eggs) laid by the animal. Fecundity can be a direct estimate of the number of young flies that emerged within a given period. It is equally a widely used proxy for fitness estimation in animals. Therefore, in the present study, copulation duration and mating latency of male individuals and fecundity of female individuals of *D. melanogaster* were analyzed to evaluate the aphrodisiac potential of *Aloe vera* gel.

MATERIALS AND METHODS

Wild type Oregon-K *D. melanogaster* flies were used in the experiment conducted at the Department of Biotechnology, University Institute of Engineering and Technology, Maharshi Dayanand University, Rohtak from October 2018 to December 2019. The flies were separated between 9.00 and 11.00 am, a suitable time for eclosion according to the biological rhythm. Virgin flies (n= 500) were separated genderwise by identifying the sex comb present on the forelegs of male. Both male and female individuals were further divided into control and treated groups. Control groups were provided standard *Drosophila* diet, whereas treated groups were provided with *Aloe vera* gel diet in 3ml, 5ml, and 7ml concentration/ l of regular diet. On the 6th day, mating assays were performed. Control and *A. vera* treated males were allowed to mate control, and treated females separately and vice versa. Copulation duration and mating latency were observed for mated pairs (30 pairs/ group) at 9.00 to 11.00 am. After mating, inseminated females were put in their respective fresh food vials, i.e., control females in standard *Drosophila* food and treated females in *A. vera* supplemented diet. The daily fecundity of all the four groups was counted for two weeks. The fecundity period from 7th to 21st day is considered the peak time for egg-laying in *Drosophila* individuals. For all the traits (copulation duration, mating latency and fecundity) mean values along with SE were used for analyses. Trait variability within as well as between treatments groups was analyzed through ANOVA. Statistical calculations and illustrations were made with the help of Statistica 5.0.

RESULTS AND DISCUSSION

In the present study, copulation duration was observed to be longer in experimental culture than in control culture; and mating latency was observed to be maximum with control culture compared to those from *A. vera* supplemented ones. For treated groups, 5 ml concentration of *A.vera* gel is more effective in decreasing the mating latency period and improving the copulation duration than 3 and 7 ml concentration (Fig. 1). Copulation duration was found to be negatively correlated with mating latency (Fig. 2), and fecundity improved with *A. vera* gel supplementation (Fig. 3). Both mating latency and copulation duration are affected by *A. vera* gel supplementation. A decrease in mating latency means an increase in the vigour of males. Thus, *A. vera* gel in diet increased the copulation duration in *D. melanogaster*. *Aloe vera* gel also affects mating latency. These results corroborate with those of previous studies which show that male *Drosophila* individuals with high vigour responded quickly in the presence of a female fly whereas male with fewer vigour response was slow (Eastwood and Burnet, 1977; Markow, 1998). Courtship is a prerequisite for copulation in *D. melanogaster*. Copulation duration is the time between initiations of copulation to termination of copulation of each pair. Naturally, copulation is severely affected when courtship is affected. The results revealed that *A. vera* gel affects behaviour, thus affecting copulation duration. Dieng et al. (2018) observed that the herbal

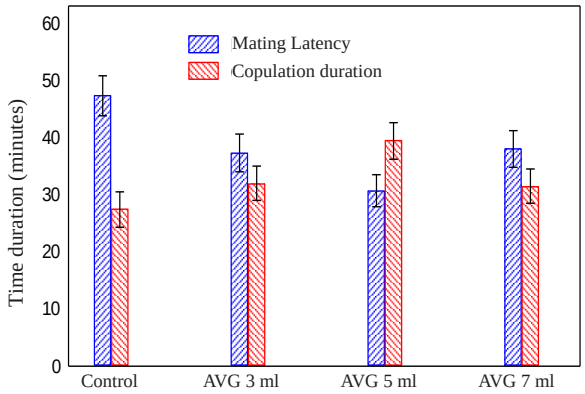

Fig. 1. Mating latency and copulation duration in *D. melanogaster*

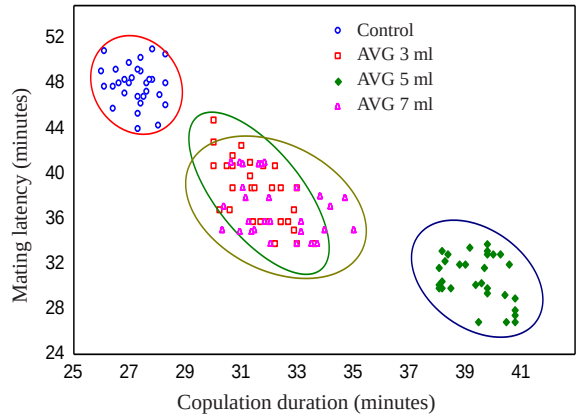

Fig. 2. Mating latency vs. copulation duration in *D. melanogaster*

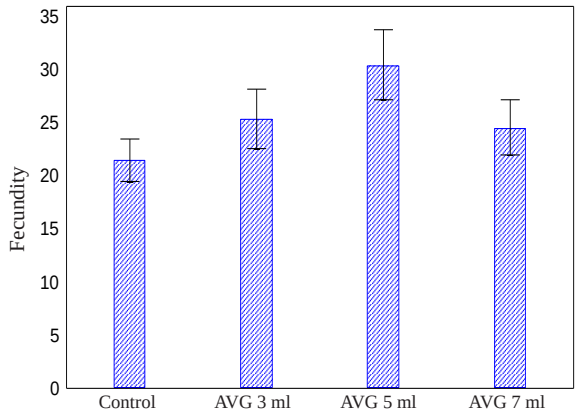

Fig. 3. Fecundity in *D. melanogaster*

aphrodisiac *Eurycoma longifolia*, stimulated the sexual activity of *Aedes aegypti* and may be useful for improving the mating competitiveness of sterile males. Mehrdad and Alireza (2014) observed that *A.vera* supplementation affects spermatogenesis in mice directly via stimulating activity of germinal cells and indirectly via stimulating Leydig cells and increasing testosterone hormone affecting the pituitary-hypothalamus-testis axis.

Varsha (2013) observed that the aqueous *Moringa oleifera* seed extract enhanced the sexual behaviour in male rats. According to Pathak et al. (2011), a longer duration of copulation permits the transfer of more sperms. This extension of copulation duration enhances the fitness of males. Fecundity is one of the fitness parameters in the different *Drosophila* spp. The present results observed a significant increase in the number of eggs laid with *Aloe vera* supplemented flies. Egg production depends on the quantity of sperm transferred during copulation (Ullah et al., 2017). The positive correlation between copulation duration and fecundity indicated that the seminal substances helped females increase their egg production and, in a time-dependent manner. It is believed that oogenesis requires a stimulus, such as seminal fluid proteins produced in the reproductive tract tissues of male *D.melanogaster*, which is transferred to females during mating; thus, stimulus induces egg production, ovulation, and/or egg-laying rates (Avila et al., 2011). *Aloe vera* supplemented groups, have increased fecundity and it may be accounted for because the phytochemicals of *A.vera* gel help male flies copulate for a longer period. Several reports support the view that chemicals alter the fertility in *Drosophila* (Pathak et al., 2011; Clare and Luckinbill, 1985; Graves, 1993). In conclusion, it is observed that worldwide numerous herbs have been used in one form or other for improving sexual performance. The utilization of herbal medicine and safer herbal products for improving sexual dynamics could provide ameliorative effects of sexual dysfunction. The present study has shown that *A. vera* gel has aphrodisiac property, which has enhanced copulation duration and reduced mating latency of male *Drosophila* individuals.

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EVALUATION OF INSECTICIDES AND BIOPESTICIDES AGAINST LEAFHOPPER *EMPOASCA KERRI* PRUTHI IN PIGEON PEA

S S Karabhantanal* and Saicharan Dharavath[1]

All India Coordinated Sorghum Improvement Project,
Regional Agricultural Research Station, Vijayapur 586101, Karnataka, India
[1]Department of Agricultural Entomology,
UAS Dharwad, College of Agriculture, Vijayapur 586101, Karnataka, India
*Email: sskarabu@gmail.com (ccorresponding author)

ABSTRACT

Green leafhopper *Empoasca kerri* (Hemiptera: Cicadellidae) is a polyphagous xylem feeder and it is a pest of pulse crops. The present study evaluated some insecticides and biopesticides against *E. kerri* in pigeonpea. The results revealed that its incidence was significantly reduced with flonicamid 50WG and tolfenpyrad 20%SC (89.39 and 81.92%, respectively) after third spray. Also, increase in yield was observed with flonicamid 50WG (13.20 q/ ha) and thiamethoxam 25WDG (12.90 q/ ha) amounting to 37.50 and 36.05%, respectively. The biopesticides viz., neemazol 1% @ 2ml/ l and *Lecanicillium lecanii* @2g/ l were found to be the least effective.

Key words: *Empoasca kerri*, pigeonpea, flonicamid 50WG, tolfenpyrad 20%SC, *Lecanicillium lecanii*, neemazol, thiamethoxam, yield, incidence

In India pigeon pea (*Cajanus cajan* L.) is cultivated in 4.78 million ha with a production of 0.98 mt (Anon, 2019). The insect pests are the main factors for the low productivity and about 250 insect pests under 8 orders and 61 families infest the crop. Since 2012, both nymphs and adults of green leafhopper *Empoasca kerri* Pruthi has been observed to be a major sucking pest and spreading to larger area on pigeonpea. The damage causes phytotoxicity, with hopper burn and economic loss (Singh et al., 2008). This study evaluates insecticides and biopesticides against this pest.

MATERIALS AND METHODS

Field experiment was conducted at the All India Coordinated Sorghum Improvement Project (AICSP), Regional Agricultural Research Station (RARS), Vijayapur, Karnataka during kharif, 2019. Insecticides including botanicals and entomopathogenic fungi were evaluated in randomized block design (RBD) with eleven treatments replicated thrice. The treatments include- flonicamid 50WG, tolfenpyrad 20SC, fipronil 5EC, thiamethoxam 25WDG, acephate 75SP, dimethoate 30EC, monocrotophos 36SL, neemazol 1%, buprofezin 20SC, *Lecanicillium lecanii* along with untreated control. Pigeonpea variety TS3R was sown in 33 plots of 5.4x 3.6 m size with a spacing of 90x 30 cm between rows and plants. The crop was raised under rainfed conditions with only one protective irrigation during the flowering stage. All the recommended agronomic practices were followed. Three sprays were adopted at vegetative and flowering stages, and counts of leafhoppers from three top leaflets were made four times for each spray, as precount, and at 5, 10, and 15 DAT (days after treatment). The data were subjected to corrections after Abbott (1925) before statistical analysis.

RESULTS AND DISCUSSION

The results revealed that all the treatments exhibited superiority over control in terms of suppressing the leafhopper incidence; flonicamid 50WG @ 100g.a.i./ ha resulted in 89.37% reduction over control followed by tolfenpyrad 20SC @ 200g.a.i./ ha with 81.92% reduction. After three sprays the treatments again, flonicamid and tolfenpyrad were the best followed by thiamethoxam 25WDG. The biopesticides *Lecanicillium lecanii* and neemazol 1% resulted in only 46.73 and 41.13% reduction. These results are similar to those of Sunil et al. (2019) that biopesticides *Metarhizium anisopliae* 1.15 WP and NSKE (Neem Seed Kernel Extract) were the least effective. Flonicamid 50WG was found to result in 93.5% reduction in leafhoppers (Duraimurugan and Alivelu, 2017). Anandmurthy et al. (2017) showed that flonicamid 50 WG @ 0.02% gave efficient leafhopper mortality with two sprays. Ram et al. (2020)

Table 1. Efficacy of insecticides and biopesticides against *E. kerri* in pigeonpea

Treatment	Dosage	Leaf hoppers / 3 top leaflets Pretreatment	15 Days after first application	15 Days after second application	15 Days after third application	% reduction over control after third application	Visual symptom (1-5 Scale)	Yield (q/ ha)
Lecanicillium lecanii	2 g/ l	25.27	19.80	10.27	5.47	46.73	4.67	9.10
		(5.08)	(4.51)	(3.28)	(2.44)			
Bufrofezin 20SC	200 g.a.i./ ha	23.60	10.87	4.47	1.87	58.16	2.33	10.30
		(4.91)	(3.37)	(2.23)	(1.54)			
Neemazol 1%	2 ml/l	28.43	18.40	14.27	8.40	41.13	4.67	9.90
		(5.38)	(4.35)	(3.84)	(2.98)			
Flonicamid 50WG	100 g.a.i./ ha	27.51	8.20	1.60	0.17	89.37	1.33	13.20
		(5.29)	(2.95)	(1.45)	(0.82)			
Tolfenpyrad 20%SC	200 g.a.i./ ha	24.60	10.03	2.60	0.47	81.92	1.67	12.40
		(5.01)	(3.24)	(1.76)	(0.98)			
Fipronil 5EC	50 g.a.i./ ha	25.80	12.20	5.27	1.93	63.37	2.33	10.40
		(5.13)	(3.56)	(2.40)	(1.56)			
Thiamethoxam 25WDG	50 g.a.i./ ha	21.00	9.67	1.80	0.33	81.66	1.33	12.90
		(4.64)	(3.19)	(1.52)	(0.91)			
Acephate 75SP	750 g.a.i./ ha	24.20	15.27	7.20	4.00	44.44	2.67	10.90
		(4.97)	(3.97)	(2.77)	(2.12)			
Dimethoate 30EC	600 g.a.i./ ha	27.33	13.67	5.40	1.80	66.66	2.00	11.30
		(5.28)	(3.76)	(2.43)	(1.52)			
Monocrotophos 36SL	360 g.a.i./ ha	24.47	14.40	7.80	3.80	51.28	2.67	10.60
		(5.00)	(3.86)	(2.88)	(2.07)			
Untreated control		24.00	26.40	28.03	29.60		5.00	8.25
		(4.95)	(5.19)	(5.34)	(5.49)			
	C.D (p=0.05)	NS	0.32	0.39	0.24			0.51
	S. Em±	0.28	0.11	0.13	0.08			0.17
	CV (%)	15.20	18.41	13.45	14.66			16.33

*- Values in parentheses arc sine values

also reported that thiamethoxam 25% WG (0.5 g/ l) reduced leafhoppers after 7 days of spray. The results on the yield indicated that maximum pod yield was obtained with flonicamid 50WG and thiamethoxam 25WDG (13.20 and 12.90 q/ ha, respectively). These results on yield are in accordance with those of Anandmurthy et al. (2017). Chaudhari et al. (2015) also reported increased yield with flonicamid 50WG in Indian bean. Sunil et al. (2019) in groundnut found that thiamethoxam 25WG has shown good yield. Ram et al. (2020) with thiamethoxam 25% WG observed more yields (Table 1).

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BIOLOGY OF DIAMOND BACK MOTH *PLUTELLA XYLOSTELLA* L. ON CABBAGE

Kawsar Rasool*, Sheikh Bilal Ahmad and Munaza Yaqoob

Division of Entomology, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Sopore 193201, Jammu and Kashmir, India
*Email: kawsarrasool31@gmail.com (corresponding author)

ABSTRACT

This study on the biology of diamond back moth revealed that the incubation period varied from 2 to 5 days (3.6± 1.34 days), while first, second, third and fourth instar larvae lived for 3± 1, 1.6± 0.54, 2.6± 0.54 and 4± 0.70 days, respectively with a total larval period of 11.4± 1.81 days. The prepupal and pupal stage lasted for 2± 0.70 and 4.4± 0.89 days, respectively. The adults lived for 5± 1.58 days and the life span of male and female varied from 22.6± 1.81 and 26.8± 1.92 days, respectively.

Key words: *Plutella xylostella*, cabbage, Kashmir, biology, morphometrics, egg, larva, instar, pupa, adult periods, lifespan

Vegetables are the important components of our daily diet, and among these crucifers (Genus: Brassica and Family: Brassicaceae) are the most commonly grown. Cabbage *Brassica oleracea* var. *capitat*a L. and cauliflower *B. oleracea* var. *botrytis* L. are amongst these. The diamond back moth (DBM) *Plutella xylostella* (L.) (Plutellidae: Lepidoptera) is the major pest of these crops causing significant economic losses up to 90% (Karlsson et al., 2013; Furlong et al., 2013). It is the most serious and widely distributed pest throughout the world (Bonnemaison, 1965), and in 1953 itself is known to have developed resistance to DDT (Ankersmit, 1953; Johnson, 1953). It has become difficult to control, primarily because of this resistance (Shelton et al., 2000). Single larvae of DBM feeds away 62 to 78% leaves, and plant growth is stunted resulting in the reduction of quantity as well as quality (Gangurde and Wankhede, 2009). The developmental time depends upon weather factors with rate of development being faster in warm and slower in cold conditions, and generations overlap during warm temperature (Zhu et al., 2018). The practicing of IPM requires knowledge on incidence, economic status and the population buildup. This study attempts its biology under Kashmir conditions.

MATERIALS AND METHODS

The initial culture of *P. xylostella* was made from larvae collected from nearby cabbage and cauliflower fields of the Faculty of Agriculture, SKUAST-Kashmir, India. The study was carried out under laboratory conditions (26± 5°C, 60± 5%RH) with larvae reared on fresh cabbage leaves in rearing cages. The experiment was replicated five times with five larvae/ replication, with fresh leaves provided as food till pupation, changed twice in a day. Pupae were sorted and transferred to rearing cages for adult emergence. The newly emerged adults were identified with their creamish-brown band on forewings which forms a diamond shaped pattern along its back (Capinera, 2000). These were transferred to rearing cages and honey solution (10%) soaked in cotton swabs provided as food. The freshly hatched larvae were transferred in petriplates provided with fresh leaves, and observations on the larval instars made on the basis of moulting, colour change and the apparent increase in size. The duration from hatching of eggs up to formation of pupa were taken as total larval period. Pupal period was recorded as the time elapsing between cessation of feeding by the last instar caterpillar and adult emergence. The total duration of adults from emergence till death was evaluated. The period between the egg laying and the mortality of the adult constituted the total lifecycle. Morphological details of lifestages were observed with ocular and stage micrometer scale in a microscope.

RESULTS AND DISCUSSION

Females laid their eggs mostly singly or in small groups on the ventral surface of the leaves and also on the walls of the container. Freshly laid eggs were pale yellowish and oval. These observations agree with those of Ramegowda et al. (2006), Dhaduk (2007), Gowri and Manimegalai (2016) on shape and colour. The incubation period had been reported earlier as 3

to 4 (Sharma et al., 1999; Gangurde and Wankhede, 2010; Jayarathnam, 2013), 3.0 to 5.25 (Ramegowda et al., 2006), 3.33± 0.42 (Dhaduk, 2007) and 2 days (Gowri and Manimegalai, 2016). The first instar larvae were small and pale white, with a dark brown head; these made small tunnels in leaves as leaf miners. As given in Table 1 the first instar occupies about 2 to 4 days; earlier, Dhaduk (2007), Jayarathnam (2013) and Harika et al. (2019) reported this as 2.50 ± 0.50, 3-5 and 2 to 3 days, respectively. The second instar was very active, larger, changed into third instar after 1 to 2 days; these were yellowish green and light brown, respectively. Sharma et al. (1999), Kumar et al. (1999), Dhaduk (2007), Jayarathnam 2013, Harika et al. (2019) observed the duration of second instar as 1.20± 0.25, 2-3 and 2 days, respectively. The third instar fed more vigorously and after 4-5 days changed into fourth instar, which were dark green with body covered with sparse, short, erect hairs. Fourth instar larva upon completion of feeding, constructed an open silken cocoon on the leaf surface and spent a two days in quiescence marking the prepupal stage. Similar results have been found by Jayarathnam, (2013) and Harika et al. (2019). Thus, the total larval period ranged from 9 to 13 days conforming the previous results of 9 to 10 (Kapadia and Koshiya, 1999), 10-15 (Devjani and Singh, 1999),7.58± 0.51 (Dhaduk, 2007) and 7 to 11 days (Gangurde and Wankhede, 2010).

The prepupal stage is contracted form of larva, sluggish, characterized by absence of feeding and lasted for 1 to 3 days; this entered into pupal stage by constructing a loosely woven cocoon around the body, with pupal period being 4 to 6 days. Earlier this pupal period had been noted as 6 to 7 (Kapadia and Koshiya, 1999), 3 to 5 (Sharma et al., 1999; Dhaduk, 2007; Gangurde and Wankhede, 2010), 3.50 to 4.75 (Ramegowda et al., 2006), 4.50 ± 1.11 (Ahmad et al., 2008), 4.6 ± 0.37 days (Ahmad et al., 2011) and 3 to 4 days (Gowri and Manimegalai, 2016). The mature caterpillar form a beautiful gauzy loosely spun cocoon (Lingappa et al., 2000). Similarly, Harika et al. (2019) observed that prepupal and pupal stage lasted for 1- 2 and 3 to 5 days, respectively. Moths were small, slender and greyish brown. The forewings were narrow, brownish grey and with a creamy coloured band along the posterior margin in the shape of a diamond. The hindwings were narrow and light grey. The adult longevity ranges between 3 to 7 days. Similarly, Harika et al. (2019) reported longevity of adults as 3 to 7 days. Chelliah and Srinivasan (1986) and Ramegowda et al. (2006) also found the longevity of the adults as 6 to 13 days and 3 to 4.27 days, respectively. The lifespan of male and female varied from 20 to 25 and 24 to 29 days, respectively. The findings are in agreement with Gunn (2008) who reported lifecycle of 25-30 days. Jayarathnam (2013) observed this as 19-27 days in different seasons, and Abro et al. (1992) and Gangurde and Wankhede (2010) observed this as 11.93 to 21.2 and 14 to 22 days, respectively.

Table 1. Lifecycle and morphometrics of *P. xylostella*

Stage	Head capsule size		Duration
Egg			3.6± 1.34
	Length (mm)	Breadth (mm)	
I Instar	1.47	1.59	3± 1
II Instar	3.19	2.78	1.6± 0.54
III Instar	4.23	4.03	2.6± 0.54
IV Instar	5.48	5.22	4± 0.70
Total larval period			11.4± 1.81
Prepupa			2± 0.70
Pupa			4.4± 0.89
Adult longevity			5± 1.58
Life span of male			22.6± 1.181
Life span of female			26.8± 1.92

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HOST PLANT RESISTANCE TO SESAMUM LEAF WEBBER AND CAPSULE BORER *ANTIGASTRA CATALAUNALIS* (DUPONCHEL)

Mitesh Makwana*, A K Panday and Kuldeep Sharma[1]

Project Coordinating Unit Sesame and Niger, College of Agriculture,
Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur 482004, Madhya Pradesh, India
[1]Department of Entomology, Maharana Pratap University of Agriculture and Technology,
Udaipur 313001, Rajasthan, India
*Email: mmitesh754@gmail.com (corresponding author)

ABSTRACT

Fifty-four genotypes of sesamum were evaluated against leaf webber and capsule borer *Antigastra catalaunalis* Duponchel. Correlation of the physiological parameters of the genotypes was observed with plant, flower, capsule damage and larval density. It was found that moisture content (%) and chlorophyll content index exhibiting significant positive correlation with damage and larval incidence. Ash content and water saturation deficit showed significant negative correlation.

Key words: Sesame, genotypes, physiological traits, *Antigastra catalaunalis*, correlation coefficient, moisture, chlorophyll, ash content, water saturation coefficients

India is one of the largest producers of oilseeds (Rai et al., 2016) and of these the sesame, *Sesamum indicum* L. is an important one. However, in India its yield potential has not been fully realized due to insect pests causing yield losses (Ahirwar et al., 2010). Sesame leaf webber and capsule borer *Antigastra catalaunalis* (Duponchel) is a serious pest as this attacks the crop in all the growth stages. If infestation occur at very early stage, the plant dies and at later stage, infested shoot remains without further growth (Karuppaiah, 2014). It feeds on tender foliage by webbing the top leaves, bores into the pods and shoots. It causes 10 to 70% infestation of leaves, 34 to 62% of flower buds/ flowers and 10 to 44% infestation of pods resulting in up to 72% loss in yield (Ahirwar et al., 2010). Insecticides though effective against this pest are not ecofriendly (Rai et al., 2002). In this context, resistance cultivars can be the most desirable, economic and best alternative. The present study evaluates genotypes for their resistance and the physiological traits that are responsible for the same.

MATERIALS AND METHODS

The experiment with 54 genotypes was carried out at the experimental farm, ICAR-Project Coordinating Unit Sesame and Niger at College of Agriculture, Jawaharlal Nehru Krishi Vishwa Vidyalayal, Jabalpur, Madhya Pradesh (22°49”- 24°8”N, 78°21”-80°58”E 411.78 masl), during 2017-2018. Randomized block design was followed with each genotype sown in rows of 3 m length and replicated thrice, and spacing between row to row and plant to plant was kept 30 cm and 10 cm, respectively. The observations on plant, flower and capsule damage (%) were made at different stages of plant growths viz. vegetative (30 DAS), flowering (45 DAS) and capsule maturity stage (70 DAS) by counting the total number of damaged and healthy plants. The larval density was worked out by counting the number of larvae on five randomly selected plants from each genotype, at weekly interval. The resistance/ susceptibility of genotypes was evaluated with the % plant, flower and capsule damage, through the rating system developed by AICRP Sesame and Niger. The physiological parameters viz. total chlorophyll content, relative water content- RWC (%), water saturation deficit (%), moisture content (%) and total ash content (%) were analysed and correlated with plant, flower, capsule damages (%) and larval density. Chlorophyll content was estimated with SPAD-502, RWC (%) after Barrs and Weatherly (1962), and water saturation deficit (WSD) was after the method suggested by Aldesuquy (2014).

RESULTS AND DISCUSSION

The differences among the genotypes evaluated from the plant, flower, capsule damage and larval incidence revealed that these varied from 7.94 to 54.43%, 8.67 to 45.45%, 7.73 to 32.15% and 0.26 and 3.03 larvae/ plant, respectively; these were minimum in SI-250 and maximum in Prachi. The entries IS-178-C and

Table 1. Physiological traits of sesame genotypes and larval density and damage by *A. catalaunalis*

S.No.	Treatment	Larval density/ plant	Damage (%)			Physiological traits (%)				
			Plant	Flower	Capsule	Ash content	Moisture content	Relative water content	Water saturation deficit	Chlorophyll content index
1.	SI-3237	2.15	24.25	32.38	21.20	2.95	94.33	46.51	53.49	42.78
2.	IC-131607	2.02	19.38	22.36	17.29	3.15	90.00	42.15	57.85	37.11
3.	SI-3179	1.76	21.65	24.73	18.61	3.00	93.33	43.32	56.68	39.84
4.	SI-3231	0.76	11.70	15.81	11.94	4.43	81.00	35.54	64.46	33.08
5.	EC-33507	0.67	12.70	18.03	12.32	4.00	82.50	36.61	63.39	33.30
6.	IS-321	1.33	15.08	20.50	17.09	3.30	89.17	42.10	57.90	36.97
7.	SI-1156	0.82	13.05	13.51	11.81	4.35	80.50	35.13	64.87	33.01
8.	EC-335011-A	1.39	18.99	18.09	18.69	3.00	94.00	43.19	56.81	39.95
9.	EC-334990	0.64	9.84	13.74	9.16	4.93	78.83	26.56	73.44	31.08
10.	EC-334989	0.67	12.94	13.95	12.68	4.35	82.48	36.69	63.31	33.66
11.	ICA-14146-A	0.94	13.53	18.33	13.37	4.20	83.45	37.34	62.66	34.10
12.	BC-303427	1.61	21.54	17.47	21.49	3.05	95.00	46.69	53.31	42.82
13.	IS-665	1.30	16.95	25.70	16.18	3.50	89.00	41.85	58.15	35.55
14.	SI-3234	1.70	18.64	12.08	19.31	3.07	94.00	44.64	55.36	40.54
15.	EC-334280	0.91	12.61	18.66	13.80	4.23	83.53	37.76	62.24	34.35
16.	S-0182-I	0.94	15.84	19.74	16.22	3.43	89.33	41.95	58.05	35.82
17.	IS-475	0.70	16.00	18.07	16.10	3.70	89.05	41.19	58.81	35.49
18.	EC-334983	0.55	15.17	25.62	15.75	3.37	87.00	40.23	59.77	35.10
19.	KIS-375	1.12	13.41	19.37	14.51	3.52	86.50	38.66	61.34	34.93
20.	Agra-balik	0.67	13.61	16.11	14.24	3.77	86.00	38.27	61.73	34.63
21.	IS-100-8	0.79	13.51	20.23	12.65	4.00	82.57	36.71	63.29	33.53
22.	SI-1679	1.12	16.39	20.57	16.13	3.58	89.40	41.14	58.86	35.28
23.	SI-76-1	0.73	10.80	13.95	9.90	4.47	80.55	26.90	73.10	31.76
24.	EC-334984	0.73	10.61	14.08	9.57	4.28	80.00	26.59	73.41	31.16
25.	SP-1144	0.88	9.94	13.83	9.88	4.77	80.50	26.62	73.38	31.61
26.	IS-723	1.12	14.67	24.96	15.65	3.78	86.05	40.09	59.91	40.20
27.	IS-253	0.70	12.92	21.97	12.81	4.05	82.50	36.57	63.43	35.60
28.	S-0388	1.30	17.12	21.66	17.08	3.05	89.45	42.07	57.93	34.47
29.	ES-75-2-84	0.85	15.19	25.89	15.40	3.52	86.00	40.31	59.69	32.80
30.	ES-334966	0.76	13.22	22.56	13.44	4.22	82.50	37.40	62.60	34.18
31.	ES-81	0.64	13.90	19.71	11.10	4.38	80.95	35.13	64.87	32.71
32.	IC-199443	0.91	12.31	18.26	12.38	4.23	82.45	36.17	63.83	33.18
33.	EC-334995	0.55	11.32	21.40	10.17	4.13	79.55	26.95	73.05	32.15
34.	EC-3349997	1.70	22.01	21.85	19.07	2.90	93.55	44.22	55.78	40.33
35.	KMR-1	0.73	14.03	12.93	13.04	3.58	82.95	37.21	62.79	34.00
36.	ES-62	0.67	9.56	13.08	9.72	4.95	80.40	26.24	73.76	31.28
37.	SI-2192	0.42	9.95	13.54	9.82	4.75	80.45	26.49	73.51	31.51
38.	IS-17	0.97	10.93	14.44	10.05	4.15	80.92	26.29	73.71	32.01
39.	IS-722-2-84	1.70	20.28	23.54	18.41	3.45	92.50	43.11	56.89	39.02
40.	IS-3179	0.85	14.99	18.16	13.98	3.82	85.82	37.94	62.06	34.37
41.	IS-446-1-64	0.52	9.19	13.67	8.87	6.23	78.55	25.80	74.20	24.84
42.	IS-391	1.03	11.09	17.16	11.32	4.28	80.25	35.24	64.76	32.99
43.	EC-303440-B	0.52	10.91	11.47	9.99	4.38	80.65	26.97	73.03	31.94
44.	IS-461-1-84-I	1.36	16.47	20.76	16.20	3.38	89.55	41.91	58.09	35.67
45.	ES-335005	0.61	9.34	12.00	8.56	5.53	78.30	25.44	74.56	24.57
46.	NIC-163-88	1.48	17.48	22.05	18.41	3.33	92.45	43.15	56.85	39.26
47.	SI-995	0.55	10.83	14.83	9.90	4.40	80.60	26.54	73.46	31.72
48.	SI-1345	0.91	12.59	17.50	11.84	4.40	80.22	35.25	64.75	33.00
49.	SI-63	1.73	18.38	21.30	18.89	3.23	92.85	43.83	56.17	39.98
50.	EC-334993	2.17	25. 51	34.49	28.02	2.90	95.37	49.64	50.36	45.65
51.	SI-250	0.26	7.94	8.67	7.73	6.50	74.33	22.60	77.40	23.45
52.	IS-178-C	0.36	8.56	9.44	8.24	6.25	75.00	24.17	75.83	24.22
53.	Prachi	3.03	54.43	45.45	32.15	1.83	97.70	56.27	43.73	49.16
54.	TC-25	2.66	48.27	42.17	29.20	2.07	96.55	51.68	48.32	46.18
SEm ±		0.10	0.48	4.93	4.01	0.05	0.08	0.05	0.05	0.05
CD (p= 0.05%)		0.28	1.17	13.81	12.09	0.13	0.20	0.13	0.13	0.12

Table 2. Physiological traits of sesame genotypes vs larval incidence and damage by *A. catalaunalis*

Correlation of	Larval incidence	Plant damage (%)	Flower damage (%)	Capsule damage (%)	Ash content (%)	Moisture content (%)	Relative water content (%)	Water saturation deficit (%)	Chlorophyll content index (%)
Larval incidence	1.00								
Plant damage (%)	0.88**	1.00							
Flower damage (%)	0.79*	0.86**	1.00						
Capsule damage (%)	0.92**	0.91**	0.85**	1.00					
Ash content (%)	-0.80**	-0.75*	-0.75*	-0.87**	1.00				
Moisture content (%)	0.87**	0.77*	0.71*	0.93**	-0.91**	1.00			
Relative water content (%)	0.83**	0.78*	0.78*	0.93**	-0.90**	0.92**	1.00		
Water saturation deficit (%)	-0.83**	-0.78*	-0.78*	-0.93**	0.90**	-0.92	-0.98**	1.00	
Chlorophyll content index (%)	0.89**	0.83**	0.79*	0.95**	-0.94**	0.93**	0.92**	-0.92**	1.00

ES-335005 were found promising in all three stages of plant growth with 8.56 and 9.34%, 9.44 and 12.00%, and 8.24 and 8.56% plant, flower and capsule damage, respectively; as regards larval incidence (0.26 larvae/ plant/ week), least values were with SI-250 followed by IS-178-C (0.36 larvae/ plant/ week); and maximum was observed on the 56th DAS (1.82 larvae/ plant) and minimum was recorded on 14th DAS (0.28 larvae/ plant) (Table 1). The present results are in conformity with the findings of Swapna et al. (2021) on the relative resistance/ susceptibility showing the 10 genotypes viz., IC-14120-1, SI-225, Jagtiala til-1, JCS 3980, JCS 3981, JCS 4053, JCS 3886, JCS 4120, YLM 11 and YLM 66 as less susceptible. Makwana et al. (2020) observed that the genotypes viz., SI-250, IS-178-C and ES-335005 were found promising. Similarly, Choudhary et al. (2018) screened 15 varieties and found that none was immune.

The significant differences were observed among the genotypes in their physiological traits. The ash content (%) was from 1.83 to 6.50%, being the lowest in Prachi and maximum with SI-250. The entries SI-250 (6.50%) followed by IS-178-C (6.25%) and IS-446-1-64 (6.23%) recorded comparatively higher ash content while the lowest ash content was recorded in entries TC-25 (2.07%), EC-334993 (2.90%) and EC-3349997 (2.90%). The moisture content was from 74.33 to 97.70%, maximum being with Prachi (97.70%) followed by TC-25 (96.55%) and EC-334993 (95.37%), and the least (74.33%) with SI-250 followed by IS-178-C (75.00%). The relative water content (%) ranged from 22.60 to 56.27%, being lowest (22.60%) in SI-250 followed by IS-178-C (24.17%), while the maximum was in Prachi (56.27%) followed by TC-25 (51.68%). The highest (%) water saturation deficit was in genotype SI-250 (77.40%) followed by IS-178-C (75.83%), with the least value (43.73%) being in Prachi followed by TC-25 (48.32%). The chlorophyll content index ranged from 23.45 to 49.16%, the least being in SI-250 (23.45%) followed by IS-178-C (24.22%), and the maximum (49.16%) was in Prachi followed by TC-25 (46.18%) and EC-334993 (45.65%) (Table 1).

Correlation coefficients of plant, flower, capsule damage (%) and larval density with physiological traits showed that the plant (r= 0.88), flower (0.79) and capsule damage (0.92) showed significant strong positive relationship with larval incidence. Moisture content (%) and relative water content (%) revealed a significant positive correlation with larval incidence (r= 0.87 and r= 0.83), and % plant (r= 0.77 and r= 0.78), flower (r= 0.71and r= 0.78) and capsule damage (r= 0.93 and r= 0.78). Ash content (%) and water saturation deficit (%) exhibited a significant negative correlation with larval incidence (r= - 0.80 and r= - 0.83), % plant (r= - 0.75 and r= - 0.78), flower (r= - 0.75 r= - 0.78) and capsule damage (r= - 0.87 and r= - 0.93). Chlorophyll content index, showed significant positive correlation with larval incidence (r= 0.89), plant (r= 0.83), flower (r= 0.79) and capsule damage (r= 0.95) (Table 2). The present findings are in conformity with those of Elanchezhyan et al. (2009) in brinjal hybrid Swetha that was highly resistant to shoot and fruit borer because of ash content (12.3%), total phenols (7.6 mg g-1), lowest moisture content (78.4%), total chlorophyll (1.2 mg g-1) and total sugars (5.8 mg g-1). Similarly, Imtiaz et al. (2015) observed that the ash and fat content were significantly negatively correlated while moisture and protein were significant positively correlated with the incidence of *Aphis gossypii*, *Amrasca biguttula biguttula* and *Leucinodes orbonalis*, respectively. In the

present findings significant differences were observed in plant, flower, capsule damages (%) and larval incidence among the 54 genotypes. The study reported a strong correlation among all the tested physiological parameters with plant, flower, capsule damage (%) and larval density and therefore, these physiological parameters can be used as markers to select resistant genotypes to manage *A. catalaunalis*.

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NEW RECORD OF *PROTOPHORMIA* SP. (CALLIPHORIDAE: DIPTERA) FROM COLD ARID DESERT KARGIL LADAKH

Mohd Hussain*, Altaf Hussain Mir and Hidayatullah Tak

Department of Zoology, University of Kashmir Srinagar, Jammu and Kashmir (UT), India
*Email: akmha168@gmail.com (corresponding author)

ABSTRACT

***Protophormia* is a genus of Calliphoridae well known species in the cold climatic areas of the Holarctic region. In the present study, *Protophormia terraenovae* (Robineau-Desvoidy) has been documented as new record from the trans-Himalayan region of cold arid desert Kargil Ladakh (UT), India. It has been found that this species is fairly distributed throughout Kargil, Ladakh.**

Key words: *Protophormia terraenovae*, Calliphoridae, Kargil Ladakh, Trans-Himalaya, survey, traps, new record, diagnosis, distribution, redescription

Protophormia is a genus consisting of species commonly called northern blow flies, blue-bottle fly, blue-assed or cold climate blow fly, and is widely distributed in the Northern hemisphere (Smith, 1986). It has been found that these flies cause myiasis in man and other vertebrates in Holarctic regions (Larbcharoensub, et al., 2018; Scholl et al., 2019) and are of medical and forensic importance (Grassberger and Reiter, 2002; Stuyt et al., 2013; Martínez-Sánchez et al., 2015). So far, 119 species of family Calliphoridae (Diptera) have been identified from India (Bharti, 2011). However, only three species viz. *Musca domestica*, *Calliphora vicinae* and *Calliphora vomitoria* have been reported from cold arid desert Kargil Ladakh (Bhagat, 2016; Hussain et al., 2020). Present study focused on the genus *Protophormia* which leads to a new record of a species under the family Calliphoridae (Diptera) from Ladakh. This species is redescribed herein.

MATERIALS AND METHODS

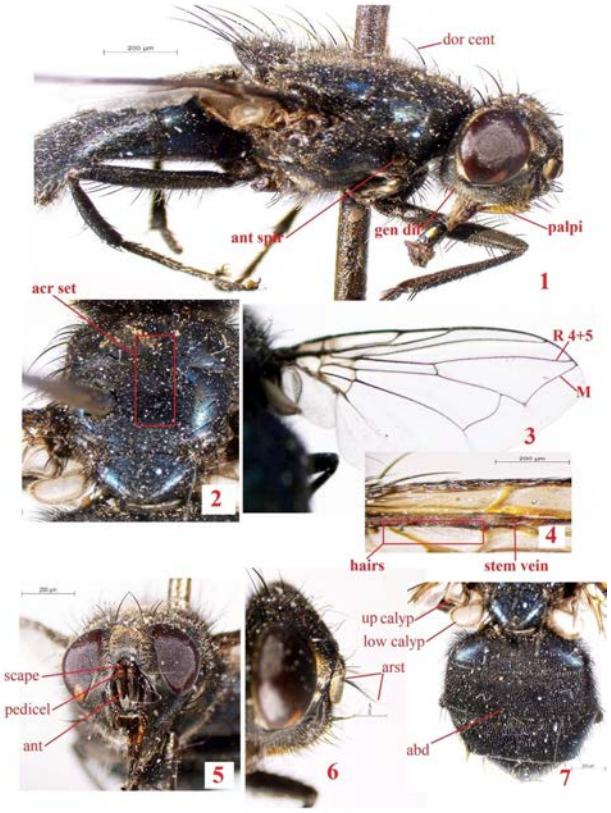
The present survey was conducted in the Trans-Himalayan region of the cold arid desert Kargil Ladakh. To ease the survey, based on geography, topography, and climatic condition; the study area was divided into eight main sites viz. Drass, Kargil city, Batalik, Chiktan, Wakha (Shargole), Trespone, Sankoo and Panikhar. Fly species were trapped by using modified plastic bottle traps, baited with unwashed goat/ sheep stomach (Khoobdel et al., 2013). Three traps were installed in all the above mention study sites with a distance of about 100 m, during the fly active period from May to July 2020. After three hours of installation, the trap was collected and the trapped flies were killed with chloroform. Based on morphology, the *Protophormia* were sorted out, counted and were identified up to species level using available keys (Rognes, 1991; Whitworth, 2006; Akbarzadeh et al., 2015). Photographs were captured using Leica S9D stereozoom microscope fitted with a camera and edited with Adobe Photoshop 7.0.

RESULTS AND DISCUSSION

Protophormia terraenovae (Robineau-Desvoidy, 1830)

Diagnosis: Body colour dark metallic blue; genae not protruding and blackish; arista hairy above and below; tip of the pedicle and basal part of the first flagellomere reddish; occiput with 6-7 black hairs and pale hair in the middle; palpi yellow; eye larger, 3/4th of head height; humeral bristle 4-5; dorsocentral bristles long; acrostichal bristles weak or absent; presutural intraalar setae present; marginal secutellar setae 3-4 pair; anterior spiracle dark brown, smaller than humeral callus; wing venation R_{4+5} and M widely separated; stem vein with hair above and basicostae black; upper and lower calypters dark brown, especially on rim; upper calypters sprout black setae; abdomen metallic blue with uniformly distributed fine hairs on dorsal side (Figs. 1-7)

Distribution: *P. terraenovae* is well distributed in the northern hemisphere and is reported from Austria (Grassberger, 2002), Pakistan, China (Zhang et al., 2017), Turkey and north-west Iran (Akbarzadeh et al., 2015), America (Whitworth, 2006; Marshall, 2011), Europe (Sánchez et al., 2015), Thailand (Larbcharoensub et al., 2018).



Figs. 1-7. *Protophormia terraenovae*; 1. Whole body, Lateral view; 2. Thorax, dorsal view; 3. Right wing, dorsal view; 4. Stem vein, dorsal view; 5. Head, anterior view; 6. Head, lateral view; 7. Thorax and abdomen, dorsal view.
dor cen = dorsocentral bristles, gen dil = genial dilation, ant spir = anterior spiracle, arc ste = acrostichal bristles, ant = antennae, arst = arista, up calyp = upper calyptera, low calyp = lower calyptera, abd = abdomen

Remarks: In the present study, 311 specimens of *P. terraenovae* have been collected from Kargil Ladakh, viz. 38 from Drass, 43 from Kargil, 30 from Batalik, 39 from Chiktan, 39 from Wakha (Shargole) 42 from Saliskote, 41 from Sankoo and 39 from Panikhar. It was found that it was fairly distributed thoughout the study area (Table 1). This is because, that Ladakh Himalaya is a part of Palaearctic (Old World), and the climatic condition is much similar to the Holarctic region of the Northern hemisphere (Akbarzadeh et al., 2015; Whitworth, 2006). This could also be a reason for this species not been reported from Oriental region.

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Table 1. *P. terraenovae* collected from Kargil Ladakh (May-July, 2020)

	No. collected								Total
	Drass	Kargil city	Batalik	Chiktan	Wakha (Shargole)	Trespone	Sankoo	Panikhar	
No.	38	43	30	39	39	42	41	39	311
%	12.2	13.8	9.6	12.5	12.5	13.5	13.2	12.5	

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EFFICACY OF MINERAL AND NON-EDIBLE SEED OILS AGAINST APHIDS AND WHITEFLY IN POTATO

Murlidhar Sadawarti*, Subhash Katare, S P Singh, M Abas Shah[1], R K Samadhiya, Sanjeev Sharma[2] and R K Singh[2]

ICAR-Central Potato Research Institute-Regional Station, Gwalior 474020, Madhya Pradesh, India
[1]ICAR-Central Potato Research Institute-Regional Station, Jalandhar 144003, Punjab, India
[2]ICAR-Central Potato Research Institute, Shimla 171001, Himachal Pradesh, India
*Email: murlidharsada@gmail.com (corresponding author)

ABSTRACT

Field experiments were conducted at the ICAR-Central Potato Research Institute-Regional Station, Gwalior, Madhya Pradesh during 2015-16 and 2016-17 to evaluate efficacy of mineral and non-edible seed oils against green-peach aphid *Myzus persicae* and cotton whitefly *Bemisia tabaci* in potato. Three sprays were done at 15 days interval revealed that maximum reduction in their incidence was observed with imidacloprid 17.8SL (0.03%) followed by mineral oil (6 ml/ l); *B. tabaci* incidence reduced by 72.63% and 61.06%, respectively, while it was 87.60% and 62.27% with *M. persicae*. Similar trend was observed with all the three sprays. The non-edible oils were not effective. Incidence of viruses was the least (0.26 and 0.27%, respectively) with imidacloprid 17.8SL (0.03%) and mineral oil (6 ml/ l). Thus, imidacloprid 17.8SL (0.03%) and mineral oil (6 ml/ l) can be recommended to manage vector-virus complex in potato.

Key words: *Myzus persicae, Bemisia tabaci*, potato, Kufri Jyoti, non-edible oil, mineral oil, imidacloprid, sprays, potato virus, vector virus complex, yield

India is the second largest producer of potato in the world (FAOSTAT, 2017), with >85% of being grown in the vast Indo-Gangetic plains of north India (subtropics) during short winter days from October to March (Khurana and Naik 2003). Potato is infested by a number of aphids transmitting more than three dozen viruses, affecting the yield and quality (Salazar, 2006; Bhatnagar et al., 2017). Peach-potato aphid *Myzus persicae* (Sulzer) is the most efficient aphid vector in potato (Bhatnagar et al., 2012). In addition, the cotton whitefly *Bemisia tabaci* (Gennadius) is a major constraint for healthy seed potato production as it transmits the Tomato leaf curl New Delhi *virus* (potato) which results huge yield loss and degeneration of seed stocks (Shah et al., 2019). Currently, the management of vector-virus complex in potato depends on synthetic pesticides, in addition to the cultural practice of growing the crops during low aphid activity period (Pushkarnath, 1959; 1967). However, the management of non-persistent viruses like potato virus Y (PVY) continues to be a challenge. Mineral oils are known as effective means to control insect pests like aphids and to reduce the spread of non-persistent viruses (Shah et al., 2021; Perring et al., 1999). These are widely used in Europe and are increasingly used in the United States and Eastern Canada for seed potato production. Several studies have shown that mineral oils interfere with virus retention in the aphid mouthparts (stylet) and foliar application of mineral oil reduced the transmission of PVY to potatoes (Boiteau et al., 2008; Najar-Rodriguez et al., 2008; Wrobel, 2009). In addition to this, various plant-derived oils have been shown to be effective against the vectors e.g., neem oil (Isman, 2006); pongamia/ karanj oil (Kumar and Singh, 2002). There is little knowledge about the effect of mineral, neem and karanj oils on the sucking pests of potato under north-central Indian conditions, and hence the present study.

MATERIALS AND METHODS

Field experiments were conducted at the ICAR-Central Potato Research Station, Gwalior, during 2015-16 and 2016-17 on potato cv. Kufri Jyoti. The experiments were laid in randomized complete block design, with six treatments and four replications. The treatments included mineral oil (3 ml/ l and 6 ml/ l), pongamia oil (6 ml/ l), neem oil (7.3 ml/ l), imidacloprid 17.8SL (3 ml/ 10l) as standard check along with untreated control. Total of three sprays were given at 15 days interval, starting from 40 days. The crops were raised with recommended agronomic practices, with crop planted on 09/11/2015 and

25/10/2016 during the two seasons. Observations on the number of adult *B. tabaci*, and adults and 3rd and 4th instar nymphs of *M. persicae* were taken from ten randomly selected plants/ plot, one day before, and 7 and 14 days after treatment (DAT). The numbers were counted from three leaves on each plant, one each from upper, middle and lower strata, preferably in the early morning hours. The reduction in incidence was calculated as per Henderson and Tilton (1955). The total tuber yield was recorded on whole plot basis, and % incidence of viruses (severe and mild mosaic, leaf roll) was taken from visual observation on all the plants in each plot. The data on number of insects, % reduction in incidence over control and tuber yield were subjected to ANOVA after appropriate transformation. The treatment means were separated by least significant difference (LSD) test.

RESULT AND DISCUSSION

Observation on *B. tabaci* revealed that the pretreatment counts ranged from 4.04 to 5.19/ 10 plants which increased till mid-December and declined sharply afterwards, again appearing towards February. Therefore, three spray treatments were given; two in November-December and one in February; and maximum reduction in incidence was observed with imidacloprid 17.8 SL (0.03%) followed by that of mineral oil (6 ml/ l). Similar consistent trend was noted for all the three sprays- its incidence reduced by 72.63% and 61.06%, respectively with these treatments. The non-edible oils did not cause an appreciable reduction, while treatments with pongamia oil gave a reduction of 51.20% and neem oil 55.16% reduction (Table 1). These results are in conformity with those

Table 1. Efficacy of mineral and non-edible seed oils against *B. tabaci* and *M. persicae* in potato

Treatments	Mean no. of from 10 plants (3 leaves/ plant)									% reduction over control
	1st Spray			2nd Spray			3rd Spray			
	Pre-count	7 DAT	14 DAT	Pre-count	7 DAT	14 DAT	Pre-count	7 DAT	14 DAT	
B. tabaci										
Control	4.19	8.98	10.30	10.30	6.10	3.80	3.80	3.25	5.33	
	(2.27)	(3.15)	(3.35)	(3.35)	(3.35)	(2.18)	(2.18)	(1.98)	(2.51)	-
Imidacloprid 17.8SL	4.04	3.00	1.75	1.75	0.00	0.38	0.38	0.13	0.17	
@ 0.03%	(2.24)	(1.89)	(1.61)	(1.61)	(1.00)	(1.14)	(1.14)	(1.05)	(1.07)	72.63
Mineral oil @ 3 ml/ l	4.57	7.75	4.25	4.25	1.75	0.50	0.50	0.25	0.42	
	(2.35)	(2.95)	(2.21)	(2.21)	(1.65)	(1.20)	(1.20)	(1.10)	(1.17)	42.97
Mineral oil @ 6 ml/ l	4.64	5.25	1.88	1.88	0.54	0.17	0.17	0.00	0.17	
	(2.37)	(2.45)	(1.61)	(1.61)	(1.23)	(1.07)	(1.07)	(1.00)	(1.07)	61.06
Pongamia oil @	4.94	5.88	5.50	5.50	2.25	0.50	0.50	0.00	0.50	
6.8 ml/ l	(2.43)	(2.59)	(2.52)	(2.52)	(1.77)	(1.20)	(1.20)	(1.00)	(1.20)	51.20
Neem oil @ 7.3 ml/ l	5.19	6.88	4.13	4.13	1.25	0.50	0.50	0.25	0.25	
	(2.48)	(2.78)	(2.24)	(2.24)	(1.49)	(1.20)	(1.20)	(1.10)	(1.10)	55.16
SEm	0.002	0.23	0.22	0.22	0.10	0.11	0.11	0.13	0.09	
CD (p = 0.05)	NS	0.71	0.68	0.68	0.30	0.35	0.35	0.42	0.27	
M. persicae										
Control	1.75	5.13	10.50	10.50	12.68	14.38	14.38	15.00	12.75	
	(1.65)	(2.47)	(3.38)	(3.38)	(3.69)	(3.69)	(3.69)	(3.99)	(3.68)	-
Imidacloprid 17.8SL	2.16	2.43	1.00	1.00	0.25	0.25	0.25	0.00	0.00	
@ 0.03%	(1.77)	(1.84)	(1.36)	(1.36)	(1.10)	(1.10)	(1.10)	(1.00)	(1.00)	87.60
Mineral oil @ 3 ml/ l	1.90	4.13	5.50	5.50	3.13	4.63	4.63	3.25	1.75	
	(1.70)	(2.26)	(2.54)	(2.54)	(2.00)	(2.00)	(2.00)	(2.05)	(1.65)	44.19
Mineral oil @ 6 ml/ l	2.28	3.25	4.13	4.13	1.75	2.38	2.38	1.50	0.25	
	(1.81)	(2.05)	(2.26)	(2.26)	(1.65)	(1.65)	(1.65)	(1.57)	(1.10)	62.27
Pongamia oil @	1.98	2.13	6.75	6.75	4.75	3.75	3.75	1.75	2.00	
6.8 ml/ l	(1.72)	(1.60)	(2.76)	(2.76)	(2.39)	(2.39)	(2.39)	(1.64)	(1.73)	49.66
Neem oil @ 7.3 ml/ l	2.09	4.50	4.38	4.38	3.00	2.75	2.75	1.75	0.50	
	(1.75)	(2.23)	(2.64)	(2.64)	(1.99)	(1.99)	(1.99)	(1.65)	(1.20)	51.58
SEm	0.038	0.23	0.13	0.13	0.10	0.10	0.10	0.08	0.13	
CD (p = 0.05)	NS	NS	0.40	0.40	0.30	0.30	0.30	0.24	0.40	

Values pooled data of two seasons; Precount- Pretreatment count; DAT – Days after treatment; values in parentheses square root transformed as √x+0.5; NS = not significant

of Bhatnagar et al. (2016). Imidacloprid 17.8SL (150 ml/ ha) at 15 days interval was the most effective (Nag et al., 2018). About the *M. persicae*, it appeared after mid-December, therefore, three sprays were made from December to February, which increased from 1.75/ 10 plants in the third week of December to 15.00/ 10 plants towards mid-February and declined afterwards. The data on the incidence pooled over two seasons revealed that maximum reduction was obtained with imidacloprid 17.8SL followed by that of mineral oil (6 ml/ l), with results being similar with all the three sprays, with incidence reducing by 87.60% and 62.27%, respectively. The non-edible oils did not show such reduction (Table 1). These results are in confirmation with those of Khan (2011), Basavaraju et al.(2015) and Nag et al. (2018). Azadirachtin results in >60% suppression of aphids (Ghosh, 2015). Neem oil (1%), NSKE (5%), pongamia (1-2%) and karanj oil (1 and 2%) are reported as effective (Kumar and Singh, 2002; Pavela, 2007). Although the incidence of viruses was low during both the seasons, significant reduction in the incidence being with treated plots, the least incidence being with imidacloprid17.8 SL (0.03%) and mineral oil (6 ml/ l). Total tuber yield (ranging 29.22 to 31.44 mt/ ha) was non significant among the treatments.

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EVALUATION OF WHORL APPLICATION OF INSECTICIDES MIXED WITH SAND AGAINST FALL ARMY WORM *SPODOPTERA FRUGIPERDA* IN MAIZE

J Divya, C M Kalleshwaraswamy*, Sharanabasappa Deshmukh, S Ambarish and C Sunil[1]

Department of Agricultural Entomology; [1]Department of Agronomy,
College of Agriculture, University of Agricultural and Horticultural Sciences,
Shivamogga 577204, Karnataka, India
*Email: kalleshwaraswamycm@uahs.edu.in (corresponding author)

ABSTRACT

The fall army worm (FAW) *Spodoptera frugiperda* is now spread all over India and at present, spraying insecticides is the primary method of control. Considering its presence in whorl and negative impact of insecticidal spray on the natural enemies, there is a need of evolving alternate techniques. In the present study, whorl application of insecticides mixed in river sand was evaluated for its efficacy. Sand mixed with chlorantraniliprole 18.5SC @0.4 ml/ kg, emamectin benzoate 5SG@ 0.4 g/ kg and spinosad 45SC @ 0.4 ml/ kg sand were found to be effective, with significant reduction in leaf damage. The quantity of insecticide required/ unit area was 50% less than the spray while maximum grain yield/ cost benefit ratio was obtained.

Key words: *Spodoptera frugiperda*, maize, chlorantraniliprole, emamectin benzoate, spinosad, sand, whorl application, grain yield, C: B ratio

Maize (*Zea mays* L.) is one of important crops having wider adaptability under varied agroclimatic conditions, and it has a good yield potential among the cereals (Singh and Jaglan, 2018). In India, it has a productivity of 2.69 mt/ ha (Anonymous, 2019), and insect pests are the reasons for the reduced productivity. As many as 141 insect pests cause a varying degree of damage from sowing to till harvest (Reddy and Trivedi, 2008). Fall army worm, *Spodoptera frugiperda* (J E Smith) is a recent invasive pest in India (Sharanabasappa et al., 2018; Mahadevaswamy et al., 2018; Shylesha et al., 2018). The pest being native to America, was reported for the first time in Africa (Goergen et al., 2016) and then in Asian countries (Sharanabasappa et al., 2018; Wu et al., 2019; CABI, 2020). It causes significant loss to maize (Deshmukh et al., 2020), strategies are essential to make the insecticides reach the leaf whorl. The whorl application of sand, soil and ash against *S. frugiperda* is a traditional management practice adopted by farmers in Africa (Kumela et al., 2019; Abate et al., 2000) and America (Wyckhuys and Oneil, 2007) but their efficacy has not been documented in India. Babendreier et al. (2020) found that whorl application of construction sand might be useful. Similarly, diatomaceous earth (DE) has long been used for insect control, especially for stored grain pests (Korunic, 2013) and many commercial products are available (Ebeling, 1971). Constanski et al. (2016) studied the effects of several inert powders, including DE and bentonite, and bentonite was found to cause 93% and DE 47% mortality. As abrasive material, sand physically damages the insects. Sand entrapment provides the plant with herbivore resistance (Neinhuis et al., 1996; Lopresti et al., 2018). In India, most of the research is concentrated on spray formulations (Deshmukh et al., 2020). As the pest hides and feed inside the whorl alternative technique need to be developed. Considering good canopy of maize plant, insecticidal spray has negative effect on the natural enemies and wastage of insecticide generally occurs. Therefore, this study to evaluate whorl application of insecticides mixed with river sand against *S. frugiperda*.

MATERIALS AND METHODS

A field experiment was conducted during kharif 2019-20 at two locations- (i) Agricultural and Horticultural Research Station, Bhavikere (13°.14'.679"N, 75°.43'.525"E, 567 masl) and (ii) College of Agriculture, Navile, Shivamogga, (13°.58'.540"N75°, 34'.754"E, 526 masl) University of Agricultural and Horticultural Sciences, Shivamogga, Karnataka, India. The experiment was laid out in a randomized complete block design (RCBD) with ten treatments in three replications. The plot size followed was 5x 4 m with 1 m replication border and 0.5 m treatment border between the plots. Experimental plots were separated by raised bunds of about 10 cm height

Table 1. Evaluation of insecticides mixed with sand against *S. frugiperda*- kharif 2019-20

T. No.	Treatments	Dose/ kg of sand	Mean no. of larvae/ plant[#] DBT	I Treatment (20 DAS) 7 DAT	I Treatment (20 DAS) 14 DAT	II Treatment (35 DAS) 7 DAT	II Treatment (35 DAS) 14 DAT	Mean	% reduction over control
AHRS, Bhavikere (Location 1)									
T1	Chlorpyriphos 20EC	2 ml	1.63 (1.45)	0.87 (1.17)^{cd}	1.20 (1.30)^{bc}	0.67 (1.07)^{bcd}	0.60 (1.05)^{bcd}	0.83 (1.15)^{cd}	53.92
T2	Thiodicarb 75WP	0.6 g	2.00 (1.58)	0.50 (0.96)^{def}	0.83 (1.15)^{cde}	0.40 (0.95)^{cde}	0.30 (0.89)^{def}	0.51 (1.00)^{ef}	71.89
T3	Chlorantraniliprole 18.5 SC	0.4 ml	2.07 (1.60)	0.13 (0.75)^{g}	0.27 (0.87)^{f}	0.00 (0.71)^{f}	0.00 (0.71)^{g}	0.10 (0.77)^{h}	94.47
T4	Malathion 50EC	2 ml	1.67 (1.47)	0.97 (1.21)^{bc}	1.30 (1.34)^{bc}	0.73 (1.11)^{bc}	0.67 (1.08)^{bc}	0.92 (1.19)^{c}	49.31
T5	Spinosad 45SC	0.4 ml	1.60 (1.44)	0.33 (0.87)^{efg}	0.70 (1.09)^{de}	0.30 (0.89)^{def}	0.10 (0.77)^{efg}	0.36 (0.93)^{fg}	80.18
T6	Emamectin benzoate 5SG	0.4 g	2.03 (1.59)	0.27 (0.84)^{fg}	0.57 (1.03)^{ef}	0.17 (0.81)^{ef}	0.07 (0.75)^{fg}	0.27 (0.87)^{gh}	85.25
T7	Neem soap 10%	10 ml	1.93 (1.54)	0.57 (1.03)^{cdef}	1.03 (1.23)^{cde}	0.43 (0.96)^{cde}	0.33 (0.91)^{cdef}	0.59 (1.04)^{def}	67.28
T8	Diatomaceous earth	200 g	1.70 (1.48)	0.70 (1.09)^{cde}	1.10 (1.26)^{cd}	0.50 (1.00)^{cde}	0.40 (0.95)^{cde}	0.68 (1.08)^{cde}	62.67
T9	Sand	5 g/ plant	2.03 (1.59)	1.37 (1.36)^{b}	1.77 (1.50)^{ab}	1.00 (1.22)^{ab}	0.90 (1.18)^{ab}	1.26 (1.33)^{b}	30.41
T10	Untreated check	-	2.10 (1.61)	2.23 (1.65)^{a}	2.27 (1.66)^{a}	1.50 (1.41)^{a}	1.23 (1.31)^{a}	1.81 (1.52)^{a}	-
	SEM ±	-	-	0.065	0.069	0.070	0.060	0.042	-
	CD (p=0.05)	-	NS	0.193	0.205	0.209	0.179	0.123	-
	CV (%)	-	8.95	10.17	9.62	12.04	10.90	6.61	-
UAHS, Shivamogga (Location 2)									
T1	Chlorpyriphos 20EC	2 ml	1.80 (1.52)	0.57 (1.02)^{bcd}	1.10 (1.26)^{bc}	0.60 (1.05)^{bcd}	0.53 (1.01)^{bcd}	0.70 (1.10)^{cd}	53.33
T2	Thiodicarb 75WP	0.6 g	1.93 (1.55)	0.37 (0.93)^{cdef}	0.73 (1.11)^{cde}	0.30 (0.89)^{de}	0.23 (0.85)^{def}	0.41 (0.95)^{ef}	72.78
T3	Chlorantraniliprole 18.5SC	0.4 ml	1.53 (1.41)	0.10 (0.77)^{f}	0.33 (0.91)^{f}	0.00 (0.71)^{f}	0.00 (0.71)^{f}	0.11 (0.78)^{h}	92.78
T4	Malathion 50EC	2 ml	2.13 (1.62)	0.70 (1.09)^{bc}	1.17 (1.29)^{bc}	0.67 (1.08)^{bc}	0.63 (1.06)^{bc}	0.79 (1.14)^{c}	47.22
T5	Spinosad 45SC	0.4 ml	1.97 (1.57)	0.23 (0.85)^{def}	0.63 (1.06)^{def}	0.17 (0.81)^{ef}	0.10 (0.77)^{ef}	0.28 (0.89)^{fg}	81.11
T6	Emamectin benzoate 5SG	0.4 g	1.90 (1.55)	0.17 (0.81)^{ef}	0.50 (0.99)^{ef}	0.10 (0.77)^{ef}	0.03 (0.73)^{f}	0.20 (0.84)^{gh}	86.67
T7	Neem soap 10%	10 ml	1.57 (1.43)	0.40 (0.94)^{cdef}	0.93 (1.20)^{bcd}	0.37 (0.93)^{cde}	0.30 (0.89)^{de}	0.50 (1.00)^{e}	66.67
T8	Diatomaceous earth	200 g	1.70 (1.47)	0.47 (0.98)^{cde}	1.00 (1.22)^{bcd}	0.47 (0.98)^{cd}	0.40 (0.95)^{cd}	0.58 (1.04)^{de}	61.11
T9	Sand	5 g/ plant	2.07 (1.60)	1.00 (1.21)^{b}	1.40 (1.38)^{ab}	0.93 (1.19)^{b}	0.87 (1.17)^{ab}	1.05 (1.24)^{b}	30.00
T10	Untreated check	-	1.80 (1.51)	1.63 (1.46)^{a}	1.80 (1.51)^{a}	1.40 (1.38)^{a}	1.17 (1.29)^{a}	1.50 (1.41)^{a}	-
	SEM ±	-	-	0.069	0.062	0.053	0.054	0.031	-
	CD (p=0.05)	-	NS	0.204	0.184	0.159	0.161	0.092	-
	CV (%)	-	8.63	11.79	9.01	9.45	9.98	5.17	-
Pooled									
T1	Chlorpyriphos 20EC	2 ml	1.72 (1.49)	0.72 (1.10)^{cd}	1.15 (1.28)^{bcd}	0.63 (1.06)^{bcd}	0.57 (1.03)^{cd}	0.77 (1.13)^{cd}	53.65
T2	Thiodicarb 75WP	0.6 g	1.97 (1.57)	0.43 (0.97)^{de}	0.78 (1.13)^{def}	0.35 (0.92)^{def}	0.27 (0.87)^{ef}	0.46 (0.98)^{ef}	72.29

(contd.)

(Table 1 contd.)

T3	Chlorantraniliprole 18.5 SC	0.4 ml	1.80 (1.52)	0.12 (0.78)^{f}	0.30 (0.89)^{g}	0.00 (0.71)^{g}	0.00 (0.71)^{g}	0.10 (0.78)^{h}	93.70
T4	Malathion 50EC	2 ml	1.90 (1.55)	0.83 (1.15)^{bc}	1.23 (1.31)^{bc}	0.70 (1.09)^{bc}	0.65 (1.07)^{bc}	0.85 (1.16)^{c}	48.36
T5	Spinosad 45 SC	0.4 ml	1.78 (1.51)	0.28 (0.88)^{ef}	0.67 (1.08)^{ef}	0.23 (0.85)^{efg}	0.10 (0.77)^{fg}	0.32 (0.91)^{fg}	80.60
T6	Emamectin benzoate 5 SG	0.4 g	1.97 (1.57)	0.22 (0.84)^{ef}	0.53 (1.01)^{fg}	0.13 (0.79)^{fg}	0.05 (0.74)^{g}	0.23 (0.86)^{gh}	85.89
T7	Neem soap 10%	10 ml	1.75 (1.49)	0.48 (0.99)^{de}	0.98 (1.22)^{cde}	0.40 (0.95)^{cdef}	0.32 (0.90)^{e}	0.55 (1.02)^{e}	67.00
T8	Diatomaceous earth	200 g	1.70 (1.48)	0.58 (1.04)^{cd}	1.05 (1.24)^{cd}	0.48 (0.99)^{cde}	0.40 (0.95)^{de}	0.63 (1.06)^{de}	61.96
T9	Sand	5 g/ plant	2.05 (1.60)	1.18 (1.29)^{b}	1.58 (1.44)^{ab}	0.97 (1.21)^{b}	0.88 (1.18)^{b}	1.15 (1.29)^{b}	30.23
T10	Untreated check	-	1.95 (1.57)	1.93 (1.56)^{a}	2.03 (1.59)^{a}	1.45 (1.40)^{a}	1.20 (1.30)^{a}	1.65 (1.47)^{a}	-
	SEM ±	-	-	0.051	0.056	0.056	0.039	0.031	-
	CD @ 5%	-	NS	0.152	0.167	0.167	0.119	0.092	-
	CV (%)	-	5.72	8.34	7.96	9.79	7.27	5.06	-
T1	Chlorpyriphos 20EC	2ml	1.72 (1.49)	0.72 (1.10)^{cd}	1.15 (1.28)^{bcd}	0.63 (1.06)^{bcd}	0.57 (1.03)^{cd}	0.77 (1.13)^{cd}	53.65

#- Observations mean of 10 randomly selected plants/ treatment; No. in parentheses √(x+0.5) transformed values; Means followed by same letters do not differ significantly by DMRT (p=0.05); DAS- Days after sowing; DBT- Day before treatment; DAT- Days after treatment; NS- Non significant; *- Significant at (p≤0.05)

Table 2. Effect of insecticides mixed with sand on yield and cost economics of maize (kharif 2019-20- pooled)

T. No.	Treatments	Dosage*	Yield (q/ ha)	Cost of cultivation (Rs/ ha)	Gross income (Rs/ ha)	Net income (Rs/ ha)	C:B ratio
T1	Chlorpyriphos 20EC	2 ml	43.91^{cde}	37,273.00	65,857.50	28,584.50	1:1.77
T2	Thiodicarb 75WP	0.6 g	49.46^{bc}	38,124.00	74,187.50	36,063.50	1:1.95
T3	Chlorantraniliprole 18.5 SC	0.4 ml	60.34^{a}	39,535.00	90,507.50	50,972.50	1:2.29
T4	Malathion 50EC	2 ml	42.64^{cde}	37,295.00	63,957.50	26,662.50	1:1.71
T5	Spinosad 45 SC	0.4 ml	53.61^{ab}	40,730.00	80,417.50	39,687.50	1:1.97
T6	Emamectin benzoate 5 SG	0.4 g	58.60^{a}	37,340.00	87,902.50	50,562.50	1:2.35
T7	Neem soap 10%	10 ml	46.43^{bcd}	38,247.00	69,647.50	31,400.50	1:1.82
T8	Diatomaceous earth	200 g	51.29^{abc}	39,087.00	76,940.00	37,853.00	1:1.97
T9	Sand	5 g/ plant	40.31^{de}	36,847.00	60,470.00	23,623.00	1:1.64
T10	Untreated check	-	36.01^{e}	33,847.00	54,010.00	20,163.00	1:1.60
	SEM ±	-	3.052				
	CD @ 5%	-	9.070				
	CV (%)	-	10.96				

*- ml or g/kg of sand, (Market price of maize= Rs.1500/q); T1: Chlorpyriphos 20EC- 380 Rs/ l; T2: Thiodicarb 75WP – 3800 Rs/ kg; T3: Chlorantraniliprole 18.5 SC – 12000 Rs/ l; T4: Malathion 50EC – 400 Rs/ l; T5: Spinosad 45 SC – 17,333.33 Rs/ l;T6: Emamectin benzoate 5 SG – 2200 Rs./kg; T7: Neem soap 10% - 250 Rs/ kg; T8: Diatomaceous earth – 20 Rs/ kg ; T9: Sand – 2.5 Rs/ kg; No. of labour required/ application /ha – 4; Cost of labour: Rs. 200/ day; Quantity of sand required/ application /ha - 280 kg; Cost of production: 33,847/ ha

all around. The maize hybrid (Pioneer 3550) was used and seeds were dibbled at a spacing of 60x 30 cm during the last week of July 2019 on well prepared fine tilth land. The crop was raised adopting a standard package of practice except plant protection measures. A total of ten treatments were evaluated, of which six were insecticides mixed with river sand, one treatment with DE, one plant product (neem soap 10 %), while the sand alone was applied to whorl as check for comparison, and an untreated control.

Before application, the insecticides were properly mixed with sand having 7% moisture and applied to the whorl within an hour of mixing. All treatments were imposed twice, once at V6 and second at V10 stages of crop growth at the 20th and 35th day after sowing,

respectively. In the first application, 5 g of treated sand or DE or neem soap was applied and 7 g was applied during 2nd application. The observations on the number of larvae/ plant in each treatment plot before and after the application were recorded with a sample of ten plants. Pretreatment count was taken one day before treatment by opening whorl, and post treatment ones at seven and 14 days after treatment. The leaf damage severity was recorded based on a 1 to 9 rating scale modified by CIMMYT, Mexico (Prasanna et al., 2018). Observations on the number of larvae/ plant were analysed after square root transformation. The data was subjected to Duncan's Multiple Range Test (DMRT). The grain yield recorded and expressed as q/ ha was also analysed. To know the economics of insecticides usage, data was pooled and the cost-benefit ratio calculated by considering the cost of plant protection and the final grain yield.

RESULTS AND DISCUSSION

In location-I, all the treatments significantly reduced the incidence of larvae at seven and 14 days after treatment; pretreatment counts varied from 1.60 to 2.10 and was statistically non-significant; and overall reduction over control indicated that chlorantraniliprole 18.5SC is the most effective (94.47%), and the next best were emamectin benzoate 5SG (85.25 %) and spinosad 45SC (80.18 %). In location-II, pretreatment counts varied from 1.53 to 2.13, and at seven and 14 days after treatments there was reduction in incidence (92.78% with chlorantraniliprole 18.5SC followed by emamectin benzoate 5SG- 86.67% and spinosad 45 SC- 81.11 %). The pooled data indicated that chlorantraniliprole 18.5SC @ 0.4 ml/ kg of sand outperformed in terms of least larval load and % reduction of incidence. Emamectin benzoate 5SG @ 0.4 g, spinosad 45SC @ 0.4 ml and thiodicarb 75WP @ 0.6 g per kg of sand followed next. The least plant damage score (0.03) was shown with chlorantraniliprole 18.5SC followed by emamectin benzoate 5 SG (0.18) as aginst the maximum of 4.86 in untreated control (Table 1). Only chlorpyriphos 20EC @ 2.0 ml/ kg of sand had a phytotoxic effect. Chlorantraniliprole 18.5SC led to maximum grain yield of 60.34 q/ ha followed by emamectin benzoate 5SG (58.60 q/ ha), with the latter giving the maximum C: B ratio (1:2.35) (Table 2).

As the chemicals were evaluated at the recommended dose, the quantity required/ ha was much less than spraying- spray solution/ ha is 500 l, as against 280 kg of river sand (5g/ plant). Thus, nearly 50% insecticide/ unit area got reduced, also sand application into the whorl directly targets the larvae, as a result larva try to come out of the whorl and hence larvae got damaged through abrasion to the cuticle (Babendreier et al., 2020). Worku and Ebabuye (2019) found that there was no significant difference in the efficacy of insecticides between whorl application and foliar spray. The present study concludes that the quantity of insecticide/ unit area is reduced, also it increased effectiveness as it remained in the whorl for 4-5 days, with additional physical effects of sand (abrasion and other physical damage to cuticle). The applied sand slowly comes out of the whorl as the plant develops without interfering in the plant growth (Babendreier et al., 2020; Worku and Ebabuye, 2019).

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IMPROVING THE EFFICACY OF PONGAMIA OIL WITH COMBINATIONS OF BOTANICAL OILS AGAINST SUCKING PESTS OF CHILLI

A S Gadge*, Venkateshalu, J B Gopali [1], H P Hadimani[2], V P Singh[3], Raghavendra[4] and Vijaymahantesh[5]

Department of Entomology; [1]Department of Vegetable Science, College of Horticulture, Bagalkote 587104, Karnataka, India
[2]Department of Entomology, RHREC, Dharwad 580001, Karnataka, India
[3]Department of PSMA, College of Horticulture, Bidar 585401, Karnataka, India
[4]Department of Biochemistry, College of Agriculture, Shimoga 577201, Karnataka, India
[5]Directorate of Extension, University of Horticultural Sciences, Bagalkote 587104, Karnataka, India
*Email: ankushgadge66@gmail.com (corresponding author)

ABSTRACT

The study evaluated the efficacy of various oils and combinations against sucking pests of chilli. The concentration of emulsifier for efficient emulsification of oils was also studied. Detergent powder @ 0.3% effectively emulsified pongamia oil @ 2.5, 5.0 and 10%. Combination of pongamia oil + neem oil + cotton seed oil + citronella oil (50:25:15:10 ratio) @ 2.0% was superior in management of sucking pests followed by pongamia oil + neem oil (50:50 ratio) @ 2.0%. Botanical oils and their combinations had no direct impact on pollinators and natural enemies except citronella oil. Pongamia oil + neem oil + cotton seed oil + citronella oil (50:25:15:10 ratio) and pongamia oil + neem oil (50:50 ratio) yielded significantly higher yield over other treatments.

Key words: Chilli, pongamia oil, botanical oils, emulsification, sucking pests, pollinators, natural enemies, efficacy, spreader, murda

In chilli (*Capsicum annuum* L.) *Scirtothrips dorsalis* Hood and *Polyphagotarsonemus latus* Banks have been identified as key sucking pests that cause upward and downward leaf curl symptoms, respectively. In terms of crop loss, *S. dorsalis* causes 30 to 50% and *P. latus* about 30 to 70% loss. These pests along with *Myzus persicae* Sulzer and *Aphis gossypii* Glover cause serious damage to the chilli crop by feeding and transmitting serious viral diseases leading to "Murda complex". Biopesticides can reduce the dependence on chemical pesticides for the management of insect pests. Among biopesticides, botanicals have enormous potential as an alternative to chemical pesticides. Botanicals are endowed with a spectrum of insecticidal activities such as repellence, insect behavior modifier and antifeedant activity in insects, mites, snails, slugs, nematodes and other agricultural pests. Botanicals are now emerging as one of the prime means to protect crops (Kovarikova and Pavela, 2019). Pongamia oil, rich in karanjin has shown excellent biological activity. Pongamia is a good synergist and has antifeedant, oviposition deterrent, ovicidal and insecticidal properties against a wide range of insect pests (Kumar et al., 2006). Combination of botanical oils have greater efficacy and broader mode of action than their individual usage (Kumar et al., 2007). Hence, this study for standardization of emulsifier concentration and evaluating the efficacy of newly formulated botanical oil combinations against sucking pests of chilli.

MATERIALS AND METHODS

Laboratory standardization of detergent powder concentration @ 0, 0.05, 0.1, 0.2 and 0.3% for emulsification of different pongamia oil concentrations @ 0.5, 1.0, 2.5, 5.0 and 10%, respectively was carried out by mixing all combinations. Totally, 25 combinations were evaluated with three replications in the laboratory in test tubes at the Department of Entomology, College of Horticulture, Bagalkote. After mixing and thorough shaking, the test tubes were placed in a test tube stand. The observations on the height of the oil film floating on the top were measured at 0, 2, 6 and 12 hr after mixing and grades were given by visual observation (Grades 0- No opaqueness, 1- 1 to 20% opaqueness, 2- 21 to 40% opaqueness, 3- 41 to 60% opaqueness, 4- 61 to 80% opaqueness and 5- 81 to 100% opaqueness). From this trial, a standard emulsifier concentration for each pongamia oil concentration was determined.

Field experiment was laid out at the College of Horticulture, Bagalkote, Karnataka (16°9'52"N, 75°36'51"E, 542 masl) during kharif, 2019. The experiment was carried in a randomized block design (RBD) with twelve treatments and three replications, with a plot size of 3.6 x 2.1 m leaving a gangway of 1 m around the plots. Thirty days old chilli seedlings of the variety Sitara Gold (Monsanto) were transplanted at a spacing of 60x 30 cm. The crop was raised by following recommended package of practices of UHS, Bagalkote (Anonymous, 2018) except for management against sucking pests. The treatments were imposed using a knapsack hydraulic sprayer at a spray volume of 500 l/ ha. The first spray was given at ten days after transplanting (DAT) after noticing the incidence of sucking pests and subsequent sprays were at an interval of 10 days. Pongamia, neem, cotton seed and citronella oils were procured from market. Spray solution of oils were prepared by mixing the required proportion of each oil together with the emulsifier @ 0.3% as per the treatment details mentioned in Table 1. Observations from 10 randomly tagged plants leaving the border rows, were recorded a day before, 3, 7 and 10 days after each spray. Incidence of *S. dorsalis* was observed from top 3 leaves; *P. latus* counts were made in 1 cm^2 area each on the lower surface from top 3 leaves using 10x lens. Leaf curl index score for *S. dorsalis* and *P. latus* was recorded from visual observations on a 0-4 scale as per the standard scoring procedure given by Niles (1980). Population of *M. persicae*, *A. gossypii* and *Bemisia tabaci* (Genn.) was counted from top three leaves. Natural enemies viz., coccinellids, spiders, *Chrysoperla* and preying mantids were counted/ plant. Occurrence of pollinators like honey bees were counted as no. of bees/ plant. Reduction in incidence after spray in treatment in comparison with control was calculated after Henderson and Tilton (1955). Data were subjected to square root transformation before ANOVA, and the treatment means were compared by Duncan's Multiple Range Test (DMRT, p=0.05).

RESULTS AND DISCUSSION

Results of laboratory studies on standardization of emulsifier concentration infer that, emulsification of pongamia oil was highest with by 0.3% detergent powder. Grade of opaqueness was 5 at 0.3% at all the tested concentrations of pongamia oil. These findings are in very close conformity with study of Kamba et al. (2013) who revealed that, the more concentration of emulsifier, the more stable the emulsion. Detergent has a large non-polar hydrocarbon end and water-soluble polar end (Swarbrick, 2002). From the laboratory studies 0.3% spreader concentration (producing lowest height of oil film floating with highest grade) was selected for emulsification of 2.0% oil, further which was used for bioefficacy study (Aliakbarpour et al., 2011; Stanley et al., 2014; Sridharan et al., 2015).

All the botanical oils and their combinations evaluated against sucking pests of chilli were found effective under field condition (Table 1). Plots treated with T_8 (Pongamia oil + neem oil + cotton seed oil + citronella oil - 50:25:15:10 ratio) recorded significantly higher reduction of *S. dorsalis* (53.92%) followed by T_6 (pongamia oil + neem oil - 50:50 ratio) and T_{10} (diafenthiuron 50WP) with 43.84 and 41.07% reduction, respectively. Lowest reduction was recorded in T_4 (cotton seed oil) with 10.33%. Treatment, T_8 recorded a significantly lower incidence of *S. dorsalis* on top three leaves (0.68) followed by T_6 and T_{10} with 0.76 and 0.89 thrips, respectively. Oil combinations were superior over their sole treatments of pongamia seed, citronella, neem seed and cotton seed oil treated plots that recorded 1.12, 1.18, 1.19 and 1.24 thrips, respectively. Reduction of leaf curl due to *S. dorsalis* was significantly higher with T_8 followed by T_6 and lowest reduction in leaf curl was with treatment T_4. Similar to the reduction in *S. dorsalis*, T_8 recorded significantly more reduction of *P. latus* (62.53%) followed by T_6 (58.14%) and T_{10} (49.25%); and cotton seed oil (T_4) recorded the lowest reduction. Treatments differed significantly in reducing the mean number of *P. latus* in 1 cm^2 area/ top three leaves- T_8 recorded the lowest number of *P. latus* (0.93) followed by T_6 and T_7 with 1.03 and 1.36 mites, respectively. Combinations of oils were superior over their sole treatments of neem, citronella, pongamia and cotton seed oil treated plots that showed 1.59, 1.75, 1.87 and 2.04 mites, respectively. Leaf curl due to *P. latus* significantly reduced with T_8 (57.95%) followed by T_{10} and T_6. Incidence of *M. persicae* and *A. gossypii* significantly reduced with treatments T_8 followed by T_6 and T_{10}. Significant reduction in *B. tabaci* was observed with T_6 followed by T_8 and T_5.

Superiority of combinations of botanical oils over their sole applications in reducing the sucking pests indicated that, multiple modes of action and their efficacy when combined may be harnessed due to oils with multi-components. Strong antifeedant effects in neem oil and repellent properties in citronella oil will have greater impact on sucking pests of chilli. According to Abdelatti and Hartbauer (2020) combined formulation of carway, orange peel and winter green

Table 1. Efficacy of botanical oils against sucking pests and their impact on beneficial organisms on chilli (2019-20)

T. No.	Treatment details	Dosage	Mean no. of sucking pests/ top three leaves						Mean no. of beneficial organisms/plant				Green chilli yield (t/ ha)	BCR
			Thrips	Thrips LCI	Mites	Mites LCI	Aphids	White-flies	Cocci-nellids	Spiders	Other preda-tors	Honey bees		
T_1	Neem oil (NO)	2.0%	1.19 (1.09)^{c}	0.61 (0.78)^{bc}	1.59 (1.25)^{f}	0.47 (0.69)^{cd}	6.36 (2.62)^{def}	0.18 (0.82)^{b}	1.36 (1.36)^{cd}	2.27 (1.66)^{e}	0.20 (0.84)^{b}	2.00 (1.58)^{bc}	15.30^{cd}	1.57
T_2	Pongamia oil (PO)	2.0%	1.12 (1.05)^{de}	0.61 (0.78)^{bc}	1.87 (1.37)^{d}	0.51 (0.71)^{c}	6.82 (2.71)^{cde}	0.13 (0.80)^{c}	1.18 (1.30)^{e}	2.13 (1.62)^{e}	0.18 (0.82)^{bc}	2.16 (1.63)^{b}	13.71^{de}	1.33
T_3	Citronella oil (CO)	2.0%	1.18 (1.08)^{cd}	0.62 (0.79)^{bc}	1.75 (1.33)^{e}	0.51 (0.71)^{c}	7.76 (2.87)^{bc}	0.12 (0.79)^{c}	0.42 (0.96)^{f}	1.71 (1.49)^{f}	0.09 (0.77)^{f}	0.69 (1.09)^{f}	4.75^{f}	0.41
T_4	Cotton seed oil (CSO)	2.0%	1.24 (1.11)c	0.67 (0.81)^{b}	2.04 (1.42)^{c}	0.42 (0.66)^{e}	8.16 (2.94)^{b}	0.18 (0.82)^{b}	1.33 (1.35)^{cd}	2.09 (1.61)^{e}	0.20 (0.84)^{b}	2.60 (1.76)^{a}	14.85^{cd}	1.28
T_5	PO + NO (75:25)	2.0%	1.08 (1.03)^{e}	0.52 (0.72)^{de}	1.66 (1.28)^{ef}	0.41 (0.64)^{e}	6.50 (2.65)^{def}	0.07 (0.75)^{e}	1.33 (1.35)^{cd}	3.29 (1.95)^{b}	0.20 (0.84)^{b}	1.51 (1.42)^{de}	16.47^{bcd}	1.67
T_6	PO + NO (50:50)	2.0%	0.76 (0.87)^{g}	0.48 (0.69)^{ef}	1.03 (1.02)^{h}	0.44 (0.66)^{de}	5.73 (2.50)^{f}	0.00 (0.71)^{g}	1.29 (1.34)^{de}	2.80 (1.82)^{cd}	0.11 (0.78)^{e}	1.56 (1.43)^{d}	23.16^{a}	2.31
T_7	PO + NO + CSO + CO (75:10:10:05)	2.0%	1.09 (1.05)^{e}	0.56 (0.75)^{cd}	1.36 (1.16)^{g}	0.48 (0.70)^{cd}	6.29 (2.61)^{def}	0.04 (0.74)^{f}	1.49 (1.41)^{ab}	3.42 (1.98)^{b}	0.20 (0.84)^{b}	1.98 (1.57)^{c}	16.87^{bc}	1.68
T_8	PO + NO + CSO + CO (50:25:15:10)	2.0%	0.68 (0.83)^{h}	0.45 (0.67)^{f}	0.93 (0.97)^{i}	0.29 (0.53)^{f}	5.60 (2.47)^{f}	0.01 (0.71)^{g}	1.19 (1.30)^{e}	3.11 (1.90)^{bc}	0.13 (0.80)^{d}	1.50 (1.41)^{de}	24.07^{a}	2.33
T_9	Azadirachtin 10000 ppm (Standard check)	1 ml/L	1.35 (1.17)^{b}	0.65 (0.81)^{b}	2.40 (1.55)^{b}	0.49 (0.71)^{c}	7.69 (2.86)^{bc}	0.13 (0.80)^{c}	1.40 (1.38)^{bcd}	3.09 (1.89)^{bc}	0.09 (0.77)^{f}	2.16 (1.63)^{b}	14.42^{cde}	1.49
T_{10}	Diafenthiuron 50WP	1g/L	0.89 (0.95)^{f}	0.53 (0.72)^{de}	1.42 (1.19)^{g}	0.31 (0.55)^{f}	5.91 (2.53)^{ef}	0.07 (0.75)^{e}	1.42 (1.39)^{bc}	2.69 (1.78)^{d}	0.16 (0.81)^{cd}	2.04 (1.60)^{bc}	22.06^{a}	2.26
T_{11}	NSPE	5.0%	1.11 (1.06)^{de}	0.62 (0.79)^{bc}	2.40 (1.54)^{b}	0.57 (0.76)^{b}	6.93 (2.72)^{cd}	0.11 (0.78)^{d}	1.29 (1.34)^{cde}	2.04 (1.59)^{e}	0.16 (0.81)^{cd}	1.38 (1.37)^{e}	18.50^{b}	1.93
T_{12}	Untreated control	-	2.04 (1.42)^{a}	1.48 (1.22)^{a}	3.58 (1.89)^{a}	0.91 (0.95)^{a}	9.67 (3.19)^{a}	0.37 (0.93)^{a}	1.62 (1.46)^{a}	4.33 (2.20)^{a}	0.31 (0.90)^{a}	2.73 (1.80)^{a}	11.52^{e}	1.20
SEm±			0.03	0.03	0.03	0.02	0.06	0.00	0.01	0.03	0.01	0.02	1.04	-
CD (p=0.05)			0.08	0.08	0.09	0.05	0.18	0.01	0.04	0.09	0.02	0.05	3.05	-
CV (%)			4.06	7.35	2.95	6.33	3.84	0.98	1.86	3.09	1.45	2.11	11.04	-

Figures in parentheses square root transformed values; Means followed by same letters in column not statistically different (DMRT, p=0.05); LCI- Leaf Curling Index; NSPE-Neem Seed Powder Extract; Others- Preying mantids, *Chrysoperla*; BCR- Benefit Cost Ratio

oils showed 80 and 100% mean mortality of desert and migratory locusts, respectively. The mode of action of the botanical oils attributed to physical impediments on sucking pests, which was observed under microscope in the laboratory in post application examinations of clipped off leaves containing sucking pests. Insecticidal property of botanical oils and their combinations against sucking pests of chilli is also attributed to the broad-spectrum activity as toxicants and physical poisons causing mortality of sucking pests. Kumar and Singh (2002) reported the broad-spectrum activity of pongamia oil against wide range of insect pests. Rajput et al. (2017) found that, neem oil and cotton seed oil were superior in reducing sucking pests of cotton. Zeeshan and Kudada (2019) found that, leaf curl disease incidence of chilli was reduced to 24.63 and 32.9% by application of neem and karanj oil @ 0.5%, respectively. Kumar et al. (2007) reported the combined formulations of neem oil and pongamia oil showed synergism against chrysanthemum aphid causing 100% mortality compared to 68.4 and 52.9% mortality in neem oil and pongamia oil alone, respectively after 48 hr at 0.5%.

Maximum number of natural enemies (coccinellids, spiders, preying mantids, *Chrysoperla*) were observed from T_{12} (Table 1); and least counts were observed in T_3, it may be attributed repellent property of citronella oil for active stages of predators and, then plant canopy compared to other treatments. There is likely shift in the predator population from treated plots as a result of botanical repellency and reduction in pest density. Vanisree et al. (2011) found that, every increase in number of thrips caused a corresponding increase of spiders and ladybird beetles in chilli. Maximum number of honey bees were observed in T_{12} on par with T_4 (2.73); and the least with T_3 (0.69), it may be due to repellent property of oils as well as poor availability of flowers to bees for foraging as evidence by low flower density in this treatment. This is because high phytotoxic effect of citronella oil which causes the leaf deformation, stunted growth and reduced flowering. There is likely shift in the bees' occurrence from treated plots as a result of botanical oils repellency. Aliakbarpour et al. (2011) reported that 2.0% neem oil was effective and brought 59.8% reduction in thrips along with 24.9% mortality of pollinators and concluded that, proper timing of neem oil application such as, at midday when pollinators are least active would prove less detrimental to mango pollinators and at the same time can control thrips.

Observations on the influence of botanical oils and their combinations on green chilli yield revealed that, T_8 treated plots gave maximum yield (24.07 t/ ha) which was statistically on par with T_6 and T_{10} with 23.16 and 22.06 t/ ha. This may be due to efficient management of major sucking pest complex of chilli with botanical oils and their combination. Lowest yield of 11.52 and 4.75 t/ ha was recorded in T_{12} and T_3 respectively. Phytotoxic effect of citronella oil causing plant deformity resulted in decrease in yield. Highest BC ratio recorded in T_8 treated plots (2.33) followed by T_6 (2.31) and T_{10} (2.26). Whereas, least BC ratio (0.41) was recorded in the plots treated with T_3. Difference in the BC ratio is may be due to differences in the cost of botanical oils. Meena and Tayde (2017) obtained maximum yield and BC ratio with pongamia oil @ 4% followed by neem oil @ 2.5ml/ l. Similarly, Zeeshan and Kudada (2019) also obtained more chilli yield with neem oil @ 0.03 and karanj oil @ 0.15%.

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BIOCHEMICAL RESPONSE OF CHICKPEA GENOTYPES AS INFLUENCED BY POD BORER *HELICOVERPA ARMIGERA* (HUBNER)

G S KARTHIK* AND A S VASTRAD[1]

Department of Agricultural Entomology, College of Agriculture,
Vijayapura (University of Agricultural Sciences Dharwad), Dharwad 580005, Karnataka, India
[1]University of Agricultural Sciences, Dharwad 580005, Karnataka, India
*Email: agrikarthik94@gmail.com (Corresponding author)

ABSTRACT

This study evaluated the biochemical changes in 15 chickpea genotypes artificially infested with pod borer *Helicoverpa armigera* (Hubner). Infested samples revealed significantly more phenols, malic acid and protein, and less reducing sugar contents. Significant differences among the genotypes for all the biochemicals were observed in the infested samples. These differences were influenced by genotype and pod damage both individually and together. Correlation analysis indicated significant associations of parameters with pod damage.

Key words: *Helicoverpa armigera*, chickpea, genotypes, infestation, phenols, proteins, malic acid, reducing sugars, pod damage, correlation coefficients, relationships

Chickpea (*Cicer aretinum* L.) is the third most important legume crop globally after dry beans and peas (Golla et al., 2018), with its production (75%) and consumption majorly centered in India (Das et al., 2017). Gram pod borer *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) is a major pest of chickpea causing significant annual losses up to 25-30% (Golla et al., 2018; Das et al., 2017). High polyphagy, fecundity, diapause and migratory behaviour ensure its survival in wide range of ecosystems. Management strategies are often compromised by varying levels of infestation, and resistance to major groups of insecticides (Kranthi et al., 2002). Further, insecticide resistance in *H. armigera* varies with space and time (Singh et al., 1994). The immediate urge to search for alternate viable control strategies drives our approach towards host plant resistance. Screening the germplasm against the pest has been done previously, however studies on biochemical responses in response to infestation are inadequate. It is important to understand the biochemical responses induced as a result of pod borer feeding to use these parameters as selection criteria in developing cultivars with resistance to the pest. Hence, the present study evaluating the biochemical responses in chickpea genotypes in relation to infestation.

MATERIALS AND METHODS

Fifteen chickpea genotypes viz., BGD (133, 1501, 1536, 103, 111-01), JAKI 9218, JG 11, A-1, DBGV (204, 209, 206, 215, 213, 212) and KAK-2 were sown in randomized block design replicated thrice with Annigeri-1 (A-1) as a susceptible check during rabi, 2017 and rabi-summer, 2017-18 at the College of Agriculture, Vijayapura, Karnataka, India. The experiments were conducted as a part of routine breeders' evaluation trial and hence a resistant check was not included. The crop was raised as per the package of practices, recommended by the University of Agricultural Sciences, Dharwad except for the insecticidal application. As the natural infestation was way below the ETL, artificially infesting plants was done. At flowering stage, two 4th instar *H. armigera* larvae were introduced on the terminal leaves of five random plants/ treatment early in the morning for feeding. Larval movement was restricted by enclosing a muslin bag and insect was allowed to feed for 24 hr. One *H. armigera* larva/ m row is above economic threshold level for chickpea crop. Uninfested and infested leaf samples were collected from upper half of the plant during both seasons at flowering stage which were later shade dried and used for estimation of phenols, proteins and reducing sugars. Leaf samples collected before artificial infestation were considered as uninfested while samples collected after infestation were considered as infested. Leaf samples were collected separately for malic acid estimation. Standard protocols were employed to estimate the total phenol content (Sharma et al., 2016), reducing sugars (Somogyi, 1952), total protein (Sharma et al., 2016) and malic acid content (Koundal and Sinha, 1983).

At harvest, number of damaged pods was recorded on ten random plants/ treatment. Data on pod damage was subjected to arc sine transformation. The data on all the parameters from both seasons were pooled and subjected to one way ANOVA followed by Tukey HSD test (p = 0.05). Further, the individual and combined effect of genotype and pod damage on various biochemical parameters was analyzed. Paired t-test was conducted to test the significant differences between uninfested and infested samples. Correlation coefficients between pod damage and biochemical parameters were conducted for individual genotypes to know the effect of infestation on damage responses. The data analysis was done in R software (4.0).

RESULTS AND DISCUSSION

The data presented in Fig. 1 represents the pooled mean of both the seasons. Significant differences can be observed in all the biochemical components between uninfested and infested samples. Feeding by *H. armigera* resulted in significantly less reducing sugars (t= 15.38; df = 89; p < 0.05) with enhanced phenols (t= -11.5; df = 89; p< 0.05), malic acid (t= -9.9; df = 89; p < 0.05) and protein contents (t= -7.57; df = 89; p< 0.05) compared to uninfested samples. No significant differences were observed among genotypes in uninfested samples. Induced biochemical defense is the most active and dynamic form of defense ensuring sufficient protection to the host against herbivory. Among the fifteen genotypes, evaluated for induced resistance against *H. armigera*, revealed that maximum phenol production was triggered in BGD 111-01 followed by DBGV 215 which were significantly more. These were significantly negatively correlated with pod damage (r= -0.85 in BGD 111-01 and r= -0.83 in DBGV 215). The least response to damage was noticed in BGD-103, BGD-133, BGD-1501 and KAK-2. Phenols constitute one of the most common, important and extensively studied groups of compounds with a major role in providing resistance (Sharma et al., 2009; War et al., 2013; War et al., 2015). They act as first line of defense by reduction of reactive oxygen species (ROS) produced as a result of insect herbivory ultimately leading to the activation of defensive enzymes (Maffei et al., 2007; Meitei et al., 2018).

Irrespective of the genotype, infested plants revealed maximum phenol contents than the corresponding uninfested plants. This suggested their role in providing protection against ROS-induced damage due to pest infestation (Sharma et al., 2016). Further, oxidation of phenols results in quinone production which inhibits protein digestion in insects (Kaur et al., 2015; Sharma et al., 2016; War et al., 2012). Accumulation of phenols (Sharma et al., 2009), qualitative and quantitative

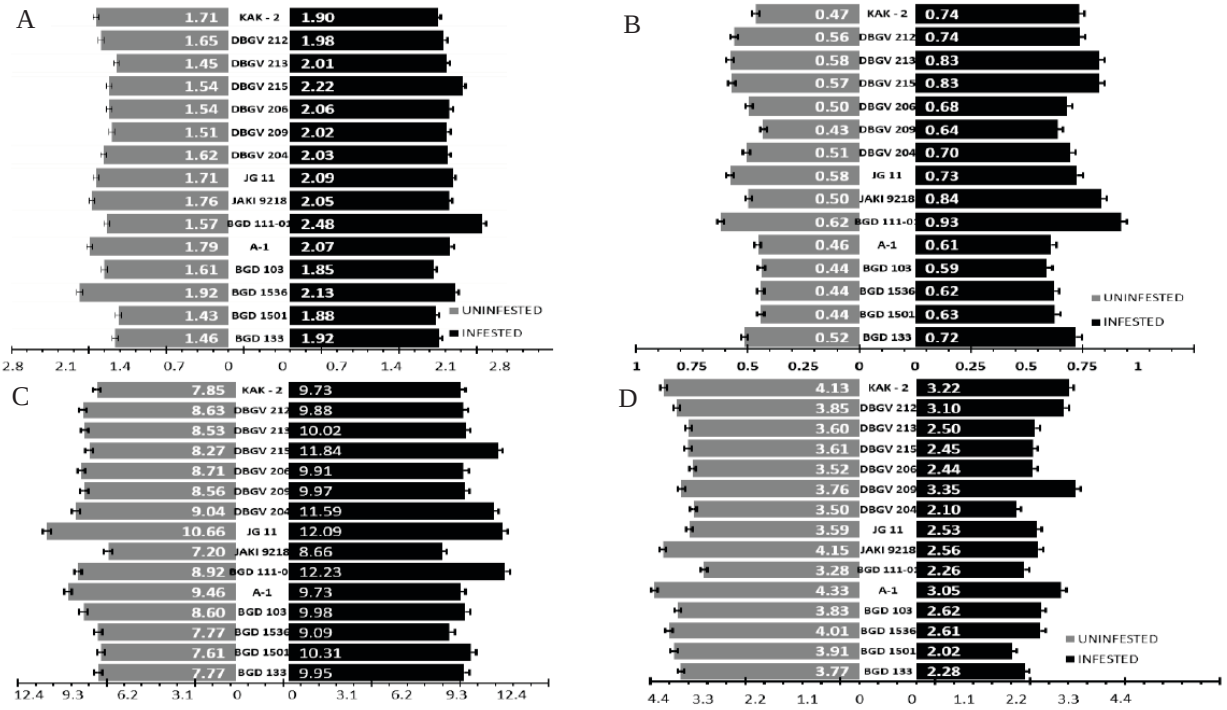

Fig. 1. Biochemical changes in leaves of uninfested and *H. armigera* infested chickpea genotypes. A) Phenols (mg GAE/ g); B) Malic acid (%); C) Proteins (mg/ g) and D) Reducing sugars (mg/ g); Error bars represent SEm.

changes in its contents in response to infestation is well known (Maffei et al., 2007). An increased production of phenols in infested leaves is in agreement with earlier reports in chickpea (War et al., 2011; Sharma et al., 2016; Kaur et al., 2017a, b) pigeon pea (Green et al., 2003; Sharma et al., 2009; Sahoo and Patnaik, 2003) and many other plant systems (Rani and Jyothsna, 2010; Senguttuvan and Sujatha, 2000).

Similarly, malic acid content was significantly high in BGD 111-01 and exhibited significant negative correlation with pod damage (r= -0.84). Moderate to low response was noticed in JAKI-9218, DBGV-213, 215. Lowest production of malic acid in response to damage by *H. armigera* was noticed in BGD-103 which was below than susceptible check (A -1). Malic acid and oxalic acid constitute the major components in the exudates of chickpea leaves. Significantly higher amount of malic acid in infested leaves indicate its role in host defense. Malic acid might have a detrimental effect on the pest mediated through ovipositional antixenosis and antibiosis. The present results are in accordance with previous studies indicating malic acid as a source of resistance (Sharma et al., 2016; Cowgill and Lateef, 1996; Simmonds and Stevenson, 2001; Devi et al., 2013). On the contrary, some genotypes with considerable amounts of malic acid also suffered from relatively more pod damage suggesting that malic acid alone might not be the source of resistance (Bhagwat et al., 1995).

Significantly high protein content was observed in BGD-111-01, JG-11 and DBGV-215 genotypes showing significant negative correlation with pod damage (r= -0.81, -0.84 and -0.81 respectively). Least response was observed with JAKI-9218 (r = -0.84) and other genotypes responded moderately to infestation. A protein mediated defense is one of the most important and widely studied defense mechanism in plants against insects (Chen et al., 2009). Increased protein content in the infested samples could be explained by the plant requirement in synthesizing defensive enzymes and other non-enzymatic proteins in large quantities in response to infestation (Chen et al., 2009; War et al., 2012; War et al., 2015). These proteins might show antifeedant property against insects. Significantly higher amount of protein in insect infested plants confer stronger resistance against the pest. The present data on accumulation of proteins and their role in resistance confirms the earlier results (War et al., 2011; Kumar, 2017) and other crops (Chen et al., 2011; War et al., 2012; Prasad, 2015).

In response to pod borer feeding, DBGV-209 revealed maximum reducing sugar content followed by KAK-2 which were significantly positively correlated with pod damage (r= 0.94 in DBGV-209 and r= 0.86 in KAK-2) while BGD-1501 revealed the least reducing sugar content. Lesser reducing sugars in infested plants can be attributed to more foliar damage due to herbivory ultimately reducing the sugar contents. Similar results were also reported by Savitri, (2016) and Sharma et al. (2016) in chickpea; and Sahoo and Patnaik (2003) and Sharma et al. (2009) in pigeonpea. All the biochemical parameters were significantly influenced by genotype and pod damage both individually and when considered together (Phenols: F-value: Genotype = 8.64^{***}, Pod damage = 76.56^{***}, Genotype x Pod damage = 4.12^{***}; Malic acid: F-value: G = 3.54^{***}, PD = 44.82^{***}, G x PD= 2.86^{**}; Proteins: F-value: G = 6.2^{***}, PD = 10.94^{*}, G x PD= 8.77^{***}; Reducing sugar: F-value: G = 9.3^{***}, PD = 6.0^{*}, G x PD= 10.53^{***}). Significant differences were observed in biochemical composition among various genotypes which indicate the ability of the genotypes to induce better damage responses as a result of pod borer feeding. It is possibly due to differences in innate nature of genotypes.

Among the genotypes, maximum pod damage was observed in BGD-103 followed by A-1 while BGD-111-01 was with the least pod damage, and significantly different from others. BGD-111-01 was superior in response to infestation followed by DBGV-215 with significantly more phenols, malic acid and proteins. BGD-103 and KAK-2 showed poor response to damage along with susceptible check (A-1) with lower phenols, malic acid and proteins and with higher reducing sugar content. Thus, the present study reports significant differences in biochemical parameters in various chickpea genotypes. Genotypes BGD-111-01 and DBGV-215 responded well to pest infestation by production of anti-nutrition factors and were found superior compared to other genotypes and hence can be used for developing resistant cultivars or as a source of resistance.

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DETECTION OF HIDDEN INFESTATION OF CIGARETTE BEETLE *LASIODERMA SERRICORNE* F. IN TURMERIC RHIZOMES BY X-RAY RADIOGRAPHY

K Ravi Kumar* and C Narendra Reddy

*Department of Entomology, College of Agriculture, Rajendranagar,
PJTSAU, Hyderabad 500030, Telangana, India
*Email: katrojuravikumar@gmail.com (corresponding author)

ABSTRACT

An experiment was conducted to detect the hidden infestation of *Lasiderma serricorne* F. in the turmeric rhizomes by X-ray radiography. Six varieties viz., Duggirala, Pratibha, Armoor, Salem, Kasturi and Tekurpeta were selected based on their size. Standardization of X-ray radiography values were done by subjecting the fingers to 120 combinations of voltage (KV), current (mA) and exposure period (s). The results revealed that the hidden infestation was detected as accurately as possible with 22 to 25 KV voltage, 3 mA to 5 mA current with 10 sec of exposure.

Key words: Turmeric, rhizomes, fingers, varieties, *Lasioderma serricorne*, X-ray, Voltage (KV), Current (mA), exposure period, radiation, infestation, developer, fixer, detection

Turmeric is a rhizomatous herbaceous perennial plant belonging to the ginger family (Zingiberaceaae), botanically known as *Curcuma longa* L., originated from Tropical south Asia (India). Various insects infest dry turmeric, of which the Coleoptera, include cigarette beetle (*Lasioderma serricorne* F.), drugstore beetle (*Stegobium paniceum* L.), red flour beetle (*Tribolium castaneum* Herbst), lesser grain borer (*Rhyzopertha dominica* F.), saw toothed grain beetle (*Oryzaephilus surinamensis* L.) and coffee bean weevil (*Araecerus fasciculatus* DeG.). Among these *L. serricorne* is serious, with the quantitative weight loss at three and six months after storage being 7.15 and 22.75% (Vidya and Awaknavar, 2004). Quarantine is the last defense against an unwanted imported non invasive alien pest. It is well known that X-rays can penetrate most materials. In addition to its application in industry and for medical examinations, X-ray radiography method can effectively be employed to detect the hidden insect infestation in stored grains (Karunakaran et al., 2003a). Electromagnetic waves with wave lengths ranging from 1 to 100 nm are called soft X-rays. The low penetration power and ability to reveal the internal density changes made soft X-rays suitable for agricultural products. The soft X-ray method is rapid and takes only a few seconds (3 to 5 sec) to produce an X-ray image.

X-ray radiography is one such great technological application in the area of plant quarantine and is an official standard method in USA for detection of hidden insect infestation in seed without destructing the high value genetic material. National Bureau of Plant Genetic Resources (NBPGR) which is a nodal organization in India is responsible for exchange of germplasm where compact X-ray machines are being used to detect the hidden insect infestation especially in case of germplasm. For standardization of X-ray radiography input factors like voltage (KV), current (mA) and exposure period (s) are required as these factors differ from one commodity to other. Some research was carried out to detect hidden infestation of insects in commodities (Karunakaran et al., 2003a; Maharajan et al., 2005; Fornal et al., 2007; Ramakrishnan et al., 2012; Boniecki et al., 2014; Chelladurai et al., 2014). However, very limited work has been done to detect the *L. serricorne* infestation in turmeric. The present investigation was undertaken for standardization of methodology for the detection and to fix the exact values of x-ray radiation related to infestation in six varieties of turmeric.

MATERIALS AND METHODS

For standardization, both infested and healthy samples were used in X-ray radiography studies to compare and analyze the X-ray images visually in order to determine and arrive at the right image of the infested ones from that of the healthy ones. A single disinfested variety of 'Duggirala' was taken as healthy one and varieties with eggs of *L. serricorne* were taken separately and maintained in separate glass jars. The X-ray film for obtaining standard images was used and

small samples (5-10) of the cured turmeric varieties were placed over the adhesive tape to pick out and separate the samples with internal (hidden) infestation while looking at the corresponding X-ray image. The cured turmeric samples were arranged in such a manner, where one row of infested ones alternated with that of healthy ones. After the exposure of these samples to radiation, the X-ray film was processed with the help of silver halide for image development and sodium thiosulphate for image fixing. After fixation, washing was done to remove the exhausted chemicals from the emulsion and to prevent the image deterioration. Finally, the X-ray film was thoroughly air dried to remove the excess moisture. After the image was fixed on the X-ray film, it was exposed to the X-ray radiation of different combinations, to find out the hidden infested areas.

The X-ray machine consists of three important factors i.e., kilovoltage (KV) is the measure of voltage potential, milliamperage (mA) is the measure of the current applied to the tube and exposure duration is the time during which the sample is exposed to the X-rays for making the radiograph. Standard cabinet X-ray machine of Faxitron series consists of a maximum of 45 kilo voltage (KV) and 15 milliamperage (mA) current. At a given voltage levels varying from 20 to 26 KV, there were 120 treatment combinations by changing of current as 2, 3, 4, 5 mA and exposure periods of 2,4,6,8 and 10 sec. Image analysis was taken up with 120 combinations to find out and standardize the right current, voltage and exposure period for detection of hidden infestation in the test samples. The hidden infestation was observed at the X-ray radiation of 25 KV and 5 mA current and 10 sec exposure period. Adjustments in combinations of current and exposure periods were made based on the preliminary image results while working in the laboratory. A highly infested variety "Duggirala" was used as the check for the standardization of current, voltage and exposure periods. The six varieties were selected based on size, which are mostly popularized and mostly cultivated by farmers for X-ray radiography studies viz., Duggirala, Pratibha, Armoor, Salem, Kasturi and Tekurpeta.

RESULTS AND DISCUSSION

Quarantine workers in India traditionally used only a range of values from 10 KV to 30 KV and a current of 4 milli ampere (mA) to 12 mA with an exposure period of 10 to 25 sec for cereals and leguminous seed materials. Ramakrishnan et al. (2012) reported that high voltage and current were required for dense seed materials to ensure adequate penetration of radiation compared to light seed materials. At different combinations of voltage, current and exposure periods, the best combination was observed by exposing to X-ray radiation of 25 KV and 5 mA for 10 seconds. Exposure to 22 KV, 4 mA for 6 seconds and at 26 KV, 4 mA for 10 sec exposures resulted in lighter and darker images, respectively. A disinfested and healthy one of Duggirala variety exposed to X-ray radiography at 25 KV and 5 mA for 10 sec, resulted in a good image. Based on these values, the combination of treatments in different turmeric varieties was standardized.

These results reveal that the current, voltage and exposure periods varied with varieties and ranged from 22 KV 5 mA 10 sec to 25 KV 5 mA 10 sec. The fingers of Pratibha which were heavily infested were selected for the investigation. Exposure of fingers to X-ray radiation of 23 KV and 4 mA for 10 sec was found to be the best combination to detect the hidden infestation. The other combinations viz., 20 KV, 4 mA for 8 sec showed lighter image and 25 KV, 2 mA for 10 sec showed darker images. Exposure to 22 KV and 5 mA for 10 sec clearly detected the hidden infestation in infested 'Armoor' variety. Other combinations like 20 KV, 5 mA for 6 sec and 24 KV, 3 mA for 8 sec resulted in lighter and darker images. With the variety Salem, best images were obtained when exposed to 24 KV and 5 mA for 10 sec, thus can be considered as standardized values for Salem. The other combinations like 22 KV, 2 mA for 8 sec exhibited lighter image and at 26 KV, 2 mA for 6 sec exhibited darker image. Among the combinations of voltage, current and exposure periods evaluated, it was observed that exposure to 25 KV and 3 mA for 10 sec clearly detected the hidden infestation of *L. serricorne* in Kasturi. Exposure to 23 KV and 2 mA for 6 sec resulted in lighter image, while a darker image was observed at 26 KV and 2 mA for 8 sec. With the variety Tekurpeta, these values were 24 KV and 3 mA for 10 sec for a clear image; and 20 KV and 2 mA for 8 sec and 25 KV and 4 mA for 10 sec resulted in lighter and darker images, respectively.

These observations indicate variation in radiation and voltage to acquire clear image with the turmeric varieties, and this variation might be due to their size, shape and thickness; voltage ranged from 22 to 25 KV. These results agree with those of Ramakrishnan et al. (2012). This study had reported that when the size of the commodity increases, the voltage value also increases- the standardized value for paddy was 15 KV, 12 mA for 25 sec and for maize it was 25 KV, 8mA for 20

sec; while for greengram and soybean the values were 20 KV, 10 mA and 25 seconds and 25 KV 10 mA and 20 sec, respectively. The present results reveal that for the better X-ray images of hidden insect infestation a minimum of 3 mA current is required. The period of exposure to radiation was also an important factor, and exposure to < 8 sec and > 10 sec resulted in lighter and darker images, respectively. Kumarasamy et al. (2002) on Sabal uresana seeds, Karunakaran et al. (2003b) on western red spring wheat, Masetto et al. (2008) on cedar seeds evaluated the radiation for detection of hidden infestation. In quarantine stations during germplasm exchange by Sarath Babu (1997), Manju et al. (2002), Gupta et al. (2004), Bhalla et al. (2008) and Bhalla et al. (2009) reported that the voltage, current and exposure periods varies depending upon the material.

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ASSESSMENT OF YIELD LOSSES DUE TO WHITE STEM BORER *SCIRPOPHAGA FUSCIFLUA* (HAMPSON) IN RICE

Vikas Tandon* and Ajai Srivastava[1]

Department of Entomology, CSK Himachal Pradesh Krishi Vishvavidyalaya,
Palampur 176062, Himachal Pradesh, India
[1]CSK HPKV Rice and Wheat Research Centre, Malan 176047, Himachal Pradesh, India
*Email: tandonvikas8763@gmail.com (corresponding author)

ABSTRACT

Field experiments were conducted to assess the extent of losses occurring in rice crop due to the white stem borer (WSB) *Scirpophaga fusciflua* (Hampson) at different stages of crop growth. Results revealed that maximum infestation in terms of deadhearts and white ears was 11.6% at maximum release level (6 larvae/ hill) and the least (6.2%) at 2 larvae/ hill. The avoidable losses varied from 7.5 to 32.3%. The infestation % of released larvae was lowest to the economic threshold level.

Key words: *Scirpophaga fusciflua*, rice, deadhearts, white ears, losses, infestation, release of larvae, artificial infestation, economic threshold level, crop stages

Rice is one of the leading staple food crops in the world. In India, rice crop is attacked by approximately 100 insect pests and out of which 20 are considered to be major pests causing up to 30% yield loss from seedling to dough stage (Atwal and Dhaliwal, 2005; Dhaliwal et al., 2010). Amongst these, which, rice stem borers are a key group of insect pests damaging rice (Dhaliwal and Arora, 1996). White stem borer (WSB) *Scirpophaga fusciflua* (Hampson) is of increasing significance in rice though its dominance has not been consistent and widespread. But, in certain pockets such as the state of Kerala in southern India and Himachal Pradesh in the northern hills, it is continuously present (Katti et al., 2011). *Scirpophaga fusciflua* infestation has been found in most of the areas of Himachal Pradesh (Srivastava et al., 2012). Rice is major cereal crop and grown in 70 % of the total cultivated area of Himachal Pradesh. Yield loss estimate across India varied from 11.2 to 40.1% due to deadhearts and 27.6 to 71.7% due to white ears, respectively (Krishnaiah and Varma, 2012). In Himachal Pradesh, work on assessment of yield losses in rice due to WSB has not been done, and hence the present study.

MATERIALS AND METHODS

The field experiments were conducted in randomized block design at the Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya Rice and Wheat Research Centre, Malan (32°07.180 N, 76° 25.065 E, 961 masl), during kharif 2016 and 2017. The area represents the mid hills sub-humid zone of Himachal Pradesh. Varying levels of pest damage were created through the artificial release of larvae. The whole experimental area (400 m^2) was divided into four equal plots (100 m^2) marked as T_1, T_2, T_3 and control (T4). Four rice hills were selected and marked by bamboo sticks and these served as one replication, like these there were nine replications. These hills were covered with nylon net supported with four bamboo sticks at the corners. Pretreatment observations were made on the total and infested number of tillers. The treatments with artificially infestation were made at tillering stage by releasing 2, 4 and 6 larvae/ hill and thereafter observations made on 42 and 72 days after transplanting (DAT). The panicles from these were harvested at maturity for recording yield data. These panicles were threshed, cleaned and weighed. The avoidable yield losses were calculated using the formula given by Atwal and Singh (1990). The data on % infestation and yield losses were subjected to analysis with factorial randomized block design using the software CPCS-1 as per procedure suggested by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

The data revealed that deadhearts and white ears incidence varied significantly amongst all release levels during both the cropping seasons. During 2016, the deadhearts and white ears incidence varied from 6.7 to 12.1% and 5.8 to 10.8%, respectively. Similar results were observed during 2017. The pooled means indicate that the maximum incidence was 11.6% at the release

Table 1. Infestation, yield and % avoidable losses with various release levels of *S. fusciflua* larvae in rice

No. of larvae released/ hill	Infestation (%) 2016 42 DAT	72 DAT	Mean	2017 42 DAT	72 DAT	Mean	Over all mean	Yield and avoidable losses 2016 Yield (g/ hill)	Avoidable losses (%)	2017 Yield (g/ hill)	Avoidable losses (%)
0	0.0 (1.00)	0.0 (1.00)	0.0 (1.00)	0.0 (1.00)	0.0 (1.00)	0.0 (1.00)	0.0 (1.00)	16.7 (4.15)	-	16.5 (4.13)	-
2	6.7 (2.68)	5.8 (2.50)	6.3 (2.60)	6.4 (2.62)	5.9 (2.54)	6.2 (2.58)	6.2 (2.59)	15.5 (4.00)	7.5	15.3 (3.97)	7.8
4	9.6 (3.17)	8.0 (2.92)	8.8 (3.05)	9.8 (3.20)	8.2 (2.94)	8.9 (3.07)	8.8 (3.06)	13.5 (3.75)	19.0	13.4 (3.72)	19.3
6	12.1 (3.55)	10.7 (3.35)	11.5 (3.45)	12.4 (3.58)	11.2 (3.43)	11.8 (3.50)	11.6 (3.48)	11.3 (3.44)	32.3	11.5 (3.46)	30.5
Mean	7.1 (2.75)	6.1 (2.57)	6.6 (2.66)	7.1 (2.76)	6.3 (2.61)	6.7 (2.69)		14.3 (3.84)	-	14.2 (3.83)	-
CD (p=0.05)											
Years (A)			: NS	A×B	: NS			Release levels (A)		: 0.68	
Days after transplanting (B)			: 0.03	A×C	: 0.07			Years (B)		: 0.48	
Released levels (C)			: 0.05	B×C	: NS			A×B		: 0.96	
				A×B×C	: NS						

Figures in parentheses square root transformed values; DAT: Days after transplanting

level of 6 larvae/ hill as against 6.2% as the least at 2 larvae/ hill; infestation was non-significant during 2016-2017. The interaction between release levels of white stem borer larvae and cropping seasons revealed that no infestation was observed at pest free level. Table 1 reveals that grain yield showed decreasing trend with increasing release levels during 2016; being the least with level of 6 larvae/ hill (11.3 g hill^{-1}) where plant infestation was 11.5% followed by 4 and 2 larvae/ hill, respectively; maximum yield (16.7 g hill^{-1}) was obtained in the treatment with no incidence. During 2017, similar trend was observed with maximum (16.5 g hill^{-1}) and least (11.5 g hill^{-1}) being at release levels 0 and 6 larvae/ hill, respectively, and the infestations were 11.8% at 6 larvae/ hill. Grain yield decreased gradually with increasing white stem borer infestation but a drastic decrease in yield was observed with increase in release levels > 2 larvae/ hill. The linear regression equation worked out between grain yield and release levels of larvae presented in Fig. 1 (pooled data) reveal that a unit increase in resulted in reduction in yield to the extent of 0.985, 0.993 and 0.99 g hill^{-1}. These results agree with those of Daryaei (2005) who revealed that at 5, 15, 30 and 60 % infestation the grain yield resulted with 5287, 4953, 4656 and 4440 kg ha^{-1} at vegetative stage and 5095, 4628, 3643 and 3155 kg ha^{-1} at panicle initiation stage. Muralidharan and Pasalu (2005) also observed that 1% deadheart or white ears infestation leads to 2.5, 4.0 and 6.4% yield loss, respectively. Islam and Karim (1997) revealed that grain yield at 1-10, 11-15, 16-20, 21-30 and 30% white ears infestation recorded 15.9, 16.2, 12.9, 10.5 and 5.2 g hill^{-1}, respectively.

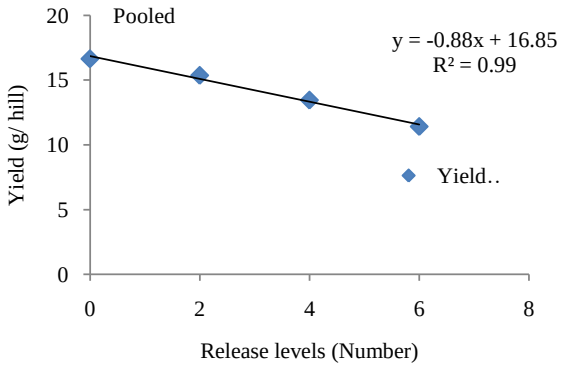

Fig. 1. Linear regression- yield vs. release levels of *S. fusciflua*

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EVALUATION OF COLOURED FRUIT FLY TRAPS IN GUAVA

Neerja Agrawal* and Neelam Yadav

Department of Entomology, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur 208002, Uttar Pradesh, India
*Email: aneeeja14@gmail.com (Corresponding author)

ABSTRACT

A field experiment was carried out in guava orchards located at Chandra Shekhar Azad University of Agriculture and Technology, Kanpur (U.P.) during December- May, 2017-18 and 2018-19. Four coloured traps i.e. green, yellow, transparent and Rakshak traps, placed at three locations for fruit fly *Bactrocera* spp., catches. Methyl eugenol was used as an attractant. The indigenously made green- and yellow-coloured vertical traps were the best as compared to transparent and Rakshak trap. Four fruit flies viz. *Bactrocera zonata* (Saunders), *B. dorsalis* (Hendel), *B. nigrotibialis* (Perkins) and *B. correcta* (Bezzi) were recorded, of which the *B. zonata* was found as dominant.

Key words: *Bactrocera* spp., *B. zonata*, *B. dorsalis*, *B. nigrotibialis*, *B. correcta*, guava, traps, green, yellow, transparent, vertical, Rakshak trap, methyl eugenol, trap catches

True fruit flies are serious pests of fruit crops (Verghese et al., 2004), and India is included in the list of those countries from where the import of fruits to many countries has been banned. Of the fruit flies, only adults are exposed to control measures while eggs and maggots remain protected in the host tissues, with most insecticidal treatments remaining ineffective (Sharma et al., 2011). Insecticides afflict many hazards warranting an integrated approach for fruit fly management (Verghese et al., 2012). Use of methyl eugenol traps and cue lure provide an ecofriendly alternative. Methyl eugenol, when used together with insecticide impregnated into a suitable substrate, forms the basis of male annihilation technique. Methyl eugenol specially attracts the males of *Bactrocera dorsalis* (Hendel), *B. correcta* (Bezzi) and *B. zonata* (Saunders) (Verghese et al., 2006), while cue lure attracts *B. cucurbitae* (Coquillet), *B. correcta, B. zonata* and *B. diversa* (Coquillet) etc. The sanitation combined with the use of lures and traps as well as baits proved to be one of the best alternatives for management of fruit flies. These traps have high efficiency, low cost and are environmentally quite safe (Sureshbabu and Virakthamath, 2003). Thus, keeping in view the economic importance of fruit flies on fruit crops, the present study evaluated with trap catches, the efficacy of locally made, low cost fruit fly traps in guava, in particular their colour.

MATERIALS AND METHODS

This experiment was conducted at the C S A University of Agriculture and Technology, Kanpur, during December 2017-18 and 2018-19. The traps used were made from waste plastic 2 l bottles painted with green, yellow and transparent with three windows. To make the solution 150 ml of alcohol, 100 ml of methyl eugenol and 25 ml of malathion (50EC) was mixed in a beaker and kept in a bottle covered with a lid. For Rakshak traps, 4 ml of mixture was taken with a disposable syringe of 5 ml capacity and injected in the wick already hung in the trap. The charging of wick and wooden pieces was done after one month. Traps were hung at a height of 1.5 -2.0 m at each location. In guava, green, yellow, transparent and Rakshak traps were hung in four replications on the trees at a distance of 50 m. The fruit flies from all three places were collected separately at weekly intervals and identified to species using keys given by Ramani (1997), with studying under stereozoom microscope. The total number of fruit flies trapped in 3 places/ trap/ week was calculated, and subjected to ANOVA (p=0.05) and CD was computed.

RESULTS AND DISCUSSION

The major fruit fly species in the study areas in Kanpur region came out to be *B. zonata* which outnumbered all the other three species viz. *B. dorsalis*, *B. nigrotibialis* (Perkins) *and B. correcta*. It was observed that females tend to be more attracted to colour, with green coloured traps attracting more males as compared to yellow traps (Table 1). The present research elaborate the study conducted by Robacker (1992) who found that for Mexican fruit fly *Anastrepha ludens* (Loew), horizontal, rectangular traps were less attractive than spheres and vertical rectangles. Overall vertical rectangles were more attractive than spheres in spring but in autumn it was vice-versa. Rajita and Viraktamath (2005) reported that in mango orchard,

Table 1. Effect of colour of traps on fruit fly catches 2017- 2019

Treatments	Mean number of catches																					
	Insectary orchard							Horticulture orchard								Home science orchard						
	Dec. 17	Jan 18	Feb 18	Mar 18	Apr 18	May 18	Dec. 17	Jan 18	Feb 18	Mar 18	Apr 18	May 18	Dec.17	Jan 18	Feb 18	Mar 18	Apr 18	May 18	Dec.17	Jan 18	Feb 18	Mar 18	Apr 18	May 18
	Dec 18	Jan 19	Feb 19	Mar 19	Apr 19	May 19	Dec 18	Jan 19	Feb 19	Mar 19	Apr 19	May 19	Dec 18	Jan 19	Feb 19	Mar 19	Apr 19	May 19	Dec 18	Jan 19	Feb 19	Mar 19	Apr 19	May 19
	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
Green trap	42.87	51.75	43.25	47.25	63.25	58.75	42.50	47.50	51.75	53.75	71.87	62.25	45.25	46.25	51.87	50.62	71.87	50.12						
Yellow trap	37.12	34.75	36.25	45.0	61.75	47.25	42.00	45.50	41.62	44.50	56.87	43.37	39.37	37.87	39.75	47.25	72.75	52.00						
Transparent trap	36.37	41.00	34.87	39.37	62.0	51.37	47.25	45.25	41.12	40.12	54.6	47.12	38.25	37.00	41.87	42.50	61.00	41.62						
Rakshak trap	34.25	37.37	31.25	33.37	49.62	42.37	31.50	35.75	32.75	33.75	53.25	41.12	35.37	32.12	40.87	40.00	54.62	41.37						
SEm	2.06	2.29	2.01	2.18	3.06	4.88	1.71	1.94	1.48	2.20	5.62	4.30	2.62	3.34	1.84	1.99	5.83	4.15						
CD (p=0.05)	11.05	11.41	9.16	10.26	16.8	27.65	8.31	10.21	7.03	11.32	26.02	21.79	13.65	18.70	8.94	10.14	30.36	21.89						

medium and big traps attracted significantly more flies. Contrary to present results, fruit flies showed greater response to spheres than to the bottles and cylinders. *Bactrocera dorsalis* was more attracted to green and big spheres while yellow and transparent traps attracted significantly more of *B. correcta* in guava and mango. Irrespective of species, yellow colour traps were attractive in guava while black colour traps in mango. According to Saputra and Marmaini (2016) only *B. dorsalis* was trapped in yellow colour baited traps with methyl eugenol, followed by the green coloured ones. Toorani and Abbasipour (2017) reported that fluorescent yellow traps at a height of 1.5 and 2 cm in south direction during October captured more of Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann). Thus, the results of the present study will assist in knowing the low-cost preparation of traps. The indigenous coloured traps can help in formulating cheap and effective IPM technology.

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EVALUATION OF INSECT GROWTH REGULATORS AGAINST LEAFHOPPERS AND WHITEFLIES IN BT COTTON

Bhagyashri Kamble*, Bhalkare S K, Poonam Deshmukh and Undirwade D B

Department of Entomology,
Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola 444104, Maharashtra, India
*Email: kambleshree38@gmail.com (corresponding author)

ABSTRACT

Studies were conducted to evaluate efficacy of insect growth regulators against leafhoppers *Amrasca (Sundapteryx) biguttula,* and whiteflies *Bemisia tabaci* (Gennadius) on cotton at the Department of Entomology, Dr. PDKV, Akola during 2019-2020. Overall four sprays were given out and the data obtained revealed that buprofezin 25%SC was found promising against leafhopper population. However, this treatment was found statistically similar to pyriproxyfen 10%EC and buprofezin 25%SC + NSKE 5%. The application of pyriproxyfen 10%EC, pyriproxyfen 10%EC + NSKE 5% and buprofezin 25%SC proved statistically equal in reducing whiteflies population. The treatments were found to be safe to the natural enemy activity. The highest seed cotton yield was obtained in the plots sprayed with buprofezin 25%SC (13.40 q/ha).

Key words: Cotton, *Amrasca (sundapteryx) biguttula*, *Bemisia tabaci*, insect growth regulators, lady bird beetle, chrysopids, natural enemies

Among the various causes of low productivity in *Bt* cotton, the incidence of insect pests is of major concern. For last few decades boll worms attack on cotton was a serious problem but with the introduction of Bt cotton this problem has been solved to some extent and a significant change in cropping scheme in the cotton growing areas has been observed (Ahsan and Altaf, 2009). But the problem of sucking pests has remained unsolved still. The pests of major significance in Bt cotton are the leafhoppers *Amrasca (Sundapteryx) biguttula* (Ishida) and whiteflies *Bemisia tabaci* (Gennadius). These still make the cotton IPM rely on insecticides, which aggravate problems due to failures in many cotton growing tracts of India. The indiscriminate use of insecticides has led to problems like insecticides resistance, pest resurgence and environmental pollution besides upsetting the natural ecosystem. Contrary to the problems associated with the use of insecticides, the advantages of insect growth regulators (IGR's) make them highly desirable in IPM, as these do not persist due to their rapid biodegradation. In addition, they exhibit low toxicity for non-target organisms (Zibaee et al., 2011). Buprofezin is an IGR that inhibits chitin synthesis in several homopteran pests, including whiteflies (De Cock et al., 1990). Pyriproxyfen is a juvenile hormone mimic affecting the hormonal balance in insects and resulting in strong suppression of embryogenesis and adult formation (Ishaaya and Horowitz, 1992). The unique mode of action of these compounds, together with their selectivity against target insect pests and relative safety to beneficial insects and other organisms, presents an opportunity for their effective integration in IPM strategies. These minimize the threat of insecticides resistance (Denholm et al., 1998). Keeping these in view, the present study evaluates some IGRs along with insecticides against *A (S.) biguttula* and *B. tabaci* in Bt cotton.

MATERIALS AND METHODS

Field experiment was conducted in the field of Department of Agricultural Entomology, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola during kharif 2019-20. The experiment was laid out in randomized block design with three replications and eight treatments. The Bt cotton (Ajeet-155 BG II) was sown on 3rd July 2019 by dibbling with spacing 90 x 60 cm. The treatments included viz., buprofezin 25%SC, pyriproxyfen 10%EC, diflubenzuron 25%WP, NSKE 5%, buprofezin 25%SC+ NSKE 5%, pyriproxyfen 10%EC+ NSKE 5% and diflubenzuron 25%WP+ NSKE%. The data were collected on the incidence of *A (S.) biguttula* and *B. tabaci* at an interval of 3, 7 and 14 days after each spraying. Similarly, data were also collected on the natural enemies, along with seed cotton yield at harvest.

Table 1. Effect of IGR's on cotton pests and natural enemies

Sl. No.	Treatments and concentration	No. of leafhoppers/ leaf				Mean	No. of whiteflies/ leaf				Mean	Mean counts of predators (No/ plant)			Seed cotton yield (q/ ha)
		1 DBS	3 DAS	7 DAS	14 DAS		1 DBS	3 DAS	7 DAS	14 DAS		LLB	Chry-sopids	Spiders	
1	Buprofezin 25%SC (0.05%)	1.12 (1.06)	0.78 (0.87)	0.82 (0.90)	1.22 (1.10)	0.94 (0.96)	1.28 (1.13)	1.07 (1.00)	1.06 (1.00)	1.84 (1.33)	1.32 (1.11)	1.17 (1.12)	1.00 (0.99)	1.29 (1.13)	13.40
2	Pyriproxyfen 10%EC (0.02%)	1.23 (1.11)	0.91 (0.95)	0.94 (0.96)	1.33 (1.14)	1.06 (1.02)	1.16 (1.08)	0.73 (0.84)	0.79 (0.87)	1.38 (1.16)	0.97 (0.96)	1.12 (1.09)	0.95 (0.97)	1.24 (1.12)	12.39
3	Diflubenzuron 25%WP (0.015%)	1.31 (1.14)	1.87 (1.35)	1.93 (1.38)	2.41 (1.54)	2.07 (1.42)	1.26 (1.12)	2.20 (1.46)	2.26 (1.48)	2.95 (1.70)	2.47 (1.55)	1.02 (1.06)	0.83 (0.90)	1.11 (1.07)	9.77
4	NSKE 5%	1.87 (1.37)	1.19 (1.08)	1.22 (1.09)	1.86 (1.35)	1.42 (1.17)	1.47 (1.21)	1.52 (1.20)	1.51 (1.20)	2.22 (1.47)	1.75 (1.29)	1.35 (1.25)	1.42 (1.18)	1.45 (1.20)	11.09
5	Buprofezin 25%SC (0.05 %) + NSKE (5%)	1.19 (1.09)	1.11 (1.05)	0.94 (0.96)	1.57 (1.24)	1.21 (1.08)	1.53 (1.24)	1.21 (1.08)	1.20 (1.06)	1.87 (1.34)	1.43 (1.16)	1.32 (1.21)	1.39 (1.17)	1.41 (1.19)	11.79
6	Pyriproxyfen 10% EC (0.02 %) + NSKE (5%)	0.96 (0.98)	1.09 (1.04)	1.22 (1.09)	1.72 (1.30)	1.34 (1.14)	1.03 (1.01)	0.88 (0.92)	0.87 (0.91)	1.46 (1.20)	1.07 (1.01)	1.27 (1.10)	1.28 (1.12)	1.39 (1.18)	11.37
7	Diflubenzuron 25% WP (0.015 %) + NSKE (+ 5%)	1.52 (1.23)	1.46 (1.20)	1.58 (1.24)	2.13 (1.45)	1.72 (1.30)	1.18 (1.09)	1.92 (1.36)	1.88 (1.35)	2.61 (1.60)	2.14 (1.44)	1.19 (1.09)	1.14 (1.05)	1.34 (1.16)	10.70
8	Untreated control	1.34 (1.16)	2.23 (1.48)	2.43 (1.54)	2.78 (1.66)	2.48 (1.56)	1.31 (1.14)	2.61 (1.59)	2.68 (1.62)	3.14 (1.75)	2.81 (1.65)	1.48 (1.22)	1.59 (1.25)	1.53 (1.24)	7.12
	SE (m) ±		0.05	0.05	0.06	0.05						0.05	0.07	0.04	0.56
	CD @ 5%		0.17	0.17	0.19	0.18						-	-	-	1.72

Note: Figures in parentheses are corresponding square root transformation, LLB: lady bird beetle, DBS: day before spray, DAS: day after spraying

RESULTS AND DISCUSSION

The data on the efficacy of IGR's on the incidence of *A (S.) biguttula* after four sprays revealed same trend of efficacy at 3, 7 and 14 days after spray; cumulative mean data showed that buprofezin 25%SC led to minimum number of leafhoppers (0.94/ leaf), statistically on par with pyriproxyfen 10%EC (1.06/ leaf) and buprofezin 25%SC+ NSKE 5% (1.21/ leaf). The treatment of pyriproxyfen 10%EC + NSKE 5%, NSKE 5% and diflubenzuron 25%WP + NSKE 5% proved moderately effective, while diflubenzuron 25%WP was found at par with untreated control (2.48/ leaf) (Table 1). The effectiveness of buprofezin against leafhoppers finds support in the research carried out by earlier workers like Kalyan et al. (2017) and Naik et al. (2017). Similar results were also obtained by Halappa and Patil (2014). Ambarish et al. (2017) and Choudhary et al. (2015) reported the effectiveness of pyriproxyfen 10%EC against leafhoppers in cotton.

Against *B. tabaci*, at three days after spray the treatments viz., pyriproxyfen 10%EC, pyriproxyfen 10%EC+ NSKE 5% and buprofezin 25%SC emerged as the most effective; buprofezin 25%SC+ NSKE 5% and NSKE 5% and diflubenzuron 25%WP+ NSKE 5% were the next best; and diflubenzuron 25%WP proved comparatively less effective. At seven and fourteen days after treatment similar trend of efficacy was observed. These results on *B. tabaci* agree with those of earlier workers- Sahito et al. (2015) on pyriproxyfen 10EC against *B. tabaci*; and those of Thumar et al. (2018) and Kumar et al. (2016). Kalyan et al. (2017) reported maximum reduction with buprofezin 25SC. Similar results were also obtained by Das and Isalam (2014) with buprofezin 40SC @ 2 ml/ l against *B. tabaci* on brinjal.

The data on the natural enemies viz; ladybird beetle, chrysopids and spiders obtained at different intervals indicated non-significant differences among the treatments**.** However, numerically a greater number of natural enemies were recorded in untreated control plots. The results revealed that all the treatments were found less detrimental to the predatory fauna. These results are in accordance with those of Gogi et al. (2006) and Naik et al. (2017) that buprofezin appeared safe to predators. Similarly, Ananthi et al. (2017) reported that, the neem seed kernel extract 5% protected the natural enemies like spiders and coccinellids as against imidacloprid spray in chilli ecosystem. As regards yield, buprofezin 25%SC was found to be the most promising treatment with seed cotton yield of 13.40 q/ ha (Table 1); this treatment was found at par with pyriproxyfen 10%EC (12.39 q/ ha) and buprofezin 25%SC + NSKE 5% (11.09 q/ ha). These results find support from those of Nemade et al. (2017) and Kalyan et al. (2017) on seed cotton yield with buprofezin 25SC. However, Choudhary et al. (2015) reported that pyriproxyfen 10EC at different doses proved better than commercial check acetamiprid 20SP @ 20g a.i./ ha and difenthiuron 50WP @ 300g a.i./ ha in harvesting higher yields. Hole et al. (2015) recorded seed cotton yield of 12.31 q/ ha in treatment with NSKE 5%.

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EFFICACY OF INSECTICIDES AGAINST SOYBEAN GIRDLE BEETLE *OBEREOPSIS BREVIS*

S C Bokan*, P R Zanwar and D G More

Department of Agricultural Entomology, Vasantrao Naik Marathwada Krushi Vidyapeeth, Parbhani 431402, Maharashtra, India
*Email: bokansc2@gmail.com (corresponding author)

ABSTRACT

Six insecticides were evaluated against soybean girdle beetle *Obereopsis brevis* Swedenboard during kharif 2017 and 2018. The results revealed that chlorantraniliprole 0.4 GR@40 g a.i./ ha, clothianidin 50 WDG@125 g a.i./ ha and fipronil 0.3 GR@ 50 g a.i./ ha were superior in reducing the incidence and at par with each other. Chlorantraniliprole gave maximum yield followed by clothianidin, fipronil and thiamethoxam 30 FS.

Key words: Soybean, *Obereopsis brevis*, kharif, insecticides, seed/ soil treatment, phorate, chlorantraniliprole, clothianidin, fipronil, thiamethoxam, imidacloprid, yield, foliar spray, replacement

Soybean [*Glycine max* (L.) Merrill] is one of the most important leguminous crops and it is infested by 380 species of insects (Luckman, 1971). In Maharashtra, especially in Marathwada 19 species of insects attack this crop (Munde, 1982) Among them girdle beetle (*Obereopsis brevis* Swedenboard) and stem fly (*Melanagromyza sojae* Zehnter) are important. Ansari and Sharma (2005) observed that incidence of *O.brevis* girdle ranged from 19.5 to 30.72%. In soybean insect pests cause 20 to 25% annual loss in yield (Sharma and Shukla, 1997). Many times insecticides are used and these hampers the activity of parasitoid and predators due to the indiscriminate use (Ansari and Sharma, 2005). Foliar sprays of organophosphorus insecticides in soybean in its early stages are very common in Maharashtra. Foliar sprays of broad-spectrum insecticides in the early crop stage causes pest resurgence in crops (Way and Heong, 1994). The present study evaluates the efficacy of insecticides as seed treatments against *O. brev*is as a possible replacement for foliar sprays.

MATERIALS AND METHODS

The experiment was conducted in randomized block design with seven treatments and three replications. The gross and net plot size were 3.15 x 5.0 and 2.25 x 4.0 m, respectively. JS-335 variety was used at a spacing of 45x 5 cm. Six insecticides were evaluated viz. seed treatments with thiamethoxam 30FS and imidacloprid 48FS were used for treating seeds. Required quantity of soybean seed and insecticides were placed in a polythene bag and mixed thoroughly. The mixture was stirred to obtain uniform coating of insecticides before spread on a paper for drying. Soil application of granular insecticides viz. phorate 10CG, fipronil 0.3GR and chlorantraniliprole 0.4GR were done at the time of sowing, Soil drenching of clothianidin 50 WDG was done at 7-10 days after germination. Observations were made at 30, 45, 60, 75 and 90 days after sowing, with total number of plants and girdled plants counted in a meter row length (5 observations/ plot) and data computed as % infestation. The data (means) obtained were subjected to statistical analysis after square root transformation and analysed as per Gomez and Gomez (1984) using OPSTAT software. When the crop attained maturity, plot wise yield was recorded and converted into kg/ ha before statistical analysis.

RESULTS AND DISCUSSION

Efficacy of insecticides on % incidence by *O. brevis* during kharif 2017 presented in Table 1 reveal that chlorantraniliprole (4.79%), clothianidin (5.34%), fipronil (6.30%), imidacloprid (7.02%) and thiamethoxam (8.04%) gave least values which were at par with each other; with phorate 10CG (8.87%) and control (10.50%) incidence was more. During kharif 2018, chlorantraniliprole (4.14%), clothianidin (4.55%) and fipronil (4.66%) were superior. The pooled data revealed that chlorantraniliprole (4.46%) and clothianidin (4.94%) followed by fipronil (5.48%) and thiamethoxam (6.60%) were the best. Choudhary et al. (2018) reported that soil application

Table 1. Efficacy of insecticides against *O. brevis* (kharif 2017 and 2018)

T. No.	Treatments	Dose (g a.i / ha)	Infestation (%) 2017	2018	Pooled	Grain yield q/ ha Pooled
T-1	Thiamethoxam 30FS	225	8.04 (12.92)*	5.16 (13.06)	6.60 (12.99)	23.42
T-2	Imidacloprid 48FS	75	7.02 (16.96)	6.61 (14.86)	6.81 (15.91)	23.06
T-3	Phorate 10CG	1500	8.87 (14.23)	7.11 (15.33)	7.99 (14.78)	22.40
T-4	Fipronil 0.3GR	50	6.30 (15.62)	4.66 (12.24)	5.48 (13.93)	25.22
T-5	Chlorantraniliprole 0.4GR	40	4.79 (12.72)	4.14 (11.63)	4.46 (12.17)	26.46
T-6	Clothiniadin 50WDG	125	5.34 (13.63)	4.55 (12.26)	4.94 (12.94)	25.93
T-7	Control	-	10.50 (16.54)	8.74 (17.17)	9.62 (16.85)	18.02
	SE±		1.22	0.79	1.00	0.72
	C D (p=0.05)		3.84	2.32	3.08	2.27
	C.V %		14.51	12.81	13.66	

* Figures in parentheses angular transformed values

of chlorantraniliprole and fipronil at planting recorded least early shoot borer infestation in sugarcane as compared to other treatments. The maximum yield of soybean was recorded in chlorantraniliprole (26.46 q/ ha) followed by clothianidin (25.93 q/ ha), fipronil (25.22 q/ ha) and thiamethoxam (23.42 q/ ha). Dhurgude (2010) revealed that the maximum yield was found in thiamethoxam (22q/ ha) followed by phorate (19 q/ ha).

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PREDATING EFFICIENCY OF *CHEILOMENES SEXMACULATA* F. ON BEAN APHID *APHIS CRACCIVORA* KOCH

Rakhshan

Aphid Systematics and Biocontrol Laboratory, University Department of Zoology
T M Bhagalpur University, Bhagalpur 812007, Bihar, India
Email: rakhshankalim@gmail.com

ABSTRACT

***Cheilomenes sexmaculata* F. (Coleoptera: Coccinellidae) is an effective biological control agent against aphids. This study observed its feeding efficiency in the grub stages, and adult male and female during March and April on aphid *Aphis craccivora* Koch in broad bean *Vicia faba*. The first to fourth instar grubs were observed in April to predate on aphids to an extent of 13.2± 0.18, 42.2± 1.98, 61.8± 1.31 and 164.2± 4.94 aphids, respectively). Male and female adults fed on 1011.4± 0.25 and 1201.2± 0.88 aphids, respectively.**

Key words: *Cheilomenes sexmaculata, Aphis craccivora, Vicia faba*, grubs, instars, male, female adults, feeding efficiency, seasonal occurrence

The bean aphid *Aphis craccivora* Koch (Hemiptera: Aphididae) is one of the destructive pests of broad bean *Vicia faba.* Ahmad et al. (2012) observed six species of aphidophagous coccinellids from northeast Bihar. Among these, *Cheilomenes sexmaculata* F. was found abundantly, and is effective as predator of *A. craccivora*. Temperature influences the development, survival, reproduction and predatory efficiency of predators (Asrar et al., 2013). The quality of prey species and host plants influence the predatory efficiency (Shah and Khan, 2014). The present study evaluates the feeding efficiency of the grubs and adults of *C. sexmaculata* on *A. craccivora*.

MATERIALS AND METHODS

The culture of *C. sexmaculata* was established on *A. craccivora* infested host plants in the laboratory, and *A. craccivora* were collected daily with leaves of host plants from field and provided as food. Mating pairs were collected from the stock culture and reared on aphids in a separate beaker (25x 10cm) at room temperature during March and April (24.55± 3.64°C, 28.13± 2.84°C, respectively). Ten such replications were maintained, with blotting paper placed at bottom of beaker and top covered with muslin cloth (Rakhshan and Ahmad, 2015). Predatory efficiency of larval instars and adult beetles were expressed by Mean± SE.

RESULTS AND DISCUSSION

The results revealed significant differences in the feeding efficiency of grubs and adults of *C. sexmaculata;* maximum feeding efficiency of first, second, third and fourth instar grubs were 13.2± 0.58, 42.2± 1.98, 67.8± 1.31 and 164.2± 4.94 aphids, respectively, during April (28.13± 2.84ºC); these values were less (11.8± 0.48, 39.6± 1.91, 62.8± 1.82, and 132.8±3.82 during March (24.55± 3.64ºC). The fourth instar grub was observed to be highly voracious, Asrar et al. (2013) reported significant effect of temperatures on feeding efficiency of *C. sexmaculata* on *Schizaphis graminum*. Chakrabarti et al. (1988) observed such variations in the predatory potential of *Harmonia dimidiata* F., feeding on woolly apple aphid *Eriosoma lanigerum*. Easwaramoorthy et al. (1998) evaluated the feeding potential of *C. sexmaculata* grubs on aphids in sugarcane. Rakhshan and Ahmad (2015) observed feeding by *C. sexmaculata* on *A. craccivora* on *Phaseolus sinensis* at different temperatures and found variations. Newly emerged adults consumed less number of *A. craccivora*, but reached 1011.4± 0.25 and 1201.2± 0.88 aphids later (during April-(28.13± 2.84ºC, with female and male, respectively; it was 1091.9± 0.30 and 812.4± 0.25 during March- 24.55± 3.64ºC). Gillani et al. (2007) observed such variations with *H. dimidiata;* also, Yu et al. (2013) on *Aphis gossypii,* observed variations with male and female.

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EFFICACY OF INSECTICIDES AGAINST SORGHUM SPOTTED STEM BORER *CHILO PARTELLUS* (SWINHOE)

N Kamakshi*, A S R Sarma and C V Chandra Mohan Reddy

Regional Agricultural Research Station, Nandyal, 518502, Andhra Pradesh, India
*Email: kamakshinaren@gmail.com (corresponding author)

ABSTRACT

Efficacy of insecticides against spotted stem borer *Chilo partellus* (swinhoe) in sorghum was studied at the institutional farm, Regional Agricultural Research Station, Nandyal, Andhra Pradesh during rabi 2016-17 and 2017-18. Deadhearts were observed to be less with spinosad (4.0%) followed by carbofuran 3G (4.10%), chlorantraniliprole 18.5SC (4.95) and chlorantraniliprole 0.4G (4.86) applied at 25 days after sowing. The least infestation at 40 days after sowing was observed with chlorantraniliprole 18.5SC (6.2%), spinosad 45SC (7.0%), chlorantraniliprole 0.4G (7.3%) and carbofuran 3G @ 10 kg/ ha (8.0%). Lesser number of larvae in the stem tunnel were observed with chlorantraniliprole 18.5SC/ 0.4G, spinosad, carbofuran 3G, phorate 10G and flubendiamide. The incremental benefit cost ratio was maximum with carbofuran 3G (5.2:1), followed by chlorantraniliprole 0.4G (4.8:1) and chlorantraniliprole 18.5SC (4.2:1).

Key words: *Chilo partellus*, chlorantraniliprole, sorghum, tunnel damage, deadhearts, exit holes, carbofuran 3G, spinosad, leaf injury scale

Sorghum is the fifth most important cereal crop cultivated for food, feed and fodder in dry lands of India over 5.024 million ha (2017-18) with productivity of 956 kg/ ha (www. statistics.com). Sorghum is damaged by >150 insect species, of which the shoot fly, stem borer, grain midge, and a complex of earhead pests are the major ones. The spotted stem borer *Chilo partellus* is the most important pest worldwide (Jotwani and Young, 1971; Sharma, 1993). Larvae of *C. partellus* after hatching, enter in to the stem and feeds on the pith resulting in deadhearts initially; and with further attack the lower nodes are damaged making tunnels resulting in ill filled grains and chaffy earheads. Yield losses of 28% had been reported by this pest alone (Sharma and Gautam, 2010). This being an internal borer, it is difficult to control with single spray. Carbamate and organophosphate insecticides which are presently recommended against this are highly toxic to natural enemies and to the environment. The present study evaluates some novel insecticides including new generation granular formulations and spray fluids against this pest.

MATERIALS AND METHODS

The field trial was conducted during rabi 2016-17 and 2017-18 at the Regional Agricultural Research Station, Nandyal, Andhra Pradesh. Sorghum variety NTJ 5 was sown with spacing of 45x 15 cm in randomized block design in three replications with ten treatments including untreated control (Table 1). Insecticides evaluated were acephate 75SP, thiodicarb 75WP, spinosad 45SC, flubendiamide 48SC, chlorantraniliprole 18.5SC, profenophos 50EC, carbofuran 3G, chlorantraniliprole 0.4G, and phorate 10G. The treatments were done as per the standard protocol. The first application was given at 25 days after sowing (DAS) and the second at 15 days after the first spray. At 25 DAS, deadhearts were counted on whole plot basis and leaf injury scale was observed on twenty randomly selected plants following the visual rating scale of 1 to 9 given by Tefera et al. (2013) and Lavakumar Reddy et al. (2003). These data were obtained at pretreatment, seven and fourteen days after the treatment. After pretreatment data, deadhearts were removed and occurrence of fresh ones was observed at seven and fourteen days after treatment. Second spray was given at 15 days after the first spray i.e., at 40 days after sowing, and the % infestation (based on exit holes) were observed at pretreatment, seven and fourteen days after second spray. Number of larvae in the stem and damaged tunnel length were also observed by destructive sampling of ten randomly selected plants at 14 days after the second spray. Grain was harvested/ plot and the yield expressed as kg/ ha. The data obtained were subjected to statistical analysis for ANOVA and least significance difference (LSD).

RESULTS AND DISCUSSION

The pooled data of 2016-17 and 2017-18 revealed

Table 1. Efficacy of insecticides against *C. partellus* (2016-17, 2017-18)

Tr. No.	Insecticide	Dose g or ml/ ha	Deadhearts (%)			Leaf damage scoring			Infestation (%)			Larvae/ stem tunnel (No.) *	Damaged tunnel length (cm)*	Exit holes (No.)
			Pre treatment	7 DAT**	14 DAT**	Pre treatment	7 DAT	14 DAT	Pre-Treatment	7 DAT**	14 DAT**			
T1	Acephate 75SP	750 g	6.95	3.81 (11.26)[a]	5.62 (13.71)[c]	2.7	4.0	4.0	10.5	14.4 (22.30)[c]	15.6 (23.26)[c]	2.37 (1.84)[b]	26.48 (5.24)[a]	3.8
T2	Thiodicarb 75WP	750 g	8.36	4.74 (12.57)[b]	8.18 (16.62)[e]	3.3	4.3	3.7	9.4	14.5 (22.38)[c]	16.2 (23.73)[c]	2.01 (1.73)[b]	30.22 (5.59)[b]	3.1
T3	Spinosad 45SC	175 ml	6.85	3.43 (10.67)[a]	4.00 (11.54)[a]	3.7	3.7	2.0	6.0	6.5 (14.77)[a]	7.0 (15.34)[a]	1.42 (1.56)[a]	21.63 (4.76)[a]	1.9
T4	Flubendiamide 48SC	100 ml	7.34	2.66 (9.39)[a]	6.78 (15.09)[d]	3.3	4.3	3.3	8.2	11.2 (19.55)[b]	11.6 (19.91)[b]	1.78 (1.67)[a]	22.78 (4.88)[a]	2.8
T5	Chlorantraniliprole 18.5SC	150 ml	8.18	4.67 (12.48)[b]	4.95 (12.86)[b]	3.3	3.7	1.7	5.0	5.8 (13.94)[a]	6.2 (14.42)[a]	1.39 (1.55)[a]	18.11 (4.37)[a]	1.8
T6	Profenophos 50EC	1000 ml	6.35	3.09 (10.12)[a]	8.59 (17.04)[e]	3.0	4.3	4.0	12.0	13.6 (21.64)[c]	14.5 (22.38)[c]	2.25 (1.80)[b]	27.91 (5.38)[a]	4.3
T7	Carbofuran 3G	10 kg	5.45	4.02 (11.57)[a]	4.10 (11.68)[a]	3.7	4.7	2.7	5.5	7.2 (15.56)[a]	8.0 (16.43)[a]	1.56 (1.60)[a]	20.28 (4.61)[a]	2.6
T8	Chlorantraniliprole 0.4G	10 kg	6.73	4.09 (11.67)[b]	4.86 (12.74)[b]	3.7	4.0	2.0	5.2	6.3 (14.54)[a]	7.3 (15.68)[a]	1.41 (1.55)[a]	23.30 (4.93)[a]	2.3
T9	Phorate 10G	12.5 kg	8.90	4.61 (12.40)[b]	6.72 (15.02)[d]	4.3	4.3	3.0	7.0	10.4 (18.81)[b]	10.4 (18.81)[b]	1.65 (1.63)[a]	20.73 (4.66)[a]	3.3
T10	Control		6.14	8.55 (17.00)[c]	11.08 (19.44)[f]	4.0	4.7	6.7	15.6	25.6 (30.40)[d]	34.5 (35.97)[d]	4.28 (2.30)[b]	34.54 (5.96)[b]	5.8
	CD (p=0.05)		NS	2.25	0.88					2.01	2.17	0.27	1.15	
	CV(%)		10.6	11. 9	8.95					7.28	8.01	9.6	10.2	

**Fgures in parentheses angular transformed values; *figures in parentheses square root transformed values; DAT- Days after treatment

that all the parameters like deadhearts, visual leaf injury score, plant infestation, number of larvae inside the stem and damaged tunnel length were significantly affected by the treatments. All the treatments were superior over untreated control. Deadhearts at pretreatment ranged from 5.5 to 8.9 without any significant differences among the treatments. At seven days after treatment, significantly less % deadhearts were observed with flubendiamide 48SC (2.66%), chlorantraniliprole 18.5SC (3.09), spinosad 45SC (3.43) against a maximum of 8.55 in untreated control. At 14 days after the spray spinosad was the best with 4.0% deadhearts followed by carbofuran 3G (4.10%), chlorantraniliprole 0.4G (4.86) and chlorantraniliprole 18.5SC (4.95). Lowest leaf injury score of 3.7 was observed with spinosad and chlorantraniliprole 18.5SC at seven days and score of 1.7 was in chlorantraniliprole 18.5SC at 14 days after treatment. The *C. partellus* infested plants were the least with chlorantraniliprole 18.5SC (5.8, 6.2%), chlorantraniliprole 0.4G (6.3, 7.3%), spinosad 45SC (6.5, 7.0%) and carbofuran 3G @ 10 kg/ha (7.2 and 8.0%) at seven and fourteen days after the treatment, respectively. Number of larvae inside the tunnel were less in chlorantraniliprole 18.5 SC (1.39), chlorantraniliprole 0.4G (1.41), spinosad (1.42), carbofuran 3G (1.56), phorate 10 G (1.65) and flubendiamide (1.78) at 14 days after the treatment (Table 1).

These findings are in agreement with those of Jawala Jindal et al. (2017) that significantly low leaf injury was in chlorantriniliprole 18.5SC over broad spectrum conventional insecticides in maize. The efficacy of chlorantraniliprole 0.4G against *C. partellus* in maize in terms of reduction in deadhearts combined with high grain yield in maize was observed by Ashwinder et al. (2018) and Arunkumara et al. (2017). Less stem tunnel damage was observed with chlorantraniliprole 18.5SC followed by carbofuran 3G (20.28) which was significantly superior. These results corroborate with those of Ramkumar and Tanweer Alam (2017) on the efficacy of chlorantraniliprole and carbofuran in maize. Bamaiyi and Joan (2011) observed that the tunnel damage was relatively less in carbofuran 3G treated plots as observed now. The exit holes caused by the adult emergence were less in chlorantraniliprole 18.5SC (1.8) followed by spinosad (1.9) and chlorantraniliprole 0.4G (2.3) Ramkumar and Tanweer Alam (2017). Khan et al. (2020a, b) proved the effectiveness of carbofuran 3G in reducing plant damage, deadhearts and larvae/ plant in maize. The gross yield varied from 4053 kg/ ha in untreated control as aginst 5236 kg/ ha with chlorantraniliprole 0.4G. The incremental benefit cost ratio was maximum with carbofuran 3G (5.2), followed by chlorantraniliprole 0.4 G (4.8) and chlorantraniliprole 18.5 SC (4.2). Singh et al. (2014) and Kumar et al. (2017) observed that the maximum cost benefit ratio was obtained with carbofuran 3G (Fig. 1).

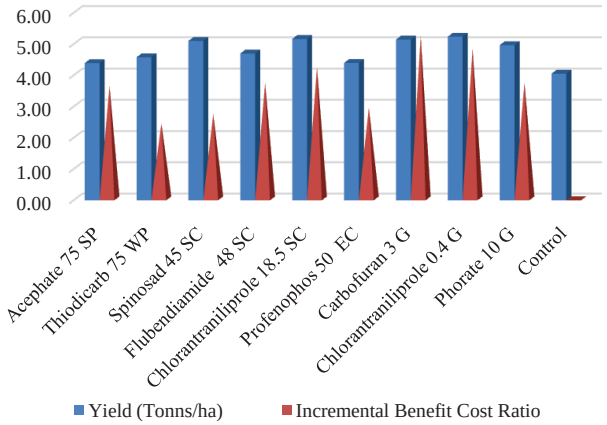

Fig 1. Effect of insecticides on yield and economics in sorghum

Thus, it is concluded that chlorantraniliprole 18.5SC, spinosad 45SC, chlorantraniliprole 0.4G and carbofuran 3G are effective against *C. partellus* in sorghum with higher yields and incremental benefit cost ratio.

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EFFICACY OF ESSENTIAL OILS AGAINST THREE STORED PRODUCT COLEOPTERA IN WHEAT STORED IN SUPERBAGS

Ranjeet Kumar*, Purnvarath S Pandey[1] and Ravindra Kumar Sohane[2]

Department of Entomology, Veer Kunwar Singh College of Agriculture, Dumraon, Buxar Bihar Agricultural University, Sabour, Bhagalpur 813210, Bihar, India
[1]Education Planning and Home Science Division, ICAR, KAB II, New Delhi 110012, India
[2]Bihar Agricultural University, Sabour, Bhagalpur 813210, Bihar, India
*Email: rkipm06@gamil.com (Corresponding author)

ABSTRACT

This study evaluates the efficacy of essential oils against *Sitophilus oryzae* (L.), *Rhyzopertha dominica* L. and *Tribolium castaneum* Herbst in wheat stored in superbags under laboratory condition. The results reveal that the essential oil of *Chenopodium botrys, Citrus reticulata, Lantana camara,* and *Pinus roxburghii* at 0.4% alone or in combination of *C. botrys*+ *C. reticulata, C. reticulata*+ *P. roxburghii, L. camara*+ *P. roxburghii, C. botrys*+ *P. roxburghii* at 0.2% each completely check the feeding and breeding of these pests. The essential oil of *C. botrys, C.reticulata, L.camara,* and *P. roxburghii* at 0.4% either alone or in combination (as above) at 0.2% check the infestation and weight loss, up to twelve months of storage.

Key words: Essential oils, *Chenopodium botrys, Citrus reticulata, Lantana camara, Pinus roxburghii,* alone or combination, wheat, superbags, storage, *Sitophilus oryzae, Rhyzopertha dominica, Tribolium castaneum,* fumigant toxicity

Sitophilus oryzae (L.) (Coleoptera: Curculionidae), *Rhyzopertha dominica* L. (Coleoptera: Bostrichidae) and *Tribolium castaneum* Herbst (Coleoptera: Tenebrionidae) are important pests of stored wheat. These insects spoil food and food security, thus, depends not only on primary agricultural production but sufficient post-harvest storage. It is essential to search the alternatives for traditional chemical fumigants, by exploring essential oils from plants like *Chenopodium botrys, Citrus reticulata, Lantana camara, Pinus roxburghii.* To deploy these in protecting stored wheat, their fumigant and contact toxicity, ovicidal activity, mortality and repellent activity need to be explored (Kumar et al., 2020; Rajendran et al., 2008; Tripathi et al., 2002). The superbags is a special type of polythene bag widely used for the storing the grain and seeds. These provide more airtight condition as compared to ordinary plastic bags. The storage of wheat in these, especially the effect of the essential oils from plants has been poorly studied. In the present experiment, attempt has been made to evaluate the efficacy of essential oils against three stored product beetles in wheat stored in superbags.

MATERIALS AND METHODS

The experiments were conducted at the Department of Entomology, Veer Kunwar Singh College of Agriculture, Dumraon, Buxar (Bihar Agricultural University, Sabour) during 2019-2020. Pure culture of *S. oryzae, R. dominica,* and *T.castaneum* were developed in the BOD incubator (27°C± 1; 70± 5% RH) in plastic jars of 1 kg capacity. These jars were having a lid with hole of 1.8 cm dia covered with 30 mesh copper wire net, holding grains of wheat variety HD-2967, and its flour fortified with 5% yeast powder (for rearing *T. castaneum*). Before use, grain was disinfested at 60°C for 12 hr in hot air oven. After disinfestations the moisture content of the grain was measured and raised to 13.5% by mixing water in the grains following Pixton (1967). Oils selected for the study were extracted by steam distillation in the laboratory by Clevenger Apparatus. The efficacy of four essential oils *Chenopodium botrys, Citrus reticulata, Lantana camara, Pinus roxburghii* and their combinations was evaluated under controlled conditions same as rearing condition. Thirty kg of wheat variety HD-2967 with moisture content (13.5%) was filled in superbags and 50 pairs of adults (0-7 days old) of *S. oryzae R. dominica* and *T. castaneum* were released in each. After 24 hr of release, required quantity of essential oil soaked on blank mat was inserted in each superbag, closed and sealed with strips. Each treatment was replicated three times. Observations were made after ten months of storage. The homogenous sample of 500 g from

Table 1. Efficacy of essential oils on the storage pests after use in superbags on wheat

S.No.	Essential oils	Con. %	Combi %	After 10 months of storage		After 12 months of storage	
				Adult emerged	% inhibition	Adult emerged	% inhibition
			S. oryzae				
1	*Chenopodium botrys*	0.4		0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
2	*Citrus reticulata*	0.4		0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
3	*Lantana camara*	0.4		0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
4	*Pinus roxburghii*	0.4		0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
5	*Chenopodium botrys+ Citrus reticulata*	0.4	0.2E	0.0 (0.0)	100.00	0.0 (0.0)	100.00
6	*Chenopodium botrys+ Lantana camara*	0.4	0.2E	4.8 (1.6)	72.42	15.0 (2.1)	57.56
7	*Chenopodium botrys+ Pinus roxburghii*	0.4	0.2E	0.0 (0.0)	100.00	0.0 (0.0)	100.00
8	*Citrus reticulate+ Lantana camara*	0.4	0.2E	0.8 (0.6)	96.14	4.7 (1.6)	89.73
9	*Citrus reticulate+ Pinus roxburghii*	0.4	0.2E	0.0 (0.0)	100.00	0.0 (0.0)	100.00
10	*Lantana camara + Pinus roxburghii*	0.4	0.2E	0.0 (0.0)	100.00	0.0 (0.0)	100.00
11	Untreated control			10.7 (1.9)	0.0	28.0 (3.3)	0.0
	S.Em. ±			0.72		0.63	
	CD (p=0.05)			1.88		1.77	
			R. dominica				
1	*Chenopodium botrys*	0.4		0.0 (0.0)	100.00	0.0 (0.0)	100.00
2	*Citrus reticulata*	0.4		0.0 (0.0)	100.00	0.0 (0.0)	100.00
3	*Lantana camara*	0.4		0.0 (0.0)	100.00	0.0 (0.0)	100.00
4	*Pinus roxburghii*	0.4		0.0 (0.0)	100.00	0.0 (0.0)	100.00
5	*Chenopodium botrys+ Citrus reticulata*	0.4	0.2E	0.0 (0.0)	100.00	0.0 (0.0)	100.00
6	*Chenopodium botrys+ Lantana camara*	0.4	0.2E	0.0 (0.0)	100.00	0.0 (0.0)	100.00
7	*Chenopodium botrys+ Pinus roxburghii*	0.4	0.2E	0.0 (0.0)	100.00	0.0 (0.0)	100.00
8	*Citrus reticulate+ Lantana camara*	0.4	0.2E	0.0 (0.0)	100.00	0.0 (0.0)	100.00
9	*Citrus reticulate+ Pinus roxburghii*	0.4	0.2E	0.0 (0.0)	100.00	0.0 (0.0)	100.00
10	*Lantana camara+ Pinus roxburghii*	0.4	0.2E	0.0 (0.0)	100.00	0.0 (0.0)	100.00
11	Untreated control			29.0 (2.7)	0.0	34.0 (2.9)	0.0
	S.Em. ±			0.41		0.46	
	CD (p=0.05)			1.23		1.27	
			T. castaneum				
1	*Chenopodium botrys*	0.4		0.0 (0.0)	100.00	0.0 (0.0)	100.00
2	*Citrus reticulata*	0.4		0.0 (0.0)	100.00	0.0 (0.0)	100.00
3	*Lantana camara*	0.4		0.0 (0.0)	100.00	0.0 (0.0)	100.00
4	*Pinus roxburghii*	0.4		0.0 (0.0)	100.00	0.0 (0.0)	100.00
5	*Chenopodium botrys+ Citrus reticulata*	0.4	0.2E	0.0 (0.0)	100.00	0.0 (0.0)	100.00
6	*Chenopodium botrys+ Lantana camara*	0.4	0.2E	0.0 (0.0)	100.00	0.0 (0.0)	100.00
7	*Chenopodium botrys+ Pinus roxburghii*	0.4	0.2E	0.0 (0.0)	100.00	0.0 (0.0)	100.00
8	*Citrus reticulate+ Lantana camara*	0.4	0.2E	0.0 (0.0)	100.00	0.0 (0.0)	100.00
9	*Citrus reticulate+ Pinus roxburghii*	0.4	0.2E	0.0 (0.0)	100.00	0.0 (0.0)	100.00
10	*Lantana camara+ Pinus roxburghii*	0.4	0.2E	0.0 (0.0)	100.00	0.0 (0.0)	100.00
11	Untreated control			11.8 (2.3)	0.0	12.7 (2.4)	0.0
	S.Em. ±			0.26		0.36	
	CD (p=0.05)			0.77		0.98	

S. No.	Essential oils	Con. %	Combi %	After10 months of storage		After 12 months of storage	
				% Infestation	% Weight loss	% Infestation	% Weight loss
1	*Chenopodium botrys*	0.4		0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
2	*Citrus reticulata*	0.4		0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
3	*Lantana camara*	0.4		0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
4	*Pinus roxburghii*	0.4		0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
5	*Chenopodium botrys+ Citrus reticulata*	0.4	0.2E	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
6	*Chenopodium botrys+ Lantana camara*	0.4	0.2E	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
7	*Chenopodium botrys+ Pinus roxburghii*	0.4	0.2E	0.94 (0.7)	0.6 (0.3)	1.82 (0.8)	0.14 (0.1)
8	*Citrus reticulate+ Lantana camara*	0.4	0.2E	0.83 (0.3)	0.3 (0.1)	0.87 (0.4)	0.25 (0.2)
9	*Citrus reticulate+ Pinus roxburghii*	0.4	0.2E	0.3 (0.1)	0.3 (0.1)	0.04 (0.3)	0.0 (0.0)
10	*Lantana camara+ Pinus roxburghii*	0.4	0.2E	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
11	Untreated control			09.63 (2.8)	0.97 (0.7)	12.78 (2.8)	0.23 (0.4)
	S.Em. ±			0.11	0.38	0.25	0.26
	CD (p=0.05)			0.45	0.96	0.76	0.77

Infestation and weight loss due to infestation of *S. oryzae*, *R.dominica*and *T. castaneum* in wheat stored in superbags
Data in parentheses indicate log (X+1) transformed value; E= Each

each replication was taken for computation of % inhibition, infestation and weight loss. Data obtained were analyzed in completely randomized design after suitable log (1+X) transformation.

RESULTS AND DISCUSSION

The number of adults of *S. oryzae* emerged and % inhibition due to treatment of essential oils in stored wheat in superbags is given in Table 1; these data reveal that the essential oil of *C, botrys, C. reticulata, L. camara,* and *P. roxburghii* at 0.4% either alone or in combination of *C. botrys+ C. reticulata, C. reticulata+ P. roxburghii, L. camara + P. roxburghii C. botrys + P. roxburghii* at 0.2% each completely check the feeding and breeding of *S. oryzae* and inhibit 100.00%, after ten and twelve months of storage. The essential oils of *C. reticulata+ L. camara* were also found highly effective against *S. oryzae* after ten months of storage and this effectiveness slightly declined after 12 months of storage. Similarly, with *R. dominica* the % inhibition was observed with essential oils either alone or in combination with 100.00% inhibition. With *T. castaneum* also similar efficacy could be observed. The data on % infestation and weight loss also similar results (Table 1).

The essential oils of *M. koenigii, C. reticulata, C. citrinus* either alone at 0.2% or two component combinations were found highly effective against *S. oryzae* and *R. dominica* (Kumar et al., 2018). Essential oil of *Artemisia annua* evaluated by Tripathi et al. (2002) against *T. castaneum* and *C. maculatus* revealed adult repellent, and effects on larval or survival and adult emergence of *T. castaneum*. (Tunc et al., 2000) observed fumigant toxicity of essential oil from cumin (*C. cyminum*) against eggs of two *T. confusum* and *E. kuhniella* with 100% mortality. The essential oil of *C. botrys, C. longa, C. reticulata, L. camara, P. roxburghii* at 0.1, 0.2, 0.3, 0.4% were found highly effective against *S. oryzae*. The essential oil of *C. botrys, C. longa, C. reticulata, L. camara, P. roxburghii, C. winerianus, E. globules, C. flexuosus, C. martini* at 0.1, 0.2, 0.3, 0.4% were found highly effective against *R. dominica*. The essential oil of *C. botrys, C. reticulata, L. camara, P. roxburghii* at 0.1, 0.2, 0.3, 0.4 percent were found highly effective against *T. castaneum* as they caused 100% inhibition (Kumar et al., 2021).

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EDIBLE INSECTS USED AS FOOD BY TANGSA AND WANCHO TRIBES OF CHANGLANG DISTRICT, ARUNACHAL PRADESH

Renu Gogoi*, Suraj Chetri and Rezina Ahmed

Department of Zoology, Cotton University, Guwahati 781001, Assam, India
*Email: renugogoi39@gmail.com (corresponding author)

ABSTRACT

In India, entomophagy practices are common among the people who consume insects as ethnic food. In Changlang district of Arunachal Pradesh, the consumption of insects as food is a common practice, with insects consumed as additional food source. The present study revealed that eleven insect species belonging to six orders are accepted as food by the two tribes (Tangsa and Wancho) of the Changlang district, Arunachal Pradesh. *Apis indica, Oecophylla smaragdina* (Hymenoptera) and *Macrotermes* sp. (Isoptera) are the three common edible insects. From the nutritional point of view, these edible insects are rich in protein content. Such insects form a regular part of the diet, whenever available. But the people of the district are not much familiar with their nutrition and market value. This study analyses these so as to inform them, the consumers, about their sustainable use as food and their nutritional importance.

Key words: Arunachal Pradesh, Changlang, Tangsa, Wancho, edible insect, entomophagy, *Apis indica*, *Oecophylla smaragdina*, *Macrotermes* sp., market value, nutrition, protein

People of Tangsa are considered as a Naga tribe of Changlang district and their lifestyle shows they are good cultivators, whereas Wancho tribes are indigenous people and are traditionally governed by a council of elderly chieftains. Both the tribes have chosen entomophagy as a sustainable source of food as it has been used since ancient times, a knowledge which has been passed down from generation to generation through word of mouth. According to Chakravorty et al. (2013) the insects in Arunachal Pradesh are not consumed for their nutritional supplement value but are appreciated for their taste when seasonally available. The present study assesses the protein content of such edible insects available in Changlang district of northeast India. Study on macronutrients composition of insects from different habitats reveal that these are rich in protein, carbohydrate and lipid (Das, 2018). According to Atanu (2017) in India different insects are consumed by ethnic tribes. People of Phek, Dimapur and Kohima District of Nagaland eat grasshoppers, crickets, red ants and larvae of mulberry silk worms. A total of 41 insect species belonging to 8 orders under 24 families and 36 genera are consumed as food in Manipur as reported by Shantibala et al. (2012). In Meghalaya, termites are consumed as a good source of proteins and carbohydrates. In Arunachal Pradesh, the Nyshi and Galo tribes consume at least 81 species of local insects, belonging to 26 families and 5 orders as shown by Chakravorty et al. (2011). Moreover, modern people are more reluctant to hold their traditional way of life, as a result consumption of insects is declining at a sharp rate. It was found that some tribes of Arunachal Pradesh still take pride in including insects as their food source. The present study provides information on edible insects and their nutritional value as protein and used as food by Tangsa and Wancho tribes of Changlang district, Arunachal Pradesh.

MATERIALS AND METHODS

Changlang district is the second largest district in Arunachal Pradesh, India and it is bounded by Lohit district on the south and Tirap district on the north (27.7422ºN, 96.6424ºE). This district is home land of fascinating and interesting tribes such as Tangsa, Singpho, Tutsa, Nocte, Wancho, Lisu, Deori, Chakma and Hajong. These tribals are mainly dependent on agriculture, forest, river and their resources for their livelihood. The insects are naturally collected from fresh water bodies (e.g., ponds and streams), paddy fields, vegetable gardens, soils and farmland, shrubs and trees, grassland and dwellings. Samples of specimens previously determined as edible by the local tribes were collected using aerial net, aquatic net, sweep net, beating sheet and forceps. These specimens were identified with key characters using photographs. A household survey was done with questionnaire having simple questions like type of edible insects, their local names, stage eaten and mode of intake. The local people were also

addressed with questionnaires as to know how the edible insects are harvested, the way they are cleaned, cooked or dried and about the body parts that are / discarded. The ages of the target group interviewed ranges between 30-70 years and included both men and women. Eleven commonly consumed insects were selected for biochemical studies viz., *Apis indica, Samia cynthia ricini, Gryllotalpa* sp., *Okanagana viridis, Oecophylla smaragdina, Brachytrupes* sp., *Heiroglyphus banian, Polistiso* sp., *Lethocerus* sp., *Macrotermes* sp. and *Phyllophagus* sp. (protein estimation). Egg, larvae, pupa and adult of each of the seasonally available edible insects were collected biochemical analysis. After collection these were brought to the laboratory, stored at -20°C, for further biochemical analysis. Total protein content was estimated by Lowry et al. (1951).

RESULTS AND DISCUSSION

Inventory knowledge about the edible insects, their mode of consumption, stages and local name by the Tangsa and Wancho tribes are presented in Table 1. The study concludes that these tribes of Changlang district prefer insects as edible by their availability and appearance. The Tangsa tribe is a community of several tens of thousands of individuals, mainly depended on forest, agriculture and the river for their livelihood and collecting varied plants, animals and insects from forest and river for food. From the selected insects these consume nine species- *Apis indica, Oecophylla smaragdina, Okanagana viridis, Polistiso* sp., *Lethocerus* sp., *Heiroglyphus banian, Gryllotalpa* sp., *Samia cynthia ricini* and *Macrotermes* sp. Mode of consumption of these insects varies according to their life stages- egg, larvae and pupa of order Hymenoptera are eaten after steam boiling by placing the wrapped insect in bamboo leaves beside a fire. Insects of other orders Isoptera, Coleoptera, Orthoptera, Hemiptera and Lepidoptera are preferred roasted and fried with oil after discarding the non-edible parts. Insects belonging to order Hymenoptera and Lepidoptera such as *A. indica* and *S. cynthia ricini* are available throughout the year, are easily reared, domesticated and commonly sold in the market. Termites (*Macrotermes* sp.) are delicious edible insect species with a high fat content. The collection is mainly done during their swarming period as in this period plenty of winged adults emerge out from the soil. Red ants (*Oecophylla smaragdina*) were collected in nest formed directly from the trees, wasps (*Polistis* sp.) also collected in nest formed when available, bugs (*Lethocerus* sp.) were collected while fishing, grasshopper (*Heiroglyphus banian*) and mole cricket (*Gryllotalpa* sp.) were collected from forest field. While, cicada (*Okanagana viridis*) was collected by attracting them using a white sheet and making sounds with the help of bamboo sticks.

The Wancho tribe is indigenous to Arunachal , and they depend on agriculture, hunting and fishing for their livelihood. Large animal, fishes, insect and different plants species are collected as food by them. They preferred six species of edible insects viz., *A. indica, O. smaragdina, H. banian, Brachytrupes* sp., *Phyllophaga* sp., and *Macrotermes* sp. Like the Tangsa tribe, Wancho tribe also prefer the same mode of insect collection and consumption i.e., boiling, roasting and fried the insect with ingredient etc. It was noted now that the insects *Phyllophaga* sp. and *Brachytrupes* sp. were collected

Table 1. Edible insects used by Tangsa and Wancho tribes of Arunachal Pradesh

Scientific name	Order	Common name	Local name (Tangsa)	Local name (Wancho)	Stage eaten	Mode of consumption
Apis indica	Hymenoptera	Honey bee	Yakay	Nakat	Egg, Larvae, Pupa, Adult	Boiled/ Fried with oil
Oecophylla smaragdina	Hymenoptera	Weaver ant	Saisho/ Hahoi	Thajao	Egg, Larvae, Pupa, Adult	Boiled/ Fried with oil
Polistiso sp.	Hymenoptera	Paper wasp	Nyasaa	----	Eggs, Larva, Pupa, Adult	Boiled/ Fried with oil
Macrotermes sp.	Isoptera	Termite	Khunkhi	Ualong	Winged adult	Fried with oil
Okanagana viridis	Hemiptera	Green cicada	Machera	----	Adult	Roasted/ Fried with oil
Lethocerus sp.	Hemiptera	Giant water bug	Kupthak	----	Adult	Roasted/ Fried with oil
Hieroglyphus banian	Orthoptera	Grasshopper	Kupchek	Okuk	Adult	Roasted/ Fried with oil
Gryllotalpa sp.	Orthoptera	Mole cricket	Kuborr	----	Adult	Roasted/ Fried with oil
Brachytrupes sp.	Orthoptera	Cricket	----	Okul	Adult	Roasted/ Fried with oil
Samia cynthia ricini	Lepidoptera	Eri silkworm	Raijung	----	Larvae, pupa	Roasted/ Fried with oil
Phyllophaga sp.	Coleoptera	Beetle	----	Notphong	White grub or adult	Boiled/ Roasted/ Fried with oil

from soil, decaying wood and directly from the field. Also, these two insects are only consumed as fried/ roasted with oil.

Protein is the main building block of life and constitutes many important components in body. From the biochemical analysis the protein content in egg and larvae of weaver ant, paper wasp and honeybee (Hymenoptera) is found to be 6.15± 0.041, 6.43± 0.038 and 8.31± 0.062, white grub of beetle (coleopteran) 6.65± 0.048, larvae of eri silk worm (Lepidoptera) 7.15± 0.053, winged adult of termite (Isoptera) 7.48± 0.057, adult of cicada (Hemiptera) 5.52± 0.034, adult of mole cricket (Orthoptera) 7.2± 0.055, adult grasshopper (Orthoptera) 6.26± 0.071, adult of giant water bug (Hemiptera) 8.19± 0.053 and adult of cricket (Orthoptera) 5.4± 0.031. Of these *A. indica* shows highest protein content and *Brachytrupes* sp. with lowest protein content. The protein content varies in different species which may be due to the different metamorphic stages of the insect, their habitat and diet. The stages eaten as food are mainly egg, larvae and adult of different insect. In order Hymenoptera all the stages egg, larvae, pupas, adult were consumed as food by the two tribes with same mode of consumption i.e., boiled/ fried with oil. Whereas, in case of order Lepidoptera is larvae and pupa, white grub of Coleoptera and adult as edible in both order Orthoptera and Isoptera. Hence, all the collected samples for biochemical test were edible stages. From the analysis it was found that edible insects are rich in protein content and all the selected insects' shows quite similar values; Hymenoptera (8.31mg/ ml) contain high protein followed by Hemiptera (8.19 mg/ ml), Isoptera (7.48 mg/ ml), Orthoptera (7.2 mg/ ml), Lepidoptera (7.15 mg/ ml), and Coleoptera (6.65 mg/ ml). Xiaoming et al. (2009) also reported that edible insect is rich in protein than carbohydrate. While examine 100 insects it was shown that the raw protein content is generally 20-70% at all the edible stages. Also, Ramons- Elorduy et al. (2002) revealed that the protein content range from 75 to 91%.

Similarly, the present study also revealed that protein content is high. Chakravorty et al. (2013) assessed that two common species of Orthoptera has high protein content followed by fat and carbohydrate. Das et al. (2016) showed that the protein content of 13 insects is much higher than other macronutrients. Ghosh et al. (2017) observed that protein content of five commercial edible insects in South Korea is high as compared to fat. Edible insects are a natural renewable resource that provides food to many ethnic groups in Changlang district of Arunachal Pradesh.

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POPULATION DYNAMICS OF CUT WORM *AGROTIS IPSILON* HUFNAGEL ON MAIZE IN KASHMIR

Danishta Aziz*, Sheikh Bilal Ahmed, Munazah Yaqoob, Khursheed Aalum[1], Sheikh Aafreen Rehman and Nahida Anjum

Division of Entomology, SKUAST-Kashmir, Shalimar 190025, J&K, India
[1]Department of Botany, Govt. MVM Bhopal, 462008, Madhya Pradesh, India
*Email: daniaziz9974@gmail.com (corresponding author)

ABSTRACT

The status of cut worm *Agrotis ipsilon* Hufnagel was studied in district Baramulla and its incidence was monitored in maize crop at the field of Faculty of Agriculture, Wadura, SKUAST-Kashmir during 2018. The incidence was observed at weekly intervals and was found to be infesting maize starting from germination to maturity. The results revealed maximum incidence and damage (74.24± 0.89%) at low altitude followed by medium (58.07± 1.87%); while the least was at high altitude (36.27± 0.78%). The larvae started occurring from 20th standard week (SW), reached its peak on 25th SW and then started decreasing from 26th SW. Incidence revealed a positive and significant correlation (r=0.634) with maximum temperature.

Key words: Maize, *Agrotis ipsilon*, north Kashmir, seasonal incidence, host range, status, altitude, weather parameters, correlation, temperature

Maize (*Zea mays* L.) is one of the most important cereal crops, with highest genetic yield potential among cereals (Shiferaw et al., 2011), and thus a miracle crop (Singh et al., 2012). In Kashmir valley, maize is usually cultivated at higher altitude terrains, karewas and plains under rainfed agriculture. According to Dhaliwal and Arora (2006), the huge gap between attained and attainable yield under Kashmir conditions can be attributed to biotic stresses, of which insect pests alone cause 15.6% yield loss. Bhagat et al. (2008) states that >130 insect pests cause damage to maize in India. Among these, cut worms (*Agrotis* spp.), borers (*Chilo* spp.), shoot flies (*Atherigona* spp.) and white grubs (*Holotrichia* spp.) are serious and only ten species cause severe damage from sowing till storage (Arabjafari and Jalali, 2007). In particular, maize cut worm causes considerable damage in hilly and submountainous regions of Jammu and Kashmir. According to Atwal (1986), cut worm has a very wide host range but seedlings are most severely damaged. This study evaluates the population dynamics of cut worm *A. ipsilon* infesting maize in north Kashmir.

MATERIALS AND METHODS

The survey on status of *A. ipsilon* infestation was conducted at three altitudes viz., high (>2200 masl), medium (1650-2200 m) and low (<1650 masl) in district Baramulla. A well-structured questionnaire was got responded from randomly selected farmer (10 farmers/ location). The data on % incidence was subjected to statistical analysis. The incidence on maize variety, Composite-4 was monitored in the field at FoA, Wadura starting from germination. The field was prepared as per package of practices on cereals (2017) published by SKUAST-K and then seeds of maize were sown in five plots (replications) of size 1 x 2 m each with spacing 60x 20 cm on 11th of May, 2018. Three quadrants (900 cm^2)/ replication were randomly selected and the mean number of larvae counted weekly from May to July, 2018. The data obtained was correlated with weather factors obtained from Division of Agronomy, FoA, SKUAST-K, Wadura.

RESULTS AND DISCUSSION

The data on incidence of *A. ipsilon* on maize

Table 1. *Agrotis ipsilon* infestation in maize- District Baramulla, kharif 2018

Altitude	Location	Distance masl (m)	*Plant Damage (%)	Pooled Mean± S.E
High (>2200)	Tangmarg	2210	35.16± 2.01	36.27± 0.78
	Kunzer	2228	37.78± 2.25	
	Kreeri	2241	35.89± 1.87	
Medium (1650-2200)	Watergam	1653	54.36± 2.13	58.07± 1.87
	Tragpora	1659	60.34± 1.79	
	Rohama	1657	59.53± 1.63	
Low (<1650)	Bijhama	1640	73.44± 1.70	74.24± 0.89
	Sopore	1591	73.27± 1.36	
	Pattan	1547	± 2.27	

*Mean of 10 replications.

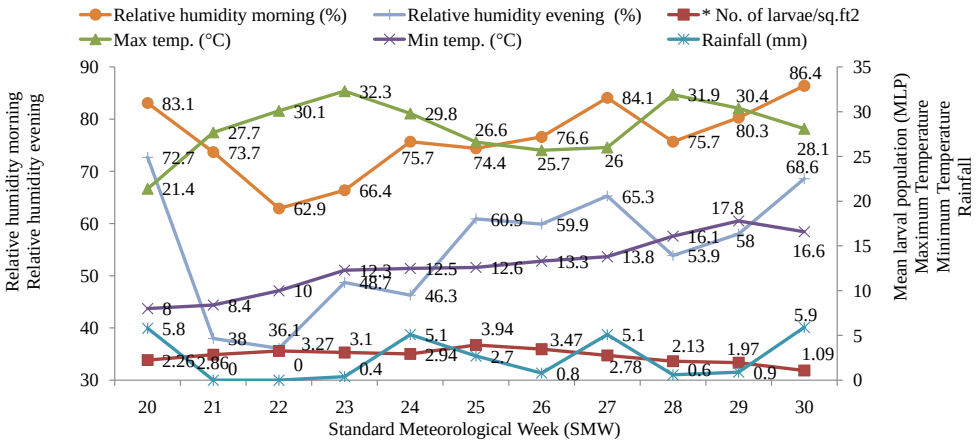

Fig. 1. Population dynamics *A. ipsilon* on maize (FoA, Wadura, kharif 2018)

altitude wise is presented in Table 1, which reveal that the damage appeared at all three altitudes viz; high (>2200 m), medium (1650-2200 m) and low (<1650 m) in the range of 36.27± 0.78, 58.07± 1.87 and 74.24± 0.89%, respectively, and maximum incidence occurred at Kunzer (37.78± 2.25), followed by Kreeri (35.89± 1.87), and the least at Tangmarg (35.16± 2.01) % incidence. At mid altitude, maximum incidence was recorded at Tragpora (60.34 ± 1.79), and at low altitude, maximum incidence was at Pattan (76.04± 2.27) followed by Bijhama (73.44 ± 1.70), and Sopore with lowest (73.27± 1.36). These data agree with those of Arifie et al. (2019) that maximum and least % incidence was on maize at low and high altitudes of Kashmir, respectively. Alexander and Hillard (1969) stated that altitude plays an important role in the distribution of plant and animal species, with large numbers being recorded at lower altitudes. Incidence occurred starting from germination to maturity. The larvae appear from 20th standard meteorological week (SMW) (2.26± 0.13 larvae/ 900 cm^2) after sowing; this reached its peak in 25th SMW (3.94± 0.99 larvae/ 900 cm^2), and thereafter decreased.

The incidence of *A. ipsilon* correlated with weather factors revealed a significant and positive correlation (r = 0.634) with maximum temperature; and a non-significant and positive correlation (r = 0.367) with minimum temperature. Non-significant negative correlation (r = - 0.099) with morning relative humidity (RH) and a non-significant positive one (r = 0.004) with evening RH; and with rainfall it is a non- significant and negative correlation (r = -0.332) (Fig. 1). Kumar et al. (2018) observed peak incidence on oats during 23rd SMW. Lone and Zaki (1999) observed that the damage occurred in maize from April to third week of June, when saplings are two to six leaf stages and May sown crop is most severely damaged.

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EFFICACY OF ETHYL ACETATE EXTRACTS OF BOTANICALS ON DIAMOND BACK MOTH *PLUTELLA XYLOSTELLA* L.

S Susmitha, M Shanthi*, M Murugan[1], K Senthil[2] and M L Mini[3]

Department of Agricultural Entomology, Agricultural College & Research Institute (AC&RI), Tamil Nadu Agricultural University (TNAU), Madurai 625104, Tamil Nadu, India
[1]Department of Agricultural Entomology, TNAU, Coimbatore 641003, Tamil Nadu, India
[2]Department of Soils and Environment, AC&RI, TNAU, Madurai 625104, Tamil Nadu, India
[3]Department of Biotechnology, Centre of Innovation, AC&RI, TNAU, Madurai 625104, Tamil Nadu, India
*Email: mshanthiento@tnau.ac.in (corresponding author)

ABSTRACT

In the present study, ethyl acetate extracts of six botanicals were extracted by continuous hot percolation process in Soxhlet apparatus and evaluated to study the antifeedant, insecticidal and the growth and development inhibitory activity on second instar larvae of diamond back moth *Plutella xylostella* L. The results showed that the *Sesbania grandiflora* at 5% exhibited maximum antifeedant index (34.27%) followed by *Swietenia macrophylla* 5% (28.91%). Extracts of these plants were also found to be the most effective against larvae giving 76.67 and 23.33% mortality, respectively. The adult emergence was 23.33 and 26.67%, respectively with these, while developmental period did not reveal any significant differences.

Key words: *Plutella xylostella*, ethyl acetate, *Sesbania grandiflora, Swietenia macrophylla,* botanicals, soxhlet extraction, antifeedant, toxicity, growth inhibition, developmental period

Cruciferous vegetables are infested by a number of insect pests, of which the diamond back moth (DBM) *Plutella xylostella* L. is the most destructive (Tamilselvan et al., 2021). Prophylactic management of vegetable crop pests with insecticides is estimated to cost US$1.4 billion worldwide, if yield losses are included it rises to US$ 2.7 billion (Furlong et al., 2013). In India, 50 to 80% yield loss in the marketable yield was observed due to *P. xylostella* in cabbage (Sandur, 2004; Ayalew, 2006), and it is known for its ability to develop resistance to insecticides (APRD, 2020). Use of pesticides in agriculture has led to resistance, outbreaks, resurgence, and such undesirable environmental effects (Negahban et al., 2006). To prevent the development of resistance, a combination of insecticides having different mechanisms of action should be used in rotation. In field populations, *P. xylostella* has developed resistance against nearly 95 conventional insecticides (APRD, 2020), including new chemistry insecticides such as cyantraniliprole in Australia (Evans, 2008), Brazil (Ribeiro et al., 2017), China (Qin et al., 2018) and Japan (Jouraku et al., 2020). Hence, the effective natural plant products can be safely incorporated as ecofriendly alternative to insecticides (Naz et al., 2018). Plants are a virtually inexhaustible source of structurally diverse biologically active substances and approximately 1800 plants possess insecticidal properties (Grainge et al., 1984). The complex combination of behavioural and physiological actions contained in these plant compounds makes it difficult for insects to evolve resistance. Sangavi and Edward (2017) reported that 10% aqueous leaf extract of *S. grandiflora* showed larval mortality in *P. xylostella*. *Nerium oleander* L. (stem, leaves and flowers) 70% hydroethanolic extract decreased the larval and pupal weight of pink boll worm *Pectinophora gossypiella* (Moustafa et al., 2018). In the present study, screening of ethyl acetate extracts of botanicals was done to evaluate their efficacy as antifeedant, insecticidal and inhibitor of growth and development on *P. xylostella*. As ethyl acetate is a commercially available solvent and approved for botanical extraction, which helps in isolation of desired compounds and provided higher purity, it has been used (Pintac et al., 2018).

MATERIALS AND METHODS

The plant parts of six botanicals viz., unripen fruits, *Azadirachta indica* (Meliaceae); oleander leaves, *Nerium oleander* (Apocynaceae); plumeria leaves, *Plumeria rubra,* (Apocynaceae); humming bird tree leaves, *Sesbania grandiflora* (Fabaceae); mahogany leaves, *Swietenia macrophylla* (Meliaceae); marigold

leaves, *Tagetus erecta* (Asteraceae) were collected from fields of Agricultural College and Research Institute (AC&RI), Madurai, Tamil Nadu. The laboratory experiment was conducted at the Department of Agricultural Entomology, AC&RI, Madurai. The collected leaves and unripen fruits of the botanicals were shade dried (15 days), powdered in mechanical blender and passed through sieve (no. 40). The powder thus obtained was stored in amber-coloured bottles, to prevent the exposure to sunlight. The ethyl acetate extract was taken from 10 g powder by continuous hot percolation technique in Soxhlet apparatus (Larkem et al., 2021). The resultant extract was filtered (Buchner funnel using Whatman No.1 filter paper), condensed (Rotary Flash Evaporator (Evator) at 45°C) and weighed, to estimate the recovery.

The bioassay was carried out based on leaf dip method under no choice condition (Ingle et al., 2017). There were nine treatments including solvent and standard checks (azadirachtin 10,000 ppm @ 2ml/ l), and untreated check, and replicated thrice. The larvae were allowed to feed on 5% treated leaf disc until pupation, to understand the impact of botanicals on the growth and development of *P. xylostella* (Baskar et al., 2011). The leaf area consumed by the larvae was measured after 24, 48 and 72 hr of treatment and antifeedant index estimated (Sadek, 2003). Larvae were observed for mortality, if any, malformations and developmental period, pupal duration and mortality, adult emergence and lifespan. Data obtained was subjected to arc sine and square root transformation and then statistically analyzed using SPSS 22 version (IBM Crop, 2013) software. Grouping was done by Duncan's Multiple Range Test (DMRT) (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

The results on extraction yields of the plant samples using ethyl acetate revealed that it is in the descending order as: *A. indica* (9.81%), *N. oleander* (9.42%), *S. macrophylla* (8.24%), *S. grandiflora* (7.27%), *P. rubra* (6.13%) and *T. erecta* (5.54%). The antifeedant efficacy of given in Table 1 reveal that larvae fed with *S. grandiflora* treated leaves exhibited the least area of feeding- antifeedant index being 46.74, 42.98 and 34.27% at 24, 48 and 72 hr after treatment, respectively;

Table 1. Effect of ethyl acetate extracts of botanicals on *P. xylostella.*

Treatments	Antifeedant Index (AI)$			Mean developmental period (days)*			Cumulative larval mortality (%)$	Adult emergence (%)$
	24 h	48 h	72 h	Larva	Pupa	Adult life span		
T_1-*A. indica*	26.74± 0.09 (31.14)e	24.07± 0.04 (29.38)^{f}	14.11± 0.19 (22.06)^{f}	12.00± 0.00 (3.46)^{b}	4.33± 0.11 (2.08)^{bc}	6.00± 0.19 (2.45)^{b}	53.33± 0.64 (46.92)^{d}	46.67± 0.64 (43.08)^{d}
T_2-*N. oleander*	31.38± 0.05 (34.07)^{d}	27.70± 0.05 (31.76)^{e}	15.80± 0.08 (23.43)^{e}	12.67± 0.11 (3.61)^{b}	4.67± 0.11 (2.16)^{b}	5.67± 0.11 (2.38)^{b}	63.33± 0.67 (52.78)^{c}	36.67± 0.67 (37.22)^{c}
T_3-*P. rubra*	20.19± 0.05 (26.70)^{f}	18.67± 0.10 (25.61)^{g}	11.40± 0.06 (19.73)^{g}	12.33± 0.11 (3.46)^{b}	3.67± 0.11 (1.91)^{bc}	7.00± 0.19 (2.65)^{bc}	56.67± 0.64 (48.85)^{d}	43.33± 0.64 (41.15)^{d}
T_4-*S. grandiflora*	46.74± 0.19 (43.13)^{a}	42.98± 0.08 (40.96)^{b}	34.27± 0.06 (35.84)^{b}	12.67± 0.11 (3.61)^{b}	4.67± 0.11 (2.16)^{b}	5.67± 0.11 (2.38)^{b}	76.67± 0.74 (61.22)^{b}	23.33± 0.74 (28.78)^{b}
T_5-*S. macrophylla*	43.11± 0.10 (41.04)^{b}	35.74± 0.07 (36.72)^{c}	28.91± 0.05 (32.53)^{c}	12.67± 0.11 (3.61)^{b}	4.33± 0.11 (2.08)^{bc}	6.00± 0.19 (2.45)^{b}	73.33± 0.74 (59.00)^{b}	26.67± 0.74 (31.00)^{b}
T_6-*T. erecta*	40.28± 0.09 (39.40)^{c}	29.96± 0.07 (33.19)^{d}	24.96± 0.06 (29.98)^{d}	12.33± 0.11 (3.46)^{b}	3.67± 0.11 (1.91)^{bc}	6.33± 0.11 (2.52)^{bc}	66.67± 0.67 (54.78)^{c}	33.33± 0.67 (35.22)^{c}
T_7-Treated check# (Azadirachtin 1%)	44.37± 0.22 (41.77)^{b}	51.15± 0.09 (45.66)^{a}	42.32± 0.07 (40.59)^{a}	0.00± 0.00 (0.71)^{a}	0.00± 0.00 (0.71)^{a}	0.00± 0.00 (0.71)^{a}	100± 0.00 (89.09)^{a}	0.00± 0.00 (0.91)^{a}
T_8-Solvent check	3.03± 0.13 (9.99)^{g}	2.21± 0.12 (8.50)^{h}	3.11± 0.16 (10.10)^{h}	10.67± 0.11 (3.32)^{c}	3.33± 0.11 (1.83)^{c}	7.67± 0.11 (2.77)^{c}	0.00± 0.00 (0.91)^{e}	100± 0.00 (89.09)^{e}
T_9-Untreated check	-	-	-	10.67± 0.11 (3.32)^{c}	3.33± 0.11 (1.83)^{c}	7.67± 0.11 (2.77)^{c}	0.00± 0.00 (0.91)^{e}	100± 0.00 (89.09)^{e}
SEd	0.426	0.387	0.477	0.056	0.106	0.112	2.368	2.368
F-value	1344.57	1689.78	849.44	526.26	41.29	69.08	287.631	287.631
P (significance)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Mean values of three replications represented as mean ± standard deviation; # 100% mortality of larvae observed after 7 days of treatment, hence developmental period was not presented. *Figures in parentheses square root transformed values ($\sqrt{x+0.5}$); $Figures in parentheses arc sine transformed values (x+0.5); In a column, mean followed by same letter not significantly different from each other, DMRT (F-test; $p \leq 0.05$; n=10); SEd: Standard error of the difference.

while with *S. macrophylla* it was 43.11, 35.7 and 28.91%, respectively, and it was statistically on par with the treated check, azadirachtin 10000 ppm @ 2ml/ l after 24 hr. The antifeedant activity declined over time from 24 to 72 hr. This observation is in agreement with that of Sangavi and Edward (2017), who reported that *S. grandiflora* 10% aqueous extracts showed 52.31% antifeedant activity after two days on *P. xylostella*. Moghadamtousi et al. (2013) reported that ethyl acetate extracts of *S. macrophylla* seeds showed good antifeedant activity against fourth instar larvae of *Spodoptera frugiperda*. Phytochemical evaluation of *S. grandiflora* showed the presence of different secondary metabolites viz., alkaloids, flavonoids, saponins, glycosides, cardiac glycosides, tannins and phenols (Bahera et al., 2012). The presence of condensed tannins in the *S. grandiflora* extract may be responsible for unpalatability of treated surface (Reed, 1994).

Developmental period of life stages, larval mortality and adult emergence details given in Table 1 reveal complete larval mortality in the treated check, azadirachtin 10000 ppm @ 2 ml/ l, which did not exhibit any phytotoxicity symptoms; among the botanicals evaluated, maximum mortality was in *S. grandiflora* (76.67%), which was statistically on par with that of *S. macrophylla* (73.33%). Similar findings were reported by Elango et al. (2011) on *S. grandiflora* that ethyl acetate leaf extract 0.01% showed 34% larval mortality of *Anopheles subpictus*. Wagh et al. (2009) observed that *S. grandiflora* contains plenty of saponins, sterols and tannins, which might be responsible for its insecticidal property. Hussain and Kumaresan (2014) with GC-MS analysis of *S. grandiflora* leaves methanolic extracts revealed that these mainly composed of oxygenated hydrocarbons and phenolic hydrocarbons. Palmitic acid (11.8%), 9-hexadecenol (9.0%) and octadecanoic acid were the major compounds having pesticidal activities (Gopalakrishnan and Vadivel, 2011; Geetha et al., 2013; Mishra et al., 2021). No pupal mortality and malformations were recorded in these treatments. There was no significant difference among the treatments regarding the developmental period (days) of life stages but all the treatments were significantly superior over untreated check. It is concluded that *S. grandiflora* and *S. macrophylla* ethyl acetate plant extracts have potential against *P. xylostella.*

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SUSCEPTIBILITY OF IMIDACLOPRID RESISTANT WHITEFLY *BEMISIA TABACI* (GENNADIUS) TO CYANTRANILIPROLE

Rajna S, Mahapatro G K[1]*, Subramanian S, Subhash Chander[2] and Sudhakar Kelageri

Division of Entomology, ICAR-Indian Agricultural Research Institute (IARI), New Delhi 110012, India
[1]ICAR-IARI Regional Station, Pune, Maharashtra, India
[2]National Centre for Integrated Pest Management, IARI Campus, New Delhi 110012, India
*Email: gagan_gk@rediffmail.com (corresponding author)

ABSTRACT

The susceptibility of five north Indian populations of *Bemisia tabaci* (Genn.) against a neonicotinoid insecticide, imidacloprid and a comparatively novel, diamide insecticide cyantraniliprole has been analysed in this study. It was found that the Sriganganagar and Bathinda populations were moderately resistant to imidacloprid with LC_{50} values 845.55 and 765.65 mg/ l, respectively; while, the LC_{50} value for cyantraniliprole was around 4.5 and 4.3 mg/ l for both the populations. The relative resistance ratio for imidacloprid was 14.53 and 13.16 for Sriganganagar and Bathinda populations, respectively, whereas, for cyantraniliprole, no resistance was observed. The pairwise comparisons of LC_{50}s of various populations did not exhibit any cross-resistance. The results of the study demonstrate the possibility of using cyantraniliprole as an alternative for imidacloprid resistant *B. tabaci* populations in north India.

Key words: *Bemisia tabaci*, cross-resistance, imidacloprid, cyantraniliprole, LC_{50}, north India, susceptibility, toxicity, Sriganganagar, Bathinda, relative resistance

Bemisia tabaci (Gennadius) is a serious pest in tropical, subtropical and low altitude temperate regions of the world (Ran et al., 2018). Its polyphagous nature, high reproductive potential, and the vectoring capacity of *B. tabaci* necessitate effective management (Horowitz and Ishaaya, 1996). Existence of a wide genetic variability, confirmed *B. tabaci* as a cryptic species complex consisting of 44 genetic groups at present (Kanakala and Ghanim, 2019). The persistence of this pest has led to widespread adoption of newer chemicals (Elbert et al., 2008). Several neonicotinoid insecticides namely imidacloprid, acetamiprid, nitenpyram, thiamethoxam, clothianidin etc. were developed to control hemipteran pests across the world (Bass et al., 2015). The systemic and translaminar properties of these neonicotinoids have enhanced their use in managing sucking insect pests (Horowitz et al., 1998). Though imidacloprid was the first neonicotinoid to be found effective against *B. tabaci* (Nauen and Denholm, 2005), its non-judicious and unilateral use has led to the development of resistance, which is a predictable outcome of insecticide use in the field (Kranthi, 2005). Severe infestation and outbreaks of *B. tabaci*, as well as several instances of resistance to imidacloprid from from India, since the last two decades (Sethi and Dilawari, 2008; Naveen et al., 2017). Among the 132 cases of imidacloprid resistance registered in the Arthropod Pesticide Resistance Database (APRD), 110 are field evolved resistance (Mota-Sanchez and Wise, 2020). Thus, it became necessary to bring an alternative to this neonicotinoid insecticide for managing *B. tabaci* in the field. An anthranilic diamide insecticide, cyantraniliprole with a novel mode of action, activating ryanodine receptors and thus the calcium channel activation, has targeted hemipteran insects (Cordova et al., 2006; Sattelle et al., 2008) and found effective with an acute toxicological profile (Ran et al., 2018). In this study, the susceptibility of *B. tabaci* populations from six locations in north India against the neonicotinoid, imidacloprid and the diamide, cyantraniliprole is evaluated.

MATERIALS AND METHODS

Bemisia tabaci populations were collected from the cotton fields from six locations in north India and reared on cotton plants (*Gossypium hirsutum* L.*)* in Insect Proof Climate Control Chamber (IPCCC), Division of Entomology, IARI (27±2^{0}C, 60-70% RH, photoperiod 14:10 L:D). The whiteflies collected in 2013 from *Leucaena leucocephala* from Pusa campus, under laboratory condition, served as the susceptible check. The details of the *B. tabaci* populations collected are New Delhi (28.64°N 77.17°E), Bathinda (30.20°N 74.95°E), Indore (22.8°N 75.73°E), Hisar (29.09°N 75.87°E), and Sriganganagar (29.52°N 74.78°E).

Commercial formulations of insecticides, imidacloprid (Confidor, Bayer Crop Science) and cyantraniliprole (Benevia, DuPont) were used for bioassay studies. The insecticides procured from the market were diluted with deionized water to make 1% stock solution and serial dilutions were prepared. Seven concentrations with three replications were set and susceptibility studies were carried out following the modified Insecticide Resistance Action Committee (IRAC) protocols.

The lethal effects of imidacloprid and cyantraniliprole were tested following the leaf dip bioassay, modified IRAC method by Naveen et al., (2017). The concentrations of insecticides in mg/ l were prepared from 1% stock solutions and water was kept as an untreated control. Cotton leaves from thirty to forty days old plants, which were grown without any infestation were used. Leaves were given a slanting cut at the petiole keeping a length of about 1 cm, completely immersed in the insecticide solutions for 20 sec, and then air-dried (30-45 min). The dried leaves were then kept in the 2% agar slants in petriplates. Using an aspirator, adult whiteflies were collected and briefly anaesthetized by CO_2 for 10-15 sec. The insects were transferred on to the treated leaves in petriplate and mortality was recorded after 72 hr. Insects with no sign of movement was recorded as dead. The estimates of lethal concentrations and 95% confidence intervals were determined for adult bioassay by log- dose probit analysis using PoloPlus 2 (LeOra Software, Petaluma, CA). Relative toxicity of insecticides was estimated following Dhole et al. (2017).

RESULTS AND DISCUSSION

The susceptibility studies were carried out keeping the laboratory population of *B. tabaci* as the baseline. The median lethal concentration of imidacloprid and cyantraniliprole is given in Table 1. In all the bioassays, mortality in control was <7%. The LC_{50} value of neonicotinoid for the susceptible population is estimated as 58.19 mg/ l. The relative resistance ratio of imidacloprid is highest in Sriganganagar (14.53) followed by Bathinda (13.16) populations with LC_{50} values 845.852 mg/ l and 765.654 mg/ l, respectively. The LC_{50} value of imidacloprid for all the populations is significantly different from the susceptible one considering the overlap of 95% fiducial limits. Moreover, the LC_{50} value for New Delhi one (120.173 mg/ l) is also significantly different. The results suggested the existence of a high amount of heterogeneity in response of each population to imidacloprid. The susceptibility of populations to imidacloprid based on the LC_{50} values are in the order of New Delhi >Indore>Hisar>Bathinda>Sriganganagar.

Log dose-probit mortality data displayed susceptibility of all populations against cyantraniliprole. The populations with maximum resistance to imidacloprid viz., Sriganganagar and Bathinda, have shown high susceptibility to cyantraniliprole (LC_{50} -4.575 and 4.308 mg/ l, respectively); the highest level of susceptibility was in Indore population (LC_{50} - 3.320 mg/ l); based on LC_{50} values, susceptibility is in the order: Indore>Hisar>Bathinda>Sriganganagar>New Delhi. The relative resistance factor of none of the populations has crossed 2.5, indicating no resistance development (Table 1). High susceptibility of *B. tabaci* populations towards cyantraniliprole is clear from relative susceptibility. When relative toxicity is compared for the two insecticides, cyantraniliprole was 32x more toxic than imidacloprid in the case of laboratory susceptible population itself. Further, the relative toxicity was higher for cyantraniliprole by 185 and 177x in Sriganganagar and Bathinda populations than the neonicotinoid insecticide, imidacloprid. Relative resistance ratios are used to know the resistance status of each population to respective insecticides (Table 4)- and those ranging between $5.0 < RR \leq 10.0$ is categorized as low level of resistance, ($10.0 < RR \leq 40.0$) as moderate level, and $RR \geq 40.0$ as a high level of resistance (Liu et al., 2010). In the present study, Sriganganagar (14.53) and Bathinda (13.16) populations showed a moderate level of resistance whereas Hisar population (RR-7.24) showed a low level of resistance against imidacloprid (Table 4). Paired comparisons of the log LC_{50}s of insecticides tested showed no correlation between imidacloprid and cyantraniliprole (r=0.671) indicating no sign of cross-resistance.

Neonicotinoids have been playing a major role in managing sucking pests for more than two decades (Bass et al., 2015); because of its extensive use in a large number of crops, researchers had reported >1000fold resistance (Nauen and Denholm, 2005). A recent study from India reported a resistance factor of 17 for Sriganganagar and 8 for Bathinda population against imidacloprid (Naveen et al., 2017); this study observed that Sriganganagar and Bathinda as the highest resistant populations with a resistance ratio of 15 and 13 folds, respectively to imidacloprid; and an increase in resistance level of imidacloprid in Sriganganagar and Bathinda population was anticipated in comparison to the values given in Naveen et al. (2017), but it was confirmed only in Bathinda population, where the resistance

Table 1. Log dose probit mortality data for imidacloprid and cyantraniliprole for different *B. tabaci* populations

Insecticide	Population	χ^2(df)	Slope	LC_{50} (mg/ l)	95 % fiducial limits LC_{50}	RR (LC_{50})	Resistance status
Imidacloprid	Susceptible	1.506 (5)	2.175± 0.353	58.187	46.265 - 70.536 (a)	1	
	New Delhi	2.110 (5)	2.270± 0.559	120.173	72.638 - 154.798 (b)	2.06	--
	Hisar	1.467 (5)	2.431± 0.352	421.138	351.835 - 509.733 (d)	7.24	Low
	Bathinda	2.139 (5)	2.178± 0.358	765.654	614.421- 928.253 (e)	13.16	Moderate
	Indore	3.311 (5)	2.755± 0.384	280.119	232.187- 328.032 (c)	4.81	--
	Sriganganagar	3.140 (5)	2.030± 0.355	845.852	678.083-1045.485 (e)	14.53	Moderate
Cyantraniliprole	Susceptible	0.854 (5)	1.971± 0.329	1.803	1.439 - 2.248 (a)	1	--
	New Delhi	3.905 (5)	1.820± 0.297	4.897	3.622 - 6.257 (b)	2.7	--
	Hisar	2.030 (5)	1.471± 0.263	3.896	2.603 - 5.237 (b)	2.161	--
	Bathinda	3.449 (5)	1.893± 0.295	4.308	3.167 - 5.477 (b)	2.399	--
	Indore	2.792 (5)	1.703± 0.255	3.320	2.349 - 4.307 (b)	1.841	--
	Sriganganagar	2.043 (5)	1.328± 0.260	4.575	3.038 - 6.310 (b)	2.537	--

factor rose to 13 from eight. The Sriganganagar and Bathinda populations were comparatively susceptible to the diamide insecticide cyantraniliprole with an adult LC_{50} value of 4.575 (threefold) and 4.308 mg/ l (two folds) respectively. Thus, cyantraniliprole showed relatively low susceptibility to New Delhi population (LC_{50} =4.897). The higher LC_{50} value of the New Delhi population may be due to the use of other diamide insecticides such as flubendiamide, chlorantraniliprole etc. against other insect pests in the cotton and vegetable fields. The polyphagous nature of the whiteflies can support the hypothesis of relatively high LC_{50} compared to other populations. A report by Dangelo et al. (2017) in Brazil also hypothesized the same when they observed resistance of *B. tabaci* against cartap hydrochloride and chlorantraniliprole which were not a part of *B. tabaci* management programme, but for other pests in the same ecosystem.

This baseline information on susceptibility obtained from the study can be used for further monitoring of resistance to cyantraniliprole in field conditions. A baseline data was developed in Florida by Carabello et al. (2013) and they found cyantraniliprole to be viable for whitefly resistance management. The adult bioassays of this study provided pooled LC_{50} values ranging from 0.037 to 0.064 mg/ l for nine field-collected populations in Florida. The lethal effects of cyantraniliprole to *B. tabaci* was also confirmed from China, where eight insecticides including six neonicotinoids were tested and cyantraniliprole was found as most toxic (Wang et al., 2017). The present study indicates a high susceptibility to cyantraniliprole in *B. tabaci* populations from north India, which suggests that this chemical is a promising alternative for the insecticide resistance management of imidacloprid. Even though cyantraniliprole does not possess a label claim against whiteflies in cotton and brinjal in India, it is recommended against whiteflies in tomato and gherkins. Considering the high polyphagous nature, the label claim of newer insecticides with a novel mode of action, the label claim can be extended for cotton making them suitable alternatives.

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HOST PREFERENCE AND POPULATION DYNAMICS OF *HOLOTRICHIA NAGPURENSIS* KHAN AND GHAI

Mayank Kumar* and A K Pandey

Department of Entomology, College of Agriculture,
G B Pant University of Agriculture and Technology, Pantnagar 263145, Uttarakhand, India
*Email: mayankkumar1411@gmail.com (corresponding author)

ABSTRACT

***Holotrichia nagpurensis* Khan and Ghai is a major white grub species of subfamily Melolonthinae. Its wide host range has been reported from different parts of India. An experiment was carried out to find host preference and population dynamics at three locations of Pantnagar in Terai region of Udham Singh Nagar District during 2018-19. Beetles were recorded from six host plants among which neem *Azadirachta indica*, was the major one. The p-value of two-way ANOVA between populations of three locations (0.0006<0.001) and from six hosts (0.0002<0.001) showed that there exists significant difference in distribution and feeding preference of *H. nagpurensis* on host plants. Among the hosts, *A. indica* was found to be the most preferred with maximum adult density (419 adults) and average 46.55 beetles/ tree; and the multiple comparisons revealed a significant host preference. Correlation coefficients revealed that minimum relative humidity exhibits a negative relationship with beetle emergence.**

Key words: Scarabaeidae, *Holotrichia nagpurensis*, adults, host preference, *Azadirachta indica*, population dynamics, weather parameters, relative humidity, correlation coefficients

White grub, also known as May-June beetles, belonging to family Scarabaeidae is a major insect pest. Its adults are nocturnal, and feed on the leaves and soft shoot and fruits of various trees, shrubs and grasses (Ritcher, 1958; Vallejo et al., 1998). Their polyphagous nature make them major pests in India (Metcalf and Luckman, 1975). Of the 2000 species known from the Indian subcontinent 40 species cause serious damage to various crops (Veeresh et al., 1991). Among these, *Holotrichia* spp. (subfamily Melolonthinae) are mostly leaf feeders in adult stage (Arrow, 1917); this genus has >100 species with wide distribution (Mathur et al., 2010). There are species like *H. consanguinea*, *H. longipennis*, *H. serrata*, *H. insularis* etc observed from 27 host plants in north India (Srivastava and Khan, 1963; Bhadauria and Nigam, 1982; Haq, 1962). Many abiotic factors influence their distribution and diversity. High diversity of phytophagous insects is also the result of factors that affecting their diet breadth (Gaete-Eastman et al., 2004). There is no information about the host range and feeding preference of *H. nagpurensis* on host plants from Terai area of Pantnagar of Udham Singh Nagar district of Kumaon. This study evaluates the host range, feeding preference and population dynamics of its adults.

MATERIALS AND METHODS

The present study was conducted at three locations i.e. Crop Research Centre (CRC), Horticulture research center (HRC) and Livestock Research Center (LRC) of Udham Singh Nagar in Kumaon region Uttarakhand during 2018-19. Weekly surveys were made to record the *H. nagpurensis* incidence on various host plants like neem, guava, jackfruit, litchi, mango, bakane, amaltash, teak, pride of India and ashok in addition to some cultivated field crops like maize, soybean, sugarcane, rice and calotropis. Weekly observations were hade starting from appearance of beetle i.e. from 10th standard meteorological weeks (SMW) to 25th MSW (from March to June), with counting the of the adults feeding on leaves using powerful torch during night. The beetles were also collected from each host plants available on experimental site by shaking the branches to dislodge the beetles. Collected beetles were brought to the laboratory where, they were killed and sorted out before storing. Number of beetles that flew away from tree were also included. Because of largeness in size these were easily identified during flight (Litsinger et al., 2002). The data on the cumulative number of beetles for each tree species was calculated to evaluate the host preference. Data on weather parameters viz., weekly maximum and minimum temperature (^{0}C), relative humidity (RH) (%) at 7:12 am and 2:12 pm, rainfall (mm), wind velocity (km/ hr.) and sunshine (hr) were obtained. The data were subjected to statistical analysis by ANOVA and LSD test (Litsinger et al., 2002) using R

and SPSS software packages, respectively. Correlation coefficients of the incidence of beetle with weather factors were computed with R software.

RESULTS AND DISCUSSION

The results of the study brought out the host range/ preference and population dynamics of *H. nagpurensis.* These included the major host plants like *A. indica*, *P. guajava*, *A. heterophyllus*, *L. scinensis*, *M. indica*, *M. azadirach*, *C. fistula*, *T. grandis*, *L. speciosa* and *Polyalthia* sp. in addition to some cultivated field crops like *Z. mays*, *G. max, S. officinarum*, *O. sativa* and *Calotropis* sp. These revealed the wide host range with significant variations and choice of host plant for feeding; significantly maximum (713 beetles) was observed at the location HRC followed by LRC (698) and CRC (503) on the preferred hosts. Among the 15 host plants selected, which are common to all the sites, six trees i.e. *A. indica*, *M. indica*, *A. heterophyllus*, *P. guajava*, *Z. mays* and *M. azadirach* inhabited maximum adults (Table 1); of these *A. indica* was the most preferred inhabiting >one fifth, and the least (11.91%) on *M. azadirach* followed by *Z. mays* (11.54%) only. On an average, *A. indica* recorded 46.55 adults/ tree. Two-way ANOVA revealed significant differences among the locations studied, and among the six host trees. The multiple comparison values also indicate that *A. indica* was significantly most preferred (Table 2). The emergence of *H. nagpurensis* started from 7 pm of 10th and up to 25th MSW with a peak during 16th MSW (Fig. 1); correlation coefficients revealed a non-significant but positive correlation with maximum temperature (r=0.167), and a negative one with minimum temperature (r=-0.130); negative relationship with both maximum and minimum RH and

Table 1. Incidence of *H. nagpurensis* on hosts in three locations (2018-19)

S. No.	Host name	CRC	HRC	LRC	Total	% of total
1	*Azadirachta indica* L.	115	147	157	419	21.89
2	*Zea mays* L.	55	98	68	221	11.54
3	*Psidium guajava* L.	85	139	138	362	18.91
4	*Atrocarpus heterophyllus* Lam.	89	142	128	359	18.75
5	*Melia azedarach* L.	64	77	87	228	11.91
6	*Mangifera indica* L.	95	110	120	325	16.98
	Total	503	713	698	1914	

Table 2. Multiple comparisons of hosts for feeding preference (2018)

S. No.	I-Sample	J- Sample	Mean Diff.	Sig.
1.	*A. indica* L.	*Z. mays* L.	66.00	.003*
		P. guajava L.	19.00	.316ns
		A. heterophyllus	20.00	.292ns
		Lam.	63.67	.004*
		M. azadirach L.	31.33	.110ns
		M. indica L.		
2.	*Z. mays* L.	*A. indica* L	-66.00	.003*
		P. guajava L.	-47.00	.024*
		A. heterophyllus	-46.00	.026*
		Lam.	-2.33	.900ns
		M. azedarach L.	-34.67	.080ns
		M. indica L.		
3.	*P. guajava* L.	*A. indica* L	-19.00	.316ns
		Z. mays L.	47.00	.024*
		A. heterophyllus	1.00	.957ns
		Lam.	44.67	.030*
		M. azadirach L.	12.33	.510ns
		M. indica L.		
4.	*A. heterophyllus*	*A. indica* L	-20.00	.292ns
	Lam.	*Z. mays* L.	46.00	.026*
		P. guajava L.	-1.00	.957ns
		M. azadirach L.	43.67	.033*
		M. indica L.	11.33	.544ns
5.	*M. azadirach* L.	*A. indica* L	-63.67	.004*
		Z. mays L.	2.33	.900ns
		P. guajava L.	-44.67	.030*
		A. heterophyllus	-43.67	.033*
		Lam.	-32.33	.100ns
		M. indica L.		
6.	*M. indica* L.	*A. indica* L	-31.33	.110ns
		Z. mays L.	34.67	.080ns
		P. guajava L.	-12.33	.510ns
		A. heterophyllus	-11.33	.544ns
		Lam.	32.33	.100ns
		M. azadirach L.		

ns=non- significant; significant at p=0.05

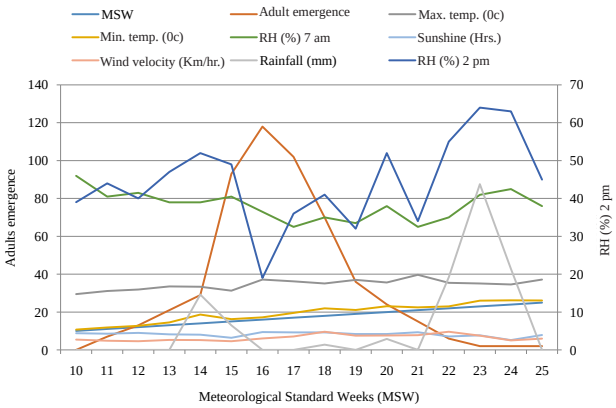

Fig. 1. Seasonal emergence of *H. nagpurensis* vs. weather factors

rainfall were also observed of which only the one with minimum RH (r=-550*) was significant. These results corroborate with those of Pal (1977) and Gupta (1973); and weather factors and availability of desirable host are importan (Veeresh, 1988; Ratnadass et al., 2012**)**. Present results are in partial agreement with those of Mishra and Singh (1999) on the favourable weather. Prathibha et al. (2013) also reported that rainfall is an important factor realting to emergence and aggregation of this beetle, and significant correlation with maximum temperature corroborates with that of Seram and Saikia (2015).

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DIVERSITY AND POPULATION DYNAMICS OF SPIDERS IN AGROECOSYSTEMS

S Raghul* and K Kumar

Department of Agricultural Entomology, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal 609603, Puducherry, India
*Email: raghulsubasekaran@gmail.com (corresponding author)

ABSTRACT

The biodiversity of spiders in agroecosystem was studied at the Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal during kharif (2019) and rabi (2019-20). The spiders were collected at weekly intervals using in situ counts, net sweeping, pitfall traps and litter sampling. A total of 30 species under 22 genera, 15 families were observed. Biodiversity indices viz., Shannon-Weiner Index (2.809- kharif and 2.766- rabi), Simpson Index (0.926- kharif and 0.909- rabi), Margalef Index (4.135- kharif and 4.22- rabi) and Pielou's Index (0.104- kharif and 0.095- rabi) were computed. Regression with weather parameters during kharif 2019, were non-significant for *Thomisus* sp. (0.107), *Pardosa sumatrana* Thorell (0.146), *Oxyopes javanus* Thorell (0.190), *Tetragnatha javana* Thorell (0.213) and *Tetragnatha mandibulata* Walckenaer (0.347); and during rabi 2019-20, for *T. javana* (0.516), *Argiope anasuja* Thorell (0.619) showed significance and *O. javanus* (0.192), *Lycosa bistriata* Gravely (0.370), *T. mandibulata* (0.437), these values were non-significant.

Key words: Karaikal, kharif, rabi, agroecosystem, spiders, biodiversity indices, population dynamics, correlation, regression, dominance, species richness, abundance

Arachnids are the largest and successful group of chelicerates. Among the arachnids, the order Araneae is the largest group (Thompson, 2015). They are the most diversified group amongst invertebrates with 48,901 species under 4,184 genera and 128 families (WSC, 2020). About 1,909 species belonging to 488 genera and 64 families are from India (WSC, 2019). Spiders play an important predatory role in agroecosystem by lowering insect densities, as well as stabilizing pest populations (Saranya et al., 2019). Spiders have been evidenced as bio-indicators in environmental habitats that could be helpful for conservation purposes (Gerlach et al., 2013). Benamu (2020) stated that studies on spider's diversity in agroecosystem have increased, demonstrating their potential to be used as biological control agents in IPM, and it can reduce the indiscriminate use of pesticides. Spiders are very sensitive to the variations in abiotic conditions, and Pitilin et al. (2019) observed that spiders influence the pest populations in the field and these are also influenced by the weather factors. Hence, it is essential to know the population dynamics in relation to weather factors and the present study evaluates the same under agroecosystem at Karaikal, U T of Puducherry.

MATERIALS AND METHODS

The present study was conducted at the Eastern farm at (10°55'N,79°49'E, 8 masl) of Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal, U T of Puducherry. Spider fauna were collected in the early hours (08:00- 10:00 hr.), in the afternoon (14.00- 15.00 hr.) and in late evening (17:00- 18:00 hr.) at weekly intervals using different methods viz., in situ count, net sweeping (Pandit and Pai, 2017), pitfall trap and litter sampling from crops like cotton, maize, rice, ragi and pigeon pea. Pitfall traps (5 no.) were placed at five random spots with 2- 3 drops of liquid soap as trapping fluid and specimens were collected next morning (Bukhari et al., 2012). Litter sampling was done by manual searching of spiders under the leaf litters at weekly intervals (Jose et al., 2018). Following Engelmann (1978), the families were distinguished with the relative abundance as- subrecedent, recedent, subdominant, dominant and eudominant. The collected specimens were killed and preserved in glass vials containing 70% alcohol before labeling. Tikader and Bal (1981) was used for the identification of species.

Diversity indices like Shannon-Wiener index (Hughes, 1978), Simpson' diversity index (Simpson, 1949), Margalef index (Margalef, 1958) and Pielou's evenness index (Pielou, 1966) were computed using standard methodology (https://www.alyoung.com/labs/biodiversity_ calculator.html). The weather factors viz., maximum and minimum temperature, morning and evening relative humidity (RH), bright sunshine hours and rainfall obtained were correlated with the occurrence of spiders with correlation coefficients and regression ($p \leq 0.05$ (*) and ≤ 0.01 (**).

RESULTS AND DISCUSSION

The study revealed a total of 30 spider species with 1,366 individuals under 22 genera and 15 families; Araneidae was the richest with 5 species followed by Oxyopidae with 4 species, Salticidae, Thomisidae and Tetragnathidae (3 species each), Lycosidae and Sparassidae (2 species each), and families Clubionidae, Corinnidae, Eutichuridae, Gnaphosidae, Philodromidae, Pisauridae, Theridiidae and Zodariidae with 1 species each (Table 1). Ambily and Antony (2016) stated that family Araneidae dominated the agroecosystem of Ernakulum, district of Kerala with 8 species. During kharif 2019 and rabi 2019-20 all the families except Corinnidae (*Castianeira zetes*) (kharif and absent during rabi), Theridiidae (*Argyrodes argentatus*) (kharif absent; rabi present), Thomisidae (*Platythomisus sudeepi*) (kharif absent; rabi present), *Tmarus fasciolatus* (kharif absent; rabi present) were observed. The relative abundance of spider fauna during kharif 2019 and rabi 2019-20 revealed that family Tetragnathidae was dominant (21.81%) followed by Oxyopidae (21.53%) and Araneidae (15.23%); Lycosidae (10.03%), Salticidae (7.68%), Thomisidae (5.48%) and Eutichuridae (4.69%) were subdominant. Pisauridae (0.44%), Theridiidae (0.15%) and Corinnidae (0.07%) were subrecedent; Philodromidae (3.66%), Gnaphosidae (3.00%), Clubionidae (2.71%), Zodariidae (2.20%) and Sparassidae (1.31%) were grouped as recedent (Table 2). Sebastian et al. (2005) stated that the Tetragnathidae was found to have high relative abundance in the irrigated rice ecosystem of Central Kerala. Ranjini (2016) also observed that Tetragnathidae (50%) was the dominant in the rice ecosystem of Palakkad district.

The biodiversity analysis indices revealed that the following viz., Shannon-Weiner Diversity Index (H') (was 2.809 in kharif and 2.766 in rabi), Simpson Dominance Index (D) was (0.926 in kharif and 0.909 in rabi), Margalef Richness Index (α) was (4.135 in kharif and 4.22 in rabi) and Pielou's Evenness Index (E1) was (0.104 in kharif and 0.095 in rabi). These indicate that the species diversity and evenness indices during kharif was more abundant compared to that of rabi; and species richness were more or less equal and exhibited a similar diversification in both the seasons. Anitha and Vijay (2016) reported that the Shannon Wiener Index (H') value was 1.53 and 1.81, Simpson Index (D) value was 0.29 and 0.19, Margelef species richness index value was 1.00 and 1.10, Pielou's Evenness Index (E1) was 0.69 and 0.76 in kharif and rabi, respectively in the rice ecosystem of Rajendranagar, Telangana.

Table 1. List of spiders observed in agroecosystems (Karaikal)*

1.	Araneidae	Orb web spiders	*Argiope catenulata* (Doleschall)
			Argiope anasuja (Thorell)
			Larinia chloris (Audouin)
			Larinia sp.
			Neoscona theisi (Walckenaer)
2.	Clubionidae	Sac spiders	*Clubiona drassodes* (O. Pickard-Cambridge)
3.	Corinnidae	Ant mimic sac spiders	*Castianeira zetes* (Simon)
4.	Eutichuridae	Yellow sac spiders	*Cheiracanthium melanostomum* (Thorell)
5.	Gnaphosidae	Ground spiders	*Zelotes* sp.
6.	Lycosidae	Wolf spiders	*Lycosa bistriata* (Gravely)
			Pardosa sumatrana (Thorell)
7.	Oxyopidae	Lynx spiders	*Oxyopes javanus* (Thorell)
			Oxyopes shweta (Tikader)
			Oxyopes sunandae (Tikader)
			Peucetia viridana (Stoliczka)
8.	Philodromidae	Running crab spiders	*Thanatus* sp.
9.	Pisauridae	Nursery web spiders	*Dolomedes fimbriatus* (Clerck)
10.	Salticidae	Jumping spiders	*Carrhotus viduus* (Koch)
			Carrhotus sannio (Thorell)
			Hyllus semicupreus (Simon)
11.	Sparassidae	Giant crab spiders	*Olios lamarcki* (Latrielle)
			Olios milleti (Pocock)
12.	Tetragnathidae	Long jawed spiders	*Tetragnatha mandibulata* (Walckenaer)
			Tetragnatha javana (Thorell)
			Tetragnatha viridorufa (Gravely)
13.	Theridiidae	Comb- footed spiders	*Argyrodes argentatus* (O. Pickard-Cambridge)
14.	Thomisidae	Crab spider	*Platythomisus sudeepi* (Biswas)
			Thomisus sp.
			Tmarus fasciolatus (Simon)
15.	Zodariidae	Ant spider	*Malinella* sp.

Table 2. Relative abundance of spider fauna in agroecosystem (July 2019 to February 2020)

S. No.	Family	No. of Genera	No. of species	Nos.	Relative abundance (%)		Dominance
					kharif	rabi	
1	Araneidae	3	5	208	9.5	5.73	Dominant
2	Clubionidae	1	1	37	1.45	1.26	Recedent
3	Corinnidae	1	1	1	0.07	0	Subrecedent
4	Eutichuridae	1	1	64	2.65	2.04	Subdominant
5	Gnaphosidae	1	1	41	1.6	1.4	Recedent
6	Lycosidae	2	2	137	6.28	3.75	Subdominant
7	Oxyopidae	2	4	294	12.03	9.5	Dominant
8	Philodromidae	1	1	50	2.1	1.56	Recedent
9	Pisauridae	1	1	6	0.23	0.21	Subrecedent
10	Salticidae	2	3	105	4.29	3.39	Subdominant
11	Sparassidae	1	2	18	0.92	0.39	Recedent
12	Tetragnathidae	1	3	298	15.2	6.61	Dominant
13	Theridiidae	1	1	2	0	0.15	Subrecedent
14	Thomisidae	3	3	75	3.38	2.1	Subdominant
15	Zodariidae	1	1	30	1.6	0.6	Recedent
	Total	22	30	1366			

* RA below (1.3)- subrecedent; (1.3 - 3.9) - Recedent; (4 - 12.4) - Subdominant; (12.5 - 39.9) - Dominant and (40 - 100) - Eudominant (Engelmann, 1978).

Correlation with weather parameters during kharif 2019 revealed that *O. javanus* showed negatively significant correlation with bright sunshine (-0.06); similarly *P. sumatrana* with evening RH, and bright sunshine (-0.02, -0.08), and positively significant (0.04) with total rainfall; *T. javana* showed a positively significant one with maximum temperature and total rainfall (0.01, 0.02) and a negatively significant one with morning and evening RH (-0.01, -0.03); *Thomisus* sp. showed a positively significant one with minimum temperature, bright sunshine (0.05, 0.02) and a negative one with morning and evening RH, and total rainfall (-0.07, -0.09, -0.03). There existed a non-significant regression with the weather parameters for *O. javanus* (0.190), *T. mandibulata* (0.347), *T. javana* (0.213), *P. sumatrana* (0.146) and *Thomisus* sp. (0.107). Correlation with weather parameters during rabi 2019-20, showed *L. bistriata* being positively and significantly correlated with total rainfall (0.01); *O. javanus* with a positively significant (0.01) one with minimum temperature and a negatively significant one with total rainfall (-0.07); with *T. javana*, a positively significant (0.08, 0.01, 0.08) correlation with morning and evening RH and total rainfall; *T. mandibulata* showed a positively significant correlation with minimum temperature, and morning and evening RH (0.04, 0.02 and 0.50).

Yadav et al. (2017) reported that maximum RH had a significant and positive impact on the population of the *Oxyopes* sp. in rice agroecosystem of Bihar; Sidar et al. (2017) reported a non-significant positive correlation with maximum (0.074) and minimum temperature (0.28), morning (0.27) and evening RH (0.15), whereas rainfall (-0.20), wind velocity (-0.39) and sun shine hours (-0.14) showed a non-significant negative correlation with maize in Chhattisgarh. Patel et al. (2020) reported that morning and evening RH and rainfall exhibited a positive correlation with spiders in cotton. In Telangana, the abundance of spiders revealed a positive correlation with RH and a negative one with temperature and rainfall in rice (Laxman et al., 2016).

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Table 3. Population dynamics of spider species (kharif 2019, rabi 2019-20)

Spider species	Kharif 2019						Spider species	Rabi 2019-20					
	Temperature (°C)		Relative humidity (%)		Bright sunshine	Total rainfall (mm)		Temperature (°C)		Relative humidity (%)		Bright sunshine	Total Rainfall (mm)
	Maximum	Minimum	Morning	Evening				Maximum	Minimum	Morning	Evening		
Oxyopes javanus	-0.34	-0.32	0.39	0.32	-0.06*	0.12	*Argiope anasuja*	0.60	0.46	-0.68	-0.38	-0.39	-0.27
	Y= -19.92-1.18X_1+1.40X_2+0.62X_3-0.31X_4-0.22X_5-0.06X_6 (0.190 NS)							Y= 65.11-0.19X_1+0.89X_2-0.85X_3-0.13X_4+1.18X_5+0.14X_6 (0.619*)					
Pardosa sumatrana	0.12	0.13	0.02	-0.02**	-0.08*	0.04**	*Lycosa bistriata*	-0.44	-0.19	0.26	0.22	-0.19	0.01**
	Y= -50.09+0.90X_1+0.03X_2+0.21X_3+0.08X_4-0.18X_5-0.04X_6 (0.146 NS)							Y= 22.01-1.77X_1+1.05X_2+0.13X_3+0.02X_4-0.29X_5-0.16X_6 (0.370 NS)					
Tetragnatha javana	0.01**	0.12	-0.01**	-0.03**	-0.26	0.02**	*Oxyopes javanus*	0.11	0.01**	0.22	-0.14	0.18	-0.07*
	Y= 2.80-1.83X_1+2.29X_2+0.35X_3-0.34X_4-0.71X_5-0.05X_6 (0.213 NS)							Y= -137.3+0.25X_1+1.29X_2+1.34X_3-0.29X_4+0.89X_5+0.11X_6 (0.192 NS)					
Tetragnatha mandibulata	-0.28	-0.24	0.31	0.39	-0.37	0.43	*Tetragnatha javana*	0.26	0.41	0.08*	0.01**	-0.32	0.08*
	Y= -33.62+3.64X_1-3.38X_2-0.53X_3-0.86X_4-1.02X_5-0.07X_6 (0.347 NS)							Y= -56.18-0.71X_1+2.12X_2+0.84X_3-0.51X_4-1.41X_5-0.04X_6 (0.516*)					
Thomisus sp.	0.11	0.05*	-0.07*	-0.09*	0.02**	-0.03**	*Tetragnatha mandibulata*	-0.16	0.04**	0.02**	0.50*	-0.27	0.44
	Y= -9.31+0.71X_1-0.60X_2-0.03X_3+0.088X_4-0.01X_5-0.03X_6 (0.107 NS)							Y= -53.36+3.54X_1-3.24X_2-0.84X_3+1.31X_4+0.96X_5-0.01X_6 (0.437 NS)					

* = Significant at p=0.05; ** at p=0.01; NS - Not significant; X_1 = Maximum temperature; X_2 = Minimum temperature; X_3 = Morning relative humidity; X_4 = Evening relative humidity; X_5 = Bright sunshine hours; X_6 = Rainfall

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INTERCROPPING AS SUSTAINABLE APPROACH AGAINST OKRA SHOOT AND FRUIT BORER *EARIAS* SPP.

Ram Kumar*, P P Singh and Kumbhar C R

Department of Entomology,
Dr Rajendra Prasad Central Agricultural University, Pusa, Samastipur 848125, Bihar, India
*Email: rk440659@gmail.com (corresponding author)

ABSTRACT

This study evaluates the effect of maize, sorghum and cowpea as intercrops with okra (at ratio of main: intercrop- of 1:1 and 2:1) against okra shoot and fruit borer *Earias* spp. incidence. The results revealed that the least shoot damage (5.00%) was observed with okra + cowpea (1:1) intercropping followed by okra + cowpea (2:1) and okra + sorghum (1:1). Maximum shoot damage (6.65%) was registered in okra + maize (2:1) as against mono-cropping (7.69%). Similarly, the least fruit damage (12.25%) was in okra + cowpea (1:1) crop statistically on par with that of okra + cowpea (2:1), okra + sorghum (1:1) and okra + sorghum (2:1); maximum (16.41%) was observed with okra + maize (2:1) and okra as a sole crop (18.42%). The okra + cowpea (1:1) recorded the maximum land equivalent ratio (1.31) followed by okra + cowpea 1.20 at 2:1 and okra+ sorghum 1.19 at 1:1 crop ratio. Okra intercropped with maize (2:1) was found less effective (0.99) than the okra sole. The maximum okra equivalent yield (111.4 q/ ha) was obtained with okra + cowpea intercropping (1:1), while the least (100.9 q/ ha) was in okra + maize (2:1).

Key words: Okra, *Earias* spp. intercrop, incidence, shoot and fruit damage, cowpea, sorghum, maize, monocropping, yield, okra equivalent yield, land equivalent ratio

Okra is an important green vegetable crop and its yield is affected by several biotic and abiotic factors, of which, insect pests are the major ones. The crop harbours to a large number of insect pests and vectors (Showkat et al., 2010), and 72 insect species are known (Srinivasa and Rajendran, 2003). Among them, okra shoot and fruit borer *Earias* spp., pose a major threat during kharif. Mohanasundaram et al. (2012) and Anand et al. (2014) observed that it causes 5.33 to 39.6% damage, while Radake and Undirwade (1981) reported it as 88 to 100% fruit damage in cotton. The farmers solely depend on synthetic insecticides for its control, which leads to many hazards like residues, insecticide resistance, pest resurgence, and secondary pest outbreaks. Use of intercropping can be an ecofriendly tool in IPM. The resource concentration hypothesis, evinced that intercropping system have more diverse habitat and thus creates barrier for insect pest movement and colonization. However, in monocropping there is no such implication (Andow, 1991). This study evaluates intercropping as an IPM strategy against okra shoot and fruit borer *Earias* spp.

MATERIALS AND METHODS

The field experiment was carried out at the Research Farm, TCA Dholi, Muzaffarpur (Bihar) during kharif 2018-19 and 2019-20. Okra (sole crop) was raised and with intercrops viz. maize, sorghum and cowpea, at the ratio of 1:1 and 2:1 (main and intercrop) each. The variety was Kashi Pragati of okra while Kashi Kanchan, Suwan and Multicut Sweet Sorghum were the varieties of cowpea, maize and sorghum. The randomized block design (RBD) was used with seven treatments, each replicated thrice. The plot size, inter and intra row spacing for the main crop were 3x2 m, 50 cm and 20 cm, respectively. All the cultural practices, recommended for the main crop were uniformly adopted with the seed rate being according to recommendation for a particular crop. Throughout the cropping period, pesticide application in any form was avoided and crop was harvested only after attaining the crop maturity by the respective crop. Starting from 30 days after sowing, the incidence of *Earias* spp., was observed. Shoot damage was counted randomly on 10 selected tagged plants in each replication at weekly interval and % shoot damage was computed. Mature fruits along with damage fruits were picked at an interval of two to three days and % damage was computed after each picking. Healthy and infested fruits were sorted out and weighed separately to work out the damage on weight basis. Observations with respect to fruit and grain yield of main as well as intercrops were also recorded plot wise. Suitability of different intercrops in okra was finally adjudged from

productivity and economic return points of view, by using the parameters like okra equivalent yield (EY) and land equivalent ratio (LER). The yield of different intercrops was converted into EY of okra crop based on price of the produce. The crop equivalent yield (CEY) was calculated as follows: Crop Equivalent Yield (CEY) = $\sum_{i=1}^{n}(Yi.ei)$, where, Y_i is yield of i^{th} component and e_i is equivalent factor of i^{th} component or price of i^{th} crop. Land equivalent ratio was calculated by using following formula: Land Equivalent Ratio (LER) = $\sum_{i=1}^{m}\frac{Yi}{Yij}$

where, Yi is the yield of i^{th} component from a unit area grown as intercrop and Yij is the yield of i^{th} component grown as sole crop over the same area. The data in respect of incidence and yield were subjected to statistical analysis by using OPSTAT online software.

RESULTS AND DISCUSSION

The data on the shoot and fruit damage in okra under different intercrops presented in Table 1 reveal that the shoot damage in all the crop combination started from 30 days after sowing -DAS and continued till 60 DAS while it attained its peak at 45 DAS. Among all the intercropping okra + cowpea (1:1) intercropping was observed with the least values of 2.85, 7.98 and 2.18% as against 4.58, 12.27 and 3.18% in sole crop at 30, 45 and 60 DAS. On the contrary, intercropping of okra with maize (2:1) led to maximum damage of 4.19, 10.35 and 2.76% at 30, 45 and 60 DAS, respectively. Similarly, on cumulative mean basis also, the least damage (5.00%) was in okra + cowpea (1:1) intercropping followed by okra + cowpea (2:1) (5.43%). The fruit damage varied remarkably among different crop combinations, the incidence started at 45 DAS and then increased continuously to it's a peak at 75 DAS, and then declined. The fruit infestation at 45, 60, 75 and 90 DAS ranged from 3.55 to 4.84, 13.17 to 18.26, 19.64 to 25.34 and 12.63 to 17.19%, respectively. However, on cumulative mean basis the least fruit damage (12.25%) was in okra + cowpea (1:1) which was statistically on par with okra + cowpea (2:1) of 13.31%, okra + sorghum (1:1) of 13.96%, and okra + sorghum (2:1) at 15.00%. The maximum fruit damage (16.41%) was recorded in okra + maize (2:1). Thus, okra intercropped with cowpea (1:1) was the best combination, which was statistically on par with okra + cowpea (2:1), okra + sorghum (1:1) and okra + sorghum (2:1). These results agree with those of Abro et al. (2004) on *Earias* spp. in cotton that okra can be used as a trap crop. Mohanasundaram et al. (2012) observed that intercropping of okra and cluster bean with Neembaan and spinosad spray led to the least fruit damage due to *E. vitella*. Sujayanand et al. (2016) observed that marigold intercropped with okra is the best followed by okra and coriander. In contrast, Mansour (2017) and Zakka et al. (2018) concluded that okra, intercropped with maize harbored maximum infestation of various pests.

Table 1. Effect of intercropping on shoot and fruit damage by *Earias* spp., in okra (pooled data, kharif, 2018, 2019)

Intercropping system	% shoot damage				% fruit damage (weight basis)				
	30 DAS	45 DAS	60 DAS	Cumulative mean	45 DAS	60 DAS	75 DAS	90 DAS	Cumulative mean
T_1 - Okra + Maize (1:1)	3.93 (11.42)#	10.00 (18.42)	2.58 (9.23)	6.35 (14.58)	4.52 (12.25)	16.65 (24.06)	24.20 (29.43)	16.13 (23.65)	15.37 (23.06)
T_2 - Okra + Maize (2:1)	4.19 (11.81)	10.35 (18.75)	2.76 (9.56)	6.65 (14.94)	4.84 (12.69)	18.26 (25.27)	25.34 (30.18)	17.19 (24.47)	16.41 (23.87)
T_3 - Okra + Sorghum (1:1)	3.46 (10.72)	9.26 (17.71)	2.45 (9.00)	5.85 (13.99)	4.25 (11.88)	15.37 (23.05)	21.88 (27.86)	14.32 (22.20)	13.96 (21.91)
T_4 - Okra + Sorghum (2:1)	3.58 (10.90)	9.59 (18.03)	2.64 (9.33)	6.08 (14.27)	4.45 (12.17)	16.24 (23.73)	23.62 (29.03)	15.70 (23.32)	15.00 (22.76)
T_5 - Okra + Cowpea (1:1)	2.85 (9.71)	7.98 (16.39)	2.18 (8.47)	5.00 (12.92)	3.55 (10.84)	13.17 (21.24)	19.64 (26.29)	12.63 (20.80)	12.25 (20.47)
T_6 - Okra + Cowpea (2:1)	3.06 (10.06)	8.69 (17.14)	2.34 (8.78)	5.43 (13.46)	4.03 (11.57)	14.09 (22.00)	20.85 (27.15)	14.27 (22.17)	13.31 (21.37)
T_7 - Okra (sole crop)	4.58 (12.34)	12.27 (20.49)	3.18 (10.26)	7.69 (16.09)	5.77 (13.88)	20.50 (26.89)	28.74 (32.40)	18.66 (25.58)	18.42 (25.39)
SEm(±)	(0.21)	(0.28)	(0.26)	(0.13)	(0.35)	(0.84)	(0.89)	(0.77)	(0.69)
CD (p=0.05)	(0.65)	(0.88)	(0.80)	(0.42)	(1.10)	(2.63)	(2.77)	(2.39)	(2.51)
CV	6.41	5.16	9.55	3.32	9.71	11.42	9.80	10.71	9.98

DAS - Days after sowing; #Figures in parentheses values angular transformation.

Table 2. Competition functions and economics of intercropping (pooled data, kharif, 2018, 2019)

Intercropping system	Yield (q ha^{-1})			Gross return (Rs ha^{-1})	Profit/ loss over okra sole crop (Rs ha^{-1})	Land Equivalent Ratio (LER)
	Main crop	Intercrop	Okra equivalent			
T_1 - Okra + Maize (1:1)	64.5	32.8	110.0	137326.0	821.0	1.12
T_2 - Okra + Maize (2:1)	73.5	19.7	100.9	125980.0	- 10525.0	0.99
T_3 - Okra + Sorghum (1:1)	71.5	19.5	110.4	137825.0	1320.0	1.19
T_4 - Okra + Sorghum (2:1)	79.5	13.5	106.4	132845.0	- 3660.0	1.10
T_5 - Okra + Cowpea (1:1)	79.0	8.9	111.4	139140.0	2635.0	1.31
T_6 - Okra + Cowpea (2:1)	89.0	5.8	111.2	137710.0	1205.0	1.20
T_7 - Okra (sole crop)	109.3		109.3	136505.0		
SEm(±)	3.39		4.06			
CD (p=0.05)	10.57		12.20			
CV	7.26		6.49			

The intercropping with okra as main component differed in productivity as per seasons (Table 2). Consistently, intercropping of cowpea with okra (2:1) was found superior with maximum yield (89.0 q/ ha) over sole crop (109.35 q/ ha), while the least (64.5 q/ ha) was obtained in maize intercropped with okra (1:1). Thus, okra + cowpea (1:1) resulted in the maximum LER (1.31) followed by okra + cowpea 1.20 at 2:1 and okra + sorghum 1.19 at 1:1 crop ratio, and it is more efficient over sole okra. On the contrary, okra intercropped with maize (2:1) was found less efficient (0.99) than the okra sole. The maximum okra equivalent yield (111.4 q/ ha) was in okra + cowpea intercropping (1:1) while it was minimum (100.9 q ha) in okra + maize (2:1). Thus, intercropping of cowpea with okra (1:1) and (2:1) worked efficiently with respect to LER and okra equivalent yield while the okra + maize (2:1) crop combination was found least effective. Mohamed et al. (2007) studied the impact of cucumber and cowpea as against okra monocropping and reported that okra and cucumber had the maximum LER. Further, Das et al. (2017) evaluated chickpea and rapeseed as intercrops in different proportions and sole crop too, and maximum LER was with intercrop.

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EFFICACY OF BOTANICALS AGAINST MULBERRY WHITEFLY *DIALEUROPORA DECEMPUNCTATA* (QUAINTANCE AND BAKER) AND THEIR SAFETY TO NATURAL ENEMIES

Ayan Das* and Hirak Chatterjee[1]

*Department of Agricultural Entomology, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur 741252, West Bengal, India
[1]Department of Agricultural Entomology, Palli Siksha Bhabana, Institute of Agriculture, Visva Bharati, Sriniketan, 731236, West Bengal, India
*Email: ayandasvb@gmail.com (corresponding author)

ABSTRACT

In the evaluation of efficacy of seven biopesticides, two foliar sprays done at fifteen days interval were effective in reducing whitefly *Dialeuropora decempunctata* (Quintance and Baker) incidence in mulberry. Neem oil (3%) was the most effective (71.10% reduction over control) followed by pongamia oil (3%) and Torpedo (plant extract of *Sophora* and *Stemona* sp.-1ml/ l) by 65.14% and 59.61%, respectively. Tobacco decoction (5%), ginger rhizome extract (15%) and chilli-garlic extract were the least effective. All the evaluated botanicals were safe to natural enemies observed on mulberry. Chilli-garlic extract and ginger rhizome extract were the safest against coccinellids and spiders, respectively.

Key words: Mulberry, *Dialeuropora decempunctata*, neem oil, pongamia oil, tobacco decoction, ginger rhizome extract, toxicity, coccinellids, spiders, safety

Mulberry (*Morus alba* L.) is the sole food source of silk worm *Bombyx mori* L. However luxuriant growth of mulberry invites > 300 species of insect and non-insect pests resulting in considerable reduction in leaf yield and quality. These are the major constraints in silk worm rearing and cocoon productivity (Reddy and Kotikal, 1988). In addition, poor quality mulberry leaves lead to disrupted growth of larvae, high larval mortality, small and thin-walled cocoons and adult deformities (Dadd, 1973). Whitefly *Dialeuropora decempunctata* (Quaintance and Baker) (Homoptera: Aleyrodidae) is a major pest infesting mulberry during July- November. Its infestation leads to 10-24% loss in leaf yield during major silk worm cocoon crop (October-November) (Bandyopadhyay et al., 2001). Sucking of plant juice by nymphs and adults and growth of sooty mould renders the leaves unfit for feeding (Patnaik et al., 2009). Sucking pests are the major production constraints in mulberry and among the sucking pests whiteflies are serious (Hosamani et al., 2020). Hence, routine insecticide application is unavoidable to protect the plants from infestation. The application of insecticides with high toxicity and prolonged residual effects in mulberry gardens is restricted because of the high sensitivity of silk worms to insecticides. Besides, the whiteflies tend to develop resistance very fast against repeated application of insecticides having the same mode of action. Hence, the present study was focused to find an effective and ecofriendly botanical pesticide to combat the whitefly infestation in mulberry.

MATERIALS AND METHODS

The experiment was conducted at the experimental plot of Central Sericulture Research and Training Institute (CSRTI) at Berhampore, Murshidabad, West Bengal during kharif season (August-October, 2016 and 2017). The trail was laid out with variety S1 in plots measuring 6x 5 m in randomized block design with eight treatments and three replications, with spacing maintained at 60x 60 cm. All agronomic practices were uniform in all experimental plots except the pest management options. Two sprays were given at fortnightly intervals with a knapsack sprayer from one month after pruning. The treatments comprised- T_1 = pongamia oil (3%), T_2 = neem oil (3 %), T_3 = NSKE (5%), T_4 = Torpedo (plant extract of *Sophora* and *Stemona* sp. @1ml/ l), T_5 = chilly-garlic extracts (5%), T_6 =15% rhizome extract of ginger, T_7 =tobacco decoction 5%, T_8 = untreated Control. Observations on *D. decempunctata* were made one day before treatment (pretreatment count) and 1, 3, 7 and 10 days after spray (DAS) from 3 leaves, one each from top, middle and bottom of 5 randomly selected plants/ plot. Simultaneously, all

Table 1. Efficacy of botanicals against adult *D. decempunctata* (2016 & 2017, pooled)

	Treatments	PTC	I Spray				II Spray				Mean
			1 DAS	3 DAS	7 DAS	10 DAS	1 DAS	3 DAS	7 DAS	10 DAS	
T_1	Pongamia oil (3%)	38.67	20.07± 1.51 (4.53)^{bc}	16.40± 0.80 (4.11)^{ab}	14.88± 0.30 (3.92)^{b}	17.47± 0.70 (4.24)^{b}	14.31± 1.09 (3.85)^{a}	12.07± 1.87 (3.54)^{ab}	11.27± 1.05 (3.43)^{b}	12.77± 1.72 (3.64)^{ab}	14.89
T_2	Neem oil (3%)	39.33	18.50± 1.10 (4.36)^{a}	12.83± 1.43 (3.65)^{a}	11.33± 0.91 (3.44)^{a}	14.70± 1.01 (3.90)^{a}	12.63± 1.04 (3.62)^{a}	9.57± 0.33 (3.17)^{a}	8.50± 1.01 (3.00)^{a}	10.60± 1.00 (3.33)^{a}	12.34
T_3	NSKE (5%)	40.67	25.80± 1.85 (5.13)^{d}	19.53± 2.10 (4.47)^{b}	17.83± 1.05 (4.28)^{c}	21.23± 1.29 (4.66)^{c}	21.03± 0.64 (4.64)^{bc}	16.43± 0.80 (4.11)^{cd}	15.40± 1.21 (3.99)^{cd}	18.27± 1.40 (4.33)^{c}	19.54
T_4	Torpedo (1ml/l)	38.33	23.75± 1.06 (4.92)^{cd}	17.43± 1.10 (4.23)^{b}	15.93± 1.21 (4.05)^{bc}	19.87± 1.00 (4.51)^{bc}	18.27± 1.74 (4.33)b	14.17± 1.88 (3.82)^{bc}	12.97± 0.57 (3.67)^{bc}	15.73± 1.10 (4.03)^{bc}	17.25
T_5	Chilli-Garlic extracts (5%)	38.67	25.79± 3.70 (5.12)^{d}	19.61± 1.91 (4.48)^{b}	18.20± 1.25 (4.32)^{c}	21.78± 1.11 (4.72)^{c}	21.93± 2.21 (4.73)^{bc}	17.47± 0.99 (4.24)^{cd}	16.23± 1.50 (4.09)^{d}	19.07± 2.93 (4.42)^{c}	20.03
T_6	15% Rhizome extract of Ginger	41.67	26.00± 1.60 (5.15)^{d}	20.30± 0.61 (4.56)^{b}	18.70± 0.75 (4.38)^{c}	22.37± 0.68 (4.78)^{c}	21.77± 2.36 (4.71)^{bc}	17.60± 1.06 (4.25)^{d}	16.43± 1.15 (4.11)^{d}	19.08± 1.10 (4.42)^{c}	20.26
T_7	Tobacco decoction 5%	41.33	26.90± 1.05 (5.23)^{d}	20.25± 1.75 (4.55)^{b}	18.57± 0.65 (4.37)^{c}	22.57± 0.58 (4.80)^{c}	22.90± 1.28 (4.84)^{c}	18.00± 0.72 (4.30)^{d}	16.80± 0.87 (4.16)^{d}	19.87± 2.59 (4.51)^{c}	20.77
T_8	Untreated Control	39.67	38.87± 1.53 (6.27)^{e}	40.70± 1.41 (6.42)^{c}	41.80± 2.27 (6.50)^{d}	45.37± 0.97 (6.77)^{d}	41.60± 1.06 (6.49)^{d}	43.43± 1.21 (6.63)^{e}	43.87± 1.80 (6.66)^{e}	45.33± 1.27 (6.77)^{d}	42.71
S. Em.±			0.10	0.10	0.08	0.06	0.10	0.09	0.09	0.12	
CD at 5%			0.30	0.31	0.22	0.18	0.29	0.27	0.25	0.36	

Mean values of three replications represented as mean± standard deviation; Figures in parentheses √(x+0.5) transformed values; Values followed by same letter not significantly different from each other, Tukey HSD ($p \leq 0.05$); S. Em: Standard error of mean; CD: Critical difference, PTC-pretreatment cum.

Table 2. Impact of botanicals against predatory fauna in mulberry (2016 & 2017, pooled; mean of 1st and 2nd sprays)

	Treatments	No. coccinellids/ plant						No. spiders/ plant					
		PTC	1 DAS	3 DAS	7 DAS	10 DAS	Mean	PTC	1 DAS	3 DAS	7 DAS	10 DAS	Mean
T_1	Pongamia oil (3%)	4.00	2.72 (1.79)^{ab}	2.32 (1.68)^{ab}	3.01 (1.87)^{a}	3.69 (2.05)^{ab}	2.93	3.83	2.91 (1.85)^{a}	3.45 (1.99)^{a}	3.58 (2.02)^{a}	3.58 (2.02)^{a}	3.38
T_2	Neem oil (3%)	4.33	2.34 (1.69)^{a}	1.68 (1.48)^{a}	2.67 (1.78)^{a}	3.32 (1.95)^{a}	2.50	4.03	3.24 (1.93)^{ab}	3.29 (1.95)^{a}	3.49 (2.00)^{a}	3.72 (2.05)^{a}	3.43
T_3	NSKE (5%)	4.67	3.69 (2.05)^{b}	2.32 (1.68)^{ab}	3.32 (1.95)^{ab}	3.99 (2.12)^{ab}	3.33	4.0	3.20 (1.92)^{ab}	3.53 (2.01)^{a}	3.66 (2.04)^{a}	3.81 (2.08)^{a}	3.55
T_4	Torpedo (1ml/l)	4.33	3.01 (1.87)^{ab}	2.72 (1.79)^{ab}	3.83 (2.08)^{ab}	4.17 (2.16)^{ab}	3.43	4.20	3.85 (2.09)^{ab}	3.66 (2.04)^{a}	3.78 (2.07)^{a}	4.02 (2.13)^{a}	3.83
T_5	Chilli-Garlic extracts (5%)	4.67	2.81 (1.82)^{ab}	3.37 (1.97)^{b}	3.90 (2.10)^{ab}	4.31 (2.19)^{ab}	3.60	3.90	3.26 (1.94)^{ab}	3.29 (1.95)^{a}	3.61 (2.03)^{a}	3.83 (2.08)^{a}	3.50
T_6	15% Rhizome extract of Ginger	3.67	3.01 (1.87)^{ab}	2.19 (1.64)^{ab}	2.95 (1.86)^{a}	3.34 (1.96)^{a}	2.87	4.00	3.63 (2.03)^{ab}	3.58 (2.02)^{a}	3.91 (2.10)^{a}	3.74 (2.06)^{a}	3.72
T_7	Tobacco decoction 5%	4.33	3.38 (1.97)^{ab}	2.72 (1.79)^{ab}	2.76 (1.81)^{a}	3.72 (2.05)^{ab}	3.14	3.80	3.24 (1.93)^{ab}	3.35 (1.96)^{a}	3.37 (1.97)^{a}	3.61 (2.03)^{a}	3.39
T_8	Untreated Control	4.00	5.42 (2.43)^{c}	5.68 (2.49)^{c}	4.88 (2.32)^{c}	5.29 (2.41)^{b}	5.32	4.12	4.52 (2.24)^{b}	4.65 (2.27)^{b}	4.22 (2.17)^{a}	4.31 (2.19)^{a}	4.43
S. Em.±			0.11	0.10	0.13	0.12			0.12	0.07	0.10	0.10	
CD at 5%			0.32	0.30	0.37	0.37			0.34	0.20	0.28	0.28	1

Figures in parentheses √(x+0.5) transformed values; Values followed by same letter not significantly different from each other, Tukey HSD ($p \leq 0.05$); S.Em: Standard error of mean; CD: Critical difference.

predatory coccinellids and spiders, irrespective of species were counted/ plant. These counts were taken up during the morning hours (Naranjo and Flint, 1995). The incidence of *D. decempunctata* observed before and after sprays were converted to % reduction as per the modified Abbot's formula (Flemings and Ratnakaran, 1985). The data were subjected to ANOVA whereas means with significant difference were differentiated using Tukey HSD (honestly significant difference; p=0.05) with SPSS® version 25.0.

RESULTS AND DISCUSSION

Efficacy of botanical extracts evaluated against *D. decempunctata* on mulberry fields as given in Table 1 reveals that there was no significant difference in pretreatment counts. However, all the treatments differed significantly in reducing the incidence after one, three, seven and ten day after spraying (DAS). The pooled data revealed that maximum reduction (71%) was observed with 3% neem oil; it is followed by 3% pongamia oil and with plant extract of *Sophora* and *Stemona* sp. @1ml/ l; NSKE (5%) gave 54.25% reduction on par with plant extract of *Sophora* and *Stemona* sp., and 15% rhizome extract of ginger. The treatments comprising of tobacco decoction (5%) (T7) was the least effective. Maximum occurrence of predatory coccinellids and spiders was observed with chilly-garlic extracts (3.60/ plant); neem oil causes up to 53.01% mortality of coccinellids, while with spiders, pongamia oil (3%) followed by 5% tobacco decoction led to reduction of 23.70% and 23.48%, respectively. The predatory coccinellids and spiders got least affected with by the application of plant extract of *Sophora* and *Stemona* sp.

These findings are in line with those of Sharma and Summarwar (2017), on cotton with whitefly- maximum with neem oil + liquid soap. Naik et al. (2012) observed that the plant product chilly-garlic extracts was the least effective compared to the neem products. Jha and Kumar (2017) also confirmed that tobacco decoction is less effective over neem in reducing whiteflies. The present study confirmed that the botanicals are slightly or least toxic towards the predatory fauna which concurs with the findings of Ranga Rao et al. (2007). Thus, it is concluded from the present study that field application of botanicals like neem oil, pongamia oil and plant extract of *Sophora* and *Stemona* sp. are efficient against mulberry whitefly, and were also less toxic to the predators.

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TOXICITY OF SOME INSECTICIDES TO THE FALL ARMY WORM *SPODOPTERA FRUGIPERDA*

S Mastan Shareef*, T Madhumathi, M Swathi and A K Patibanda

Department of Entomology, Agricultural College, Bapatla 522101, Andhra Pradesh, India
*Email: mastanshareefsyed91@gmail.com (corresponding author)

ABSTRACT

A laboratory bioassay (topical application) was conducted to evaluate the relative toxicity of ten insecticides against third instar larvae of fall army worm, *Spodoptera frugiperda* (J E Smith). Emamectin benzoate was found to be the most toxic with least LC_{50} value (1 ppm). The order of toxicity was emamectin benzoate (1 ppm)> spinetoram (1.2 ppm)> chlorantraniliprole (1.8 ppm)> novaluron+ emamectin benzoate (7.7 ppm)> novaluron (18 ppm)> novaluron+ indoxacarb (31.7 ppm)> flubendiamide (33.8 ppm)> indoxacarb (42.3 ppm)> lambda-cyhalothrin (77.2 ppm)> chlorpyriphos (184.7 ppm). Emamectin benzoate, spinetoram, chlorantraniliprole, novaluron+ emamectin benzoate, novaluron, novaluron+ indoxacarb, flubendiamide, indoxacarb and lambda-cyhalothrin showed 184.70, 153.92, 102.61, 23.99, 10.26, 5.83, 5.46, 4.37 and 2.39 folds toxicity over chlorpyriphos, respectively at 72 hr after treatment.

Key words: *Spodoptera frugiperda*, bioassay, topical application, novaluron, emamectin benzoate, indoxacarb and spinetoram, relative toxicity, LC_{50}

Fall army worm (FAW) *Spodoptera frugiperda* (J E Smith) is an invasive pest, which was first reported from Karnataka, in maize fields during mid-May 2018 (Sharanabasappa et al., 2018a). Since then, it has spread to different southern states of India on maize (Mahadevaswamy et al., 2018; Sharanabasappa et al., 2018b). It is a severe polyphagous pest with a wide host range of 186 plant species including many economically important crops such as maize, sorghum, sugarcane, rice, wheat, cowpea, groundnut, potato, soybean and cotton (Casmuz et al., 2010). Adult moths can travel up to 500 km during a single season to seek out oviposition sites and can fly over 100 km for seeking the host plants. It is capable of causing 34% yield losses in maize. In America and Africa, insecticides are used widely for its management (Hardke et al., 2011; Gutierrez-Moreno et al., 2019; Sisay et al., 2020). The present study evaluates the toxicity of some new molecules with a different mode of action against *S. frugiperda* through laboratory bioassay.

MATERIALS AND METHODS

The present study was carried out under laboratory conditions during 2019-2020 at the Department of Entomology, College of Agriculture, Bapatla. The egg mass of *S. frugiperda* was collected from the maize fields of Agricultural College Farm, Bapatla and reared on maize leaves under laboratory condition until pupation (27±2˚C; 70±2% RH). The commercial formulations viz., emamectin benzoate (Proclaim 5 SG; Syngenta Private Limited), spinetoram (Largo 11.7SC; Dhanuka Agritech Limited), chlorantraniliprole (Coragen 18.5SC; DuPont India Private Limited), novaluron (Rimon 10EC; Gharda Chemicals Limited), lambdacyhalothrin (Karate 5EC; Syngenta Private Limited), flubendiamide (Fame 39.35SC; Bayer Crop Science Limited), novaluron+ indoxacarb (Plethora 5.25EC+ 4.5SC; Adama India Private limited), novaluron+ emamectin benzoate (Barazide 5.25EC+ 0.9SC; Adama India Private Limited), indoxacarb (Kingdoxa 14.5SC; Gharda Chemicals Limited) and chlorpyriphos (Lethal 20EC; Insecticides India Limited) were evaluated. The third instar larvae were used for bioassay with the topical application method. 10000 ppm stock solution of 100 ml was prepared for each insecticide by dissolving in distilled water. From this stock solution the desired concentration was prepared by serial dilution using distilled water as a solvent. Initially, a broad range of concentrations was tested and depending on the mortality narrow range were tested until larval mortality could be obtained to a range of 10 to 90%.

Ten 3rd instar larvae were used in each treatment and replicated thrice. 1µl of the insecticidal solution was applied on the thoracic dorsum of third instar larvae using Hamilton microsyringe and in control larvae were treated with distilled water only. A larva was considered dead if it could not turn itself right

after being placed on its dorsal surface. The mortality at 72 hr after treatment was considered as the endpoint for the assessment of the toxicity and the corrected % mortality of larvae was calculated as per Abbott's (1925). Data on % corrected mortality was subjected to probit analysis (Finney, 1971) with SPSS (Statistical Package for Social Science) 21.0 version software. LC_{50}, LC_{75}, LC_{90}, heterogeneity (χ^2), intercept (a), slope of the regression line (b), regression equation and fiducial limits (at 95% C.L) were computed for each insecticide, and the relative toxicity was determined with the least toxic one taken as an unit.

RESULTS AND DISCUSSION

Among the ten insecticides evaluated against third instar larvae of *S. frugiperda* using topical application method, emamectin benzoate proved to be highly toxic to *S. frugiperda* with the least LC_{50} (1.0 ppm), LC_{75} (2.7 ppm) and LC_{90} (6.7 ppm) values followed by spinetoram, chlorantraniliprole, novaluron + emamectin benzoate, novaluron, novaluron + indoxacarb, flubendiamide, indoxacarb, lambdacyhalothrin and chlorpyriphos. The order of relative toxicity based on LC_{50}, LC_{75} and LC_{90} values in the descending order over chlorpyriphos was emamectin benzoate > spinetoram > chlorantraniliprole > novaluron + emamectin benzoate > novaluron > novaluron + indoxacarb > flubendiamide > indoxacarb > lambda-cyhalothrin (Table 1).

At 72 HAT, the LC_{50} value of emamectin benzoate was 1 ppm. The present findings are in agreement with observstions of Sharanabasappa et al. (2020) with second instar larvae of *S. frugiperda*; emamectin benzoate was the most toxic with LC_{50} value of 0.0051 ppm and novaluron was the least toxic with LC_{50} value of 0.061 ppm. Similarly, Dhawan et al. (2007) reported that emamectin benzoate was the most toxic against *S. litura*. Spinetoram also exerted toxicity with an LC_{50} value of 1.2 ppm and this corroborates with the the results of Sanjeevi Kumar and Muthukrishnan (2017) of spinetoram on third instar larvae of *Exelastis atomosa*. Karuppaiah et al. (2017) reported that chlorantraniliprole was found effective with LC_{50} values of 1-4 ppm against third instar larvae of *S. litura*. Dhawan et al. (2007) reported that novaluron was found effective against *S. litura* with an LC_{50} value of 0.0020%. At 72 HAT the LC_{50} value of novaluron + indoxacarb was 31.7 ppm and which is in agreement with the results of Patra et al. (2015) who evaluated the toxicity of novaluron + indoxacarb against third instar larvae of *Plutella xylostella*. Dhawan et al. (2007) found that the toxicity (LC_{50}) of flubendiamide was 0.0040%

Table 1. Relative toxicity of insecticides against 3rd instar larvae of *S. frugiperda* at 72 hr after treatment

Tr. No.	Insecticide	LC values (ppm)			Fiducial limits (ppm) (95% C. L)		Relative toxicity			Hetero-geneity (χ^2) d. f = 5	Slope (b) ± S. E	Regression equation (Y = a + bx)
		LC_{50}	LC_{75}	LC_{90}	LC_{50}	LC_{90}	LC_{50}	LC_{75}	LC_{90}			
1	Emamectin benzoate	1.0	2.7	6.7	0.08-1.2	5.3-8.9	184.70	108.52	66.25	1.768	1.56±0.59	Y = 0.02+1.56x
2	Spinetoram	1.2	3.8	10.2	1.0-1.5	7.8-14.3	153.92	77.11	43.52	1.552	1.42±0.59	Y = 0.13+1.42x
3	Chlorantraniliprole	1.8	4.6	11.0	1.5-2.1	8.8-14.3	102.61	63.70	40.35	1.904	1.61±0.77	Y= 0.42+1.61x
4	Novaluron	18.0	33.8	59.8	16.1-20.0	51.2-72.1	10.26	8.67	7.42	0.380	2.45±0.21	Y = 3.07+2.45x
5	Lambda-cyhalothrin	77.2	132.0	213.7	70.2-84.6	119.3-148.3	2.39	2.22	2.08	1.332	2.80±0.39	Y = 5.30+2.80x
6	Flubendiamide	33.8	68.5	129.1	29.4-38.2	60.9-77.8	110.6-156.2	5.46	4.28	3.44	0.362	2.21±0.27
7	Novaluron + Indoxacarb	31.7	56.0	93.4	28.7-34.9	56.0-62.8	81.7-109.0	5.83	5.23	4.75	0.113	2.72±0.27
8	Novaluron + Emamectin benzoate	7.7	15.7	29.8	6.7-8.7	13.8-18.1	25.1-36.7	23.99	18.66	14.90	2.212	2.07±0.16
9	Indoxacarb	42.3	72.4	117.3	38.3-46.4	60.0-80.1	104.0-135.5	4.37	4.05	3.78	1.949	2.87±0.33
10	Chlorpyriphos	184.7	293.0	443.9	169.5-200.3	269.2-321.7	398.2-505.4	1.00	1.00	1.00	2.851	3.43±0.49

LC_{50}= Concentration that confers 50% mortality (95% Confidence Intervals); LC_{75} = Concentration that confers 75% mortality (95% Confidence Intervals); LC_{90} = Concentration that confers 90% mortality (95% Confidence Intervals)

against *S. litura*, whereas in the present study it is 33.8 ppm. The LC_{50} value at 72 HAT for indoxacarb was 42.3 ppm and a similar type of results was reported by Gupta et al. (2005) against *H. armigera*. Chlorpyriphos exerted the least toxicity with LC_{50} of 184.7 ppm and these results were in accordance with the reports of Mahesh et al. (2020) on *S. litura*.

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ELYTRAL POLYMORPHISM IN SEVEN SPOTTED LADYBIRD BEETLE *COCCINELLA SEPTEMPUNCTATA* L.

Mohammad Thamseer M K*, S S Yadav, Rahul Saini and Krishna Rolania

Department of Entomology, Chaudhary Charan Singh
Haryana Agricultural University, Hisar 125004, Haryana, India
*Email: thamseeransar@gmail.com (corresponding author)

ABSTRACT

The existence of polymorphs in the seven spotted ladybird beetle *Coccinella septempunctata* L. (Coleoptera: Coccinellidae) when analysed revealed five morphs collected in different seasons. These were predating on sucking pests infesting cotton and wheat. The morphological characters including male genitalia were studied in these. The abundance of various morphs revealed morph 1 with maximum abundance (73.3%), and the frequency of the melanic forms increased with the decrease in temperature.

Key words: *Coccinella septempunctata*, elytra, colour, polymorphs, Haryana, pronotal pattern, spots and patterns on elytra, temperature, abundance, wheat, cotton, aphids, whitefly

Polymorphism is the occurrence of phenotypic variation within a species (Gullan 2014). The ground colour, patterns and spots on wings are among the characters that vary. Polymorphic trait may be present in both the sexes or may exhibit sexual dimorphism (Bonduriansky, 2017). The phenomenon of polymorphism has been attributed to various causes including structural (Kurachi et al., 2002), physiological and molecular basis (Nijhout, 1982;Van Gossum, 2008). Coccinellidae is a large family with around 6000 species globally (Vandenberg, 2002) and 520 species are in India (Poorani, 2004). The polymorphism in coccinellids is widely studied and numerous morphs are known among ladybird beetles (Blehman, 2007; Karthika, 2017; Kawakami et al., 2013; Singh et al., 2016; Zare et al., 2012). Such morphs lead to misidentifications- for instance, the two variants of *Coccinella septempunctata* L. namely *C. septempunctata* var. *divaricata* and *C. septempunctata* var. *confusa* were considered as separate species (Olivier, 1808; Wiedemann, 1823) while others regarded them as mere genetic variants (Mader, 1936; Varma, 1954; Rao, 1962).

Hence, the knowledge of polymorphism is imperative to identify the species accurately. The elytral polymorphism is maintained in the natural population through non-random mating with the male elytral colour being one of the key factor in mate selection by female (Osawa and Nishida, 1992).Thus the study of polymorphism both at the morphological and genetic level is warranted (Hodek et al., 2012). Polymorphism in ladybird beetles has been well studied and provide evidence of natural variation and micro evolutionary processes occurring in nature (Honek et al. 2012; Gautier et al., 2018). The knowledge on the polymorphs of the coccinellids is scanty in India, and in *C. septempunctata*, one of the most common predators found in both agricultural and horticultural habitats, it is poorly studied (Hodek and Honek, 2013). The present study documents the presence and frequency of different morphs of *C. septempunctata* in Haryana.

MATERIALS AND METHODS

The study was carried out with samples collected from different locations of Haryana comprising all the three agroclimatic zones of the state namely arid, semi-arid and subhumid zones spanning over (27^{o} 37'- 30^{o}35'N, 74^{o}28'- 77^{o}36'E). The ladybird beetles were collected by both hand collection and using aerial nets during winter between March and November, 2020. These were collected from wheat fields on aphids namely *Sitobion avenae* and *Rhopalosiphum maidis* (Hemiptera: Aphididae) while in summer and kharif, were collected on the whitefly *Bemisia tabaci* (Hemiptera: Aleyrodidae) in cotton. The collected specimens were killed using ethyl alcohol in killing bottles and stored in vails containing 70% ethyl alcohol. The beetles were observed under stereozoom microscope (Zeiss Stemi 508) and the differences in characters such as pronotal pattern, spots and patterns on elytra were used to designate the morphs. The species identity was confirmed through morphological and male genitalia characters using the available key (Gordon, 1985)

RESULTS AND DISCUSSION

Among the 605 specimens collected across Haryana, five morphs of *C. septempunctata* were designated based on the variation in the elytral patterns (Fig. 1). The seasonal variation of polymorph frequency is depicted in Table 1. The characters of morphs are as follows:

Morph-1: Elytra with seven distinct spots (Fig 1a). The ground colour is highly variable and may be yellow, orange, red, brownish red or pinkish orange. There is no distinct sutural line. A large eye drop with a neck shaped maculae is present on the scutellum with white triangular spots on the base of both the elytron lying adjacent to it. Both the elytra contain three circular spots each with two spots present at around the end of anterior one third of the elytron and the third spot present at the beginning of the posterior one third of the wing. This morph was found in highest abundance (73.3%) across the collection sites and accounted for 100% of the specimen collected in summer and kharif.

Morph-2: Elytra with two pairs of fused spots and a free scutellar spot. The spot on the scutellum is same as present in morph 1 (Fig. 1b). Each elytron with three fused oblique spots. Two lateral spots on each elytron forming a dumb bell shape with the posterior spot being bigger and connected by a narrow bridge. Other spots present on either side of the sutural line midway through the elytron is nearly as big as the posterior spot and is joined broadly to the smaller maculae situated adjacently. This morph corresponds to *C. septempunctata* var. *confusa* as described by Wiedmann (Weidmann, 1823).

Morph-3: Elytra with separately fused scutellar and fused lateral spots. The scutellar spot is fused with the anterior spots on each elytron forming a triangular pattern (Fig. 1c). Both the lateral spots on each elytron are very narrowly joined by a thin black line. The posterior maculae reach the caudal end of the elytra and on dorsal view, the distal one third of the elytron appears black. The ground colour of elytra may be yellow, orange or red.

Morph-4: Elytra with distinct scutellar and anterior circular spots and fused lateral spots with vague black strips in elytra joining them. The scutellar spot is eye drop with a neck shaped while the anterior spots adjacent to the sutural line are circular in shape and free (Fig 1 d). The lateral spots are relatively closely spaced and joined together by a broad bridge. A faint black pattern runs in the elytron which passes through all the spots. No distinct sutural line and the ground colour is red.

Morph-5: All the spots coalesce to form a continuous anchor shaped pattern on the elytra. The spots present on both elytron fuse horizontally and vertically along the margin of the sutural line (Fig. 1e). The posterior pattern ends parallel to the elytra without touching the caudal margin. The coalesced spots leave a yellowish nearly triangular area in between them. This was the least abundant morph with only twelve specimen (3.2%).

The results of the present study agree with Kalaisekar et al. (2012) who identified three morphs on the basis of elytral base colour rather than the patterns

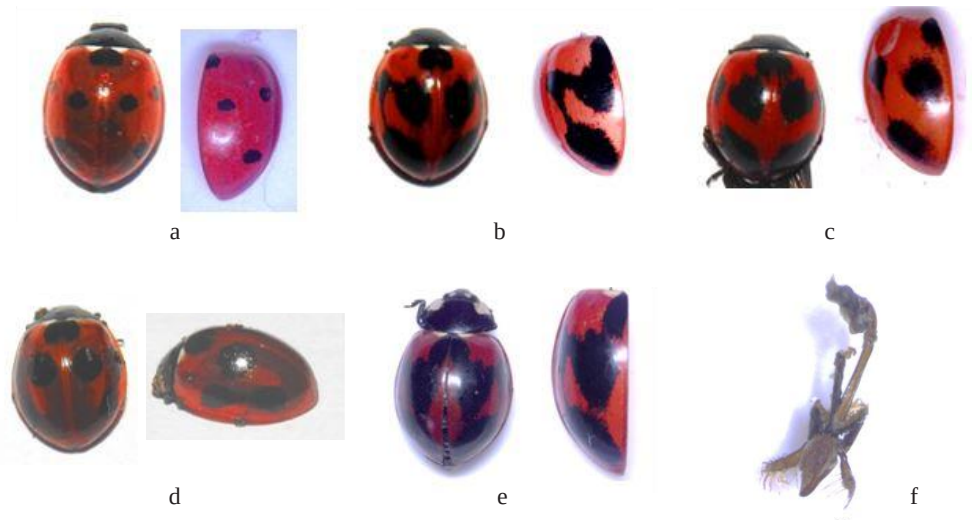

Fig. 1. *C. septempunctata*; a-e: Polymorphs- elytral patterns; f. Male genitalia (tegmen and sipho)

Table 1. Frequency of polymorphs of *C. septempunctata* across seasons

Morph	Seasons			
	Winter		Summer	
	No. of specimens	%	No. of specimens	%
1	272	73.3	234	100
2	46	12.4	0	0
3	23	6.2	0	0
4	18	4.8	0	0
5	12	3.2	0	0
Total	371	100	234	100

but is significantly <16 morphs of *C. septempunctata* which were described by Rao et al. (1962).

The present results corroborate with the argument that temperature is a predominant factor in morph frequency (Honek et al., 2012) as only the morph 1 was present in the field during summer (Table 1) and with the onset of the winter, more melanic forms began to appear. But, this correlation with temperature is contradicted by some studies which ascertain that the polymorph development is a mere genetic function (Lamana and Miller, 1995). Polymorphism in ladybird beetles is also linked to mate preference along with the body size (Muggleton, 1979; Majerus et al., 1982; Brakefield, 1984c; O'Donald et al., 1984). The melanic forms which absorb more sunlight during the winter season reported higher mating success compared to the non-melanic forms which explain the variation in morph frequency during different seasons (Ueno et al., 1998). An extensive study across a wider area and different ecosystems, both natural and manipulated may lead to the identification of more morphs and a conclusive result can be drawn on the true basis of polymorphism. There is a need to understand the trends in the pattern evolution and their exact function in the species.

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IMPACT OF BEE POLLINATION IN BRINJAL

Parameswara Reddy, Avinash Chauhan* and H K Singh

Department of Entomology, School of Agricultural Science and Rural Development, Nagaland University, Medziphema 797106, Nagaland, India
*Email: avi_shimla@hotmail.com (corresponding author)

ABSTRACT

Impact of bee pollination on brinjal (*Solanum melongena* L.) under protected condition was assessed with five pollination treatments viz., *Apis mellifera* L., *Apis cerana* F., *Tetragonula iridipennis* S., open pollination and control (pollinator exclusion). Comparative foraging activity and pollination efficiency index of the pollinators was recorded along with fruit production and quality parameters (fruit yield, length, diameter and weight, seed number and weight). Data revealed maximum pollination efficiency index (21) for *A. cerana.* The weight of fruit (96.30 g), diameter (56.54 cm), healthy fruits (53.89 %) observed with *A. cerana* was maximum. However, fruit length (15.10 cm), fruit yield (48.33 %) and seed weight (5.79 g) were found at par in all the pollination treatments. Significantly least crooked fruits (13.73%) were obtained when *A. cerana* was used, along with many folds increase in fruit set (26.69 %) and quality.

Key words: Pollination, *Apis mellifera*, *Apis cerana*, *Tetragonula iridipennis*, *Solanum melongena*, pollination index, protected condition, yield and quality, fruit weight, length and shape

Honey bees are the primary and only dependable pollinators of many crops (Free, 1993). *Apis mellifera* L , *A. cerana* L, *A. dorsata* F., and *A. florea* F., are the main pollinators abundantly found. Of which the domesticated ones viz., *A. mellifera* and *A. cerana* posess special value while others not studied widely (Meena, 2016). Stingless bees are now emerging as pollinators for crops grown under protected conditions (Chauhan et al., 2019). Horticultural crops such as pomegranate, ber, aonla, phalsa, citrus, brinjal, tomato, bale, field beans, cucurbits, jamun and fig etc. need insect pollinators for pollination and for maximizing yield (Haldhar, 2018). Brinjal is self-pollinated, but cross pollination resulted in maximum fruit yield and quality (Chaudhary, 1970). The limitation of cross pollination in brinjal is up to 48% and hence it is also identified as cross-pollinated crop; anthers are cone like in formation which favours self-pollination but since the stigma ultimately projects beyond the anthers, there is an ample chance for cross pollination. Crossing usually takes place with the help of insects (Gallaiet, 2009); and hymenopterans are the superior flower visitors (90.75%) over lepidopterans in brinjal (9.25%) (Mainali, 2015); insect's activity (above 60%) was observed to be maximum at morning hours with less numbers (12.54%) visiting during noon (Waqar, 2013). Pollination requirements of brinjal were observed by Herren (2008) which revealed that *Xylocopa caffra* L., and *Macronomia rufipes* S., as important pollinators. Patricio (2012) investigated how dependent brinjal is on bees for fruit production. In brinjal, production of fruit and seed was enhanced by pollinator's visitation and pollen complementation; and the highest yield in was insects were used as pollinators (Miyamoto, 2006). Keeping in view the importance of insects in pollination of brinjal, effectiveness of different modes of pollination on its production and productivity were evaluated in this study at Nagaland.

MATERIALS AND METHODS

The experiment was carried out at the Experimental farm, Department of Entomology, School of Agricultural Science and Rural Development (23°45'43"N, 93°52'04" E). Colonies of *A. mellifera* (T_1), *A. cerana* (T_2) and *Tetragonula iridipennis* (T_3) were introduced at 10% blooming stage in separate cages and T_5-control (no pollinator was introduced). Similarly, crop was grown under open condition (T_4) for treatment with four replications and plot size of cages being 40 m^2. All agronomical practices were done as per good agricultural practices, with the crop sown in the first week of April, 2019. The crop came to bloom in the second week of May. After that the colonies were shifted and data were recorded. Foraging activity of bees and other pollinators was recorded as per the method adopted by Chauhan (2015) under open field conditions from early morning (0600 hr) till late evening (1600 hr) at two hours interval for seven days continuously.

Pollination efficiency was derived for each species as suggested by Bohart and Nye (1960). Impact of bee pollination on brinjal was evaluated with % fruit set, for which ten plants were tagged randomly, and fruit set observed along with yield calculated on fruit set basis. Healthy (%) and crooked fruits (%) were also calculated. Fruit length, diameter and weight were observed (10 fruits/ treatment) using the scale, digital vernier callipers and digital weighing balance, respectively. Similarly, seed weight and number were also calculated. The increase (%) over control in fruit set, healthy fruits, length, diameter, weight, number of seeds, weight of 1000 seeds was also calculated.

RESULTS AND DISCUSSION

The results revealed that *A. mellifera* and *A. cerana* were the most significant flower visitors in brinjal followed by *T. iridipennis, A. dorsata* and *Lophotrigona canifrons* as frequent visitors; while *Lasius niger* and *Aulacophora nigripennis* were observed to be less frequent. The activity of honey bees was maximum during 0600-0800 hr and *A. cerana* (6.07/ 5min/ m^2) significantly outnumbered the *A. mellifera, T. iridipennis, L. canifrons, L. niger* and *A. nigripennis* (Table 1). Waqar (2013) described *A. cerana* and *A. mellifera* as major visitors, and Amano (2000) observed 24 insects, of which hymenopterans were predominant. Girlish (1981) concluded that *A. cerana* was more active, followed by *A. mellifera* and *T. iridipennis*; most efficient and important pollinators were observed to be *A. cerana* and *A. mellifera*. Similarly, Grewal et al. (1971) concluded that *A. cerana* is the major one in solanaceous crops; *A. cerana* significantly visited more flowers (8.07/ 5min/ m^2) as compared to *A. mellifera, T. iridipennis, L. canifrons, L. niger* and *A. nigripennis*. Mainali (2015) reported that honey bees were the most abundant flower visitors over Lepidoptera and Coleoptera; *A.cerana* most frequently visited flowers followed by *A. mellifera* and *T. iridipennis;* and maximum foraging speed/ time spent was observed with *A. cerana* (5.20 sec/ flower) as compared to *A. mellifera* and others; and *A. cerana* showed maximum pollination efficiency (21.00) and is better in terms of pollination potential (Table 1).

Longer fruits were obtained from plants pollinated by *A. cerana* over *A. mellifera, T. iridipennis*, open pollinated and control; and these treatments being significantly at par to each other. Similarly, significantly at par fruit set (48.33 %) was recorded with *A. cerana* compared to that of *A. mellifera, T. iridipennis*, open pollinated and control were recorded at par to each other; likewise fruits having more weight and diameter were recorded with *A. cerana*. Bee pollinated flowers yielded fruits having significantly more seeds, and less crooked fruits were obtained when *A. cerana* was used; and significantly more healthy fruits (53.89 %) were produced from *A. cerana* pollinated plots (Table 2). Santos and Bego (2007) reported that *A. cerana* effectively pollinated brinjal under closed environment, and maximum increase in fruit weight and number of seeds/ fruit was observed with pollinated treatments. Rajasri et al. (2012) studied effect of bee pollination on seed yield of sunflower and observed improvement (633 g) with pollination by *T. iridipennis* while it was only 352 g in self pollinated crops. Viana et al. (2014) found that stingless bee (*Melipona quadrifasciata* L.) play an important role as pollinator of apple flowers-with increase in fruit set, healthy fruits, diameter, length, weight, weight of 1000 seeds and number of seeds with *A. cerana* pollination. Chauhan et al. (2019) also

Table 1. Foraging activity and pollination efficiency index of pollinators on brinjal

Time	*Apis cerana*				*Apis mellifera*				*Tetragonula iridipennis*			
(h)	*RA	FR	FS	LPG	RA	FR	FS	LPG	RA	FR	FS	LPG
0600	5.97	9.54	6.14		5.67	6.91	5.94		4.17	6.14	7.28	
0800	8.93	9.82	6.52		4.93	7.92	5.42		4.33	7.22	4	
1000	6.82	8.84	5.82	1970	4.82	6.84	4.92	1648	6.02	5.24	5.72	1564
1200	5.98	7.85	4.95	± 24	5.38	6.55	4.85	± 31	5.88	5.15	5.55	± 27
1400	4.82	6.97	3.93		4.32	5.87	3.63		4.56	4.97	4.82	
1600	3.91	5.42	3.85		3.31	4.94	2.85		3.91	3.42	4.66	
Mean	6.07	8.07	5.20		4.73	6.50	4.60		4.81	5.35	5.82	
$CD_{0.05}$	0.54	0.47	0.58		0.54	0.47	0.58		0.68	0.47	0.60	
Pollination Efficiency Index			21				12				5	

*Relative abundance = number of foragers/ 5 min/ m^2; Foraging rate = Number of flowers visited / 5 min; Foraging speed = time spent / flower (in seconds); Loose pollen grains = the total number of loose pollen grains in the whole rinsate was calculated

Table 2. Impact of modes of pollination on fruit quality and production in brinjal

Treatment	Fruit length (cm)	Fruit diameter (cm)	Fruit weight (kg)	Fruit set (%)	Healthy fruit (%)	Crooked fruits (%)	Number of seeds/ fruit	Weight of 1000 seeds (g)
A. cerana pollination	15.10	56.54	96.30	48.33	53.89	13.73	307	5.79
A. mellifera pollination	14.42	55.78	90.44	47.45	51.58	15.86	223	5.32
T. iridipennis pollination	14.19	53.67	88.31	45.76	49.68	20.62	183	4.16
Open pollination	13.64	52.33	82.20	39.34	40.91	25.37	165	3.10
Pollinator exclusion (control)	13.03	49.03	68.81	33.84	32.63	28.90	138	3.01
CD (p= 0.05)	1.6	0.45	0.19	0.90	0.82	0.51	0.61	0.98
Increase (%) over control	90.25	68.53	442.56	26.69	29.84	139.12*	628	111.58

*Reduction

observed similar results with stingless bee pollinated crop.

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EVALUATION OF BIOPESTICIDE FORMULATIONS AGAINST BANANA STEM WEEVIL *ODOIPORUS LONGICOLLIS* (OLIVIER)

Mani Kannan, Balakrishnan Padmanaban* and Kammatterikunnu Ashif

Department of Crop Protection, ICAR-National Research Centre for Banana, Thayanur, Thogamalai Road, Tiruchirappalli 620102, Tamil Nadu, India
*Email: bpadmanabannrcb@gmail.com (corresponding author)

ABSTRACT

This study evaluated the laboratory and field efficacy of some biopesticides against the banana pseudostem weevil *Odoiporus longicollis* (Olivier). Sprays were applied five times from 3rd to 11th month at 45 days intervals. The observations such as the oviposition marks, larval galleries, plant death and yield revealed 100% mortality in Avaya and chlorpyriphos and 91.66% in CTCRI-Nanma and neem based product Nimbicidine treatments. The field observations indicated that Nimbicidine and cassava based Nanma significantly reduced the infestation similar to positive control chlorpyriphos, and these were considered under 1st category. The botanicals Zimmu plant extract, gallic acid and Aavya (2nd category) and pongamia and neem soap (3rd category) provided moderate/ less protection. It is concluded that the neem based botanical formulations could be effective and safe to use in banana against stem weevil.

Key words: Banana, *Odoiporus longicollis*, neem based biopesticides, cassava leaf extract, chlopyriphos, pongamia, neem soap, gallic acid, oviposition marks, larval galleries, plant death, yield

The banana stem weevil (BSW) *Odoiporus longicollis* (Olivier) (Coleoptera: Curculionidae) is an important insect pest of banana (Padmanaban et al., 2001). The commercial varieties are highly susceptible this and the rhizome weevil *Cosmopolites sordidus* (Germar) that cause yield loss from 10 to 90% (Padmanaban et al., 2020a,b). Stem injection of monocrotophos and swabbing insecticides along with surfactants affect adult interaction with host plants thereby preventing oviposition. Soil application of pesticides against banana weevil is of little success (Dutt and Maiti, 1971; Bujulu et al., 1983; Visalakshi et al., 1989; Padmanaban, 2018). Chemical control provides a short time solution, and its use for a longer period leads to development of resistance (Gokool et al., 2010). Use of botanicals for stem weevil management can be of use to develop ecofriendly IPM. Botanical pesticides are emerging as promising one now (Reddy et al., 2020), as these are environment friendly (Bhagawati et al., 2009; Awasthi et al., 2016). Using neem oil (*Azadiracta indica)*, crude extract of *Lantana camera* and *Gliricidia sepium* are known to be effective against *O. longicollis* (Irulandi et al., 2009); also monocrotophos (4ml/ plant) in combination with azadirachtin (2ml/ plant) by stem injection proved to be more effective compared to monocrotophos. Stem injection of monocrotophos, azadirachtin along with *B. bassiana* were effective with increased yield and cost benefits (Awasthi et al., 2016). Insecticidal activity of cassava extract (contain isothiocyanates) parts such as leaf and tuber rind are known as effective against *O. longicollis* (Krishnan et al., 2016). Aguilar et al. (2014) suggested on-farm trials with botanicals. Hence, the present study to evaluate the laboratory and field efficacy of some biopesticides against *O. longicollis.*

MATERIALS AND METHODS

The field trial was carried out at Kuruvadi, Tiruppanandal, Thanjavur district where the banana weevil infestation is >60%, with cv Poovan (AAB-Mysore). There were nine treatments: two ICAR-IIHR Bengaluru commercial botanical formulations, pongamia soap and neem soap (these formulations were dissolved 10 g/ l- w/v as recommended; ICAR-CTCRI, Thiruvananthapuram biopesticide, Nanma a formulation made out of tapioca leaves. This formulation was prepared using 50 ml in 1 l of water. Zimmu plant extract (an interspecific hybrid of *Allium cepa* x *A. sativum*) was prepared by grinding 100 g of fresh leaves in 1 l of water (w/v) and 30 g of gallic acid was dissolved in 1 l of water (w/v). Nimbicidine (5000 ppm) and chlorpyriphos 20SL (v/v) as commercial formulations were dissolved each 2.5 ml separately in 1 l of water. These two products were used as positive control, and adjutant-Triton-x 100 in water 50 ml/ l as a negative control. Each treatment had 9 replications, and the biopesticide formulations

were applied on the leaf axils and at the cut ends of the already removed senescent leaves, as these areas are identified as targets for adult entry. Spray was given from 3rd month onwards at 45 days' interval until 11th month. After 11th month spray, observations were made on oviposition marks, larval galleries, plant death and bunch yield, regarded as characteristics for identifying the effectiveness of treatments. The data were subjected to ANOVA with Tukey's pairwise comparison analysis using ICAR Software-WASP 2.0.

RESULTS AND DISCUSSION

The results of in vitro study for botanical formulations revealed that neem based formulation (Nimbicidine), ICAR-CTCRI-Nanma and Aavya gave maximum mortality after at 72 hr post treatment which was similar to chlorpyriphos (Fig. 1). Similarly, Reddy et al. (2020) also suggested neem-based formulations as effective. The laboratory study extended to the field condtions focused on the larval damage, adult infestation (oviposition) and % plant mortality on post application of last spray. These data given in Table 1 reveal that the plant mortality did not show any significant difference; interestingly, neem based formulations (azadirachtion 5000 ppm- Nimbicidine and ICAR-CTCRI-Nanma) significantly reduced the adult contact due to repellency and reduced larval damage similar to chlorpyriphos. Similarly, Awasthi et al. (2016) studied the effect of leaf extracts from few botanicals including neem oil (3%), on the mortality, repellence and antifeedant properties to adults of *O. longicollis* under laboratory condition; maximum protection score with leaf extract of *Lantana camara* (10% concentration) was observed. In this study, the botanical formulation Aavya gave maximum mortality under in vitro study but not responded well under field conditions. Interestingly, CTCRI Nanma product was found effective under invitro and field conditions. The disadvantage with Nanma is non- availability on commercial basis and the recommended dose is also very high. This study revealed the importance of site of application to prevent the entry of adults, such as through the leaf axil a gap present in between the stem and leaf petiole and through cut ends of senescent leaves. Instead of spraying on the entire plant, spot application at the above said two regions may reduce the requirement of spray solution, labour and provide good control.

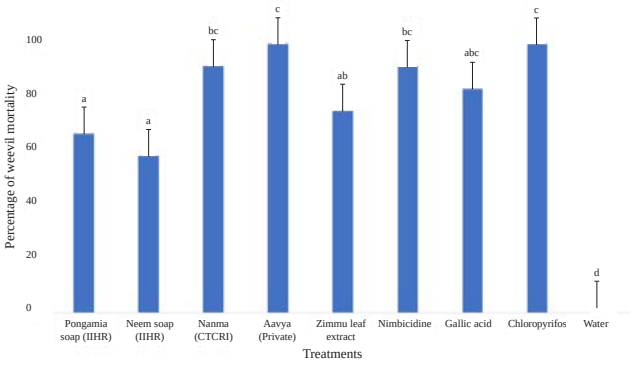

Fig. 1. Efficacy (in vitro) of botanical formulations against *O. longicollis* Different letters above bar indicate treatments differ significantly (ANOVA- Tukey's pairwise comparison analysis)

The biopesticides from botanicals reveal insecticidal,

Table 1. Efficacy (field) of botanical formulations against *O. longicollis*

S.No.	Treatments	Plants mortality on post spray *	Level of adult infestation*	Level of grub damage*	Fruit yield (kg/ plant)	Rank
1	Pongamia soap	0.22	22.67^{B}	1.67^{B}	8.5	8
2	Neem soap	0.11	20.33^{BC}	1.11^{B}	10.5	7
3	Nanma	-0.00	1.55^{DE}	-0.00^{B}	13.04	2
4	Avaya	-0.00	13.00^{BCD}	0.55^{B}	10.88	6
5	Azadiractin	-0.00	2.78^{DE}	0.22^{B}	14.38	3
6	Zimmu	0.11	9.33^{CDE}	0.55^{B}	11.77	5
7	Gallic acid	0.11	8.67^{CDE}	0.55^{B}	11.16	4
8	Chlorpyriphos	-0.00	0.00^{E}	-0.00^{B}	14.77	1
9	Control	0.22	39.33^{A}	8.33^{A}	6.5	9
General Mean		0.09	13.07	1.44	-	-
p-Value		0.3919	<.0001	0.0021	-	-
CV (%)		174.09	54.55	136.60	-	-

*The values arcsin transformed; significant difference between means analyzed by ANOVA with Tukey's pairwise comparison analysis; Different letters within the column indicate significant different between treatments; CV and SE- coefficient of variation and standard error respectively; NS: not significant.

repellent and antifeedant properties which are useful in the ecofriendly weevil management. The available information from the literature and GC-MS analysis of botanicals used in this study indicated the presence of ingredients like karanjin and pongamal in pongamia, azadirachtin in neem, isothiocyanates in nanma; and digitoxin and isothiocyanates in Aavya are responsible for phagorepellent (antifeedant) and insecticidal activity (Gore and Sathyamoorthy, 2000); similarly, cyanoglycosides from cassava plant utilized as a key component in ICAR-CTCRI Menma preparation, can be used for injection for the effective management (Krishnan et al., 2016). Likewise, Sahayaraj et al. (2015) extracted and identified the chemical constituents of *Tephrosia purpurea* and *Ipomoea carnea* by GC–MS and found the presence of hexadecanoic acid as a principal component from stem and root oils. The oils of *T. purpurea* and *I. carnea* showed stronger repellent activity for males than females.

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SPATIAL DISTRIBUTION OF PROTEINASE INHIBITORS AMONG DIVERSE GROUPS OF SUGARCANE AND THEIR INTERACTION WITH SUGARCANE BORERS

M Punithavalli

Division of Crop Protection, ICAR-Sugarcane Breeding Institute,
Coimbatore 641007, Tamil Nadu, India
Email: punithaentomol@yahoo.co.in

ABSTRACT

Profiling of proteinase inhibitors (PIs) was done on the diverse group of sugarcane viz., exotic clones, hybrids and *Erianthus arundinaceus*. Their inhibitory activity against commercial trypsin enzyme and midgut protease of sugarcane borers was investigated. Proteinase inhibitors were extracted from leaf sheath, meristem and stalk tissue of selected groups. The results revealed that the PIs were in maximum quantity in meristem followed by leaf sheath and stalk tissue of hybrids and *E. arundinaceus*. The trypsin inhibition was maximum in leaf sheath (11.51- 32.26%), meristem (15.86- 90.94%) and stalk tissue (1.62- 39.62%) of *E. arundinaceus* compared to those of hybrids and exotic clones. Subsequently, extracted meristem and stalk tissue PIs were assayed against midgut protease of sugarcane early shoot borer (ESB) and internode borer (INB). The results showed that PIs from *E. arundinaceus* meristem significantly inhibited the midgut protease of ESB and INB up to >70 and >60%, respectively. However, the PI from the meristem of exotic clones and hybrids showed considerable inhibition to midgut proteases of ESB. The PIs from stalk tissue of all groups were ineffective as regards gut protease inhibition in the sugarcane borers.

Key words: Sugarcane, exotic clones, hybrids, *Erianthus arundinaceus*, meristem, stalk, leaf sheath, proteinase inhibitors, trypsin, *Chilo infuscatellus*,*Chilo sacchariphagus indicus*

Sugarcane (*Saccharum officinarum*. L) is one of the important industrial crops. Of late more than 200 insect pests are reported to attack sugarcane. In peninsular India, the early shoot borer, *Chilo infuscatellus* Snellen (ESB) and internode borer *Chilo sacchariphagus indicus* Kapur (INB) (Crambidae: Lepidoptera) together pose a major threat, causing serious economic losses. The estimated yield losses and sugar recovery with these pests account for 22-33% and 2% CCS and 34.88% and 1.7-3.07%, respectively (DAC, 2015). Although sugarcane borers can be efficiently checked with biocontrol using predators, parasites and pathogens, there is a residual damage of about 10%, which justifies the search for increased plant resistance. In this context, identification of resistance sources and deciphering the mechanism responsible for imparting resistance to major pests is an effective IPM strategy.

Plant proteinase inhibitors (PIs) are diverse group of proteins which have been extensively studied due to their potential for protecting plants against herbivorous insects by inhibiting digestive midgut proteases. These are classified mainly as serine, cysteine, aspartic and metallo PIs. The Kunitz (18-22 kDa proteins) and Bowman-Birk inhibitors (8-10 kDa proteins) of serine PIs are well characterized and have gained importance as biopesticides (Laskowski and Qasim, 2000; Macedo et al., 2015). The PIs are known to influence the growth and development of insects by binding tightly and irreversibly to the active site of its digestive gut proteases, which are essential for various metabolic processes. The mechanism leads to critical amino acid deficiency and eventually insect death due to over production of digestive proteases by diverting the essential amino acids available for the production of other proteins. These herbivores challenged proteinase inhibitors have been identified in many agricultural crops. Their biological functions against important pests particularly *Helicoverpa armigera* and *Spodoptera litura* are known (Bown et al., 1997). However, quantitative variations of trypsin inhibition among different groups of sugarcane genotypes are yet to be documented. It is important to profile the proteinase inhibitors from *Saccharum* and its allied genera. Also, their insecticidal potential has to be evaluated against gut proteases of sugarcane borers. The study may facilitate to identify the elite cultivars from diverse groups which could be used as donors in future breeding of borer resistant sugarcane varieties.

MATERIALS AND METHODS

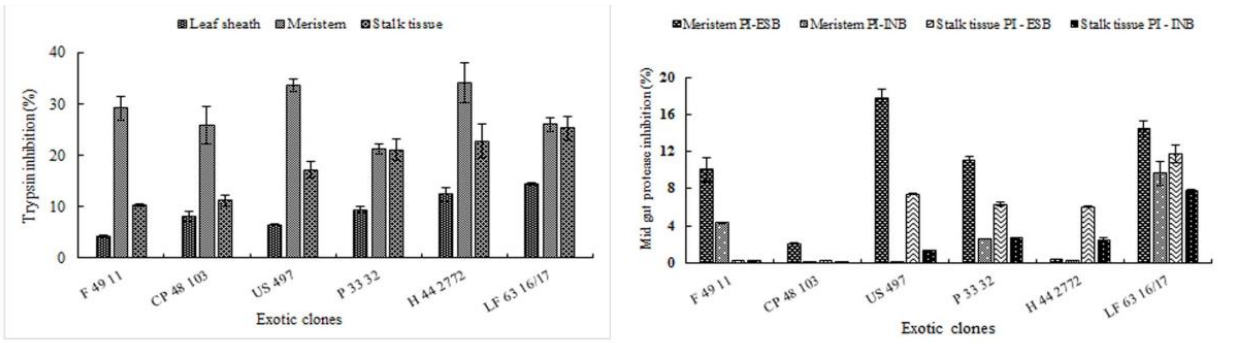
Three groups of sugarcane genotypes viz., exotic clones, hybrids and *E. arundinaceus* were selected. Based on the field screening (2013-2015), promising borer resistant genotypes from each group were selected for the profiling of proteinase inhibitors. The seed material of three groups were brought from the Regional station of Sugarcane Breeding Institute (SBI-RC), Kannur, Kerala. Two budded setts were planted in a randomized block design with three replications with spacing of 6x 0.9 m. The crop was raised following recommended agronomic practices without any plant protection measures. Healthy leaf sheath, meristem and stalk (cane tissue) samples were collected randomly from 3- and 5-months old plants for proteinase inhibitor (PI) extraction. The methodology of PI extraction and assay protocols were followed as per Ramesh Babu et al. (2012). Proteinase inhibitory activity of the extracted PIs were evaluated against trypsin from bovine pancreas under laboratory conditions. The trypsin inhibitory assay was performed using BApNA (Nα-Benzoyl-DL-arginine 4-nitroanilide hydrochloride) as substrate. 0.3ml of sample extract was added to 60 µg of bovine trypsin in 0.6 ml of assay buffer and incubated at 37°C in a water bath for 10 min. Residual trypsin activity was measured by adding 3ml of 1mM BApNA in pre-warmed (37°C) assay buffer and incubated at 37°C for 10 min. Reactions were arrested by adding 0.6 ml of 30% glacial acetic acid. After centrifugation at 5000 rpm for 6 min, the liberated p-nitroaniline in the clear solution was measured at 410 nm. All assays were performed in triplicate with sample and reagent blank.

To assess the potential effects of the extracted PIs from the exotic clones, hybrids and *E. arundinaceus* on the digestive proteinases of ESB and INB, midguts of the fifth instar larvae were removed by carefully dissecting and storing at -20°C. Protease enzyme from the midgut tissue were extracted separately in equal volume of ice-cold 0.2M glycine-NaOH buffer (pH 10) (containing 2mM DTT and 10% PVP) for 2 hr at 4°C and then centrifuged at 8000 rpm for 15 mins at 4°C (Telang et al., 2003). The resulting supernatant was collected and analyzed for gut protease inhibition against the PIs extracted from meristem and stalk tissues. The procedure for ESB and INB gut protease inhibition was as similar to the plant proteinase inhibition except for the gut protease in place of trypsin. The data obtained were statistically analyzed in a complete randomized block design and different parameters observed were subjected to ANOVA and means were compared with Duncan's Multiple Range Test (DMRT, p= 0.05). The analysis based on students' "t" test was also done.

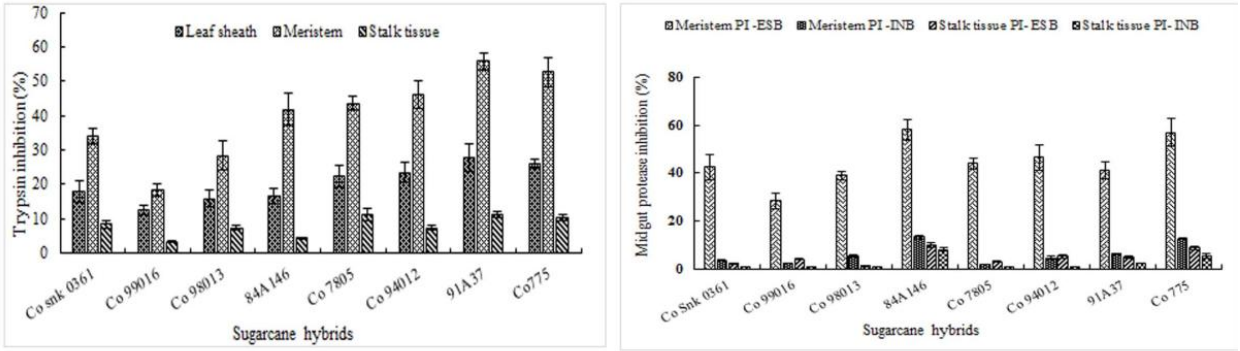
RESULTS AND DISCUSSION

The results obtained on the extraction of the PIs from different plant parts of exotic clones revealed that the meristem showed maximum trypsin inhibition (>30%) followed by those from stalk tissue (>10-20%) (Fig. 1a). The stalk tissue of the genotypes H 44 2772 and US 497 followed next. In sugarcane, increased level of trypsin inhibitor had been detected in the preferential feeding sites of sugarcane borer *Diatraea saccharalis* (Falco et al., 2001). Many studies report that the PIs inhibit the larval gut proteases conferring resistance to insect pests (Amarjit et al., 2015). The present results show that the PIs from meristem of exotic clones considerably inhibit the midgut proteases of ESB than INB. On the contrary, PIs extracted from stalk tissues reveal only meagre inhibition of midgut protease in both ESB and INB. In general, cultivated plants have a relatively lower level of resistance to biotic stresses when compared to wild relatives of crops (Wang et al., 2015). Among exotic clones screened for PIs, those from meristem of US 497 and LF63 16/17 exhibited significantly more inhibition of midgut protease of ESB compared to other evaluated genotypes. Allsopp et al. (1996) identified PIs in many resistant sugarcane clones and found that the clones fed to the Australian cane grub reduced their growth and survival significantly. The PIs from *Theobroma* seeds showed adverse effect on fecundity and survival rate of velvet bean caterpillars (*Anticarsia gemmatalis*) and sugarcane borer (*D. saccharalis*) (Paulillo et al., 2012).

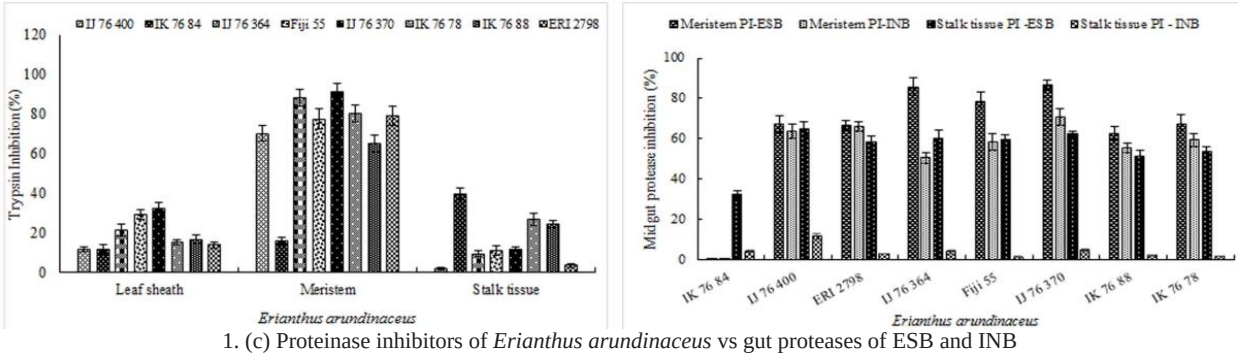
Proteinase inhibitors (PIs) quantified from different plant parts of eight borers promising sugarcane hybrids are presented in Fig 1b. The results showed that the amount of trypsin inhibition in leaf sheath, meristem and stalk tissues differed significantly among the chosen genotypes. However, it was comparatively higher in meristem (35- 55%) followed by leaf sheath (20- 25%) and stalk tissues (5-10%) in the evaluated genotypes. The trypsin inhibition was maximum with the PIs extracted from the meristem of genotypes 91A37 and Co 775 (55.78 and 52.67%, respectively), and was the least with that from the meristem of the genotype Co 99016 (18.36%). None of the genotypes showed marked increase in trypsin inhibition in stalk tissues. While selecting candidate PIs for use in developing insect resistant plants, their stability against digestion by insect gut proteinases is very important. The PIs extracted from meristem and stalk tissue were



1. (a) Proteinase inhibitors of exotic clones vs gut proteases of ESB and INB



1. (b) Proteinase inhibitors of sugarcane hybrids vs gut proteases of ESB and INB



1. (c) Proteinase inhibitors of *Erianthus arundinaceus* vs gut proteases of ESB and INB

Fig. 1. Proteinase inhibitor profiles and their interaction with sugarcane early shoot borer and internode borer

screened in vitro for their inhibitory activity against gut proteases (Fig 1b). The PIs extracted from meristem of all the hybrids showed significantly more inhibition in ESB. According to Balaji et al. (2012), inhibitors from *Saccharum* spp. stem tissue extracts inhibited >30% gut proteinase activity of *C. infuscatellus*. The midgut protease inhibition in ESB was observed to be maximum with the PIs extracted from the meristem of 91A37 and Co 775 (reduction of 58.25 and 56.96%, respectively). However, PIs extracted from meristem and stalk tissue were ineffective as regards mid gut protease inhibition of IB.

The PIs extracted from eight field promising *E. arundinaceus* genotypes viz., IJ 76 400, IK 76 84, IJ 76 364, FIJI 55, IJ 76 370, K 76 78, IK 76 88 and ERI 2798 were studied (Fig. 1c). There existed inter-varietal quantity differences among the plant parts of these genotypes. Results showed that the trypsin inhibition was significantly maximum with PIs extracted from meristem; it was > 85% with those from IJ 76 364 and IJ 76 370 followed by > 75% in IK 76 78, Fiji 55, ERI 2798 and IJ 76 400. This inhibition was the least with those PIs extracted from leaf sheath and stalk tissues of *E. arundinaceus* genotypes. Allsopp and Cox (2002) identified a number of clones of wild species *Saccharum spontaneum* and *E. arundinaceus* as sources of enhanced resistance to sugarcane cane grub.

Several Erianthus clones were observed to be resistant to nematodes and root parasites (Stirling et al., 2011).

PIs extracted from all the *E. arundinaceus* genotypes revealed significant inhibition of midgut proteases in both ESB and INB indicating their insecticidal potential (Fig. 1 c); PIs extracted from meristem provide significant inhibition; the PIs from the stalk tissue were effective only in ESB. This inhibitory activity towards general proteolysis would give more pronounced effects on larval growth and physiology (Srinivasan et al., 2005). The PIs extracted from meristem and stalk tissue of IJ 76 370 and IJ 76 364 gave maximum inhibition of midgut proteases. Daniels and Roach (1987) reported that hybrids derived from *E. arundinaceus* showed exceptional tolerance to salinity, drought and imparted resistance to pest and diseases. In an earlier study, significant reduction of shoot borer larval and pupal survival along with extended larval duration was observed with *E. arundinaceus* (Punithavalli and Jabamalaimary, 2019). The PIs are abundant in *E. arundianceus* in comparison to that of hybrids and exotic clones. Besides, *E. arundinaceus* PIs showed strong inhibitory activity against the proteolytic activity of ESB and INB, proving their insecticidal potential. In the current sugarcane breeding programme, allied genera of *Saccharum* complex like *Erianthus* spp. are extensively used for the development of intergeneric hybrids adapted to diverse environments, resistance to insect pests and diseases, and tolerant to abiotic stress. Hence, the results of the present study could be of use in the breeding for borer resistant sugarcane varieties.

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FALL ARMY WORM *SPODOPTERA FRUGIPERDA* STRAINS IN GOA AND ITS INCIDENCE ON FODDER MAIZE

Maruthadurai R* and R Ramesh

Crop Protection Section, ICAR- Central Coastal Agricultural Research Institute,
Ela, Old Goa, Goa 403402, India
*Email: duraiento@gmail.com (corresponding author)

ABSTRACT

Fall army worm (FAW) *Spodoptera frugiperda* (J E Smith) is a highly destructive invasive insect pest. Its incidence was observed during post kharif season 2019 at Old Goa, and it ranged from 43 to 83% @ 0.67 larvae/ plant with a maximum of 1.16 larvae/ plant during vegetative stage, and it was more than the reproductive stage. The mtCO1 analysis of the populations from Goa revealed the presence of both Rice (R) strain and Corn (C) strain which feed on fodder maize and sweet corn, and this confirms the prevalence of both the strains in Goa on fodder maize.

Key words: *Spodoptera frugiperda*, Old Goa, fodder maize, invasive pest, mtCO1, R and C strains, incidence, host plants, vegetative and reproductive stages, post kharif

Fall army worm (FAW) *Spodoptera frugiperda* (J E Smith) (Lepidoptera: Noctuidae) is a highly voracious insect pest native to tropical and subtropical region of Americas. It has a wide host range of >353 host plants (Montezano et al., 2018). The most frequently damaged plants are maize, sorghum, rice, millet, soybean, peanut, cotton, Sudan grass and other fodder grasses. In India, FAW was first reported on maize from Shivamogga district of Karnataka (Sharanabasappa et al., 2018). It is highly migratory and has rapidly spread all over the country and also reported in neighbouring countries like Nepal and China (Ratna et al., 2019; FAO 2019). The incidence on maize ranged from 9.0 to 62.5% and 6 to 100% (Shylesha et al., 2018; Mallapur et al., 2018) in different districts of Karnataka. This has two strains that are morphologically indistinguishable but differ in their host plant preference. The Rice (R) strain most consistently feeds on rice, Bermuda grass, and other small grasses while the Corn (C) strain prefers maize, sorghum and other large grasses (Pashley et al., 1985). Recent studies on its populations in India have revealed that majority of these were 'R' strain- feeds on maize, sorghum and sweet corn; while 'C' strain- feeds on sugarcane (Mahadevaswamy et al., 2018; Chormule et al., 2019). The knowledge on its strains and genetic diversity is important for developing IPM strategies (Srinivasan et al., 2018). Hence, the present study to explore the presence of FAW and its strains in the state of Goa on different host plants and to assess the damage incidence on fodder maize.

MATERIALS AND METHODS

Fodder maize variety African Tall was sown with the spacing of 50x 20 cm during post kharif season 2019 at the experimental farm of ICAR- Central Coastal Agricultural Research Institute, Ela, Old Goa, Goa. The area of experimental field was 1000 m^2 from which 30 plants were randomly selected and weekly observations were made on the number of larvae/ plant and plants damaged, assessed based on the damage symptoms viz., skeletonizing the upper epidermis, windows on leaves and faecal pellets in the whorls. To know the status of FAW strains in Goa, larvae were collected from the experimental field at ICAR as well as in other locations on different host plants viz., fodder maize, sweet corn and water melon. Larvae were placed in 1.5 ml micro centrifuge tubes separately. A single larva was selected and ground in a pestle and mortar using liquid nitrogen. About 25 mg of the ground powder was used to isolate the genomic DNA by using Wizard Genomic DNA purification kit (Promega Corporation, USA Cat. A1120) as per the manufacturer's instruction. The remaining individuals were preserved as voucher specimens at -70°C in ICAR-CCARI, Goa. PCR Amplification of a 658 bp region near the 5' terminus of the CO1 gene from the genomic DNA using primers (LCO 1490 5'-GGTCAACAAATCATAAAGATATTGG-3') and (HCO 2198 5'-TAAACTTCAGGGTGACC AAAAAATCA-3'). PCR reaction was carried out with a 20µl reaction mixture containing 1.0 µM of each primer, 10 µl master mix (Promega Corporations)

and 50ng of the DNA template in Mastercycler Pro (Eppendorf, GmBH) thermal cycler with the following conditions. Initial denaturation of 94°C for 5 min; 35 cycles of 94°C for 60 sec, 50°C for 60 sec, 72°C for 60 sec and final extension of 10 min at 72°C. The amplicon was visualised on 1.2% agarose gel containing 0.5 µg/ml of ethidium bromide the amplified product was purified using Qiagen Mini elute PCR purification kit (Qiagen India) and quantified using Nano drop-1000 (Thermo fisher scientific, USA). The purified fragments were sequenced by M/S Eurofins Genomics India Pvt. Ltd., Bengaluru, India. Sequences were edited manually and aligned using Clustal W and submitted in NCBI GenBank. Phylogenetic analysis was performed using MEGA-X (Kumar et al., 2018) by using neighbor-joining (NJ) and the algorithm of maximum composite likelihood with 1000 bootstrap re-samplings. The phylogenetic tree was generated using mtCO1 sequences of 45 *S. frugiperda* from the NCBI Genbank database which include the sequences from India, from across the world and representing both 'R' and 'C' strains.

RESULTS AND DISCUSSION

The data reveals that FAW larval counts and damage incidence varied in different growth stages, ranging from 0.67 to 1.16 larvae/ plant during vegetative stage, with more larvae in the vegetative stage compared to the reproductive stage. Damage in vegetative to reproductive stage revealed that 18.72 plants got infested/ 1000 m^2 amounting to 43 to 83% with maximum being during vegetative stage. In India, severe damage had been reported in various states 9.0 to 62.5% in Karnataka, 56 to 92% in Rajasthan and 16 to 52% on fodder maize in Goa (Shylesha et al., 2018; Meena et al., 2019; Maruthadurai and Ramesh, 2020). Jaramillo et al. (2019) in different phenological stage of corn found more larvae in the vegetative stage than in the reproductive stage.

There are two morphologically identical host strains of FAW that are defined by their host plant preferences but can be distinguished by molecular techniques (Pashley et al., 1985). The BLAST analysis of the sequences took into account all the NCBI GenBank sequences and obtained accession numbers of the mtCO1 DNA sequences (MT791628 to MT791636). The analysis revealed that the Goa populations were 99% identical to the sequences from India and other countries. Phylogenetic tree of mtCO1 gene sequences was generated using the neighbor joining (NJ) algorithm and the phylogenetic tree carrying boot strap values is presented in Fig. 1. Further sequence analysis for mtCO1 5' revealed the presence of both 'R' strain and 'C' strains in Goa. Seven isolates (S1, S2, S3, S4, S5, S6 and S7) were aligned with 'R' strain and two isolates (S8 and S9) were aligned with 'C' strain. The previous studies on isolate MK368810 was found aligning with 'R' strain (Maruthadurai and Ramesh, 2020). Nucleotide variations between 'R' strain and 'C' strain are observed in 11 positions (34, 79, 133,169, 220, 451, 526, 532, 562, 596, 625) when 'R' and 'C' strains of Indian and global population was analysed (Table 1). Similar results were reported by Mahadeva Swamy et al. (2018). Periodical sampling during the entire crop period, revealed the presence of 'R' strain and 'C' strain in Goa on fodder maize which indicated that both strains of *S. frugiperda* have been occurring in the Coastal state of Goa. These results derive support from those of Bhavani et al. (2019) in which the analysis indicated the presence of 'R' strain and 'C' strain in sugarcane at Anakapalle in Andhra Pradesh; also with those of Chormule et al. (2019) on the presence of 'C' strain

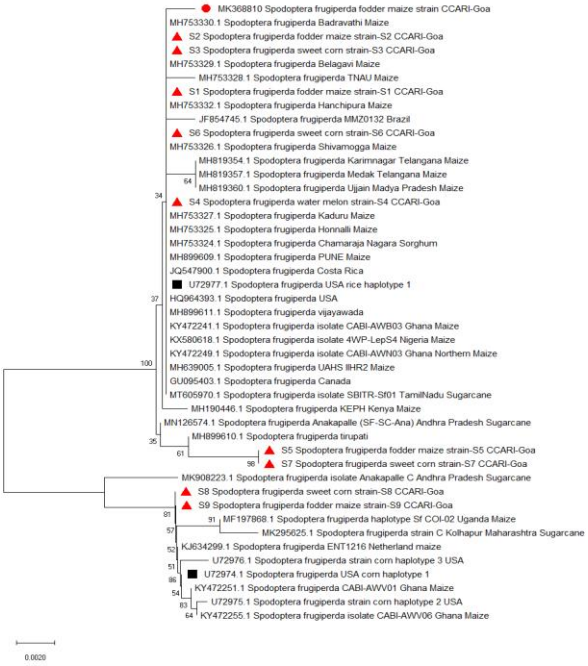

Fig. 1. Phylogenetic neighbor-joining tree based on the partial 5'mtCO1 gene sequences of isolates of *S. frugiperda*; isolates from this study represented by red triangular block, previously reported 'Rice' strain from Goa is represented by red circular block and 'Rice' and 'Corn' reference strains by a square block. All others strains are reference strains obtained from the GenBank database for phylogenetic analysis. The tree was generated by MEGA-X software using the NJ and the algorithm of Maximum composite likelihood with 1000 bootstrap re-samplings. Numbers at each branch indicate bootstrap value. Scale bar represents 2 nucleotide substitutions/ 1000 nucleotides.

Table 1. Position-wise nucleotide variations in 5' terminus of mtCOI gene of FAW of "Rice strain" and "Corn strain"

Nucleotide position in the 5' mtCO1	Rice strain	Corn strain
34	A	G
79	A	G
133	C	T
169	A	T
220	T	C
451	C	T
526	C	T
532	T	C
562	T	C
596	C	T
625	A	T

Total number of strains used is 45 (34 rice, 11 corn strains)

on sugarcane in Maharashtra. Nagoshi et al. (2007) reported that both 'R' and 'C' strains feed on maize and other crops during the same crop period in Brazil. Nagoshi and Meagher (2004) compared the distribution of two strains from corn fields before and after harvest and found that the 'C' strain constitutes 72 and 39%, respectively. However, molecular diversity studies of Indian populations of FAW collected on maize, sweet corn and sorghum from six states of the country revealed the prevalence of 'R' strain (Mahadeva Swamy et al. 2018). It appears that 'R' strain has colonized maize, sweet corn and sorghum while 'C' strain has started adapting to sugarcane, fodder maize and sweet corn. Thus, the present study reports the presence of 'R' strain and 'C' strain of FAW from Goa on fodder maize and sweet corn. It also provides basic information on damage potential and larval density on fodder maize.

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BIOLOGY OF GROUNDNUT BRUCHID *CARYEDON SERRATUS* (OLIVIER)

Poonam Deshmukh, Mane P N[1*], Undirwade D B and Sonalkar V U[2]

Department of Entomology; [1]Oilseed Research Unit; [2]Sorghum Research Unit,
Dr Panjabrao Deshmukh Krishi Vidyapeeth, Akola 444104, India
*Email: pnmane_ento@rediffmail.com (corresponding author)

ABSTRACT

Life stages of groundnut bruchid *Caryedon serratus* was studied in the laboratory of Seed Technology Research Unit, Dr Panjabrao Deshmukh Krishi Vidyapeeth, Akola during 2019-20. The bruchid was multiplied under laboratory conditions at 25± 2°C and 70% RH on groundnut pods. Egg, grub and pupal periods, adult longevity and total life period were examined. The mean life period of male groundnut bruchid was 69 days and for female it was 76.50 days. The grub (damaging stage) period lasted for 33 days.

Key words: *Arachis hypogaea*, *Caryedon serratus*, coleoptera, incubation period, grub, life stages, pupal period, storage, total life period.

Groundnut (*Arachis hypogaea* L.) is an important oilseed crop (Sakhare et al., 2018), and it is stored as pods (unshelled form) and in kernels (shelled form) by farmers, processors, seed agencies and other oil extraction units for about 6-9 months before final use. In India, storage losses of groundnut range between 10 and 15%. The postharvest losses in groundnut caused by insect pests, moulds and rodents vary from 10 to 25%. Among the pests, post-harvest insect pests like groundnut bruchid, *Caryedon serratus* (Olivier) is a primary feeder causing approximately 17-47% pods damage (Bhogeesh et al., 2014). It is the only species that can penetrate intact pods to infest kernels, and causes 19 to 60% loss. The grubs bore into the seeds via small holes and feed on the embryo and the endosperm and final instar grub comes out for pupation through exit holes (Sakhare et al., 2018). Its damage leads to poor germination and thus reduces the seed quality. The egg, larval and pupal periods of this ranged from 3 to 9, 19 to 38, 9 to 34 days, respectively, while the adult longevity and total lifecycle occupied 19 to 30 and 43 to 70 days, respectively (Sandeep et al., 2005). Such knowledge on life cycle is useful in synchronizing the timing of application of pest management tactics (Arif et al., 2017). Keeping this in view, a study was conducted on life stages of *C. serratus* on groundnut *Arachis hypogaea* from Akola, Maharashtra.

MATERIALS AND METHODS

The experiment was undertaken in laboratory of the Seed Technology Research Unit, Dr PDKV Akola during July 2019. Initial culture of *C. serratus* was obtained from naturally infested pods, with the beetle identified by the small black markings on the elytra, incompletely covering the abdomen, broad hind femur with serrated antennae. The bruchid was then multiplied at 25± 2°C and 70% RH on groundnut pods, in plastic jars. Life stages were studied, and for adult emergence, a pair of male and female was kept in a container for mating and allowed for egg laying. Three vials were taken and 30 groundnut kernels with freshly laid egg such that one egg/ kernel were studied by putting it into vial and the open end of the vial was tied with muslin cloth. Observations were taken on egg, grub and pupal period, adult longevity and total life period. Egg period is the length of time taken from egg laying to hatching. It can be recognized by egg turning to opaque due to accumulation of bored material in the chorion. The grub period was recorded as the number of days taken from hatching of egg till last instar grub (i.e. fourth instar stage) which spins the papery cocoon. Pupal period is the period from the formation of cocoon till the adult emergence. Adult longevity is the period from adult emergence to its mortality.

RESULTS AND DISCUSSION

The egg period of *C. serratus* ranged from 7 to 8 days, with freshly laid eggs being creamy, translucent with tough chorion. The egg shell becomes opaque white or grey at hatching. The grub makes a circular cut on the surface of egg chorion a day before hatching, and grub period lasts for 32 to 34 days (mean 33 days). The grubs passed through four larval instars before pupation. The newly hatched first instar is creamy white, C shaped with prominent mandibles; while the full grown is pale pink. The pupal period lasts for 12

to 15 days (mean 13.5 days), with the pupa being dull white and papery. Adult longevity ranges from 14 to 16 days (mean 15 days) in case of males, and 20 to 25 days (mean 22.50 days) in females. Adult is reddish dark brown with small markings on the elytra, prominent compound eyes and 11 segmented antennae and showed sexual dimorphism; antennae were long and serrated in males than in females, whereas the pygidium (dorsum of posterior abdomen) was exposed in females than in males; in males, pygidium was projected downwards, so that in dorsal view it was hidden by the elytra; while in females the pygidium is visible dorsally projecting beyond the elytra. The females were slightly bigger than males. Total life period of the male from egg to adult ranged from 65 to 73 days (mean 69 days), while in female it was from 71 to 82 days (mean 76.50 days).

Mishra and Ranjan (2005) and Sakhare et al. (2018) observed 4.20 and 3.50 to 8.50 days as egg period of *C. serratus*, respectively. The grub period was 34.69 days, 19 to 38 days, 29 to 41 days and 28 to 34 days, respectively as given by Joshi and Ghorpade (2001), Sandeep (2005), Bhogeesh et al. (2014) and Sakhare et al. (2018). Mishra and Ranjan (2005) and Behera et al. (2016) reported these as 26.68 and 42.2 days of grub period, respectively, and Sakhare et al. (2018) observed 12.75 to 15.25 days of pupal period. Bhogeesh et al. (2014) observed 14.80 days as male adults period and 21.34 days as female adults period. Sundria et al. (2004) and Sakhare et al. (2018) found that it was 40.54 to 78.35 days, 89.9± 3.44 days and 67.50 to 76.00 days as its life period, respectively.

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TOXICITY OF SOME INSECTICIDES AGAINST THRIPS INFESTING TOMATO

Timmanna, Mohan I Naik, Jamuna B[1] and Ravichandra N G[2]

Department of Entomology; [2]Department of Plant Pathology,
University of Agricultural Sciences, Bengaluru 560065, Karnataka, India
[1]Pesticide Residue Laboratory, University of Agricultural Sciences,
Raichur 584102, Karnataka, India
*Email: thimsento@gmail.com (corresponding author)

ABSTRACT

Bean dip bioassay was performed with six insecticides on the mortality response in tomato thrips- *Thrips palmi* Karny and *Scirtothrips dorsalis* Hood. The LC_{50} values ranged from 1.591 to 17.018 ppm, and spinosad with the least LC_{50} value of 1.591 ppm at 95% confidence limit was the most toxic. It was followed by cyantraniliprole (2.425 ppm), diafenthiuron (2.396 ppm), imidacloprid (5.110 ppm), fipronil (13.560 ppm) and dimethoate (17.018 ppm). Thus, spinosad, diafenthiuron and cyantraniliprole were observed to be more toxic.

Key words: Tomato, thrips, tospoviruses, vectors, *Thrips palmi*, *Scirtothrips dorsalis*, insecticides, bioassay, LC_{50}, spinosad, cyantraniliprole, diafenthiuron, imidacloprid, fipronil, dimethoate

The plant viruses cause enormous economic losses, and diverse agroclimates in India favour their spread with their vectors, among which tospoviruses are most threatening (Anupam Varma, 2007). Thrips are the vectors of tospoviruses in most of the vegetable and pulse crops causing significant yield loss in South East Asian countries (Mound, 2001; Whitfield et al., 2005). *Groundnut Bud Necrosis Virus* (GBNV) in solanaceous and pulse crops and *Watermelon Bud Necrosis Virus* (WBNV) in cucurbits are widely distributed and most devastating in India, and these are difficult to manage. Indirect methods like cultural practices (resistant planting material, avoidance of virus infection, use of reflective mulch, crop rotation, etc) and chemical control of insect vectors are followed to manage these (Sastry and Zitter, 2014). Most of the time, improper insecticidal sprays cannot reach thrips, because of their cryptic living habit (feed and reside in unopened shoot and flower buds). Correct diagnosis of thrips infestation at early stage and selection of suitable insecticide at right time are critical to manage viral diseases in tomato. The present study evaluates the toxicity of some insecticides against tomato thrips viz., *Thrips palmi* Karny and *Scirtothrips dorsalis* Hood.

MATERIALS AND METHODS

Bioassay study was conducted at the toxicology laboratory, Division of Entomology, Indian Agricultural Research Institute, New Delhi. After series of host preference and mass rearing experiments with selected hosts (groundnut cv. Kadri-9, cowpea cv. Pusa Komal, watermelon cv. Arka Manik and brinjal cv. Pusa Hybrid 9), it was concluded that the one-month-old brinjal plants are suitable for rearing and mass multiplication of the tomato thrips- *T. palmi* Karny and *S. dorsalis*. Thrips were collected from tomato crop during morning hours-plant shoots were tapped on to a white paper and fallen thrips were collected using aspirator. Collected thrips were released on one-month-old brinjal plants raised in sterile pot mixture (soil: cocopit: vermiculite at 3:1:1 ratio) and kept under transparent and ventilated acrylic cages. Six commercial grade insecticides recommended against thrips and other sucking pests (Anonymous, 2017) were subjected to bioassay as given in Table 1. Bioassay was carried out on adult thrips (5 days old) of F1 and F2 generations with bean dip method (Insecticide Resistance Action Committee-IRAC susceptibility test method 10). The experiments were started with % of required dose of the insecticides, and preliminary screening done with non-replicated experiment called bracketing (approximation of 20-80% mortality with wide range of concentrations). Eight concentrations were prepared in each insecticide for calculation of median lethal concentration (LC_{50}) and repeated thrice. Mean mortality data obtained were subjected to statistical analysis to calculate the LC_{50} using log dose probit analysis (Finney, 1947, PoloPlus 2.0 of LeOra Software, Petaluma, CA). Data in which the probit

Table 1. Toxicity of insecticides against tomato thrips

Insecticide	DF	Slope± SE	χ^2	LC_{50} (ppm) (95% CI)	Fiducial limits Lower limit	Upper limit
Fipronil 5SC	6	3.311± 0.449	2.086	13.560	11.602	15.287
Imidacloprid 17.8SL	6	3.627± 0.675	3.033	5.110	3.966	5.896
Spinosad 45SC	6	2.015± 0.307	2.737	1.591	1.127	1.990
Diafenthiuron 50WP	6	2.561± 0.338	6.859	2.396	1.590	3.091
Dimethoate 30EC	6	3.118 ± 0.489	1.809	17.018	14.766	19.221
Cyantraniliprole 10.26OD	6	2.782± 0.377	4.198	2.425	1.807	2.949

analysis did not calculate the confidence interval (CI) or when the resulting $\chi 2$ statistic/ and non-significant ($p < 0.05$) were discarded.

RESULTS AND DISCUSSION

Bioassay results indicated that the evaluated insecticides exhibited varied mortality response with the LC_{50} values ranging from 2.396 to 17.018 ppm; spinosad with least LC_{50} value (1.591 ppm) at 95% CI followed by diafenthiuron (2.396 ppm), cyantraniliprole (2.425 ppm), imidacloprid (5.110 ppm), fipronil (13.560 ppm) and dimethoate (17.018 ppm) (Table. 1). These results indicated, spinosad is the most toxic to thrips. These results are in conformity with earlier ones of Greenberg et al. (2011) on spinosad as most toxic against onion thrips and *Frankliniella occidentalis* (Shan et al., 2012). Present findings are also in conformity with those of Buli et al. (2018) on cyantraniliprole as the most toxic followed by spinosad and imidacloprid; and the latter was the most toxic after spinosad (Walter et al., 2018). Thus, spinosad and cyantraniliprole are more toxic, and these results can facilitate the selection of suitable insecticides for the management thrips and associated viral diseases in tomato.

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MORPHOLOGICAL AND BIOCHEMICAL BASIS OF RESISTANCE TO POD BORER *HELICOVERPA ARMIGERA* IN PIGEONPEA

Saniya Tyagi*, Ram Keval, Sunil Verma and Dhruba Narayan Kohar

Department of Entomology and Agricultural Zoology, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi 221005, Uttar Pradesh, India
*Email: saniyatyagi2311@gmail.com (corresponding author)

ABSTRACT

This study evaluates sources of resistance to the pod borer *Helicoverpa armigera* (Hubner) in 15 long duration pigeonpea genotypes with experiments done during 2017-19. Association of morphological and biochemical traits was also evaluated. The results revealed that the least pod damage was attributed to high phenol content in pods (-0.668), seeds (-0.719**) and high trichomes density (-0.637*). The susceptibility of genotypes (IVT-1-903, IVT-12-904, IVT-703) was indicated by their high pest susceptibility rating (PSR), and due to greater pod length (0.563*) and width (0.603**). The activity of protein, reducing sugars, chlorophyll, carbohydrates, pod wall thickness and number of seeds/ pod was also studied. Genotypes IVT-705, IVT-706 and IVT-1-901 emerged out to be the least susceptible (PSR = 4). Role of these traits are discussed to identify basis of resistance.**

Key words: Pigeonpea, *Helicoverpa armigera*, pod and seed damage, host plant resistance, biochemical traits, morphological traits, pod wall, pod length, trichome density, susceptibility rating

Pigeonpea [*Cajanus cajan* (L.) Millsp.] is a major seed legume of semi-arid tropics which is attacked by more than 250 insect pests (Sharma et al., 2008). Pod borer *Helicoverpa armigera* (Hubner) is the most serious insect pest of pigeonpea causing substantial crop loss worldwide. Its control is quite difficult due to its polyphagous nature, high fecundity and strong migratory ability, further it attacks the critical stages of growth viz. flowering and pod filling (Pandey, 2017), acting as a significant constraint. Hence, primarily it is controlled with insecticides, resulting problems like resistance, outbreak of secondary pests and pesticide residues (Kranthi et al., 2001). Insect pests are often affected by physical (pod length, pod width, pod wall thickness, number of seeds/ pod, pods/ plant, trichome density, orientation etc.) and biochemical traits (phenols, proteins, total carbohydrates, reducing sugars, secondary metabolites etc.) of the host plant. These traits can help in determination of potential resistance in them by influencing host plant selection primarily due to elimination of other insect density and environment associated variables on the expression of resistance to insects (Sai et al., 2018). Hence, the present study on evaluating the response of *H. armigera* in different pigeonpea genotypes and understand their respective physico-chemical resistance mechanism for further utilization in resistance breeding programmes.

MATERIALS AND METHODS

The study evaluated 15 long duration pigeonpea genotypes including two checks (Bahar and MAL-13) in two consecutive kharif seasons of 2017-2018 and 2018-2019. The experiment was conducted at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi (25°16'10.1"N, 82°59'06.8"E) in randomized block design under unprotected conditions. To categorize the infestation caused by *H. armigera* round bored holes in the pods were considered (Yadav et al., 1987). To assess the damage 100 pods were randomly plucked from five plants of each genotype/ replication at the time crop maturity, from which numbers of damaged pods were counted and converted into % pod damage. Seed damage % was also calculated in a similar way. Based on pod damage, % pest susceptibility rating (PSR) was assigned to the genotypes- from 1 (highly resistant) to 9 (highly susceptible) (Lateef et al., 1982). Data on morphological characters of the genotypes were recorded from five tagged plants/ replication; length and breadth of the uniformly developed pods were measured with digital vernier callipers; pod wall thickness was measured with thickness of the outer peel section of the pods. Pod trichome density was estimated by cutting the pod walls into bits of 25 mm^2; these bits were then treated with dimethyl sulfoxide (DSMO) and later

stained with safranin; after mounting on a slide in a drop of glycerol and covered these were observed under microscope. Total number of trichomes (glandular and non-glandular type) were calculated and converted/ unit area (mm^2) (Bondada, 2012).

Biochemical traits were analyzed from pod wall and green seeds of 15 days old pods (stored at 4°C in deep freeze in airtight conditions). Pod walls and seeds were macerated with pestle and mortar to make an extract for further analysis. Protein content of the pod and seed extracts were estimated by the method of Bradford protein assay using bovine serum albumin as a standard. Reducing sugars were analysed using alkaline copper tartrate and arsenomolybdate reagent (Nelson-Somogyi method). The estimation of carbohydrate was done by anthrone method where concentrated sulphuric acid was used to dehydrate carbohydrate to form furfural. It was then reacted with anthrone to form a green-colored compound that was measured colorimetrically (Loewus, 1952). The quantitative determination of phenolic content was done using Folin-Ciocalteu reagent. Total phenol in terms of mg/ g of pod or seed was measured from the standard curve using gallic acid as a reference. Estimation of chlorophyll of the pod wall was done by maceration-less method developed by Hiscox and Israelstam (1979). The total chlorophyll was calculated with the Arnon's (1949) equations. The data attained in both the years were pooled and computed for two factors repeated ANOVA at $p = 0.05$. Before the analysis. % pod and seed damage were subjected to angular transformation. Correlation coefficients were computed for pod damage vs. morphological and biochemical traits. Statistical analysis was carried out using software R (4.0.0).

RESULTS AND DISCUSSION

Fifteen pigeonpea genotypes evaluated for their reaction to the infestation of *H. armigera* showed significant variations ($p \leq 0.05$) in pod damage ranging from 3.67 to 7.33% (Table 1); least pod damage was observed in IVT-705 (3.67%) followed by IVT-706 (3.83%) and IVT-1-901 (4.50%) indicating their lesser susceptibility; maximum pod damage was observed in IVT-12-904 and IVT-1-903 (7.33%) followed by IVT-1-704 (6.17%) against the susceptible check Bahar (6.17%) and resistant check MAL-13 (4.67%). The seed damage inflicted by *H. armigera* varied significantly from 0.89 to 2.11% (Table 1); least damage was observed in IVT-701(0.89%) followed by IVT-703 (0.92%) and IVT-12-904 (0.96%); and the maximum was observed in IVT-1-704 (2.11%) followed by IVT-702 (2.06%) and IVT-1-903 (2.00%) against the checks Bahar (1.76%) and MAL-13 (3.27%). The pooled mean of 2017-18 and 2018-19, revealed that the least susceptibility rating (4) was obtained for the genotypes IVT-705, IVT-706 and IVT-1-901 (Table 1); and three genotypes exhibit the least susceptibility with pest susceptible rating of 5 (IVT-208, IVT-907, IVT-1-2-908); genotypes were moderately susceptible with ratings of either 6 or 7. None of the genotypes; and all the rest fell under resistant or highly resistant category. It can be conferred that the genotypes showing maximum pod damage were most susceptible showing highest rating (Mareyam Mukhtar et al., 2020).

The morphological characters revealed that the pod length in mm varied significantly in the 15 genotypes; IVT-703 showed maximum pod length (57.74 mm) followed by IVT-1-704 (57.13 mm), IVT-1-903 (55.57 mm); the least was observed in IVT-705 (43.89 mm), followed by IVT-1-901 (47.9 mm) against the checks Bahar (51.84 mm) and MAL-13 (46.44 mm). The correlation analysis of the pod length revealed a significant positive relation ($r = 0.563$) with *H. armigera* as had been reported earlier (Jagtap et al., 2014 and Kamakshi and Srinivasan, 2008). The pod width varied from 6.50 (IVT-706) to 8.89 mm (IVT-1-903); apart from IVT-706, other genotypes exhibited lesser pod width- IVT-705 (6.91 mm) and IVT-1-901 (7.14 mm); the checks measured 8.26 mm (Bahar) and 7.89 mm (MAL-13). A highly significant positive correlation ($r = 0.603$) was observed between pod width and *H. armigera* damage. The pod wall thickness was found to be maximum in the genotype IVT-705 (0.58 mm) followed by IVT-208 (0.57 mm), IVT-706 (0.56 mm); and the least with IVT-703 (0.46 mm) followed by IVT-1-704 (0.47 mm), IVT-702, IVT-12-904 (0.52 mm); and thicker ones revealed less damage exhibiting a significant negative correlation ($r = 0.535$) (Table 1). Jat et al. (2018) also reported that pod borers infestation was negatively associated with the pod wall thickness. Amongst the 15 pigeonpea genotypes evaluated, the number of seeds/ pod varied significantly from 3.51 to 4.43; maximum being with IVT-1-903 (4.43) and the least in IVT-12-904 (3.51); and its correlation with *H. armigera* damage showed positive association in conformity with reports of Jalondhra et al. (2017). The number of trichomes/ 25 mm^2 of pod wall revealed maximum counts in genotype IVT-705 (302.34), superior to the next best one viz., IVT-701 (296.67); the least values were in IVT-703 (269.17) followed by IVT-1-704 (274.17). The pod trichome density revealed

Table 1. Characters of pigeonpea genotypes and damage done by *H. armigera* (kharif 2017-19, pooled data)

Genotypes	Morphological characters						Biochemical characters										% Pod damage	% Seed damage
	Pod length (mm)	Pod width (mm)	PWT (mm)	Seeds per pod	Trichome density	PSR	Phenol (mg/g)		Protein (%)		Reducing sugar (%)		Carbohydrate (%)		Chloro-phyll	PSR		
							Pod	Seed	Pod	Seed	Pod	Seed	Pod	Seed				
IVT-1-704	57.13	8.43	0.47	4.03	274.17	6	1.4	0.29	5.51	13.47	9.36	15.75	9.44	5.19	1.79	6	6.17 (14.30)^{abc}	2.11 (8.26)^{b}
IVT-702	54.16	8.02	0.52	4.05	283.17	6	2.14	0.47	5.17	14.47	11.37	16.71	8.62	2.43	2.05	6	5.67 (13.71)^{bcde}	2.06 (8.23)^{bc}
IVT-703	57.74	7.63	0.46	3.94	269.17	6	1.49	0.55	5.85	14.62	10.23	18.36	10.81	4.87	1.54	6	6.00 (14.17)^{abcd}	0.92 (5.47)^{d}
IVT-706	48.38	6.5	0.56	3.94	296.34	4	5.04	2.13	4.01	12	9.78	14.16	7.48	1.3	0.67	4	3.83 (11.18)^{f}	1.96 (7.99)^{bc}
IVT-705	43.89	6.91	0.58	4.37	302.34	4	5.56	2.19	3.68	11.75	7.7	11.63	5.96	1.09	0.33	6	3.67 (10.93)^{f}	1.82 (7.63)^{bc}
IVT-701	52.03	7.68	0.55	3.67	296.67	6	3.38	1.25	3.97	9.97	10.35	12.89	7.63	2.15	1.17	6	6.00 (14.17)^{abcd}	0.89 (5.41)^{d}
IVT-208	52.97	7.45	0.57	3.84	296.17	5	3.93	1.93	5.17	12.1	8.12	14.98	7.21	2.24	0.67	5	4.83 (12.55)^{cdef}	1.60 (7.20)^{bc}
IVT-907	49.94	8.36	0.54	3.69	292.17	5	3.85	0.67	4.17	10.86	10.73	11.68	8.45	2.56	1.67	5	5.50 (13.50)^{bcde}	1.92 (7.88)^{bc}
IVT-1-901	47.9	7.14	0.55	3.58	294	4	4.43	1.55	4.28	13.94	11.35	13.61	6.87	2.41	0.58	4	4.50 (12.23)^{ef}	1.75 (7.58)^{bc}
IVT-12-904	49.3	7.32	0.52	3.51	289.5	7	3.31	0.64	3.8	13.47	8.87	15.68	8.47	3.26	0.31	7	7.33 (15.68)^{a}	0.96 (5.61)^{d}
IVT-1-903	55.57	8.89	0.55	4.43	280.5	7	2.39	0.76	4.38	14.17	12.36	17.58	8.65	2.47	1.5	7	7.33 (15.69)^{a}	2.00 (7.98)^{bc}
IVT-1-2-908	50.87	8.08	0.55	4.1	293.34	5	5.16	1.7	5.65	12.78	10.88	15.05	7.11	3.51	0.58	5	5.50 (13.55)^{bcde}	1.84 (7.74)^{bc}
IVT-1-2-902	48.46	7.91	0.55	3.69	290.34	6	3.55	1.07	4.08	12.62	9.76	14.88	7.44	3.46	0.52	6	6.00 (14.14)^{abcd}	1.46 (6.95)^{cd}
BAHAR	51.84	8.26	0.51	4.0	278.17		1.15	0.44	6.03	14.18	13.2	16.94	10.32	4.32	2.62		6.17 (14.34)^{ab}	1.76 (7.61)^{bc}
MAL-13	46.44	7.89	0.58	3.73	302.17		4.64	1.64	3.41	12.93	7.8	14.14	6.24	2.47	1.55		4.67 (12.44)^{def}	3.27 (10.35)^{a}
CD (0.05)	1.42	0.58	0.22	0.38	17.85		1.06	0.56	1.35	1.03	1.08	1.16	1.2	0.93	0.78		1.94	0.99
SE (m) ±	0.71	0.29	0.11	0.19	8.91		0.53	0.28	0.67	0.51	0.54	0.58	0.6	0.47	0.39		0.97	0.49
C.C	0.563*	0.603**	-0.535*	0.035	-0.585*		-0.649**	-0.715**	0.22	0.265	0.424	0.475	0.553*	0.47	0.3		-	-

( ) = Indicate that figures in parenthesis arc sin transformed values; Means followed by same letter(s) on par by LSD (p= 0.05); *Significant at p= 0.05; ** p= 0.01; C.C= Pooled correlation coefficient of biochemical traits with *H. armigera* damage; PWT= Pod wall thickness; PSR= Pest susceptibility rating

a significant negative association (r = -0.585) with % pod damage, and similar observations had been earlier shown by Sai et al. (2018).

Of the biochemical traits, phenol content (mg/g) in pods was maximum at 5.56 mg/g (IVT-705), and the least with 1.40 mg/ g (IVT-1-704); and in seeds it varied from 0.29 (IVT-1-704) to 2.19 mg/g (IVT-705); correlation of these with *H. armigera* revealed highly significant negative value (r = -0.649**) (Table 1). These results confirm those of Jagtap et al. (2014) and Kamakshi et al. (2008) that total phenol content is a good indicator of resistance to *H. armigera* in pigeonpea. The protein content (%) was maximum with the pod walls in IVT-703 (5.85%) followed by IVT-1-2-908 (5.65%); and the least values were with the pods of IVT-705 (3.68%). The seed protein content varied from 9.97% (IVT-701) to 14.62% (IVT-703). The protein content of the pods revealed a non-significant association with the per cent pod damage of *H. armigera* (Table 1). However, Cheboi et al. (2019) reported significant positive correlation of seed crude protein with pod damage in pigeonpea. The reducing sugar content of the pods was higher than of seeds; in pod walls, it was observed to be minimum with IVT-705 (7.70%), followed by IVT-208 (8.12%) whereas, IVT-1-903 (12.36%) contained maximum; while the seeds sugar content was maximum with IVT-703 (18.36%) and minimum with IVT-705 (11.63%). The correlation analysis did not reveal any significant relation between reducing sugar and *H. armigera* damage. Total carbohydrate content of pod walls and seeds of the genotypes indicated significant differences; maximum was observed in the pods of IVT-703 (10.81%) and the least was in IVT-705 (5.96%); in seeds, the maximum was with IVT-1-704 (5.19%) and the least with IVT-705 (1.09%). The correlation of total carbohydrate content of pod wall with the *H. armigera* damage was significantly positive (r = 0.553), The chlorophyll content of the pod walls varied from 0.31 (IVT-12-904) to 2.05 (IVT-702); correlation of *H. armigera* pod infestation with this was non-significant (Table 1). Elanchezhyan et al. (2009) observed a positive relationship whereas Jagtap et al. (2014) found a negative relationship between them.

Pigeonpea genotypes when evaluated based on the pod/ seed damage and pest susceptible rating in association with various plant characters revealed genotypes IVT-705, IVT-706, IVT-1-901 were the least susceptible to pod borer damage. The induced mechanism of resistance in these genotypes is contributed to various defence related plant traits like pod wall thickness, trichome density and phenols in higher amounts as compared to susceptible genotypes. On the other hand, higher pod length and width experienced increased susceptibility towards pod borer. This information can be utilised to select, modify and cross resistant genotypes for improving host plant resistance against *H. armigera*.

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PREVALENCE OF INVASIVE FALL ARMY WORM *SPODOPTERA FRUGIPERDA* (J E SMITH) ON ORGANIC MAIZE IN SIKKIM

Chandramani Raj, Shweta Singh*, Ravi Kant Avasthe, Yona Pradhan[1], D M Firake[2], G T Behere[2] and B K Kandpal[2]

ICAR Research Complex for North Eastern Hill Region, Sikkim Centre, Tadong, Gangtok 737102, Sikkim, India
[1]Agriculture Department, Namchi 737126, South Sikkim, Sikkim, India
[2]ICAR Research Complex for North Eastern Hill Region, Umiam 793103, Meghalaya, India
*Email: shwetabac@gmail.com (corresponding author)

ABSTRACT

Fall army worm (FAW) *Spodoptera frugiperda* (J E Smith) has been observed invading the north eastern region of India during April 2019 in Mizoram and on maize crop of Namphing GPU, South Sikkim, during May 2019. The detailed survey in the maize growing areas of state revealed the presence of early to fourth instar larvae feeding on the leaves and whorls. The identification was confirmed by morphological characters and DNA barcoding with mtCO1. The study indicated range (8.8 to 71.4%) of FAW infestations on maize. During survey, microbial infection in few larvae, and predatory wasps and spiders as predators were found. This is the first record of FAW on organic maize of Sikkim.

Key words: *Spodoptera frugiperda*, Sikkim, organic maize, first record, field survey, diagnosis, mtCO1, DNA barcoding, wasps, spiders, microbial infection, Mizoram

Sikkim, the first organic state of India, cultivates cereals, pulses, vegetables, tuber crops and oilseeds in organic manner on an area of about 75 thousand ha **(**Bhutia et al., 2014) of which maize, a staple food crop of Sikkim, is grown in all four districts during February to November (Rahman and Karuppaiyan, 2011) over an area of 38 thousand ha from altitude 300- ≥2200 m (Avasthe et al., 2018). Many insect pests attack maize viz., maize stem borer (*Chilo zonellus* Swinhoe and *Sesamia inferens* Walker), aphid (*Rhopalosiphum maidis* Fitch), grasshoppers (*Chrotogonus robertison* Blanchard and *Oxya chinensis* Thunberg), semilooper (*Trichoplusia orichalcea* Martyn), army worm (*Mythimna separate* Walker) and defoliating beetles (*Centrocorynus scutellaris* Gyllenhal) (Azad Thakur, 1998). In May 2018, the invasive fall army worm (FAW) *Spodoptera frugiperda* (J E Smith) was observed on maize for the first time from Karnataka (Sharanabasappa et al., 2018a) and later spread to many southern states (Mahadevaswamy et al., 2018). Later it has been spread to north eastern states of India since March 2019 (Firake et al., 2019). The FAW incidence appeared for the first time during first week of May, 2019 in maize fields of Sikkim. In this preliminary study, the level of FAW infestation in organic maize fields at Sikkim is reported and efforts made to provide details of its natural enemies.

MATERIALS AND METHODS

Maize fields were surveyed during May 2019 to April 2020 to know the level of FAW infestation in different parts of Sikkim. The observations were made by adopting standard scouting methods for FAW (FAO and CABI, 2019). The numbers of plants damaged were counted based on the characteristics damage symptoms like skeletonising the upper epidermis of maize leaves, windows and ragged holes on leaves, faecal matter in the whorls and damaged cobs. The field collected larvae were brought to the ICAR Research Complex for NEH Region, Sikkim Centre, Tadong laboratory for detailed observation on lifestages. Its larvae were reared on maize leaves until these complete development. The characteristics morphological characters like presence of inverted "Y" on head with distinct black dots on the body with four black dots in a square pattern on the 8th abdominal segment were found on the larvae and the observed specimen were also matched with the identification keys of *S. frugiperda* (Passoa, 1991; Sharanabasappa et al., 2018b). The damage symptoms and lifestages were captured with a Canon EOS 200D 24.2MP Digital SLR Camera, 18-55 mm macrolens and Leica S8 APO stereozoom microscope with Leica MC120 HD inbuilt camera, respectively. The larvae collected from five locations of Sikkim were

reared on maize leaves until complete development. Mitochondrial DNA from two individuals (adult moths) was extracted by the procedure described by Firake and Behere (2020a,b). Overall procedure for amplification of mtCOI, sequencing and further analysis was adopted from Behere et al. (2016).

RESULTS AND DISCUSSION

The FAW *S. frugiperda* being a highly destructive pest, causes significant yield loss in maize and other economic crops (Maruthadurai and Ramesh, 2020; Montezano et al., 2018). In India, its incidence ranged from 2.0 to 100% in maize growing areas (Sharanabasappa et al., 2018a; Shylesha et al., 2018; Mallapur et al., 2018; Chormule et al., 2019; Padhee and Prasanna 2019; Srikanth et al., 2018). In the present study, the survey conducted in districts of Sikkim revealed the presence of early to fourth instar larvae feeding on the leaves and whorls of maize plants. The infested plant exhibited characteristic symptom of papery windows, pin or shot holes and ragged appearance of whorl along with moist saw dust-like faecal matter in the form of lumps either on leaves or inside the whorl. Scrapping of leaves by early instar larvae, stem scrapping, presence of bore holes along with whorl toppling by matured larvae were noticed. The incidence was from 8.8 % on RCM 1-1 (a composite germplasm of maize from Meghalaya) to 71.4% on C.P. 333 (hybrid variety from Charoen Pokphand India Private limited, India) in East district of Sikkim. For the first time FAW infestation was noticed in Namphing village of South Sikkim during kharif season (May 2019) which acted as an epicenter for other maize growing areas of maize in the South and other district of Sikkim. The maximum incidence (56.4± 2.51%) at same place was observed during rabi season in September, 2019, compared to that of kharif season (41.6± 2.28%) and early infestation (55.4± 1.60%) during this year in April 2020 (Table 1).

Subsequently, the damage was detected in other maize growing areas of Sikkim. The initial outbreak in maize field of South district of Sikkim could be reasoned due to two-season cropping of maize (kharif and rabi season) in the area and prevalence of hot and humid condition well in season than other parts of Sikkim. Heavy infestations in late planted maize of double-cropping systems had been reported **(**Robert and All, 1993). Favourable environment like warm and humid season along with rainfall favour the population buildup and spread (Stokstad, 2017). The

Table 1. Fall army worm *S. frugiperda* infestation on maize in Sikkim

Place	Latitude	Longitude	Altitude (feet)	Infestation (%)	Date of observation	Cultivar/ variety
Namphing, South Sikkim	27.228	88.483	2273	41.6± 2.28	10.5.2019	Setimakai
Namphing, South Sikkim	27.228	88.483	2273	56.4± 2.51	28.9.2019	Setimakai
Passi, South Sikkim	27.131	88.451	1943	69.8± 2.14	18.07.2019	Setimakai
Phensang-Kabi, North Sikkim	27.425	88.678	4189	43.8± 1.27	13.06.2019	Setimakai
Lingthem-Passindang, North Sikkim	27.510	88.438	3000	44± 1.14	30.05.2019	Setimakai
Ringhim-Mangan, North Sikkim	27.498	88.535	3136	17.6± 1.91	23.05.2019	Setimakai
ICAR-NOFRI, East Sikkim	27.324	88.601	3882	8.8± 1.15	21.06.2019	RCM 1-1
ICAR NOFRI, East Sikkim	27.323	88.601	3901	33.8± 2.77	25.04.2020	MS 4-1
Zijtlang, Rangpo, East Sikkim	27.181	88.524	1483	44.2± 2.74	2.5.2020	Setimakai
Namphing, South Sikkim	27.228	88.483	2273	55.4± 1.60	5.4.2020	Setimakai and CP 333 (hybrid)
Radong, East Sikkim	27.269	88.580	3364	26.6± 2.46	19.04.2020	JKMH 1701
Passi, South Sikkim	27.13	88.451	1975	52.8± 2.06	12.04.2020	Setimakai
Passi, South Sikkim	27.128	88.452	1942	14.6± 1.71	19.04.2020	Bio-9544
Passi, South Sikkim	27.131	88.451	1944	54.2± 2.18	19.04.2020	CP 333
Amba, East Sikkim	27.209	88.625	3056	68.2± 1.60	23.04.2020	Setimakai and 33M66
Namchebong, East Sikkim	27.260	88.591	3522	71.4± 0.85	10.4.2020	C.P. 333
Naibutar, East Sikkim	27.246	88.591	4826	16.6± 1.68	30.4.2020	Setimakai
ICAR-NOFRI, East Sikkim	27.326	88.598	3669	28.6± 1.94	25.04.2020	RCM-76
Krishi Vigyan Kendra, Ranipool, East Sikkim	27.285	88.591	2629	69.8± 1.41	8.6.2020	MS 8-1
Lower Sajong, East Sikkim	27.314	88.571	3862	26.6± 1.04	4.6.2020	Pehnlo Makai
ICAR NOFRI, East Sikkim	27.323	88.603	3897	52.6± 0.97	3.6.2020	Murali Makai

species identity was confirmed at molecular level by sequencing standard barcoding region of mtCOI gene. After trimming the ambiguous ends (5' and 3'), a final 626bp good quality sequence was obtained for both the individuals. BlastN search of our FAW 626bp sequences shown 100% similarities with FAW reported from China (MK860942), South Africa (MK493021), Kenya (MK492973) and others regions of India (MT644266) including North Eastern region of India (MN640599 and MN640598). The two sequences of FAW sequenced in the study showed 100% similarities, and a representative sequence submitted to the NCBI vide accession number 'MT621018'. The nucleotide composition of sequence reported in this study has A-29.1%, T-40.4%, G- 14.9% and C-15.7%.

Although the FAW has invaded and spread to different parts of Sikkim, the organic ecosystem has potential to restrict the pest below economic threshold level (Wyss et al., 2005; Zehnder et al., 2007). The native biocontrol agents against other *Spodoptera* spp., could possibly manage this invasive species as related indigenous pest species have been considered as first line of defense (Firake and Behere, 2020a). For instance, >26 species of natural enemies of FAW have been reported in similar agroecosystem of Meghalaya (Firake and Behere, 2020a; Firake and Behere, 2020b; Firake et al., 2020). In this study, predatory wasps (Hymenoptera: Vespidae) and different species spiders (unidentified) were found predating on FAW larvae during survey. Besides, microbial infection was also noticed in few larvae in organic maize fields. Therefore, there is huge scope for availability of several potential biocontrol agents of FAW in Sikkim which could be instrumental in managing the spread of FAW infestation.

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ARTHROPOD PESTS AND THEIR NATURAL ENEMIES ASSOCIATED WITH COTTON IN INDIA: A REVIEW#

V S Nagrare*, Babasaheb B Fand, Rishi Kumar[1], V Chinna Babu Naik, Kundan Bhure, Bhausaheb Naikwadi, Nandini Gokte-Narkhedkar and V N Waghmare

ICAR-Central Institute for Cotton Research (ICAR-CICR), Nagpur 440010, Maharashtra, India
[1]ICAR-Central Institute for Cotton Research (ICAR-CICR), Regional Station, Sirsa 125055, Haryana, India
*Email: vs.nagrare@gmail.com (corresponding author)

ABSTRACT

Globally cotton is the most important natural fibre crop being cultivated commercially for domestic textile needs and export. Cotton plays an important role in India's economy, occupies largest acreage and highest production in the world. In India, cotton is being grown in 10 major states divided in 3 distinct zones viz., north, central and south with varying climate and soil. Despite large acreage, cotton productivity in India is far below world average due to variety of reasons. Among them damage caused due to arthropod pests is vital. In this article authors have attempted through extensive literature survey, to provide up to date information on arthropod pests and their natural enemies associated with cotton crop in India. It is observed that, in India, cotton crop is attacked by 251 arthropod pest species (including insect and mites) belonging to 9 insect orders and 1 order from Acarina. Among these, about 12 species of insects are major pests causing significant losses to cotton crop while remaining species are either occasional, sporadic or minor in nature. Overall these pests cause economic damage to cotton crop in a range between 20-60 per cent. The major arthropod pests are sucking insects namely leafhopper *Amrasca biguttula biguttula* (Ishida), aphid *Aphis gossypii* Glover, thrips *Thrips tabaci* Lindeman., whitefly *Bemisia tabaci* (Gennadius), Cotton mealybug *Phenacoccus solenopsis* Tinsley, Papaya mealybug *Paracoccus marginatus* Williams and Granara de Willink, and Indian cotton mirid bug *Creontiades biseratense* (Distant). The bollworm complex is another major group of insects that attack cotton and comprises of American bollworm *Helicoverpa armigera* (Hubner), spotted bollworms *Earias insulana* (Boisduval), *E. vitella* (F.) and pink bollworm *Pectinophora gossypiella* (Saunders). Other pests like stem weevil *Pempherulus affinis* Faust and tobacco caterpillar *Spodoptera litura* F., are also categorized as major pests. A rich fauna of 368 natural enemies (including 174 species of predators and 194 species of parasitoids/ parasites) play significant role as biological control agents to check arthropod pests in cotton ecosystems of India. In this review there is addition of 85 arthropod pests over previously reported 166 arthropod pests. This updated information on cotton pests and their important natural enemies may serve as an important guide to researchers and policy makers in carrying out potential pest risk assessment and devising appropriate management strategies for economically damaging cotton pests.

Key words: Cotton, India, cotton ecosystem, arthropod pests, fauna, insects, mites, sucking pests, bollworms, resurgence, natural enemies, predators, parasitoids

Cotton is the most important natural fibre crop cultivated commercially for domestic textile needs as well as export. Cotton plays a major role in India's economy, both in terms of providing employment directly and indirectly to more than 60 million people. India occupy largest cotton acreage (13.373 m ha) and production (36.5 m bales, 1 bale=170 kg) in the world (CICR, 2020). India is the only country where all the four cultivated species of cotton viz., *Gossypium hirsutum* Linn., *G. barbadense* Linn., *G. arboreum* Linn., and *G. herbaceum* Linn. being grown for lint, oil and feed. In India, cotton is being cultivated in 10 major states classified into 3 distinct zones viz., north zone comprising of Punjab, Haryana and Rajasthan; central zone comprising of Madhya Pradesh, Maharashtra and Gujarat, and south zone comprising of Andhra Pradesh, Telangana, Karnataka and Tamil Nadu. These three zones have distinct bio geographical features with varying climate and soil. Though, India shares largest area under cotton, however Indian cotton productivity is lowest (464 kg lint/ ha) due to variety of reasons, among them damage due to various arthropod pests is one of the major yield limiting factors.

#Table 1-3 available ONLY IN ONLINE PUBLISHED VERSION- see indianentomology.org or entosocindia.org

Previous records revealed, worldwide, cotton crop is attacked by 1326 species of arthropod pests (Hargreaves, 1948). In India, initial records indicated 109 species of insects and mites infest the cotton crop (Nangpal, 1948). Later, this number increased to a total of 166 species (Khan and Rao, 1960). These pests were reported attacking cotton crop at different stages of growth causing losses ranging between 50-60% (Puri et al., 1999). There is gap of almost 60 years since 1960 (Khan and Rao 1960) on the updating of arthropod associated with cotton in India. Since then updated information on new records of pests on cotton is seriously lacking. The major insect pests documented in above reports include: i. Bollworm complex comprising of American bollworm *Helicoverpa armigera* (Hubner), spotted bollworms *Earias insulana* (Boisduval), *E. vittella* (F.) and pink bollworm *Pectinophora gossypiella* (Saunders); and ii. Sucking pest complex consisting of leafhopper (*Amrasca biguttula biguttula* Ishida), aphids (*Aphis gossypii* Glover), thrips (*Thrips tabaci* Lindeman) and whitefly (*Bemesia tabaci* Gennadius). With the introduction of genetically modified cotton, popularly known as 'Bt cotton' in 2002 for bollworm control, Indian cotton ecosystem experienced a phenomenal change in its pest profile. There have been frequent pest resurgences of already existing pests as well as few recent invasions which were hitherto not reported to be the pests of cotton. In this review, an attempt has been made through an extensive review of literature to provide an up-to-date information on pest fauna associated with cotton in India. Additionally, a comprehensive list of diverse natural enemy complex including both predators and parasitoids that are prevalent in Indian cotton ecosystem have been provided as a ready reckoner for researchers, extension workers and policy makers in assessing the potential pest risks and formulating effective management strategies for various insect pests in cotton.

Arthropod pests

The information updated through extensive literature survey revealed that the number of pests (including insects and mites) attacking cotton crop in India has been increased to 251 from earlier report of 166 species (Table 1)[#]. These 251 species documented here belonged to 9 different insect orders and one order from Acarina. The reported insect pest species attacking cotton crop have been categorised broadly in two groups; one group included sucking pests and another group included chewing, biting and borer insects. Among sucking pests, insect order Hemiptera contributed 72 species belonging to 18 families viz., Aleyrodidae (1), Aphididae (2), Capsidae (3), Cercopidae (2), Cerococcidae (1), Cicadellidae (8), Coccidae (3), Coreidae (8), Diaspididae (1), Eurybrachidae (1), Fulgoridae (2), Lygaeidae (8), Membracidae (2), Miridae (9), Monophlebidae (1), Pentatomidae (5), Pseudococcideae (11) and Pyrrhocoridae (4). It was followed by 4 species of Thysanoptera belonging to a single family Thripidae. Among chewing, biting and borers insects; insect order Coleoptera contributed 41 species from 11 families which comprised of Anthribidae (1), Bostrichidae (1), Bruchidae (1), Buprestidae (1), Cerambycidae (1), Curculionidae (25), Chrysomelidae (2), Galeracidae (1), Meloidae (4), Scarabaeidae (2), Tenebrionidae (2); order Lepidoptera contributed 60 species from 12 different families Arctiidae (6), Cassidae (1), Cosmopterigidae (1), Crambidae (2), Erebidae (2), Gelechiidae (1), Lymantriidae (5), Lyonetiidae (1), Noctuidae (35), Oracilariidae (1), Pyralidae (3), Tineidae (2); order Orthoptera included 33 species from 05 families viz., Acridiidae (20), Gryllaeridae (1), Gryllidae (10), Pyrogomorphidae (1), Tettigoniidae (1); order Hymenoptera comprised of 9 species from single family Formicidae while order Isoptera had 6 species from family Termitidae. Order Diptera contributed 5 species from four families Agromyzidae (1), Cecidomyiidae (1), Chloropidae (1) and Sarcophagidae (2). The order Dermaptera contributed only 3 species from families Anisolabididae (2) and Forficulidae (1) (Table 1). In mite pests, the only Order Acarina of mites contributed 18 species from six different families viz., Eriophyidae (3), Erythraeidae (1), Phytoseiidae (2), Tarsonemidae (1), Tenuipalpidae (1) and Tetranychidae (10) (Table 1). Over the previously reported 166 arthropod pest species (Khan and Rao 1960) there is addition of 85 arthropod pests in this review.

Among the 251 arthropods species, 12 species of insects are major pests causing significant losses to cotton crop while remaining species are occasional, sporadic or minor in nature. The sucking insect pests (leafhopper, aphid, thrips, whitefly, cotton mealybug, papaya mealybug and Indian cotton mirid bug), the bollworm complex (American bollworm, spotted bollworms and pink bollworm) and the other pests like stem weevil *Pempherulus affinis* Faust and tobacco caterpillar *Spodoptera litura* F., are the major pests of cotton in India. These arthropod pests cause yield

[#]Table 1-3 available ONLY IN ONLINE PUBLISHED VERSION- see indianentomology.org or entosocindia.org

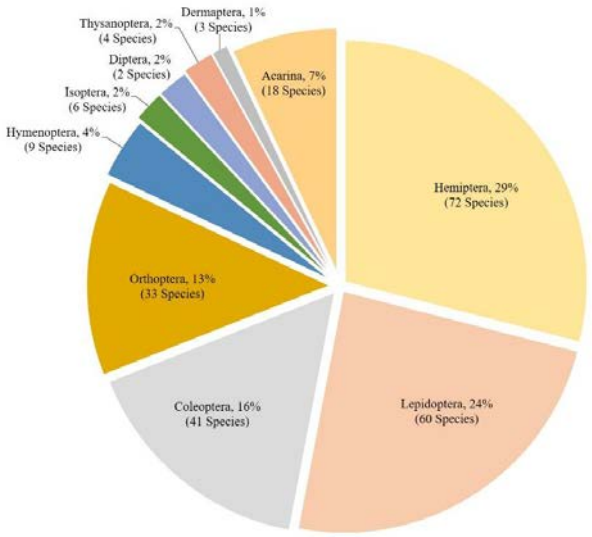

Fig. 1. Number of arthropod species and its relative proportion from ten different orders recorded on cotton ecosystems of India

losses ranging from 20-60 %. Current status of these pests is given in later part of this article. The relative proportion of insect species from different orders is presented in Fig. 1.

Natural enemies

Interestingly, a rich fauna of 368 natural enemies have been recorded on various insect pests of cotton from different cotton growing zones of India (Table 2 and 3)[#]. These natural enemies are key component of cotton ecosystem and are playing a vital role in natural suppression of insect pests therein. Thus, looking at the vast diversity of predators and parasitic fauna associated with pests of cotton ecosystem, there is a great potential for implementation of environment friendly biological control of cotton insect pests.

Predators

The predatory fauna appetizing on various cotton insect pests comprised of 174 species (Table 2). Predators from insect order Coleoptera contributed 23 species mainly from Coccinellidae (22) and Staphylinidae (1); order Neuroptera contributed 9 species from Crysopidae (8) and Hemerobidae (1); order Diptera contributed 14 species from Asilidae (1), Cecidomyiidae (1), Chamaemyiidae (3), Drosophilidae (1) and Syrphidae (8); order Hemiptera contributed 20 species from families Anthocoridae (4), Geocoridae (4), Miridae (2), Pentatomidae (1), Pyrrhocoridae (1), Reduviidae (8); order Lepidoptera contributed 3 species from Lycaenidae (1), Noctuidae (2); Mantodea contributed 3 species from Mantidea; order Hymenoptera contributed 16 species from Aphelinidae (1), Formicidae (3), Scoliidae (1), Sphecidae (8), Vespidiae (3); order Odonata contributed 4 species from Libellulidae (4); Araneae contributed 76 species (44.25%) from Araneidae (11), Clubionidae (2), Dictynidae (1), Eutichuridae (1), Gnaphosidae (1), Lycosidae (6), Oxyopidae (19), Parassidae (1), Pisauridae (1), Salticidae (14), Sparassidae (1), Tetragnathidae (5), Theridiidae (3), Thomisidae (9), Uloboridae (1); Mite order Acarina contributed 5 species of predatory mites from two families Phytoseiidae (4) and Pyemotidae (1). The relative proportion of predatory species from different orders is presented in Fig. 2.

Parasitoids/ Parasite

There are total 194 different species of parasitoids associated with insect pests of cotton ecosystems in India (Table 3). The Hymenoptera, a single insect order contributed 163 species which accounts for about 83.85% of the total parasitic fauna. The Hymenopteran parasitic families included Aphelinidae (13), Braconidae (53), Chalcidae (21), Elasmidae (5), Encyrtidae (31), Eulophidae (9), Eurytomidae (1), Ichneumonidae (14), Mymaridae (2), Pteromalidae (3), Scelionidae (2), Thysanidae (1) and Trichogrammatidae (8) (Fig. 3). Another insect order Diptera contributed remaining 30 species (15.63%) from two families Chloropidae (1) and Tachinidae (29). Only one parasite from Acarina belonging to family Pyemotidae has been reported.

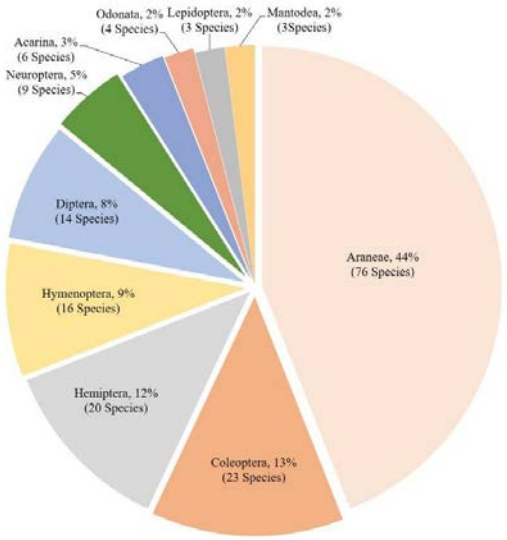

Fig. 2. Number of predatory arthropod species and its relative proportion (%) from ten different orders recorded in cotton ecosystems of India

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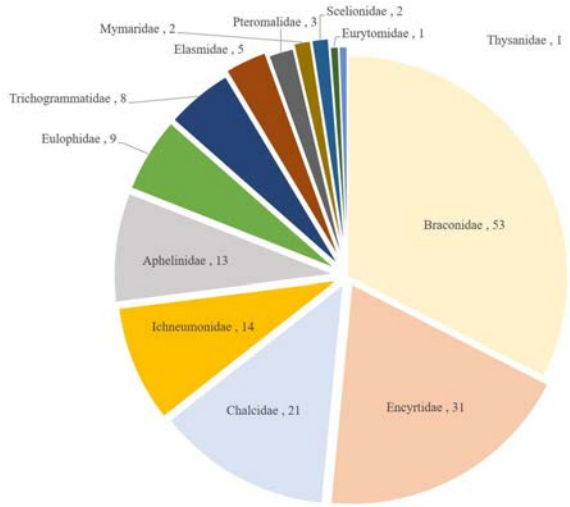

Fig. 3. Distribution of number of species in each family of order Hymenoptera

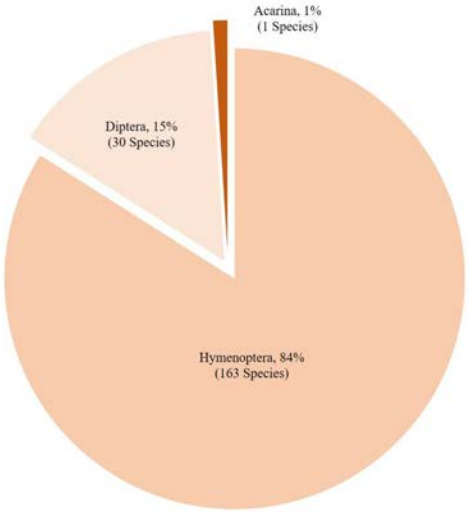

Fig. 4. Number of parasitoids species and their relative proportion from three orders recorded in cotton ecosystems of India

The relative proportion of parasitoid species from different orders is presented in Fig. 4.

Present status of major pests

Sucking insects

1. Leafhopper *Amrasca biguttula biguttula* (Ishida)

Leafhopper *Amrasca biguttula biguttula* (Ishida) is one of the most important pests of cotton in India (Pruthi, 1940; Husain, 1937; Shivanna et al., 2009; Murugesan and Kavitha, 2010). Leafhopper is a major and regular pest feed on the sap of mesophyll and vascular tissues through cell rupture and cause phytotoxic symptoms known as causes 'hopperburn' consequently leading to reduction in crop vitality and cotton yield loss up to 30%. The pest is distributed in all the three cotton growing zones and is a regular pest. It is a polyphagous insect pest of Asia and Southeast Asian countries. Genetic divergence analysis of leafhopper population across India confirmed the presence of single species. North India populations were dominated by single haplotype while, the south and central Indian populations show dispersion of different haplotypes across the region (Kranthi et al., 2017).

2. Aphid *Aphis gossypii* Glover

Aphid has been reported as a major pest of cotton causing significant damage to the cotton crop. This species has been reported as a vector of Polerovirus infecting cotton in India (Mukherjee et al., 2012). Nagrare et al. (2019) studied the temperature effects on phenology of *A. gossypii* and reported that temperatures between 22 - 27°C favoured its optimum development. Further, they estimated through fitting of non-linear models to temperature dependent development data, the lower and upper thresholds temperatures of 6.24°C and 34°C, respectively for *A. gossypii* development.

3. Thrips *Thrips tabaci* Lindeman

Thrips lacerate the tissue and de-sap the plants from the upper and lower surfaces of leaves, resulting in silvery or brown necrotic spots. Infested plants demonstrate hampered growth, loss of vigor. Leaves turned into wrinkled and distorted, curl upward with white shiny patches, resulting in dropping of squares, delayed crop maturity and reduction in yield. Tobacco streak virus disease transmitted by *T. tabaci* has been recorded in central and south zone of India (Bhat et al., 2002; Jagtap et al., 2012).

4. Whitefly *Bemisia tabaci* (Gennadius)

Whitefly is a major pest occurring in all the three cotton growing zones of India, but it is the most important sucking pest in North Indian cotton growing states of Punjab, Haryana and Rajasthan by virtue of its capability to transmit cotton leaf curl virus disease (CLCuD), especially in *hirsutum* cotton. Several outbreaks of whitefly were reported in India (Basu, 1986; Jayaraj et al., 1986) but the recent one was witnessed during 2015 in north India (Kranthi, 2015b). *Bemisia tabaci* is a vector of begomoviruses (family *Geminiviridae*). *Bemisia tabaci* is reported to transmit 111 viruses (Tiwari et al., 2013). Whitefly causes direct damage by sucking phloem sap from plant tissues, while indirect damage through the excretion of sticky honeydew which promotes a fungal sooty mould that

interfere in photosynthesis in leaves and deteriorate the quality of cotton.

5. Cotton mealybug *Phenacoccus solenopsis* Tinsley

Widespread outbreak of invasive species of mealybug occurred on cotton in India during 2007 which caused economic damage, thereby reducing yields up to 50% in affected cotton fields (Nagrare et al., 2009). The infestation was recorded in nine major cotton growing states of India. Infestation of cotton mealybug at most of the places in north and central zones was high during 2007 and 2008 but it was reduced to a minor pest from 2009 onwards. *Phenacoccus solenopsis* suck sap from all parts of the plant, resulting stem distortion, twisting and bushiness of the affected portion and death of plant in severe infestation. Since its invasion in India, *P. solenopsis* is the most extensively studied insect pest of cotton so far with respect to various aspects like host range and infestations levels (Tanwar et al., 2007; Jhala et al., 2008; Nagrare et al., 2009; Fand et al., 2010; Venilla et al., 2011), important biological control agents including predators and parasitoids (Tanwar et al., 2008; Rishi et al., 2009; Fand et al., 2010b, c; Fand et al., 2011; Suroshe et al., 2013) and potential geographic distribution, temperature dependent biology, within plant distribution (Rishi et al., 2013) and climate change impact on future invasiveness (Fand et al., 2014a-c). A detailed account of this mealybug with a major focus on its origin and distribution, biosystematics, bioecology, host range, management options and its potential threat under future climate change has been reviewed by Fand and Suroshe (2015).

6. Papaya mealybug *Paracoccus marginatus* Williams and Granara de Willink

Papaya mealybug was recorded in a severe form for the first time on cotton in Coimbatore in 2008-09, infestation leads to drying of the sympodial branches (Dhara Jothi et al., 2009). The mealybug also found in other districts like Erode, Tirupur, Salem, Namakkal and Karur districts of Tamil Nadu (Tanwar et al., 2010). The pest is now seen in traces.

7. Indian cotton mirid bug *Creontiades biseratense* (Distant)

Infestation of Indian cotton mirid bug was observed in Karnataka (Patil et al., 2006). An epidemic form in Coimbatore on cotton during 2006 (Surulivelu and Dhara Jothi, 2007) led to significant reduction in seed cotton yield of Bt cotton. The pest feeds on the flower bud result in oozing out of yellow fluid from the buds and staining of this yellow fluid on the inner surface of the bracts. Cotton mirid bug is a major pest restricted to Tamil Nadu and Karnataka states of South Zone.

Cotton bollworms

8. American bollworm *Helicoverpa armigera* (Hubner)

It is considered as a major and most notorious and obnoxious pest of cotton in Indian sub-continent. Heavy infestation of American bollworm witnessed during 1995-2000 in view of the injudicious use of insecticides, especially synthetic pyrethroids that led to problems of insecticide resistance. Subsequently, after 2000, with the introduction new technologies like Bt-cotton, new chemistry insecticide, etc. (Kranthi and Russell, 2009), *H. armigera* infestation reduced significantly and in the last two decade it hardly ever exceeded economic threshold levels in majority of the cotton growing regions on Bt cotton of India. However, infestation of *H. armigera* observed on non-Bt cotton. The pest feed on squares/ bolls and results in yield loss up to 40% in non-Bt cotton.

9. Spotted bollworms *Earias insulana* (Boisduvel)

Spotted bollworm *Earias vittella* (Fabricius) and spiny bollworm *E. insulana* (Boisduvel), (Lepidoptera: Noctuidae) are the major pests of cotton in India. *Earias vittella* is seen in Central and South India while *E. insulana* is predominant species in North India. At present both these species are under control on Bt cotton (Rishi et al., 2019). Larvae of the pests initially bore into terminal shoot that dry and wither away when the larvae bore into the pre-squaring plants. As like *H. armigera*, *Earias* spp hardly exceeded economic threshold level on Bt cotton, however, seen to damage non Bt cotton.

10. Pink bollworm *Pectinophora gossypiella* (Saunders)

Pink bollworm *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae) is destructive pest of cotton in India. Larvae mainly feed on developing cotton seeds. Quality of lint deteriorated due to the presence of larvae and lint get stained by the pest. Up to 61.9 per cent loss in seed cotton yield, 47.10 per cent loss in oil content and 59.20 per cent loss in normal opening of bolls was reported (Patil, 2003). Presently, Bt technology is unable to protect cotton crop from *P. gossypiella* due to development of resistance against Cry1Ac and Cry 2Ab toxins in India. Widespread infestation of pink bollworm on Bt cotton was reported

from major cotton growing Indian states like Gujarat, Maharashtra, Andhra Pradesh, Telangana, Karnataka and Madhya Pradesh starting from 2015 onwards (Kranthi, 2015; Naik et al., 2018, 2020, Fand et al., 2019). The pest also seen infesting Bt cotton during 2018-2019 and 2019-2020 in north zone especially in Jind district of Haryana (Rishi et al., 2020).

Other insects

11. Tobacco caterpillar *Spodoptera litura* Fabricius

During eighties to late nineties, Tobacco caterpillar, *Spodoptera litura* Fabricius (Lepidoptera: Noctuidae) was one of the economically important polyphagous pests of cotton which exhibited high resistance levels when pyrethroids were first introduced in India in 1982 (Ramakrishnan et al., 1984; Kranthi et al., 2002). The pest was severe in most parts of Andhra Pradesh (Armes et al., 1997).

12. Stem Weevil *Pempherulus affinis* Faust

Stem weevil *Pempherulus affinis* Faust (Coleoptera: Curculionidae), is an endemic pest in some parts of south India, particularly Tamil Nadu, causes 65.8% plant mortality, 72.0% reduction in boll production and 78.9% reduction in yield of seed cotton (Parameswaran and Chelliah 1984). Grub tunnel the stem which damages the vascular tissues. Infested plant gets killed in the course of time either due to blockage of plant nutrients or break down at the gall region due to strong winds. The pest is mostly prevalent in irrigated tracks.

CONCLUSIONS

Over the period of time, Indian cotton ecosystem has witnessed a sea change in its cultivation practices and pest profile. In the context of climate change and introduction of Bt cotton for commercial cultivation, the cotton crop has experienced very frequent invasions of some new insect pests as well as resurgence of already existing insect pest. There is gap of almost 60 years since 1960 on the updating of arthropods associated with cotton in India. Our efforts to provide an updated list of insect pests and natural enemy fauna associated with cotton brought to the forefront an important information that presently the cotton crop in India is attacked by 251 arthropod pest species (including insect and mites) belonging to 9 different insect orders and 1 acarina. Among these species, about 12 species of insects are major pests during last two decades causing overall losses to the tune of 20-60% to cotton crop while remaining species are occasional, sporadic or minor in nature. A rich fauna of 368 natural enemies (174 predators and 194 parasitoids/ parasites) found to play a significant role in regulation of arthropod pests of cotton in India, indicating a great potential for conservation and promotion of eco-friendly biological control in cotton ecosystem.

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WILD BEES AND THEIR CONSERVATION

Amarjit S Tanda

School of Horticulture, University of Western Sydney, Richmond Australia, CSIRO, Australia
Current Address 2/49 Arthur Street Rose Hill NSW 2142 Australia
Email: drtanda101@gmail.com

ABSTRACT

About sustainable agricultural environment and world food security, major crops mainly dependent upon managed honey bees and wild bee pollinators which are of great significance. Bee pollinated crops being a great part of the bio-diverse system, 4,000 native bees, and offer over US$1.5 billion each year in North America. In US, the value of wild bees in food production was determined to be over $1.5 billion annually. However, the worth of wild bee pollination in insect cross pollinated crops may be much more. These great wild players are now in fast declining phase or possibly extinct due to human-disturbed habitats. More investigations are required in various topics of wild bee fauna, such as basic studies in population biology, abundance, bee protection measures, suitable habitat, nesting sites especially their immediate conservation strategies. After realizing the importance of wild bees in pollination, in the present review, we highlight the various measures and actions to conserve the wild bees so that they can serve the growers as co-players to managed honey bees in boosting the agricultural food production worldwide.

Key words: Wild bees, pollinators, bio-diversity, habitat, crop, improvement, yield, buzz pollination, conservation, ecosystem, management, sustainability

Globally, wild bees are the major crop pollinators, being responsible for the cross pollination, seed setting and fruit production of various major field crops. For many years, being neglected part of bio-diverse system, they have been badly suffering from a decline by the unnecessary human-disturbances and farm practices in the environment. Apiculturists are now anxious about the immediate and effective measures to protect the native bees for using in crop pollination, enhanced agriculture production and for the sustainability of bio-diverse ecological environment. Human interest in the bee conservation increased greatly, due to many new research findings presented on the newspapers radio and TV (Schatz, 2020; Tanda, 2019, 2021a-c). Some insects remain unnoticed from people acceptance which are less-charming (Hart and Sumner, 2020), encouraging bee pollinator protection program is an interesting subject to educate majority of the people groups. Although this subject is familiar to many, a lack of knowledge and understanding of the topic is blatant and has a gap between information and its comprehension (Wilson et al., 2017). This break is due to the absence of knowledge about role of hoverflies and butterflies in bio-diverse ecosystem. About 80% and 99% of the reports in Great Britain and the United States described that bees are the key crop pollinators (Wilson et al., 2017). Mostly, people understood the honeybee *Apismellifera*, as the main crop pollinators. Further, the crop pollination mechanism now known as entpollinatology (Tanda, 2021c), the significance of flower assets and nesting site environment, major groups of pollinators with specific needs has become more significant. The insufficient reports may result in irrelevant activities for the conservation of endangered bee pollinators (Wilson et al., 2017; Schatz, 2020; Didham, 2020; Penn, 2021; Tanda, 2019, 2021a-h). Harvey et al., (2017) designed a program for pollinator's conservation and their retrieval as a base for bee scientist studies. In the last 10 years, the population of several insect species has disappeared by 9% and including the native bees (van Klink et al., 2020). Observations on the illeffects of ecosystem on the population dynamics of native bees are abundant (Potts et al., 2010; Goulson et al., 2015; Tanda, 2019, 2021a- d, h) and several bees are endangered locally and facing disappearance, but still survive in their geographical habitat (Primack et al., 2012). This unique event can be observed by looking at European and IUCN Red Lists studies (IUCN, 2016). A number of native bees are under threat in Belgium, or even disappeared locally but their population is not absent at the European scale (Drossart et al., 2018) showing the protection activities in various regions. There is a gap between the scientific information and awareness (Wilson et al., 2017). This gap is generally described by an ignorance of knowledge about the prominent abundance of bees, hoverflies, and

butterflies in the living environment. Survey reports in Great Britain and the United States identified that bees are important, but only 3% and 14% can assess the pollinator's distribution in different regions (Wilson et al., 2017). Many people are capable to recognize honeybees and bumblebees crop pollinators, however the other native bees are poorly identified as main species. Less than 50% of the participants were even unable to name at least one bee worker (Wilson et al., 2017). Through large presentations, mainly focused on the honeybee *Apis mellifera*, the general public was understanding the value of crop pollination, but not the distribution and its population size. Flowers importance, sites of bee nesting, favorable environment and the existence of main bee pollinators with their specific requirements were also not known to the people. This incomprehension of scientific reports could therefore may support to unrelated activities, wrong, or even ineffective measures for the conservation of endangered bees (Wilson et al., 2017; Drossart and Gerard, 2020). This shows that with the scientific understanding, the public awareness has not advanced. For workers, bee identification and ranking endangered species is challenging and a principal project to ongoing studies and an informative program for wild bee conservation and their improvement system to be framed. About 9% terrestrial insect populations per decade has perished and the wild bee abundance are also not an anomaly (van Klink et al., 2020). On wild bee populations, studies on the harmful impact of pressures are sufficient (Potts et al., 2010; Goulson et al., 2015; Tanda, 2019, 2021a-h). Knowing the harmful impacts of climate, decrease in the bee population, national and regional actions associated with the wild bee fauna conservation and their protection methods should be implemented urgently. Allthe possibleconservation measures will be of great importance in the preservation of native bees and their bio-diverse habitat. As many native bees are threatened and vanishing, they may still survive quite long time in their habitats (Schatz, 2020; Penn, 2021; Tanda, 2021h). Such changes can be reported in IUCN Red Lists and the European scale studies (IUCN, 2016). Many bee species are disappeared in Belgium, as their abundance are not good at European level (Drossart et al., 2018). Undoubtedly, the bee population degree as well as the declining factors are greatly investigated, still reports on the preservation methods of wild bees are not well described. A general and up-to-date evaluation of the conservation actions, technology as well as their effectiveness and efficiency, is still wanting. Keeping this in mind, firstly, we reviewed the significance of preserving native bees, bee population's assessments at risk alongwith the factors associated with declining their abundance. Secondly, we emphasized on the conservation measures, associated factors, and the effectiveness of these methods. We have highlighted on the conservation actions that improve the bee-friendly environment such as semi-natural landscapes to urban and crop habitats naming the required floral resources and nesting sites, and alien species with habitat control process. To fill many gaps of native bee protection studies, some new projects and reports have been presented in this review.

Wild bee's protection should be our priority

Bees being the main flower pollinators in many bio-environments, pollinators are involved in the propagation of 80% of angiosperms (IPBES, 2016). Due to this breeding technology, crosspollination is contemplated as one of the most crucial jobs in the working of bio-diverse system and boosting in crop production globally (IPBES, 2016; Potts et al., 2016). About 85% of field crops benefit from insect pollination service that directly influences the quality and quantity of food production (IPBES, 2016) which is worth 100 to 500 billion euros annually globally (Lautenbach et al., 2012). The decline in wild bees is fascinating move in humans to non-pollinator dependent crops for food and fronting lack in essential nutrients, causing economic and health problems (IPBES, 2016; Potts et al., 2016; Bauer and Wings, 2016). Native bees can be the key pollinators in few field crop productions (IPBES, 2016), while other crops are cross pollinated by managed honeybees. Only a little bee population forage on crop plants. So, pollination management alone is not enough to confirm true alone for the protection of local bees. Wild bees are also of specific significance due to their capability to visit flowers in a different type of climatic conditions and environment (Brittain et al., 2016). Bumblebees can forage even in cold weather and even visit at high sonication. In wild flora, the high strength and diversity of local plant pollinators increases a complementary and synergistic activity with domesticated honeybees (Fründ et al., 2013; Garibaldi et al., 2014; Isaacs et al., 2017). Grab et al., (2019) has mentioned this in the phylogenetic diverse studies and bee abundance related with crop pollination. Engaged bee population also act like a main operator to boost the crop yield (Martins et al., 2015). In the urban area too, (Säumel et al., 2016), forests (Cummings et al., 2016), and natural bio-ecosystem (Cummings et al., 2016; Massaro et al., 2013), the significant contribution of native bees has also been reported and their abundance is associated to the density wild flowers (Ollerton,

2017). In bees and flowers, the ecological interaction disappearance, is disregarded frequently instead of the bee extinction reports (Valiente-Banuet et al., 2015). This loss of bio-diverse factor still occurs at the same time or may result in the disappearance of the bee species (Valiente-Banuet et al., 2015; Jacquemin et al., 2020). Many bees are related to a specific habitat and food resources, which make them resist that environment and agitating food. Specialist bees forage on a few flowers whereas generalist pollinators have great foraging alternatives (Jacquemin et al., 2020). Thus the all-rounders are more resistant to the different climatic environments associated with human actions as they are capable to manage on other food resources (Roger et al., 2017). Damage of these biotic interplay effect in rapid species disappearances and negatively influence the working of the eco-bio-structure (Diaz et al., 2017). To avoid the collapse in environmental services to humans, the importance of interplay of biotic agents be contemplated (Jacquemin et al., 2020) to assess the fitness of environment and to determine the possible environmental matters (Aizen et al., 2012; Dirzo et al., 2014). The aim in Andalucía BeeFun project, is on the increase of knowledge and understanding of the impact of habitat, bee crop-pollination process and social groups (Underwood et al., 2020;Drossart and Gerard, 2020).

Bees are disappearing-a warning

Studies and assessment of bee population technology needs a basic action for global fluctuations in the decline and benefit of the bee species. In this worldwide transformation, a few species can survive or finish as described in the United Kingdom (Powney et al., 2020). IUCN Red List technology guides to assess the possible extinction of a bee species at regional, national, and global levels (IUCN, 2016) and there may be variations in the assessment techniques in different environments. To establish a fundamental base for the preservation actions and assessment of the species to execute monitoring, conservation strategy, management and policy formation, this is the most powerful technology. For wild bees Red List, at European level and many more countries are also compiling their Red Lists at national and regional level (Drossart et al., 2018; Reemer et al., 2018). At continental scale, in North America, IUCN has also undertaken the efficiency evaluation for the *Bombus* spp. (Hatfield et al., 2020). This research report for wild bees helps in indicating the bee abundance, species, and areas under threat. Bee conservation measures also indicate to record the factors influencing the bee abundance (Harvey et al., 2020; Primack et al., 2012; IPBES, 2012). Scientists are focusing at the degree of decline and factors responsible for the population withdrawal (Forister et al., 2019). Besides fire, drought, hydrological and geophysical events having a non-negligible influence on native pollinators (Nicholson et al., 2019), global warming, crop escalation, habitat and diseases greatly influence the bee populations (Potts et al., 2010; IPBES, 2016). Either effect of single element (Potts et al., 2010) and expected feasible interactions (Goulson et al., 2015; Meeus et al., 2018) have been reported in many countries, still a detailed scientific informationgap remains in the measurement of the spatial and temporal influences from the various threats alongwith the historical information independently (Bartomeus et al., 2019). Furthermore, the knowledge of the genetic variation in species, population dynamics and speciation are also important and more and more utilized in conservative biological aspects (Epps and Keyghobadi, 2015). New reports in genetic conservation has encouraged the scientists to utilize molecular biotechnology to determine more better about bee bio-diverse system (Epps and Keyghobadi, 2015; Lopez-Uribe et al., 2017), with new gene bio-techniques also appearing (Woodard et al., 2016). This is clear in cryptic bumblebee species having high degree of morphological convergence. Less genetic diversity which can result in inbreeding depression and lessen the health is alarming (Packer et al., 2016). Based on the historical reports and distance assessments (IBD), the assessment of the relation among bee population, their effective part and biotic and abiotic operators, researchers can classify the vanishing bee species (Cerna et al., 2017; Lecocq et al., 2017; 2018). Using various tools and the assessment of the threatening elements, through population assessments scientists are now capable of conservation tactics by policy agreements, applied plans, and actions with ongoing studies (van Klink et al., 2020; Forister et al., 2019; Drossart and Gerard, 2020).

Protection measures is the answer

After knowing the population tendencies and decline operators, then important action is to protect the suitable environments. In fact, based upon the scale and the landscape, there is a great wild bee heterogeneity and population diversity (Belsky and Joshi, 2019). Native bee make-up is framed by landscape fitness globally, from mountainous tropical habitats of Colombia (Cely-Santos and Philpott, 2019) to dry grasslands in Missouri, USA (Grover et al., 2017). Grasslands with blossoms provide a great bee abundance and habitats

than crops devoted to livestock and full of flowers. So to protect such suitable habitats can be attained by the development of safe areas using legal actions to avoid any changes, and by buying such important ecosystems. Flexible management of bees and environment, in such protected areas, have to be established to explain the best programs and adaptive actions for the success and failures of the bee management. Nevertheless, many anthropogenic urban environments can never offer the same degree of bee shelter than the semi-natural ecosystem, but still need conservation activities. To attain similar targets, many joint programs aiming at the environment, intensification of bio-diverse ecosystem, least entry of alien bees or the communication about diversity damage have been undertaken by the World Bee Project. To integrate cloud computing with wild bee research worldwide the World Bee plan aims to serve all new intuitions and information to design modern programs for bee decline globally, various environment conditions and enhanced food sustainability and subsistence to intercontinental extent merging other strategies undertaken by the European Union (EU, 2011) implemented nationally (Belgian NFP-CBD, 2020) and in USA at other different scales to manage the bee disappearance (Heinz Center,2013); in France, (Gadoum and Roux-Fouillet, 2016); in Ireland, (PPSG, 2015). Bee and Butterfly Habitat Fund, Seeds for Bees, and The Dutch Bee Strategy, the English National Pollinator Strategy are helping stakeholders to exchange their expertise and information collectively from various cultures (Saunders et al., 2018; Turo and Gardiner, 2019). Public advice and the participation of youth is significant for running such projects (Turo and Gardiner, 2019). We suggest that main efforts should be concentrated on the safety, preservation and the restoration of native bee habitats, concentration on the urban and agricultural fields, and execution of man-made tools to provide nests, potential invasions by alien species and the training of people groups with efficient transmission.

Do wild bee environment renovation

Preservation of native bees can be started by the protection of semi natural environments to rebuild huge natural habitats for the establishment of a bio-diverse ecosystem. In the decline and protection of terrestrial insects in the safety of habitat Bee environment is most important (van Klink et al., 2020). These environments are bio-diverse activities to explain the important action to consider for the distinct diverse habitat (Sobral-Souza et al., 2018). Such new standardized models can be assessed by the Ecological Niche Models (Krechemer and Marchioro, 2020) as tested in bumblebee species in South-America. Protected eco-environments can boost native bees in landscapes and geographic regions (Tonietto and Larkin, 2018). Improvement of the environment by repairing techniques implicit an investigation of the habitat of the target species. They evaluated the preferences of bumblebee likings in the crops and suggested natural landscapes and field boundaries for the bee population survival. Wild bees can react differently in changed environments. Carrié et al. (2017) described that hedgerows, grasslands, and forest edges with potential attributes for example in solitary and ground-dwelling bees foraging a large number of flowering plants, but the social and above ground nesting bees visiting a few blooms in such ecosystem. Rainforest could improve above-ground nesting for bees as found in Brazil, conversely (Ferreira et al., 2015) showing the conservation activities importance in a protected bee-habitat. The restoration devices can be made double-edged and depending upon the demand and situation. As grazing and burning are followed in grasslands to aid floral blooming, however they can also destroy wild bees hibernating in the plants (Tonietto and Larkin, 2018). These restoration measures are conducted in the framework of LIFE plans funded by the European Union. They focus to renovate bee habitats directed in Natura 2000 bee sites mentioned in "Birds" and "Fauna-Flora-Habitats". If bee protection is at its inception compared to birds and mammal's safety, aiming at butterflies and LIFE in Quarries will indirectly help to local bee fauna with the bee conservation and the environment renovation similar to quarries, peat bogs, biological meadows, and hedgerows (Folschweiller et al., 2019). As LIFE projects failed, similar program such as Urban bees LIFE are in action (www.urbanbees.eu) and are targeting management to increase the bee population and bio-diverse environment of local bees in potential urban and peri-urban areas. Hall and Steiner (2019) described that US state projects did not consider the significance of bees in comparison to vertebrates leading in less understanding of their needs, and restoration actions. Few conservation focusing in semi-natural environments are believed in schemes at national/sub-national level.

Develop and use conservation methods

In Urban and Agricultural Areas Conservation measures are crucial and in anthropogenic areas more than 55% of bees live in the peri-urban regions. Under such important programs, hedgerows, parks, roadsides, and urban gardens can constitute crucial environments for bee multiplication in quality and quantity, and

transitional areas as beneficial environment (Hall et al., 2017; Nowakowski and Pywell, 2016; Gosselin et al., 2018; Crone et al., 2019). Such ecosystems can assist in building big specific diversity and an boosting factor for rare bees (Senapathi et al., 2017) and often pillar a great bee diverse ecosystem (Fortel et al., 2014). Bee-friendly plans using roof-top gardens, parks, and roadsides, has increased the populations of native bees in Amsterdam (Givetash, 2018) as this environmental interconnection proved important ecological segmentation could be harmful for little bee species. Tiny bees in segmented habitats, can be incompetent to approach the favorable landscapes and face difficulties in anthropogenic environments (Warzecha et al., 2016; Gérard et al., 2020; La Vie Sauvage, 2020; François and Féon, 2017).

It has been revealed largely that the strength of floral wealth is a key framework for native bee diversity, when renovating prairies as in Minnesota, USA (Lane et al., 2020; Ritchie and Roser, 2020). Agro-environment actions, as flower strips have been accepted in Europe to increase biodiversity in assiduously managed agro-landscapes (Grass et al., 2016; Cole et al., 2020) and beneficial for bumblebees, honeybees, and hoverflies in Germany, Belgium, and in England (Wood et al., 2015). More flower supplies mostly helped in the improvement of bumblebee population, size, density and young ones number (Wood et al., 2015; Vaudo et al., 2018). The impact of AES was determined rarely (Batáry et al., 2015) and Geppert et al. (2020) observed the effect of organic practices and floral strips for bee population survival and development. Both actions were positively corresponding to pollinators' strength and population and growth of bumblebee hives, but the efficiency of these actions relied firmly on the landscape around (Geppert et al., 2020). In England, (Wood et al., 2017) also assessed a Higher Level Stewardship farms—HLS to experiment if grown flowers helped the native solitary bee populations. For instance, as honeybees and bumble bees were positively influenced by the affair of *Phacelia* sp., solitary bees mostly foraged sunflower and seed mixes of wildblooms (Mallinger et al., 2020; Nichols et al., 2019). Still, a move in flower resources happened among the most environments of native bees facing stress and could result in the exhaustion of flower assets and alterations in the crop-pollinator web (Gérard et al., 2020; DEFRA, 2020). The restructuring of flower mixtures could also be effective in bee environments with maximum flower density in areas under crop and uncultivated land (Quinet et al., 2016; Moquet et al., 2017). Angiosperms should offer the flow of floral gifts throughout the flowering season for sufficient food needs (Vaudo et al., 2015; Filipiak et al., 2018) based on the floral phenology and specific behavior of bee species. Gresty et al., (2018) demonstrated that plants like *Rosa canina, Malvasylvestris, and Ranunculaacris* allured specifically those solitary bees living in cavities.

This framework is pivotal for bee multiplication and abundance but is often neglected during the selection of bee-friendly flowering plant cultivars. This is accurate for the brood nutritional needs, which vary from adult requirements (Filipiak et al., 2018). The strength and nutritional power of crops like *Brassica napus* for *Osmiabicornis*) can positively help in the development rate of bee abundance (Bukovinszky et al., 2017; Filipiak, 2019). In fact, the variety of proteins and essential amino acids required is important for the growth and development of bee population. This can help bee species health through nutritional needs using floral assets available in the habitats, particularly in flower resource-exhausted environments. Different agrotechnology could also be tested such as friendly planting, which can enhance the quantity and quality as in the strawberry *Fragariax ananassa* and the borage *Borago officinalis* (Griffiths et al., 2020) but the effect on pollinator abundance was not studied. So it is difficult to describe the chemical toxicity taken from reports on honeybees and generalize about bumble bees and solitary bee taxa, furthermore, solitary bee's sensitivity will be highly different. POSHBEE, European strategies could be beneficial in comprehending how pesticides can influence these native bee fauna and synergistic effect with other decline elements. Still, it has been demonstrated to also influence bee pollinators and is not a particular reaction to safeguard the bee world (Dicks et al., 2016; Egan et al., 2020). Egan et al., (2020) demonstrated a newly designed strategy that is known as Integrated Pest and Pollinators Management (IPPM; Biddinger and Rajotte, 2015) the same we propose to be called as, "Pollinator and integrated pest management technology (PIPMT)", as this is a technology, or holistic strategy to amalgamate crop pollinators, bio-control agents, minimum use of pesticides and various other IPM procedures, aiming at the management of the pests below economic injury levels for enhancing the agriculture food production (Tanda, 2019, 2021a-h). Applied management actions are also recommended, such as the choosing of varieties with great bee pollinator allurement and maximum pest resistance. In Ireland, The Protecting Farmland Pollinators plan is reliant upon the designing of a crop bee pollinator assessing campaign which can permit growers to determine simply which control processes on agro lands

help to pollinators in decreased pesticides usage, offer little environments and floral resources for example, flowering pattern at the farmland level. Additionally, the Interreg-Sudoe Poll-Ole-GI project (2016-2019) focused recognizing and suggesting efficient practices as green infrastructures (GI) to positively effect on bee pollinator abundance and bee ecosystem amenity in the two most significant Mediterranean crops of arable farmland in the South-western European Space (SUDOE) which comprises Southern France, Spain, and Portugal, including sunflower and oilseed rape.

Bee hotels

To increase the accessibility of flower assets for pollinators in research, however, barely few studies have targeted the bee nesting sites (Fortel et al., 2016). Endangered bees could be settled in soil-nesting and other wild bees with special nesting behavior, nesting in cavities, subterranean, carder bees and in snail's shells. We recommend copious nesting provisions, including the development of Wild Bee Inns for little bee species for wide distribution areas (Fortel et al., 2016). Maclvor and Packer (2015) also established the newly protected environmental enhancement strategies for wild bee needs. They highlighted that about 50% of the bee population housed in the bee hotels were newly introducedalien bees, however 75% of them were lived in by wasps. Alarmingly, they found a negative interrelationship between the wild bees and the species present in bee hotels (Geslin et al., 2020). This study described the positive reaction of artificial devices for native bees nesting, and exhibits the role of developing nesting sites to multiply various bee species for the crop pollination (Maclvor and Packer, 2015; Fortel et al., 2016). In fact, aim should be on the present and bee hotels cavities hole diameter as needed by various bees for nesting, as small diameters could help many wild species and prevented by bigger exotic bees like *M. sculturalis* to adopt bee hotel lodging (Geslin et al., 2020). May this be the little patches of bare soil installations, bee inns or the bee hotels, the empirical use of their positive contribution should be thoroughly studied.

Alien plants and their role

Local plants can be managed by professionals using protection strategies, many alien species can invade and populate bee-friendly habitats, or even they are grown voluntarily. However, the effect of alien plants can depend upon various ecological factors or life history characteristics, resulting in some species to suffer from the invasions whereas for others it may be favourable (Davis et al., 2018; Drossart and Gerard, 2020). Incursion only happens when an exotic species is having invasive power andsufficiently suitable environment to survive. Generally such plant species have been developed in habitats closely associated with human existence. Pretentious habitats related to humans, alien plants can offer food resources for some bee pollinators and improve crop production via cross pollination (Hobbs et al., 2013; Drossart et al., 2017; Jachuła et al., 2020). They may have detrimental effects on specific bees with small diet flexibility. However, some unwanted alien plants contend with local vegetation and can oust plants that are visited byspecific pollinators. Few non-indigenous species also show resources that are inaccessible to most wild bees such as, *Petunias* sp., (Lowenstein and Minor, 2016). Majewska and Altizer (2018) described in a meta-analysis that no organized positive or negative effect on pollinator population could be attributed to exotic species and that their influence is case-specific. It can be hypothesized that all exotic species are harmful and thus as detrimental to the knowledge magnification as is the principle that these species are fully protected (Boltovskoy et al., 2018). In the future, the Asian hornet *Vespa velutina*, for example, could be a threat for wild or managed bee pollinators (Arca et al., 2014; Keeling et al., 2017; Laurino et al., 2020). In importation programs, planned international measures to prevent bio-invasions of alien species should thus be a main important matter (Sutherland et al., 2016). Observing invasive species should be kept on top of the activities, it could allow acquiring the data required to carry out the population dynamics research and test their potential effect on native species and eco-environments (Le Féon et al., 2018; Aizen et al., 2019). A law to prevent and alleviate the harmful effects of alien species in the European Union entered in 2015 (EU Regulation (EU) No.). Assessing the IUCN Red Lists, a parallel program called as "Black List" has been recommended for invasive alien species and contemplates the extent of climatic effect for the species assessed. The IUCN Invasive Species Specialist Group (ISSG) gathers specialists in minimizing challenges developed by aliens to native habitats and the species they restrain by increasing awareness, elimination, management, or removal pertaining to them. Each group is accountable and adapted nationally, making and improving invasive species list in their respective country.

Building bee populations

The effectiveness of preservation actions, from the scientific knowledge and liaising more efficiently and

correctly with scientific data to a large audience is a base to set up a solid conservation starting point. Few precedents in education, training and communication can be explained to strengthen the bee conservation technology (Saunders et al., 2019). In various taxa, maximum use of citizen sciences in bee conservation procedures encouraged monitoring population studies over a long time period (Gardiner and Didham, 2020; Ubach et al., 2020). Many people have paid attention to wild bee pollinator's conservation in the last decade. Despite notable biases in records, such as observing the most striking and colorful species, cryptic species incorrect identification, using this tool, permits to effectively note a large number of specimens in large area, showing an important part of the species in an environment and assessing the species dynamics for scientific research (Duchenne et al., 2020) and Red Lists program. Silva and Minor (2017) observed that the degree of education and knowledge about wild bees were directly related to the positive attitudes of the respondents towards the native bee abundance, encouraging the pivotal role of people's awareness. This information should be exchanged largely among scholars, and social media groups and also true in demonstrating the geographic and taxonomic extent of reports (Saunders et al., 2019). Scientific information favouring different concepts prior to the pesticides, mowing/pruning agenda constitutes a main action to efficiently integrate bee groups pollinators in the management system of all parks, gardens, and flowering patches (Schonfelder and Bogner, 2017; Folschweiller et al., 2019; Turo and Gardiner, 2019). Austria designed several research projects targeting the positive impact on wild pollinators for the renovation of flowering areas in 20ha using 18 local officials by monitoring native bee populations (Underwood et al., 2017). Apart from this pilot project, they also established many acceptable green habitats in orchards, road edges, schools, nurseries, and along waterways for bee conservation (Underwood et al., 2017). An alliance was established between an NGO and a supermarket chain for bee conservation actions. Similar collaborative programs are initiated between fruit growers and local city municipalities in Flanders (Belgium) or between a beer brewer, NGO, and public officials to boost bee conservation schemes (Underwood et al., 2017).

Wild bee populations are decreasing globally for the last few decades, mostly by the human interferences. The people interest for their protection increased greatly, through scientific publications communicated through various media sources. Despite this large interest, due to the shortage of knowledge and subject comprehension is flagrant and describes a space between consciousness and apprehension. As bee disappearance is studied, knowledge on conservation actions is still scattered in literature. We lack bee preventativeconcepts and scientists are working for efficient tools for enhancing native bee populations and the improvement of bee environment. In this review, we present a recent new analysis of the wild bee conservation methods, and their utilization in habitats and the advance scientific programs that fill up the gaps in literature and reframe new applied conservation strategies. Focusing on wild bee pollinators, we applied our main information on (i) the modern protection methods in anthropogenic environments, (ii) the preservation and renovation of native bee habitats, (iii) implementation of newly designed tools, (iv) actions to control exotic species, and (v) how to educate public with the new concepts efficiently for maximum bee pollination benefits. This review can be beneficial to implement a factual and experimental native bee protection strategy for the enhanced and sustainable food production globally.

Wild bee conservation -challenges and threats

The importance of wild bee conservation requires bee scientists to transmit new concepts and guidance relying on the research observations in bee diversity protection and tools used (Primack et al., 2012). Bee protection actions are carried out research on honeybees or bumblebees, but, conclude such reports and can rarely be considered as an alternative for local solitary bees (Schmitt et al., 2020; Wood et al., 2020). The recent naming visited flowering plants (Gresty et al., 2018) liking the foraging period of selected wild bee and the food necessities of adults and immature stages (Filipiak, 2019). This subjectis roughly investigated at the time of designing new strategies of bee protection. Besides, there is an important imbalance between the investigations regarding the bee flora, favorable habitats and safe nesting site provisions. Such studies have to be handled in reframing the bee conservation plans, further investigations needed to study such crucial subjects more thoroughly, especially in assessing a large area of bee dwellings than only bee resorts, and hotels. The globe which is progressively anthropogenically-moving forward, different bee flora habitats could be, promptly, an answer to the deficit world food problem. In habitats having little native bee-flora, few alien invaded species can assist bee abundance to recuperate. Such topics should be considered depending upon proofs as in New-York a new report described that exotic species could help honeybees better than the native wild

bee populations (Urbanowicz et al., 2020). In such anthropogenic habitats, the method to run bee-friendly environments have also to be re-consider, in particular by discovering options to pesticide applications. Dealing with such circumstances, the influence of techniques like IPPMT could be enormouslyexplored for the maximum safety of pollinator's world. Additionally, the overwhelming most environment renovation research is carried out in North America and Europe, which constitute only a little portion of worldlyenvironments occupied by native bees. Similar bee restoring methods could not be prototypical of what should be adopted in other bee habitat having dissimilar landscapes (Tonietto and Larkin2018; Drossartand Gerard, 2020;Tanda, 2019, 2021) also needs attention. Further studies should be carried out to assess conservation methods extensively in rainforest and arctic environments. The transmission of education about wild bees have to be redesigned in gathering facts. It is a fact that we do not preserve birds by offering hen homes, so we will have to maximize our attempts so that the beautiful world of bees does not go around the hives,for honeyand waxes. To handle this, we should not disregard to involve work packages in our research work about the communication of knowledge to various schools and those who are realistically employed to implement conservation activities. These plans are often the ones that are rejected while they should be the acme of scientific work. In spite ofgathering information about bee population threatening elements, we should share, import, away from the preventativeideas as they are generally studied, established, recognized and at least assessed in part (Folschweiller et al.,2019;Tanda, 2019, 2021;Penn, 2021). Now specialists are inviting for measures, which need the immediate main attention (Folschweiller et al., 2019). Research strategies as the Interreg SAPOLL project, designing a strategy for wild bee conservation as the chief target or the biodivERsA NUTRIB2 project could support to fill thegaps. Designing of such actions and combine the various beeconservation players would further strengthen the public awareness to bee biodiversity and environmental services in bio-ecosystems where people are more disconnected from the natural bee world for instance, the house tops, commercial buildings, roadsides, near bridges, and railway track sides etc. (Fortel et al., 2016; Penn, 2021). Some actions which can conserve the bee populations are described below;

- Promise to protect the bee pollinators and join BEE-SAFE on your piece of land, garden, and the backyard of your company and your rooftops. Towns, schools, corporations, and individuals lands can be used.
- Say no tochemical uses on your flowering plants to prevent any insecticidal harm to bee fauna. Inspect plants bought are not pre-treated with neonics.
- Grow bee pollinator's preferred flowering plants as they are a big asset for bees and butterflies providing nectar and pollen.
- Keep away from lawnsas they desert for bee pollinators, so plant prairies.
- In early spring don't weed your gardens as dandelions are best source of bee food and medicine.
- Install water basins in summer with pebbles or floating corks on water to prevent bees from drowning in every balcony.
- To get enlightened and sign regular petitions to pressurise the world countries to pass laws to conserve the bees banning neonicotinoids, keep in touch with the Facebook page of New York Bee Sanctuary and Instagram account.
- In your back yard or your rooftops, install a bee hive and modified handmade tools for wild bee conservation and protection. It's an excellent and wonderful strategy to offer home and nesting sites to many bee populations.
- Train the public and educateyour families by showing bee documentaries. Native bees are harmless, and visit flowers. Know about the valuable bee services in food production globally and respect them.

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HABITAT MANIPULATION- A TOOL TO MANAGE INSECT PESTS

Talim Hussain*, P K Kumawat, Rafakat Hussain[1], Reena[2] and Arti[3]

Division of Entomology; [1]Division of Plant Pathology, SKUAST-Jammu, Chatha 180009, Jammu UT, India
[2]ACRA, Dhiansar, SKUAST-Jammu, Dhiansar, Bari Brahmana 181133, Jammu, India
[3]Department of Plant Protection, AMU-Aligarh, Uttar Pradesh 202001, India
*Email: bkreena12@gmail.com (corresponding author)

ABSTRACT

Habitat manipulation results in diversification of habitats and enables natural enemies to access resources. Effective conservation biological control provides tactics that enhance the relative abundance of effective predator among the predators. Varying types of resources provide protection, suitable microclimatic conditions, oviposition sites and plant-provided food (pollen and nectar) by increasing vegetation diversity which favour the attraction and retention of natural enemies. Landscape management may be important if successful biocontrol has to rely on a wide range of natural enemies. The density of some common species can indeed be increased through enlarging the community, however species richness is often determined by the landscape composition. The intercrop may create the favourable microclimate to hasten the activity of predators and parasitoids while hindering the pest survival. The choice of the intercrop also plays a significant role for the effectiveness of biocontrol.

Key words: Habitat manipulation, microclimate, intercropping, covers crops, natural enemies, predators, biological control, cultural practices

Habitat manipulation, often known as "Ecological Engineering", focuses on reducing natural enemy mortality, giving more resources, and changing host plant characteristics for the benefit of natural bioagents. It can be accomplished by improving plant diversity within the agroecosystem by providing suitable refugia. Habitat manipulation is a new concept in biological control that increases biodiversity and leads to agro-ecosystem stability and sustainability (Kumar et al., 2013). The enhancement of natural enemy populations by agricultural system changes is also part of habitat manipulation. The addition of extra resources for natural enemies, like pollen, nectar or alternate prey, through habitat diversity, has shown to increase the percentage of natural enemies in the field (Landis et al., 2005). Agricultural habitats will be changed in order to increase predator population or diversity, with the ultimate goal of improving biological pest management (Root, 1973; Barbosa, 1998; Landis et al., 2000). Shifting the cropping system to increase the effectiveness of a natural enemy is known as habitat manipulation. Many adult parasitoids and predators like nectar sources, so refuges such as grasses, thin borders and cover crops provide refuge. Mix crops can increase the diversity of ecosystems and present natural enemies with alternate food sources and refuge. The key to effective biological control in conservation is to create strategies that increase the relative abundance of the most effective predator within the predator community, as well as various expanding vegetation diversity, we can supply more resources like as refuge, oviposition sites, acceptable microclimatic conditions, and plant-provided food (nectar and pollen) (Straub and Snyder, 2006; Andow, 1991).

In agricultural settings, where wide monocultures are typical, providing any non-crop plant or resource from which a natural enemy can benefit is essential. For example, the cultivation of strip crops around a wheat field may provide the floral resources required by hover flies adults, reducing the amount of space the adults must forage for food and possibly increasing the number of hover flies in the region. It has been observed that predators and parasitoids aggregate around plants with rich various sources (Berndt et al., 2002; Hickman and Wratten, 1996; Hooks et al.,1998; Root, 1973; Van Emden, 1963) and other research shows that floral resources help parasitoids increase their reproductive success by increasing their longevity and fecundity (Arthur, 1945; Dyer and Landis, 1996; Jacob and Evans 2000; Heimpel et al., 1997; Jervis et al., 1993; Wheeler, 1996), which this might cause reduced number of pests in the field (Irvin et al., 2000; Patt et al., 1997). Natural enemies will be highly polyphagous to utilize other diets during periods of low pest population, even if they do not demonstrate

life-history omnivory. On farms, habitat alteration may provide natural enemies with nutrients such as pollen and non-pest herbivores until pest numbers begin to improve. The main function of these strategies is to improve diversity while also preventing insect pest attacks caused by vegetation.

Intercropping is defined by Andrews and Kassam (1976) as the planting of two or more crops in same region, as its supplementary crop sown in rows or strips within the primary crop. Due to the close proximity of appropriate refugia, intercropping has the benefit of promoting natural enemy dispersal to the most crop. The ideal supplementary crop placement should be determined to increase natural enemy transmission out of the most crop, allowing for maximum predation or parasitism rates. Insect pest outbreaks are more likely in monocultures than in diversified crop conditions, which has long been associated as a potential for pest management through habitat manipulation. According to Root (1973), pest densities were found to be lower in poly-culture of cabbage (kale) and grassland flora than in crops of cabbage. Numerous habitat manipulation studies such as the incorporation of various flowering plants into crops have shown the potential and applicability of this pest control method (Baggen and Gurr, 1998; Bostanian et al., 2004; Lee and Heimpel, 2005; Irvin et al., 2006). Strip harvesting was discovered to be advantageous to natural enemies in Lucerne. Strips that grew taller had a greater population of predators and parasitoids than strips that were harvested recently (Kumar et al., 2013).

Predators, parasitoids, and herbivores are examples of beneficial invertebrates that help increase or maintain crop production by reducing pest insect and weed populations. In many agricultural systems around the world, parasites, predators, and Entomopathogens are key factors of pest control for predatory insects, whereas larval herbivores and crop pathogens are used for biological weed control. Pest control by natural enemies is now a horny alternative due to rising chemical costs, a shrinking variety of accessible pesticides, and increased customer awareness of pesticide residues on fresh produce (Bostanian et al., 2004). Whenever natural enemies are given resources that are limited in agro-ecosystem (Barbosa 1998; Pickett and Bugg 1998; Gurr et al., 2004; Landis et al., 2000; Jonsson et al., 2008). This method can increase biological control, but it frequently needs a thorough understanding of natural enemies and, like a result, the most appropriate, selective resources to deploy.

Enhancement of natural enemies

As part of habitat management, natural enemies should be provided materials that are necessary for organisms but have no disadvantages. The presence rate of natural enemies inside the field was studied as a suitable technique of show vast numbers of food vegetation (Fiedler and Landis, 2007). This technique can provide information on the attractiveness of food crops, which is an important element when determining which vegetation kinds to supply for biocontrol.

Crop diversification

Herbivores, parasitoids, and predators may benefit from increased availability of food sources like nectar. Also as result, cautious plant selection is necessary to avoid increasing pest populations or providing an alternative host for a plant pathogen or other insect pests. A selective diversification with plants which are botanically unrelated to the crop is required. Gurr et al. (1998) proposed a checklist approach that enables a semiquantitative assessment of hazards similarly as economic and biological factors. Food supplies are provided via wildflower strips (nectar, pollen, alternative prey, honeydew-producing insects). If there is enough alternative prey, generalist predator populations can develop foothold within a crop prior to the arrival and seasonal increase of pests (Van Emden, 1990). In order for natural enemies to succeed, habitat management must provide them with sources that are always limited for these organisms that do not provide anything new and exciting. Crop diversification can help the natural enemy population thrive during survival situations or off-seasons when their main food source is declining and not under cultivation. Every plant's attraction to natural enemies must be studied, which is an essential thought while choosing which crop species to grow for bio control. However, before selecting a suitable plant species for cultivation, consider the variety of natural enemies supported by the crop ecosystem, due to intra-guild predation or inter-specific communication, natural hazards enemies' diversity can sometimes have a negative impact on biocontrol (Rosenheim et al., 1993; Finke and Denno 2004, 2005; Costamagna et al., 2008). The target of IPM is to increase the impacts of parasitoids on pests (Holland and Thomas 1997; Furlong et al., 2004; Agarwal et al., 2007). Pesticides non-target impacts are reduced by altering the environment to increase habitat biodiversity (Gurr et al., 2004).

Habitat diversity: Crop diversification within a field can benefit over the duration of the crop cycle,

and that in the case of field crops, the overall habitat is commonly diversified by the addition of perennial components to help in the survival of natural enemies. Hedgerows, shelterbelts, conservation headlands, and beetle banks will all be planted with permanent plants to promote habitat diversity (Gurr et al., 2004) if the diversity of species within the refuges and neighbouring areas can grow with the refuge's age (Frank, 1997), these structure might have to be conventional for several duration to manage their complete possible. The supply of beetle banks is one method for increasing natural enemy populations through habitat diversification. These are recognized by grass-covered soil banks in the central of grassland (Thomas et al., 1991, 1992). Tiger beetles (Cicindelinae), predatory carabids, rove beetles (Staphylinidae), sphecoid wasps, and even a number of the spiders that make nests in the ground can find protection and overwintering grounds in these places (Thomas et al., 1991, 1992) and variety (MacLeod et al., 2004). Although increasing predation has been recorded around beetle banks (Collins et al., 2002), this effect is not widespread (Prasad and Snyder, 2006).

The development of blooming strips to provide nectar from flowers as nutrients for natural enemies also is excellently technique of ecosystem management to protect natural predators (Pfiffner and Wyss, 2004; Gurr et al., 2005; Heimpel and Jervis, 2005). If effective biological control requires on a wide range of biological predators, landscape managing is important (Tscharntke et al., 2008). The density of such common species can be increased by management; however species richness is often determined by the landscape composition (Roschewitz et al., 2005; Schmidt et al., 2005, 2008). The addition of organic amendments to the soil, such as composts, crop grasses, or animal wastes, resulted in increased in the number of general predators in many agro-ecosystems (Badejo et al., 1995; Brust, 1993; Culliney and Pimentel, 1985; Litsinger and Ruhendi, 1984; Larsen et al., 1996; Pimentel and Warneke, 1989; Morris, 1922; Riechert and Bishop, 1990).

Cover crops: Cover crops provide a ground cover and their flowers can act as attractants for the natural enemies by providing pollen and nectar other than altering the microclimate which is suitable for the natural enemy population. Cover crops, on the other side, can act as weeds if not managed effectively, competing with both the crops for nutrients and water (Bugg and Waddington, 1994; Meyer et al., 1992; Nyczepir et al., 1998), They'll likely improve production value or reduce yields (Brown and Glenn, 1999) , Annual plant vegetation, whether grown for nuts and seeds or moderately (perhaps designated areas for biological diversity), can create a complex environment, specifically when understory vegetation is present to provide various levels. These types of environment components can host combinations of beneficial and pest invertebrates with a wide range of trophic connections (Bugg and Waddington, 1994; Altieri and Schmidt, 1985). Recent events in study of selection processes appeared to be promising for identifying flower species that serve the needs of parasitoids while providing utility to pests. It's frequently difficult to forecast how a particular covering plant may affect the number of natural enemies (Letourneau, 1998; Barbosa and Wratten, 1998). Very less research has been carried on the usefulness of canopy crops in pest management because the primary function of such crops is to supply a ground cover and not the enhancement of the predator populations.

The effect of canopy crops on beneficial organisms may generally be examined by looking at insect-natural enemy complexes, which include insect and enemy dispersal capabilities, environment needs, and resources required for reproduction and survival (Ferro and McNeil, 1998). for example, Manipulation of land cover structure within a crop and its surrounding vegetation, such as, can improve biological control of certain arthropod pests. However, by intensifying other insect species, increasing a crop disease, or adding a weed species, it can have the opposite influence on the overall target of included production (Prokopy, 1994; Barbosa and wratten, 1998). Improved crop cover can sometimes induce hyper parasitism of natural enemies by attracting secondary parasites, resulting in an increase in pest numbers (Stephens et al., 1998). Pests of natural nemies adversaries can get in each other's way. Through a widespread effect below the trophic level, such impacts may result in reduced crop growth (Snyder and Wise, 2001).

Intercropping and mixed cropping: Intercropping is the farming of two or many crops in different field, with the supplementary crop often seeded in rows or sheets alternating within the main crops, whereas mixed cropping is the planting of various crops on the same piece of ground with no regard for row proportions (Andrews and Kassam, 1976). The proximity of adequate refugia facilitates natural enemy dissemination to the major crop, which is a major advantage of intercropping. This is ready to support a greater load of natural enemies through the provision of subsidies

within the type of nectar and pollen to optimise movement of biological control into the major crop, so predation or parasitism rates succeed, the effective distance of secondary crops must be determined. Intercropping cereal crops through molasses grass (*Melinis minutiflora*) improved stem-borer parasitism by Cotesia sesamiae in Africa (Khan et al., 1997). Intercropping can produce refuge or nutritional sources for natural enemies by growing crop or non-crop plants in close proximity to the major crop. The intercrop can even create the favourable microclimate to hasten the activity of predators and parasitoids while hindering the pest survival. The choice of the intercrop also plays a significant role within the effectiveness of Bio control. Natural enemies were observed in wheat field follow maize crops rather than alfalfa crops. (Gallo and Pekar, 1999). As the period since pasture increased, beneficial insect numbers in a wheat agroecosystem reduced.

Other cultural practices: Ploughing, growing, and harvest are examples of cultural methods that can drastically affect the quantity of predators such as spiders, birds, and small animals. Clean cultivation of a fields or nearby trees can help crops survive, but it also kills animals, small rodents, insects, and carabids that rely on the vegetation for protection. Other cultural practices like soil management e.g., NPV of cabbage semilooper (*Trichoplusia ni*) is more persistent in less acid soils and liming of soil for virus conservation. Watering was found in increase efficacy of *Verticillium lecanii* in greenhouse aphids. Crop residue management is found effective for parasitoids viz. *Epiricania melanoleuca*, *Parachrysocharis javensis* on *Pyrilla perpusilla* if crop residues of sugarcane were left unburnt in field (Odum, 2003).

CONCLUSIONS

Habitat manipulation is a new technology in biological control that promotes biodiversity and ensures the stability and sustainability of the agro-ecosystem by enhancing predator species, which helps in pest biological control while also increasing food resources (nectar, pollen, alternative prey, honeydew-producing insects of natural enemy). The mixture of natural enemies supported by the crop ecosystem must even be considered before selecting an appropriate plant species for cultivation, Increased natural enemy diversity may have a negative influence on bio control agents in some situations because to intra-guild preying or inter-specific interaction. If bio control relies on a diverse spectrum of natural predators, landscape management could be critical. It may enhance the properties of some common species, however species diversity is usually determined by the community structure. Clean cultivation of a fields or surrounding trees can make crops grow, but it can also harm birds, smaller animals, insects, and carabids that depend on the trees and shrubs for refuge.

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BLACK SOLDIER FLY *HERMETIA ILLUCENS* (L.): IDEAL ENVIRONMENTAL CONDITIONS AND REARING STRATEGIES

Anshika Singh[1], Deepak Marathe[1] and Kanchan Kumari[1]*

CSIR- National Environmental Engineering Research Institute,
Kolkata Zonal Centre, Kolkata 700107, West Bengal, India
[1]Academy of Scientific and Innovative Research (AcSIR),
Ghaziabad 201002, Uttar Pradesh, India
*Email: onlinekanchan1@gmail.com (corresponding author)

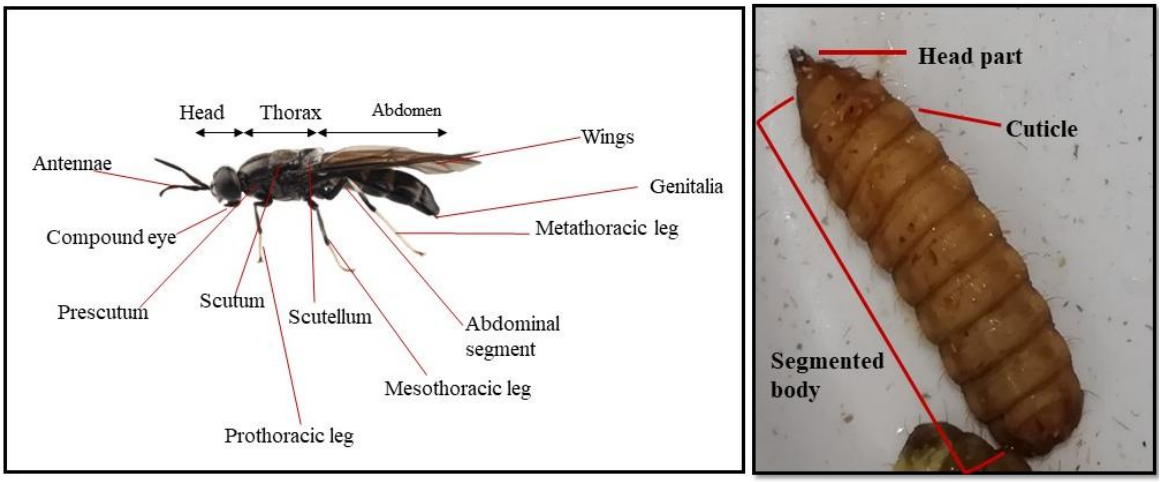
ABSTRACT

Endeavours to recycle organic waste by utilizing black soldier fly (BSF) *Hermetia illucens* (L.) into waste management and high nutrient biomass development have indeed picked up momentum recently. But there is not much data on their appropriate rearing conditions. Very few studies delineating the fecundity and reproduction capacities of BSFs concluded that the presence of natural sunlight or artificial light with intensity of 110-200 µ mol m^2s^{-1} and above triggers mating and oviposition (about 85-90%) at successfully higher rates along with ideal temperature (26 to 40°C) and relative humidity (40-70%) conditions. Optimum food moisture (50-80%) also plays a vital role in enhancing the consumption rate of waste and therefore the treatment efficiency of the larvae. Significant development of the BSF larvae and the treatment efficiencies were also observed to be governed by the pH of waste and the optimum range was defined to be of 6.0 to 9.0. The type of organic waste also equally influences the development, fecundity, and the lifespan of flies. The present review highlights the significant research that has been conducted with respect to lifecycle of BSFs, under the set of different light combinations (LED and fluorescent lights), temperatures and organic waste composites (protein rich and fat rich substrates). Conclusively, it was inferred that ameliorations in rearing conditions such as investigation of suitable light source, modifications in egg collection and hatching structures and knowledge of biology of flies can further boost the reproductive capability of fly thereby promoting successful insect rearing and mass production.

Key words: *Hermetia illucens*, mating, environmental factors, oviposition, lifecycle, mass rearing, organic waste, development time, survival rate, adult weight, life-history traits

Form the past few decades, black soldier fly (BSF) *Hermetia illucens* (L.) larvae have played a vital role in treatment of organic waste such as food waste, abattoir waste, animal, and human faeces, etc. embracing the prospects of circular economy worldwide. The larvae are also regarded as the impeccable source of proteins, lipids and carbohydrates supplementing the animal feed crisis (Tomberlin et al., 2009). Apart from this, bioactive compounds, degrading enzymes and antimicrobial peptides secretions within the species offers a tremendous outlook from industrial point of view. The larval extracts have now become of great interest as they make the insect mass rearing economically sound because of their inherent distinctive properties and pave the ways for development of antimicrobial compounds (Muller et al., 2017). Promoting the excellent breeding activity among species to recover huge quantity of eggs and thus the larvae are the most troublesome task to manage. Therefore, rearing the species demands the utmost care and improved technical skill especially dealing with the oviposition and mating events in the BSFs. In general, insects are ubiquitously distributed in environment based on their degree of tolerance, adaptivity and physiology (Dixon et al., 2009). Certain set of environmental conditions such as temperature, relative humidity, moisture, sunlight, and aeration are crucial factors for successful copulations among individuals of opposite sex, egg laying activities and successful mass production (Jarosik et al., 2004; Singh and Kumari, 2019). One such study stated that regions with wider temperature profile is highly favourable for insect development encompassing higher population comparative to the regions with smaller temperature profiles (Addo-Bediako et al., 2000; Deutsch et al., 2008).

Black soldier flies [BSF-*Hermetia illucens* (L.)] has the capability to thrive even under hostile conditions (Diener et al., 2011a) and has a typical life cycle of 1- 2 months. The basic anatomy of adult fly and the larvae is shown in Fig. 1. The larval stage is the only feeding stage wherein they feed voraciously on



a. BSF adult b. BSF larval stage

Fig. 1. *H. illucens*- larvae and adult

organically rich waste (Alvarez, 2012; Caruso et al., 2013; Barragen-Fonseca et al., 2017; Dormants et al., 2017). The longevity of adult flies may be significantly increased by providing the continuous water source (Myers et al., 2014; Hassan and Dina, 2019). The adult flies have single mating in their entire life span of 7 to 8 days. The number of eggs per clutch may vary between 300-500 or even more whereof the hatching occurs after 3-4 days of mating (Sheppard et al., 2002; Park, 2016; Sharanabasappa et al., 2019). The larval development takes about 13-16 days under optimum environmental conditions however, it may last for 24 to 30 days under unfavourable conditions. Pupation of adult flies takes about 5-14 days and the cycle of mating and egg hatching starts again initiating the next cycle (Yu et al., 2009; Pathak et al., 2015; Barragen-Fonseca et al., 2017; Win et al., 2018; Sharanabasappa et al., 2019). The physiological differentiation between male and female is made on the basis of the appearance of their genitalia otherwise both of them looks similar from naked eyes (Oonincx et al., 2016).

Many researchers have meticulously studied the life cycle of BSFs in order to develop skills to significantly enhance the reproduction rate, larval development and survival of the flies. Notably, BSF larvae has been certified as animal feed for poultry animals and fishes because of its high nutritive values such as protein content in between 40-50% and fat being 25-40% of the total dry weight of BSF larvae (Renna et al., 2017; Gasco et al., 2019). Despite that, it also contains huge amounts of fatty acids, micronutrients, and other essential nutrients (Nowak et al., 2016; Spranghers et al., 2018). Different controlling factors such as substrate moisture level, ambient temperature conditions, suitable light exposure and intensities have also been investigated many times and still is an ongoing activity demanding the unique consideration to develop skill and promote mass rearing (Sheppard et al., 2002; Tomberlin et al., 2009; Holmes et al., 2016; Cammack and Tomberlin, 2017). The pioneer studies of Sheppard et al. (2002), Tomberlin et al. (2009), Holmes et al. (2012) and others have also defined that the ideal rearing conditions for of BSF larvae are as follows; i) temperature should be ideally between 26-27°C based on time taken for development, larval and adults' survival, ii) relative humidity should lie in between 60-70% and iii) optimum moisture levels in the substrate should be between 40-85% wherein the larval development is highest at moisture levels between 40-70%, oviposition is highly significant at 40-60%. Humidity levels below 30% causes larval dehydration and egg desiccation (Holmes et al., 2012). However, the favourability of environmental conditions may vary with varying climatic zones since the species has a cosmopolitan distribution ranging from tropical to temperate regions (Ustuner et al., 2003; Martínez-Sánchez et al., 2011; Tsagkarakis et al., 2015) and consequently the outcomes may be varied.

The present review describes the suitable range of environmental factors for BSF rearing such as temperature, relative humidity, moisture, light and pH. It also compiles the findings of previous studies related to rearing strategies in order to study life cycle of BSF in response to different light source and exposures, different temperatures and organic waste having different nutritional composition. Learning such skill of BSF rearing would be promoting enhanced mass rearing of BSF which will further facilitate

its utilization for organic waste treatment and other societal benefits.

1. Environmental factors

Mating among opposite sexes of BSFs is strongly under the control of surrounding temperature, substrate properties and moisture content. Not just this, the natural conditions (relative humidity, sunlight) contribute towards ideal egg laying and incubation events and the larval development. Besides that, substrate selection also equally contributes to the successful eggs laying and hatching activities since the females prefers to lay eggs near to the food source with strong putrescence (Tomberlin and Sheppard, 2001; 2002).

Ideal thermal conditions (temperature) and the relative humidity: Earlier studies have concluded that about 99% mating and oviposition occurs in the temperature range of 27.5 to 37.5°C combined with 60% relative humidity (Sheppard et al., 2002; Holmes, 2010). In a similar setting, 50-90% relative humidity has been defined as the ideal condition for enhancement of BSF rearing at research centres in temperate regions according to different group of others (Diener et al., 2009). So also, Tomberlin et al. (2009) found significant development of males and females at 27°C± 2 however at higher temperatures (30-36°C) smaller males and females were observed in the study and life expectancy was also decreased. On the other hand, it was noticed that temperature and humidity can have genuine impacts on egg eclosion and development at different stages if not looked after ideally (Park, 2016). Holmes et al. (2012) additionally reasoned that less than 25% relative humidity can have higher parching rates and higher mortality of species. In the context of eggs hatching, the lower humidity levels cause moisture loss from egg membrane leading to desiccation. A humidity level as low as 25% results in higher desiccation and mortality rates whereas at 70% and above, adults live longer, and the eggs retains the proper health conditions. More precisely, relative humidity between 70-90% provides the absolute conditions for mating and oviposition activities mediated by the adults in combination with 27°C temperature of the surrounding air (Holmes et al., 2012; Park, 2016). Chia et al. (2018) also stated in his study, that presence of optimum temperature conditions improves the fertility and fecundity rate of adult flies.

Substrate moisture levels: The development and endurance of the species is exceptionally affected by the moisture of the feed (Cheng et al., 2017). Numerous researchers have peculiarly identified that the unnecessary moisture levels (more than the optimum levels) in the feeding substrates can impact feeding rate and might result in the development of thick and clumpy material causing trouble in further handling (Diener et al., 2011b). Another group of researchers have reasoned that 80% moisture content in the feed is ideal for BSF development (Cheng et al., 2017; Dortmans et al., 2017). Similarly, Barragan-Fonseca and her co-workers defined that the moisture level in between 52-70% are the most suitable conditions for proper larval growth and development (Barragan-Fonseca et al., 2017). Comparable results were likewise referenced in the investigation of De Smet et al. (2018) where a moisture level underneath 40% was unfit for development of the flies at various stages therefore influencing the fecundity rate or the mating in the files.

Optimum light exposure and intensities: In general, different parts of an insect's eye have different spectral sensitivity and the spectral sensitivity functioning may differ among species. The ommatidia are the structural unit of insect's compound eyes and have photoreceptor cells arranged in different fashion. Most of the insect species have the light sensitivity lying in the range <300 to >700 nm. They don't see the light past 700 nm, a light source with corresponding wavelength between 450-700 nm is ideal for reproductive activities in adult flies (Briscoe and Chittka, 2001; Zhang et al., 2010). The visual pigment or photoreceptors in insect eyes is composed of chromophore and opsin protein which interacts with light sensitivity of shorter or longer wavelengths (Peitsch et al., 1992; Stavenga, 1992; Cronin et al., 2000). Similarly, BSFs have photoreceptors belonging to a specific class which is highly sensitive to UV light (367 nm) and blue light (440nm). Ventral part of eye was maximally sensitive to blue light whereas dorsal retina was sensitive to blue green (504 nm) and UV light has additional peak in both ventral (40%) and dorsal retina (20%) (Fig. 2) (Oonincx et al., 2016).

For successful mating in BSF, direct daylight is assumed to be significant in the common habitat and this is the explanation that huge mating doesn't happen in winter seasons however creating a similar warm environment may promote high mating activities. Studies considering the indoor investigations on BSF require artificial light source. About 85% mating events happen within the sight of common daylight with an intensity of 110 µmol m^2s^{-1} however the mating rates decreases below that (Park, 2016). Previously, Briscoe and Chittka (2001) also stated that a 500-watt quartz

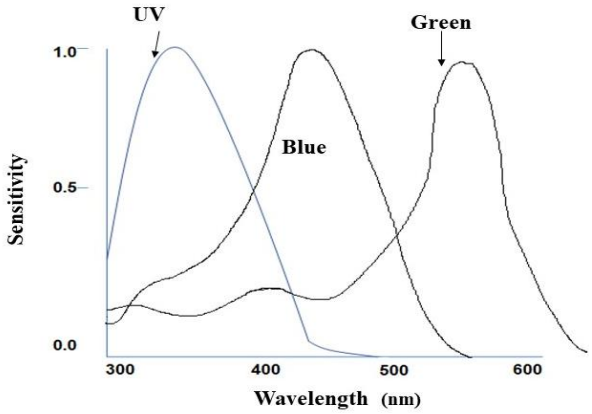


Fig. 2. Spectral sensitivity of compound eye (retina) of *H. illucens*

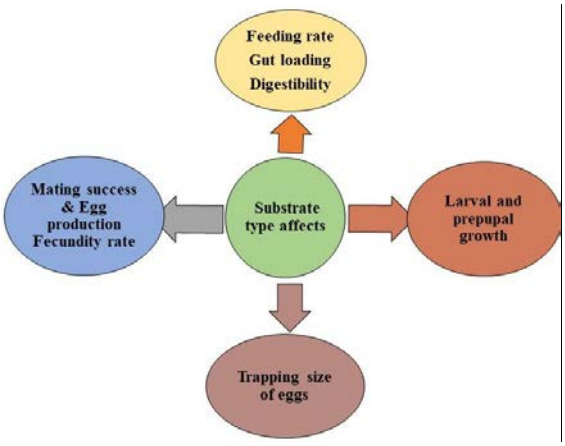


Fig. 3. Substrate effect on different traits of *H. illucens*

iodide lamp with an intensity as high as 135 µmol m^2s^{-1} was able to promote the mating and oviposition at rates similar to those observed in the presence of natural sunlight. Similarly, in another study, artificial light source was accounted to have effect on mating wherein the mating and oviposition of the species was associated with the utilization of Quartz-iodide light (61% efficiency) with the same intensities as the counterfeit light source as compared to natural sunlight and rare earth lamps (Zhang et al., 2010). This specific strategy can be extremely worthwhile and compelling for raising the species outside their local natural surroundings, where daylight is the principle affecting source. Besides that, Tomberlin and Sheppard (2001) have also reported that lekking behaviour among male and females is restricted by the type of habitats, *for instance*, males aggregate near bushy areas establishing the territory which serve as the attractant for females and initiating the mating. Notwithstanding, to have better comprehension of science of species affected by light and other factors as discussed above, extra research is required to significantly promote the mass scale rearing of the insect (BSF).

Effect of substrate: The substrate (diet) composition has been extensively studied worldwide to raise BSF however due to their diversity to eat any kind of waste (food waste, poultry waste, animal faeces, human faeces, animal waste, etc.) such problems are not usually encountered (Boykin, 2019). But still, the substrate composition is equally influential for the healthy profile (nutritional aspects) and development of life history traits of BSF (Sheppard et al., 2002; Tomberlin et al., 2002; Boykin, 2019) because it affects the feeding rate and conversion, the gut loading and digestibility (Fig. 3). For instance, larvae prefer to consume food with high fat content (Nguyen et al., 2015). Moist diet is preferred by the BSF unlike the other insects such as mealworms (Tomberlin et al., 2002). Similarly, the high protein or highly fibrous food often lowers the larval or prepupal growths, the mating behaviour, and the eggs resilience (Tschirner and Shimon, 2015; De Smet et al., 2018). Regardless of that, the higher larval development was likewise seen in the neonates fed with plant-based substrate when contrasted with animal-based diet since they harbour microorganisms delivering plant processing enzymes (Liu et al., 2008; Tomberlin et al., 2009; Manyara, 2018). In one such study of Chia et al. (2018), considering the mating and eggs production, it was found that heavier prepupae were obtained in the treatment where the larval were fed with Brewer's spent grain supplemented with Brewer's yeast (nutritionally balanced diet).

Danieli et al. (2019) also suggested that a mix of different by-products of food such as alfalfa, barley, and wheat by products are remarkable source of feed for enhanced larval development enhancing the nutritional accumulation and survivorship of the BSFs. He also added, diet should be fat enriched instead of protein or carbohydrate rich substrates because the latter two can negatively affect the rearing and overall development. In addition, Ewusie and his co-workers, also determined that the type of substrate affects the trapping size of egg clutches of BSF in combination with the other environmental factors. In their study, among the piggery, sheep, and poultry waste, the piggery waste was the most influential (Ewusie et al., 2019).

pH: A concern for pH effect on BSF development and survival has been also raised by Green and Popa (2012). Larvae were found to regulate a pH of 9.0 occurring in leachates or other substrates (Green and Popa, 2012). Similarly, the increased larvae growth

and heavier pupal mass can be positively correlated with substrates having pH in between 6.0 to 10.0 however; a greatly reduced development is seen at pH below 2.0 (Ma et al., 2018). In one such recent study, in which the researchers examined the effect of pH and the feeding system on BSF larvae found that initially for a week pH significantly affected the larval weight however at the end it was same at all pH between 6 to 9 under the environmental conditions of 29.3± 1.4°C temperature and 70.0± 5.0% relative humidity. In fact, the larval feeding activity also modifies the pH of the feed in between 8.9 to 9.4. But, larval and pupal weight, pupation rate, sex ratio survival and mortality rates were majorly influenced by the feeding system (Meneguz et al., 2018).

2. Rearing

Effect of temperatures and substrate types: Upkeep of appropriate ecological conditions has always been the chief significant thing to effectively manage the mass rearing activities of BSF. In the similar context, researchers are trying their best to introduce best suitable conditions to manage the species to offer secondary solution for the public and the concerned people i.e., the waste management and its valorisation. One of the more recent study examined the effect of different ecological factor (i.e., temperature, relative humidity, and substrate moisture) on different life history traits of BSF in which the baiting material used for trapping adult flies included a mix of manures of chicken and rabbits, food and household wastes. The development was monitored for different array of temperatures (10 to 42 °C) combined with relative humidity between 70 to 72% and 12:12: Light: Dark photoperiod. The population growth rate was highest in treatments as compared to controls (without Brewer's yeast). The authors concluded that the number of successful mating and fecundity rate can also be correlated with pupal mass of insects. The temperatures below 15°C and above 40°C was found to negatively impact the survival of the fly at all stages resulting in extremely high mortality rates. The findings of Chia et al. (2018) have been shown in Table 1. Likewise, Shomu et al. (2019a; 2019b) also published work closely related to the study of Chia et al. wherein they examined the effect of temperature and substrate type (brewer's spent grain and cow dung) on the growth, development, and survival of BSFs and mating rates in adults. The findings stated that the development was faster for the larvae fed with brewer's spent grains as compared to cow dung and the optimum range of temperature suitable for BSF was 25-30°C. Srikanth and Sharanabasappa reported that kitchen waste was significantly superior obseved with maximum larval (0.22g/ larva) and pupal weight

Table 1. Effect of temperature on life history traits of *H. illucens* (Chia et al., 2018)

S. No.	Light history traits	Temperature	Days	Survival rate (%)
1.	Egg eclosion	15°C	14 (both D1 and D2)	Highest at 35°C (75% and 30°C (80%) for both D1 and D2
		35°C	2.60(both D1 and D2)	-
2.	Larval development	15°C	13.14 (both D1 and D2)	-
		30°C	62.4 (both D1 and D2)	-
3.	Prepupal development (Failed at 40°C)	15°C	83-86 (both D1 and D2)	-
		30°C	8-10 (both D1 and D2)	-
4.	Larval to adult development	15°C	184 (D1); 181(D2)	-
		30°C	28 (D1); 31(D2)	-
5.	Oviposition period	20°C	16 (both D1 and D2)	-
		35°C	5 (both D1 and D2)	-
6.	Larval survival rate	-	-	92% (35°C); 90% (30°C); 28% (40°C) for both D1 and D2
7.	Prepupal survival rate	-	-	83% (25°C) and 82% (30°C) for D1; 79% (35%) and 77% (30°C) for D2
8.	Pupal survival rate	-	-	77% (30°C) and 5% (37°C) for D1; 75% (30°C) and 20% (37°C)
9.	Adult survival rate	Decreased with increase in temperature from 15°C to 37°C with increased fecundity at higher temperatures		

D1: BSGs with brewer's yeast; D2: BSGs without brewer's yeast (control)

(0.20g/ pupa). The Fecundity was observed to be 698 eggs/ female when reared up to 14 day, significantly the maximum amount of feed consumed was 18100g in 20days, feed conversion ratio (97.37) was maximum in mixed vegetable waste.

The selection of substrate should be wise as it effects both the physiological and morphological development (gonads development, sex ratio, mortality, duration of different stages) of both neonates and the adult flies. Gobbi et al. (2013) testified the insect's development against three different diets i.e., hen feed, fish meal and a mixture of both. The larvae fed with fish meal and mixed diet showed the prominent growth and development than the larvae fed with pure meat meal (Gobbi et al., 2013). Notably, till date various examinations have been set up testing the effect of various sorts of organic waste on life history attributes of BSF and their performances, for example, larval growth and development, pupal development, adult weights and lengths, longevity, and the endurance. Similar in case, the investigations of Tomberlin and Sheppard (2001), Diener et al. (2011b), Gobbi et al. (2013), Nguyen et al. (2013), Li (2014), Oonincx et al. (2015a, b) and Srikanth and Sharanabasappa, (2021) have affirmed the BSFs against various natural substrate to assess diverse life stages. Table 2 has compiled the studies on life history traits of BSF fed against variety of organic diets having different nutritional contents which was originally combined in the studies of Barragan-Fonseca et al. (2017) from the studies executed up until now. The abiotic conditions were as follows: temperature- 27± 2°C; relative humidity-70± 10%; food moisture- 66± 4%. Interestingly, a conclusion was also drawn that the availability of abundant food positively affects the larval growth and development however, the waste reduction efficiency is greatly reduced (Liu et al., 2008; Diener et al., 2009; Banks, 2014).

Harden and Tomberlin (2016) also deeply investigated the synergistic effect of temperature and diet on BSF development. A mix of grains (corn meal, wheat bran and alfa alfa), beef and pork meet were used as the diet source and the temperatures conditions were

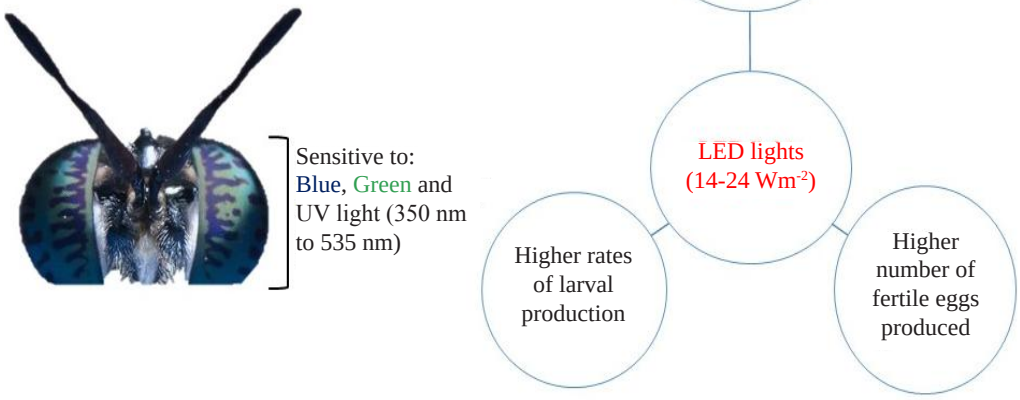
Table 2. Life history traits and performance of *H. illucens* larvae fed with organic waste

S. No.	Life history traits (Mean± SD)	Organic waste			
		Chicken feed (or feed with similar nutrient content i.e., Protein~14%; Fat~4%)	Meat waste	Faeces	Vegetable waste
Larval stage					
1.	Development time (days)	24.6± 6.2	32.5± 8.2	27.5± 3.8	34± 13.5
2.	Survival rate (%)	89.4± 9.4	48.2± 8.7	89± 7.5	78.9± 13.2
3.	Fresh matter (FM) weight (g)	0.158± 0.02	0.158± 0.0	0.17± 0.03	0.13± 0.03
4.	Dry matter (DM) weight (g)	.044± 0.0	-	0.031± 0.02	0.028± 0.01
5.	Larval dry matter (DM) content (%)	36± 1.8	-	-	36.3± 2.5
Prepupal and pupal stage					
6.	Pupal development time (days)	14.8± 6.8	16.5± 7.5	17.8± 3	22.9± 1.2
7.	Fresh matter (FM) prepupal weight (g)	0.105± 0.005	0.115± 0.01	0.193± 0.08	0.179± 0.03
8.	Dry matter (DM) prepupal weight (g)	0.037± 0.004	-	0.018; 0.04	0.071± 0.01
9.	Fresh matter (FM) pupal weight (g)	0.150± 0.03	-	-	-
Adult stage					
10.	Adult weight (g DM)	0.021± 0.0	-	-	-
11.	Adult weight (g FM)	0.053± 0.01	-	0.046± 0.01	-
12.	Adult length (mm)	15.8± 0.0	-	-	-
13.	Adult longevity (days)	9.4± 0.2	-	12.5± 2.1	-
14.	Total cycle (days)	40.2± 6.4	-	-	-

between 29-33°C and average relative humidity was 71.0± 16.3%. They found that eggs development was not significantly affected with variations in temperature. However, larval length and development was affected notably with temporal variations and was highest at 32.2 and 27.6°C. Moreover, about 23.1%- and 139.7% more-degree hours were required to complete the larval development fed with pork diet in comparison to beef and grain-based diet. Comparatively, larval development fed with grain diet was inconsistent when assessed with the age of field larvae and the pork and beef based larval development were appreciable.

Effect of light: Oonincx et al. (2016) and Nakamura et al. (2016), studied LED expand based radiance on indoor reproduction rates and the oviposition periods. The former study included the photoreceptor spectral sensitivity of the compound eyes of BSF while the latter investigated the oviposition and survival rates under natural sunlight supplemented with LED irradiation. Oonincx et al. (2016) found that the ommatidia of BSF contains photoreceptors cells sensitive to blue, green and UV light having trichromatic visibility; therefore, the LEDs based illumination significantly increased the egg clutch yields resulting in higher larval production comparative to fluorescent tubes (control) (Figs. 4, 5). Similarly, small cage (27 x 27 x 27 cm) study of Nakamura et al. containing 100 adult flies (50 male and female each) in each implied similar patterns of oviposition in both LED illumination and natural sunlight however the number of fertilized eggs obtained were higher under the effect of natural sunlight in comparison to LED illumination. The oviposition was considerably increased from 4 to 17 days. Examining the sugar solution treatment and water treatment it was observed that the longevity of adults (3 times in males and 2 times in females) increased when fed with sugar solution comparative to water alone (Nakamura et al., 2016). The findings also concluded the absence of mating below 69 µmol m^{-2} s^{-1} and highest at 200 µmol m^{-2} s^{-1}.

Heussler et al. (2018) scrutinized the impact of three different artificial light sources (LED green, fluorescent lamp, and halogen lamp) on the life history traits (oviposition and half-life) and mass production of BSF where the larvae were reared in a plastic box under the environmental conditions at 27°C temperature and 60% relative humidity respectively. He also encountered the similar observations for oviposition as in above-mentioned studies. Three replications were made for each light source with intensity of 59 µmol m^{-2} s^{-1} in different cages having a light: dark photoperiod of 16 and 8 hours. Mating and oviposition rates were found similar in all the three conditions where the peak was observed from 4 to 8 days of emergence however the half-life of both males and females significantly reduced. Shorter half-lives of adults were observed under halogen light conditions as compared to LED illumination lasting from 6 to15 days for males and



a. BSF compound eye sensitivity for LED illumination

b. Effect of LED illumination over control (fluorescent light)

Fig. 4. Diagrammatic representation of photosensitivity of *H. illucens* and effect of LED illumination on adult survival and larval development (Oonincx et al. 2016)

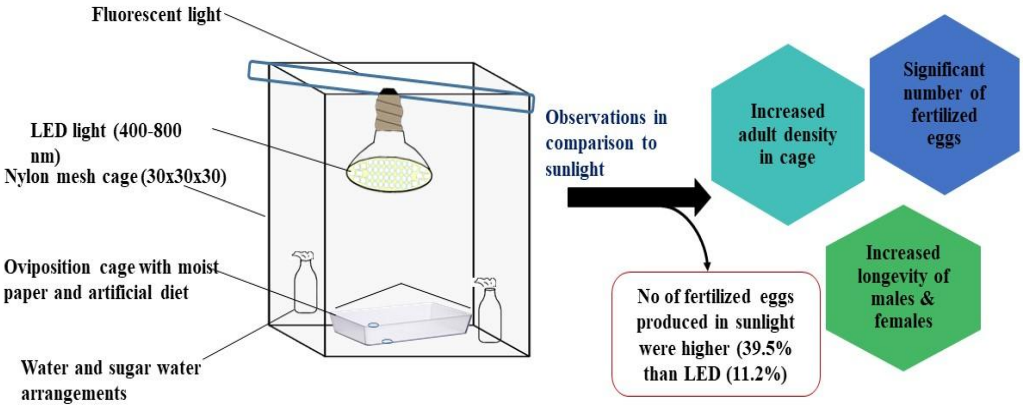


Fig. 5. Schematic view of effect of LED illumination on egg production and adult longevity and survival in *H. illucens* (Nakamura et al., 2016)

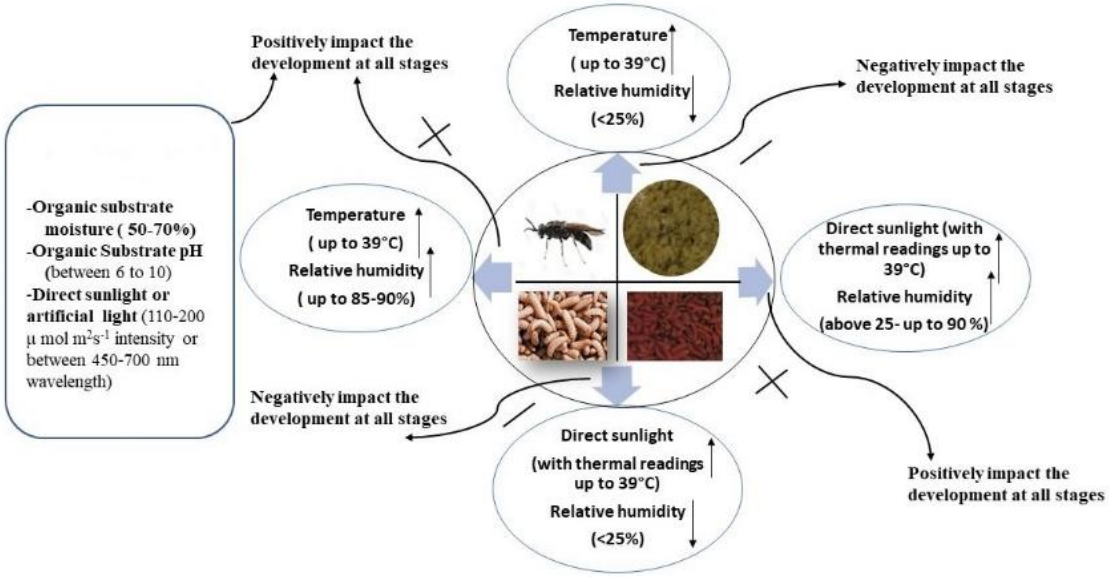


Fig. 6. Different set of environmental conditions ideal for BSF development

3 to 13 days for females. The authors also concluded, the shorter half-lives of adults in Halogen light may be due to unsuitably higher temperature and excess heat generation. Attiogbe et al. (2019) also applied the similar microclimatic conditions to achieve maximum mating, suitable oviposition and larval development in order to get higher efficiency towards mercury contaminated waste wherein direct association between larval density and reduced mercury content from waste was observed.

In the similar context, Boaru et al. (2019) described that suitable oviposition structures improves the reproductive process of adults in captivity. The study included four different types of cage structure for oviposition or egg laying sites i.e., wood cages, glass cage, corrugated cardboards, and plastic material along with similar microclimatic conditions (22-28°C temperature, 40-60% humidity and 8 hours of artificial light exposure) and the substrate (brewer's grains). In all setups over 98% of adult emergence were recorded and maximum amount of egg masses was found in experimental cage made up of wood followed by corrugated cardboard, plastic structures, and glass structures wherein each cage was populated with 50g of pupa at the start of experiment (Boaru et al., 2019). Based upon the findings of different studies the range for different set of environmental conditions ideal for BSF development is shown in Fig. 6.

3. Cooccurrence of house flies while rearing BSF

While rearing, co-occurrence of houseflies along with BSFs is also very evident and need to be discussed as it impacts the waste conversion efficiency and the

insects' growth. Though the BSF are reported to repel the housefly oviposition yet the experimental areas established for BSF rearing and mass production often experiences the presence of house flies ensuing competition for the available substrate. In one such study (Miranda et al., 2019), no BSF pre pupation occurred in the treatment (pig manure) inoculated with house fly larvae at initial stages and reached maximum pupation when reared alone on the fresh pig manure. In addition, the negative impact on BSF growth was also attributed to the presence of houseflies and age of resource. Similarly, Hassan and Dina (2019) also encountered the co-occurrence of a total of 3554 insects including the BSF where the fermented coconut waste was used as egg laying sites in plastic bins. BSF larvae were highest in number in oviposition media but *Drosophila melanogaster* and *M. scalaris* also have significant counts in competition to BSF.

CONCLUSIONS

Black soldier flies have been performing outstandingly well to deal with the concerns of waste management and feed supplementation. Correspondingly it demands the thorough knowledge on specific tolerance limits of BSF towards ecological conditions. It was concluded that BSF growth and development is directly influenced by temperature and the diet composition serving to be the most crucial factor in environment. The temperature and relative humidity largely control the insect development, daily cycles, and seasonal variations and affects the biology of insects, their survival, life span, reproduction rate, population growth parameters and the sex ratio. Optimum light conditions, humidity also equally contribute to the insect's physiology, behaviour and morphological traits. Moreover, wood based, and plastic material-based egg hatching structures may serve as the better oviposition sites and mass egg production in comparison to other conventional setups. However, it should be emphasized that breeding activity is largely influenced by the specific environmental conditions.

Further, intensification of fecundity rate in BSF under indoor environment requires appropriate investigation of suitable light source and intensities which may effectively enhance the mating rates, egg production and thus other life history parameters. In addition, there is a need to examine how to improve the reproductive capacities of the flies for a progressive proficient raising at the study sites. Future research ought to build up extra models for distinguishing improvement of every instar, which may help in improving the exactness and accuracy of larval age gauges which would serve for other important purposes such as sustainable and environmentally sound management of organic waste as it outshines the present conventional techniques in several ways (less time for composing, higher efficiencies of waste reduction, carbon sequestration, pathogen control).

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THE BIOLOGICAL DIVERSITY OF THYSANOPTERA IN INDIA — IS THERE A WAY FORWARD?

Laurence A. Mound

CSIRO Australian National Insect Collection, Canberra, ACT 2601, Australia

This discussion is targeted at the problems of taxonomy in India, but the comments could apply equally well to the situation of thrips taxonomy in many countries. At first sight, the available data for India suggest that the Thysanoptera fauna is reasonably well known. Two recent checklists are available for the described members of this Order of insects (Tyagi and Kumar 2016; Rachana and Varatharajan 2017), and together these lists indicate that about 750 species of thrips in 260 genera are recorded from India. Indeed, as early as 1928 that great entomologist, T. V. Ramakrishna Ayyar, produced a 100-page summary of what was then known of the thrips of India. That publication indicated that 126 species of Thysanoptera were then known from India, having increased from a mere 14 species known in 1915 (Ramakrishna, 1928). More recently, two further workers have made enormous contributions to our knowledge of this fauna: T. N. Ananthakrishnan emphasised the faunal richness by describing over 300 new species in about 70 new genus-group names, and J. S. Bhatti has added greatly to our knowledge of the taxonomy of these insects particularly through highly original and detailed accounts of their external morphology. Moreover, in recent years innovative contributions by K. Tyagi and her colleagues have emphasised the significance of DNA studies in thrips taxonomy (Tyagi et al., 2020). But how does all this taxonomic data contribute to our knowledge of *biological diversity*? The answer to that question depends on how one interprets those two words.

To many people, including many taxonomists, biological diversity is measured in terms of taxon richness. Furthermore, taxonomy is commonly regarded as the process of naming and describing the entities that we call species or genera. But the published descriptions of many thrips species from India often involve little more than sufficient comments on colour and shape to validate a new name under the requirements of the Code of Zoological Nomenclature. This activity contributes to our knowledge of structural diversity within a particular genus or family, but it tells us little about the biological significance of that diversity. I suggest that the most important attribute of a species is how it perpetuates itself – that is, how it lives and breeds. From this point of view, the most important aspects of biological diversity are the differences in biology between species, yet for most described thrips species we remain ignorant of the host plant and habitat that are essential to their continued existence. Each species has presumably evolved from some population that developed slight differences in behaviour, diet or ecological preferences. It is these biological differences that lead to genetic isolation between populations, and subsequently facilitate the evolution of those structural differences that taxonomists recognise.

Limiting the objectives of taxonomy to a series of structural descriptions is traditional, and it reflects the way that the subject has developed, based on the recognition of differences. Curiously, some modern taxonomy also emphasises differences in molecular structure rather than differences in biology. But this commonly accepted dichotomy between 'taxonomists' and 'biologists' is destructive of our efforts to understand and protect biological diversity and ecological systems. When I first joined the staff of a museum, I was told that taxonomists work alone and publish only single authored papers. This contrasted with my previous experience as a research biologist in tropical agriculture, because that had involved collaboration with plant breeders, agronomists and physiologists. The taxonomist's approach is derived from the concept of the 'authorities' who provide a name for a species, and as a result this is often competitive rather than collaborative. Students quickly acquire the idea that there is some sort of prestige in having one's own name published in association with the name of a taxon. But this approach is focussed on self-satisfaction rather than on contributing to general knowledge within the scientific community, or on the well-being of society.

My major interest has been in the many species of thrips that exhibit remarkable differences in body structure – sometimes in association with body size, including extensive allometry, but often between

sexes and winged and wingless morphs. Taxonomists commonly regarded as different species the different forms that can be found. This changed with more intensive field work involving larger samples that established the reality of intra-population structural variation. In discovering and describing such highly polymorphic species, I needed to consider why such structural variation is maintained within populations and how these species spend their lives. This necessitated collaboration with other biologists to understand what levels of competition, intra- and inter-specific, were driving the structural differences. The resultant associations with botanists, ecologists, geneticists, and even medical entomologists, as well as with other thrips taxonomists, has been highly productive - most noticeably in the crude measure of how many taxa were described. But in increasing our knowledge of thrips taxon diversity and structural variation, it has also increased our understanding of the biological diversity that can be found among Thysanoptera. These studies have commonly targeted particular groups of plants, with a view to examining the diversity and radiation of their associated thrips. This approach has thus been based on the biology of species,leading to an understanding of their systematic and taxonomic position. Curiously, such an approach reverses the one that is often stressed- that we must first describe species in order to study their biology. That more traditional approach considers taxonomists as the providers of the taxon building blocks and framework that can then be used by ecologists and evolutionary biologists.

Ideas in all sciences change with time, in response to new data and new methods of analysis. Thus, conclusions in taxonomy and systematics also change, stemming from newly acquired field observations,specimens and molecular data. The taxonomy of all groups of organisms is thus never static — it is constantly evolving in association with new interpretations, new techniques and new concepts. As a result, published information in taxonomy needs regular re-interpretation, to reflect revised taxonomic and evolutionary concepts. The subject is therefore rooted not in the available published descriptions, but in the specimens that were studied by each original author. Preserving those original specimens is an onerous task and has clear financial implications for depositories. But these specimens are essential for the future expansion of knowledge generated by subsequent workers. Such workers need information about, and access to, these original specimens. Some depository institutes produce web-based lists of the type-material that is preserved in their collections, thus facilitating the integration of the specimens into new studies by other taxonomists. However, in India such information is not available about the major collections of Thysanoptera. The original descriptions of the 300new species of thrips described by Ananthakrishnan often did not include character states that are required by more recent taxonomists. But it remains impossible to obtain any information about the whereabouts or accessibility of his type specimens. The identity and relationships of many of these species remains unknown. Theyaremerely names on paper,with no prospect of considering their significance to Indian biological diversity. Thus, work on the biological diversity of these insects in India is effectively frozen in time. Such problems may be related to the taxonomic disease of 'mihi-itis'— the competitive and solitary way in which taxonomy has so often been practised. Unfortunately, many taxonomists are content with this situation, practising their relatively inexpensive discipline in private,whilst universities regard taxonomy as merely descriptive and of limited intellectual interest. This can lead to separate departments of molecular taxonomy that are independent of the collections, with the latter becoming the responsibility of non-specialist collections managers emphasising the protection rather than the use of archival material.

For a biologist, the Indian thrips fauna provides many fascinating problems that involve taxonomy. The remarkable differences in body form of males in many fungus-feeding species is probably related to male–male competition, but there have been remarkably few behavioural studies to confirm this, or to determine if structural differences are nutritionally determined or represent genetically distinct morphs. Similarly, the extraordinary crab-clawed species of *Veerabahuthrips* seem to be associated with bamboo species, but there is no explanation of their bizarre structure and relevance to how these thrips live and behave. Molecularly distinct sibling species are increasingly reported amongst common pestiferous thrips, but the sophisticated molecular work is not associated with critical studies on host specificity or virus vectoring ability by the different siblings, nor are there serious breeding studies to establish the effect of host plants and climate on the commonly observed structural and colour differences. Investigations such as this require collaboration between different groups of biologists. One recent example is the remarkable demonstration by K. Tyagi and her colleagues that gut bacteria may be important in gall induction by *Gynaikothrips* on *Ficus* trees (Tyagi et al., 2022). Such a collaborative approach

to studying biological diversity requires considerable changes in thought processes, in defining research objectives, and in how funding is approached. Changes of this kind involve how taxonomists think of themselves and of the objectives of their work. Funding agencies and administrators will need to be more imaginative in how they deploy their available scientific and financial resources across disciplines, toward an objective of achieving a greater understanding of biological diversity.

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