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ORIGINAL ARTICLE

INTERACTION STUDY OF VOLATILE CUES EMITTED FROM POTATO VARIETY KUFRI SURYA AND FOUR TRICHOGRAMMATIDS

Surabhi Singh, Bishwajeet Paul and Archna Kumar*

Amity Institute of Biotechnology, Amity University, Noida - 201 313, India.
E-mail: akumar21@amity.edu

Abstract : Bioassays were carried out to observe the impact of volatile cues obtained from Potato variety Kufri Surya in vegetative and flowering phase of growth on four Trichogrammatids. Gas Chromatography-Mass Spectrometry (GC-MS) profiling was performed to identify the signaling molecule present in pool of volatile cues obtained from vegetative and flowering phase of Kufri Surya. Significant enhancement ($P < 0.05$) in foraging behaviour of *Trichogramma brasiliensis* (Ashmead) and *Trichogramma japonicum* (Ashmead) was noticed after application of volatile cues obtained from different growth phases of targeted variety. GC-MS analysis based on comparison with National Institute of Standards and Technology (NIST) library indicated presence of seven alkanes *viz.*, Tetradecane ($C_{14}H_{30}$), Heptadecane ($C_{17}H_{36}$), 2-methyltetracosane ($C_{25}H_{52}$), Pentacosane ($C_{25}H_{52}$), Triacontane ($C_{30}H_{62}$), Dotriacontane ($C_{32}H_{66}$) and Tetracontane ($C_{40}H_{82}$) in vegetative phase whereas in flowering phase nine alkanes *viz.*, Pentadecane ($C_{15}H_{32}$), Hexadecane ($C_{16}H_{34}$), Heptadecane ($C_{17}H_{36}$), Tetracosane ($C_{24}H_{50}$), Pentacosane ($C_{25}H_{52}$), Triacontane ($C_{30}H_{62}$), Dotriacontane ($C_{32}H_{66}$), Tetratriacontane ($C_{34}H_{70}$) and Tetracontane ($C_{40}H_{82}$) were present in varying quantity. Presence of these alkanes may be responsible for eliciting significantly higher foraging response in *T. brasiliensis* and *T. japonicum*.

Key words : *Trichogramma*, Integrated Pest Management, Volatile cues, Foraging behaviour, Potato, Gas Chromatography-Mass Spectrometry.

1. Introduction

Proper understanding of the behavior of the natural enemies in relation to their habitat is an important aspect of success of Integrated Pest Management (IPM) strategies. Behavioural interaction of tritrophic components, *i.e.*, pest, plant and natural enemies of a crop ecosystem is governed by an array of chemical cues. Volatile cues emitted from plants or pests, play important role in alteration of behaviour of parasitoids. Exploitation of chemical cues responsible for enhancing foraging behaviour of natural enemies is an eco-friendly way of IPM practice [Ahmad *et al*. (2004)]. Until few decades, the control of pest infestation on several commercial crops has relied upon the use of the traditional pesticides and insecticides. Recently, biological control using insect natural enemies population and volatile cues has emerged as a powerful tool in pest management program [Romeis *et al*. (2005), Hossain *et al*. (2017)]. Egg parasitoids of genus *Trichogramma* (Hymenoptera : Trichogrammatidae) has gained popularity worldwide against several lepidopteran pests [Puneeth and Vijayan (2013), Tang *et al*. (2017)]. Integration of volatile chemical cues especially alkanes in release programs is helpful in increasing effectiveness of Trichogrammatids during implementation of biological control programs [Van Lenteren (2000), Archna *et al*. (2009), Kelly *et al*. (2014)].

Thus, study is based on interaction mechanism of Potato volatile cues and Trichogrammatids. Potato (*Solanum tuberosum* L.) is one of the major commercial crops grown worldwide [F.A.O. (2004)]. Selected potato variety Kufri Surya, is an early maturing, heat tolerant, high yielding variety [Minhas *et al*. (2006)]. In proposed study, volatile cues were collected from leaf samples of Kufri Surya during different

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phases of growth and their impact was examined on Trichogrammatids. Identification of signaling molecule present in targeted volatile cues pool was tested through Gas Chromatography-Mass Spectrometry (GC-MS) analysis with main emphasis on the scrutiny of straight chain saturated hydrocarbons.

2. Materials and Methods

Synomonal extraction

Thirty gram leaf samples of potato variety Kufri Surya were collected in the month of October (when crop was approximately 40 days old referred to as vegetative phase of growth and in the month of February (when crop was approximately 120 days old referred as flowering phase of growth) from farmers field of village Simroli, district Hapur, Uttar Pradesh, India. Volatile cues of selected samples were collected by preparing hexane leaf extracts as per method opted by Archna *et al*. (2009). From the volatile extract stocks, aliquots were used for preparing different concentration (C5 = 4,00,000 mg/L, C4 = 2,00,000 mg/L, C3 = 1,00,000 mg/L, C2 = 50,000 mg/L, C1 = 25,000 mg/L) for use in bioassay and GC-MS studies.

Culture establishment

The culture of facilitated host, *Corcyra cephalonica* Stainton (Lepidoptera : Pyralidae) was established in Pest Control Laboratory, Amity University Uttar Pradesh, Noida (U.P.), India as described by Sreekumar and Paul (2000).

Isofemale lines of Trichogrammatids (*Trichogramma chilonis* Ishii, N.A. No. NBAII-MP-TRI-13; *Trichogramma japonicum* Ashmead, N.A. No. NBAII-MP-TRI-65; *Trichogramma brasiliensis* Ashmead, N.A. No. NBAII-MP-TRI-70, *Trichogrammatoidea bactrae*, N.A. No. NBAII-MP-TRI-02) were procured from National Bureau of Agricultural Insect Resources (NBAIR), Bengaluru, India. Cultures of these Trichogrammatids were maintained in Pest Control Laboratory, Amity University, Noida (U.P.), India.

Bioassay protocol

Petri dish bioassays were carried out by placing six tricho cards (30 eggs per card) in each 150 mm X 15 mm petri dishes. Five tricho cards were treated with 50 µl of desired concentration of volatile cues whereas sixth card was applied with 50 µl HPLC grade hexane as control [Srivastava *et al*. (2017)].

Statistical analysis

Data obtained from interaction of four Trichogrammatids and five concentrations of volatile cues was tabulated for parasitoid activity index (PAI) and parasitisation (PARA). Parasitisation values were converted into percent parasitisation (%PARA). Data was analysed through two way Analysis of variance (ANOVA) using Windostat software version 8.5 developed by Indostat Services, Hyderabad, India. All interaction values were observed. For PAI, Square Root Transformation (SRTM) was applied. In case of %PARA, Angular/Arc Sine transformation (ATM) was applied. Difference between total mean and control mean was calculated to check the fact that whether volatile cues act as attractant or repellent by observing Least Significance Difference (LSD) at 5% significance level ($P < 0.05$). For every individual concentration showing positive response as compared to control, P-value and t-value were calculated by using Graph Pad software to test the significance of results.

Gas Chromatography-Mass Spectrometry Analysis

GC-MS analysis of the hexane extract of Kufri Surya in both the phases of growth was performed using SHIMADZU-GCMSQP2010ULTRA. For GC-MS detection, an electron ionization system was operated in electron impact form with ionization energy of 70 eV. Helium gas (99.99%) was used as carrier gas at a constant flow rate of 1 ml/min and an injection volume of 1 µl was provided (a split ratio of 10:1). The injector temperature was maintained at 270°C, ion source temperature was 230°C. Mass spectra run were taken at 70 eV (electron volt). Total run time provided was 60 minutes. Mass to charge ratio (m/z) taken was 40.00.Elucidation on mass spectrum GC-MS was conducted using the database of National Institute Standard and Technology (NIST). The spectrum of unknown components was compared with the spectrum of known components stored in the NIST library.

3. Results

Interaction of volatile cues and selected Trichogrammatids indicated that all Trichogrammatids were sensitized by cues emitted from Kufri Surya. Interaction of various targeted concentrations and *T. brasiliensis* indicated that orientation response of parasitoid was significant ($P < 0.05$) towards 2,00,000 mg/L and 50,000 mg/L (3.05 ± 0.46, P-value:0.0312, t-value: 2.9693) (5.29 ± 0.21, P-value: 0.0053, t-value: 4.7061) concentration of volatile cues emitted from vegetative phase and 50,000 mg/L (2.67 ± 0.41, P-value: 0.0347, t-value: 2.8768) from flowering phase whereas mean percent parasitism for *T. brasiliensis* was significantly high towards 2,00,000 mg/L (23.25 ± 4.51, P-value: 0.0310, t-value: 2.9753) of volatile cues emitted from vegetative phase and 2,00,000 mg/L, 1,00,000 mg/l and 50,000 mg/L (24.18 ± 6.35, P-value: 0.0396, t-value: 2.7643) (21.73 ± 4.70, P-value: 0.0421, t-value: 2.7143) (24.22 ± 4.33, P-value: 0.0347, t-value: 2.8768) from flowering phase. Interaction study of Kufri Surya and *T. japonicum* revealed that cues of vegetative phase exhibit were not able to generate any significant response, but in flowering phase significant orientation response was noticed at 4,00,000 mg/L and 2,00,000 mg/L (3.05±0.17, P-value:0.0131, t-value: 3.7632) (2.85±0.19, P-value:0.0050, t-value:4.7809), whereas parasitism was significant at 4,00,000 mg/L in vegetative phase (33.13±3.51, P-value:0.0465, t-value:2.6304) and 2,00,000 mg/L in flowering phase (18.75±2.54, P-value:0.0074, t-value: 4.3386). Cues emitted from Kufri Surya were not able to generate significant response in foraging behaviour of *Tr. bactrae* in vegetative phase of growth but at 2,00,000 mg/L concentration of volatile cues obtained from flowering phase of growth, they were able to generate significant orientation response in parasitoid (1.67±0.29, P-value: 0.0274, t-value: 3.0813). This variety was not able to generate any significant parasitisation response in *Tr. bactrae*. Significant mean PAI of *T. chilonis* was observed towards volatile cues of Kufri Surya at 50,000 mg/l in vegetative and flowering stage (3.330.27, P-value: 0.0428, t-value: 2.6990) (1.600.43, P-value:0.0331, t-value:2.9190) and also exhibited good parasitisation response at 2,00,000 mg/L in vegetative stage (27.272.79, P-value: 0.0083, t-value: 4.2274). In flowering stage, this variety was not able to generate any significant parasitisation in *T. chilonis*. Results indicated that overall response of all concentrations tested with each parasitoid was significantly higher for *T. japonicum* in vegetative phase as evidenced by high mean parasitoid activity index and mean percent parasitism values. While volatile cues obtained from flowering phase elicited higher foraging response in *T. japonicum* and *T. brasiliensis*. Comparision of response of five concentrations of allelochemical cues of both the phases for various parasitoid indicated that 2, 00,000 mg/L concentration was found to be the most preferred concentrations by maximum Trichogrammatids (Tables 1 and 2).

GC-MS analysis of volatile cues obtained from Kufri Surya on comparision with NIST library indicated presence of 29 compounds in vegetative phase and 32 in flowering phase, which were different in composition and concentration in both the phases. Pool of compounds indicated presence of Alkanes, Alkenes, chain fatty Alcohols, Alkynes, Alkaloids etc. GC-MS chromatogram of vegetative phase revealed the presence of Tetradecane ($C_{14}H_{30}$), Heptadecane ($C_{17}H_{36}$), 2-methyltetracosane ($C_{25}H_{52}$), Pentacosane ($C_{25}H_{52}$), Triacontane ($C_{30}H_{62}$), Dotriacontane ($C_{32}H_{66}$) and Tetracontane ($C_{40}H_{82}$) and in flowering phase of Kufri Surya indicated the presence of Pentadecane ($C_{15}H_{32}$), Hexadecane ($C_{16}H_{34}$), Heptadecane ($C_{17}H_{36}$), Tetracosane ($C_{24}H_{50}$), Pentacosane ($C_{25}H_{52}$), Triacontane ($C_{30}H_{62}$), Dotriacontane ($C_{32}H_{66}$), Tetratriacontane ($C_{34}H_{70}$) and Tetracontane ($C_{40}H_{82}$) in varying quantities (Table 3).

4. Discussion

In an agro ecosystem, insect natural enemies are dependent on an array of volatile cues for inter species communications, which are helpful in enhancing their foraging response [Yousuf *et al*. (2015), Rodriguez-Saona *et al*. (2012), El Wakeil *et al*. (2017)]. Utilization of Polyphagous parasitoid *Trichogramma* is popular for control of lepidopterous pests in high valued crops like rice, cotton, tomato, cole etc. [Babendreier *et al*. (2003), Fatouros *et al*. (2008), Jalali *et al*. (2016)]. In the present study, interaction between various concentrations of host plant emitted volatile cues and four Trichogrammatids was assessed. Findings revealed that extract of Kufri Surya in both the phases of growth was successful in significant enhancement in the foraging response of *T. japonicum* and *T. brasiliensis*. Study also revealed that very low concentration (50,000 mg/L) was also able to evoke the synomonal response in parasitoids even though 2,00,000 mg/L was most preferred concentration for all parasitoids. Nordlund *et al*. (1985) studied response of cues emitted from tomato towards *Trichogramma pretiosum* and observe that cues emitted from tomato were able to evoke host searching behaviour in *T. pretiosum*. Madhu *et al*. (2000) observed the response of *T. brasiliensis* and *T. japonicum* on aqueous extracts of sorghum, maize,

Table 1 : The effect of potato emitted volatile cues on parasitoid activity index of four Trichogrammatids.

Trichogra-mmatids (A)	Growth stage	Concentrations are in mg/L (B)						
		4,00,000	**2,00,000**	**1,00,000**	**50,000**	**25,000**	**Hexane**	**Mean**
T. brasiliensis	Vegetative	3.87±0.41	3.05±0.46	4.88±0.47	5.29±0.21	3.99±0.37	3.91±0.18	4.21±0.22
	Flowering	1.40±0.32	2.52±0.62	2.50±0.45	2.67±0.41	2.77±0.54	1.69±0.47	2.37±0.22
Tr. bactrae	Vegetative	3.57±0.33	3.55±0.52	3.04±0.39	3.61±0.25	3.05±0.21	3.20±0.23	3.36±0.15
	Flowering	1.11±0.14	1.67±0.29	1.10±0.30	0.88±0.11	0.88±0.11	0.94±0.15	1.13±0.10
T. chilonis	Vegetative	2.57±0.46	3.85±0.55	3.36±0.42	3.33±0.27	3.05±0.73	2.44±0.49	3.23±0.23
	Flowering	3.22±0.23	3.33±0.33	2.68±0.44	1.60±0.43	2.10±0.46	3.17±0.35	2.59±0.20
T. japonicum	Vegetative	3.82±0.42	3.93±0.38	3.40±0.34	2.40±0.28	3.71±0.47	2.67±0.64	3.45±0.19
	Flowering	3.05±0.17	2.85±0.19	2.17±0.22	2.73±0.27	2.07±0.27	1.52±0.36	2.58±0.12
	Standard Error		**Critical difference**		**P-value**		**t-value**	
	V	F	V	F	V	F	V	F
A × A	1.25	0.66	3.49	1.85	0.0001***	0.000***	1.97	1.97
B × B	1.52	0.82	4.27	2.26	0.3718	0.0744		
A × B	3.05	1.62	8.55	4.53	0.0059**	0.0033**		

*A- Trichogrammatids, B- Concentration, V- Vegetative phase, F- Flowering Phase.

Table 2 : The effect of potato emitted volatile cues on mean percent parasitism of Trichogrammatids.

Trichogra-mmatids (A)	Growth stage	Concentrations are in mg/L (B)						
		4,00,000	**2,00,000**	**1,00,000**	**50,000**	**25,000**	**Hexane**	**Mean**
T. brasiliensis	Vegetative	29.29±4.73	23.25±4.51	36.21±1.45	41.35±3.64	30.21±3.26	34.18±1.36	32.06±1.92
	Flowering	15.13±2.79	24.18±6.35	21.73±4.70	24.22±4.33	22.45±5.45	10.72±4.27	21.54±2.12
Tr. bactrae	Vegetative	29.77±2.12	28.51±4.47	24.19±2.12	27.94±1.71	26.43±1.44	25.12±1.80	27.37±1.14
	Flowering	4.05±2.79	7.53±2.42	7.39±3.34	4.05±4.33	4.05±5.45	4.06±4.27	5.42±0.83
T. chilonis	Vegetative	22.72±4.60	27.27±2.79	27.96±3.19	17.79±3.84	24.16±4.68	18.11±3.46	23.98±1.75
	Flowering	27.11±3.15	30.73±4.91	20.71±7.02	14.79±4.47	19.28±5.09	26.94±4.36	22.53±2.36
T. japonicum	Vegetative	33.13±3.51	32.81±3.12	29.36±2.35	19.54±3.83	30.81±3.78	19.04±4.51	29.13±1.68
	Flowering	15.14±1.76	18.75±2.54	6.21±1.36	16.25±3.71	13.18±3.48	6.95±2.89	13.91±1.38
	Standard Error		**Critical difference**		**P-value**		**t-value**	
	V	F	V	F	V	F	V	F
A × A	1.87	1.77	5.24	4.97	0.00***	0.0***	1.97	1.97
B × B	2.29	2.17	6.41	6.08	0.4097	0.1703		
A × B	4.58	4.34	12.83	12.17	0.0023**	0.2416		

*A- Trichogrammatids, B- Concentration, V- Vegetative phase, F- Flowering Phase.

sugarcane, pigeonpeas, cotton, tomatoes, chickpeas and marigold. Further, they observed that synomones (allelochemical) of pigeonpea elicited max response for both the parasitoids, whereas Marigold extract was able to generate higher response in *T. brasiliensis*. Yadav *et al.* (2001) reported that volatile cues emitted from various potato varieties were able to enhance the host searching behaviour in *T. exiguum*. Archna *et al.* (2009) studied and compared leaf extracts of nine varieties of rice in different phase of growth and concluded that volatile cues have varied response on foraging behaviour of *T. japonicum* and *T. chilonis*. Maruthadurai *et al.* (2011) observed that attractiveness and parasitisation rate of *T. brasiliensis* and *T. chilonis* due to presence of Bt cotton hybrids Bioseed 6488-I and Mrc 6025 extracts. Asfiya Zayeem and Archna Kumar (2012)

Table 3 : GC-MS profile of potato variety Kufri Surya.

S.no.	Name	Vegetative phase		Flowering phase	
		RT	Area%	RT	Area%
1	Tetradecane	15.947	0.180	ND	ND
2	Pentadecane	ND	ND	11.230	0.100
3	1-Pentadecanol	20.203	0.080	ND	ND
4	Hexadecane	ND	ND	15.947	0.400
5	Heptadecane	20.341	0.230	20.339	0.300
6	Tetradecanoic acid, trimethylsilyl ester	21.417	0.460	21.413	0.160
7	Heptadecane, 2,6,10,15-tetramethyl-	ND	ND	22.391	0.070
8	Hexadecanoic acid, methyl ester	22.950	0.410	ND	ND
9	N-(2-Aminophenyl)acetamideditms	ND	ND	23.627	0.100
10	Hexadecanoic acid, trimethylsilyl ester	25.295	1.730	25.288	2.120
11	9,12-octadecadienoic acid (z,z)-, methyl ester	26.201	2.250	ND	ND
12	9-octadecenoic acid (Z)-, methylester	26.303	0.80	ND	ND
13	Linolsaeure, trimethylsilylester	28.311	0.920	28.310	0.910
14	Trans-9-Octadecenoic acid, trimethylsilyl ester	28.403	1.920	ND	ND
15	Oleic acid, trimethylsilyl ester	ND	ND	28.401	2.51
16	Octadecanoic acid, trimethylsilyl ester	28.851	0.850	28.849	0.860
17	2-methyltetracosane	29.767	0.160	ND	ND
18	Celidoniol, deoxy-	31.418	0.110	ND	ND
20	Trimethylsilyl(9z)-12-[(trimethylsilyl)oxy]	31.746	0.560	31.744	0.63
21	Pentacosane	37.883	10.050	37.889	9.450
22	2-methyloctacosane	39.012	0.810	ND	ND
23	Tetracontane	41.406	35.54	41.441	36.130
24	3,11-Dimethyl-nonacosane	ND	ND	42.730	0.680
25	Triacontane	43.021	4.510	43.024	4.690
26	Triacontane, 1-bromo-	45.346	4.670	45.363	4.450
27	Dotriacontane	49.003	1.110	49.000	0.930

*RT- Retention Time *ND- Not Detected.

studied the effect of plant volatiles emitted from various cole crops on foraging behaviour of *T. brasiliensis* and reported significant enhancement. They observed highest mean parasitoid activity index and mean percent parasitism from hexane leaf extract of PSBK-1. Bhagat *et al*. (2014) concluded from their study that *T. japonicum* showed increased parasitisation when volatiles of different rice cultivar were present. GC-MS profile of Kufri Surya in vegetative stage revealed the presence of Tetradecane ($C_{14}H_{30}$), Heptadecane ($C_{17}H_{36}$), 2-methyltetracosane ($C_{25}H_{52}$), Pentacosane ($C_{25}H_{52}$), Triacontane ($C_{30}H_{62}$), Dotriacontane ($C_{32}H_{36}$) and Tetracontane ($C_{40}H_{82}$) and in flowering stage Pentadecane ($C_{15}H_{32}$), Hexadecane ($C_{16}H_{34}$), Heptadecane ($C_{17}H_{36}$), Tetracosane ($C_{24}H_{50}$), Pentacosane ($C_{25}H_{52}$), Triacontane ($C_{30}H_{62}$), Dotriacontane ($C_{32}H_{66}$), Tetratriacontane ($C_{34}H_{70}$) and Tetracontane ($C_{40}H_{82}$) in varying concentration and quantity. Presence of this compound/s may be responsible for alteration in behaviour of targeted Trichogrammatids. Madhu *et al*. (2000) observed that GC profile of pigeon pea indicated the presence of Octacosane (C_{28}) and Nonacosane (C_{29}), which seemed to play a role in provoking maximum responses in *T. brasiliensis*. Yadav *et al*. (2001) reported that response of *T. exiguum* to leaf extracts of different varieties of potato differed due to the presence of various hydrocarbons. They reported the presence of Pentacosane in leaf extracts of Potato and classified Pentacosane as favourable hydrocarbon for enhancement of foraging response of *T. exiguum*. Singh *et al*. (2002) studied the response of *T. brasiliensis* upon 11 straight chain saturated hydrocarbons and reported Heneicosane, Pentacosane, Hexacosane and Octacosane as favourable hydrocarbons for *T. brasiliensis*. Paul *et al*. (2002) also reported that

Pentacosane and Hexacosane were able to generate high parasitoid activity index and parasitism for *T. brasiliensis* and *T. exiguum*. Yonggen *et al*. (2006) and Rani *et al*. (2008) revealed that variation in the quantity and concentration of saturated hydrocarbons influenced the parasitisation efficiency of Trichogrammatids. Paul *et al*. (2008) also observed the emission of various alkanes (C_{21}-C_{35}) from aerial parts of tomato cultivars and found to be responsible for generating higher rate of parasitism by Trichogrammatids. Oliviera *et al*. (2005) studied the difference in concentration of plant volatiles isolated at different stages of growth. Pattern indicated that hydrocarbons were main produce. Various studies have proved these volatile cues, which enhance the host searching behaviour of Trichogrammatids are mainly saturated hydrocarbons in nature [Paul *et al*. (2002), Archna *et al*. (2009)]. Razavi (2011) demonstrated a considerable difference in the hydrocarbon profile of the aerial parts of *Prangos ferulacea* at different stages of growth. Thirty one compounds were identified in the vegetative stage and seven in flowering stage, respectively. Maruthadurai *et al*. (2011) observed that different Bt cotton hybrids revealed the presence of varied saturated hydrocarbons in their vegetative and flowering phases of growth. GC studies of different Bt cotton hybrids revealed the presence of saturated hydrocarbons ranging from C_8 to C_{38}. Differences in the number and concentration of plant volatiles isolated at different stages of growth was observed.

5. Conclusion

Study revealed that regular release of Trichogrammatids in combination with alkane type of volatile cues will be an effective biocontrol practice against lepidopterous pests of potato crop. Study will be an aid on help to bring a huge relief to potato growing farmers, mankind and environment.

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References

Ahmad, F., M. Aslam and M. Razaq (2004). Chemical ecology of insects and tritrophic interactions. *Journal of Research Science*, **15**, 181-190.

Archna, A. K., A. Singh, V. N. Paul and A. Jain (2009). Synomonal effect of nine varieties and one culture of rice on *Trichogramma japonicum* Ashmead and *Trichogramma chilonis* (Ishii) (Hymenoptera : Trichogrammatidae). *Acta Entomologica Sinica*, **52**, 656-664.

Asfiya Zayeem and Archna Kumar (2012). Impact of synomones emanating from cole crops on foraging behaviour of *Trichogramma brasiliensis*. *Annals of Plant Protection Sciences*, **20**, 481-482.

Babendreier, D., S. Kuske and F. Bigler (2003). Parasitism of non-target butterflies by *Trichogramma brassicae* Bezdenko (Hymenoptera : Trichogrammatidae) under field cage and field conditions. *Biological Control*, **26**, 139-145.

Bhagat Deepa, N. Bakthavatsalam and G. Ramu (2014). Effect of volatiles from leaves of rice cultivars on the foraging behaviour of *Trichogramma* spp. (Hymenoptera: Trichogrammatidae). *Oryza-An International Journal on Rice*, **51**, 255-257.

El-Wakeil, N., M. Saleh, N. Gaafar and H. Elbehery (2017). Conservation biological control practices, pp. 41-69 In: V D C Shields (ed.) *Biological Control of Pest and Vector Insects*, In Tech Publisher, Croatia DOI: 10.5772/66312.

Fatouros, N. E., M. Dicke, R. Mumm, T. Meiners and M. Hilker (2008). Foraging behavior of egg parasitoids exploiting chemical information. *Behavioural Ecology*, **19**, 677-689.

Food and Agriculture Organization (FAO) (2004). Agricultural data Production and Indices Data Crop Primary, http:// www.fao.org/ 15,2-2010.

Hossain, L., R. Rahman and M. S. Khan (2017). Alternatives of pesticides, pp. 147-165, *In*: M. S. Khan & M. S. Rahman (eds.), *Pesticide Residue in Foods*, Springer International Publishing.

Minhas, J. S., Devendra Kumar, T. A. Joseph, B. T. Raj, S. M. Paul Khurana, S. K. Pandey, S. V. Singh, B. P. Singh and P. S. Naik (2006). Kufri Surya : a new heat-tolerant potato variety suitable for early planting in north-western plains, peninsular India and processing into French fries and chips. *Potato Journal*, **33(1-2)**, 35-43.

Jalali, S. K., T. Venkatesan, K. S. Murthy and R. Ojha (2016). Management of *Helicoverpa armigera* (Hubner) on tomato using insecticide resistance egg parasitoid, *Trichogramma chilonis* Ishii in farmers' field. *Indian Journal of Horticulture*, **73**, 611-614.

Kelly, J. L., J. R. Hagler and I. Kaplan (2014). Semiochemical lures reduce emigration and enhance pest control services in open-field predator augmentation. *Biological Control*, **71**, 70-77.

Madhu, S., A. V. N. Paul and D. B. Singh (2000). Synomonal effect of different plant extracts on parasitism by

Trichogramma brasiliensis (Ashmead) and *Trichogramma japonicum* (Ashmead). *Shashpa*, **7**, 35-40.

Maruthadurai, R., R. D. Gautam and Archna (2011). Behavioural response of Trichogramma chilonis Ishii (Trichogrammatidae : Hymenoptera) to kairomones. *Indian Journal of Entomology*, **73(3)**, 247-252.

Nordlund, D. A., R. B. Chalfant and W. J. Lewis (1985). Response of *Trichogramma pretiosum* to extracts of two plants attacked by *Heliothiszea*. *Agriculture, Ecosystem and Environment*, **12**, 127-133.

Oliveira, M. J., I. F. Campos, C. B. Oliveira, M. R. Santos, P. S. Souza, S. C. Santos, J. C. Seraphin and P. H. Ferri (2005). Influence of growth phase on the essential oil composition of *Hyptis suaveolens*. *Biochemical Systematics and Ecology*, **33**, 275-285.

Paul, A. V. N., M. Srivastava, P. Dureja and A. K. Singh (2008). Semiochemicals produced by tomato varieties and their role in parasitism of *Corcyra cephalonica* (Lepidoptera: Pyralidae) by the egg parasitoid *Trichogramma chilonis* (Hymenoptera : Trichogrammatidae). *International Journal of Tropical Insect Science*, **28**, 108-116.

Paul, A. V. N., S. Singh and A. K. Singh (2002). Kairomonal effect of some saturated hydrocarbons on the egg parasitoids, *Trichogramma brasiliensis* (Ashmead) and *Trichogramma exiguum*, Pinto, Platner and Oatman (Hym : Trichogrammatidae). *Journal of Applied Entomology*, **126**, 409-416.

Puneeth, P. and V. A. Vijayan (2013). Biocontrol efficacy and viability of *Trichogramma chilonis* on *Corcyra cephalonica* and *Spodoptera litura* under laboratory conditions. *International Journal of Research in Biological Sciences*, **3(1)**, 76-79.

Rani, P. U., Y. Jyothsna and M. Lakshminarayana (2008). Host and non-host plant volatiles on oviposition and orientation behaviour of *Trichogramma chilonis* Ishii. *Journal of Biopesticides*, **1**, 17-22.

Razavi, S. M. (2011). Chemical composition and some allelopathic aspects of essential oils of (*Prangos ferulacea* L.) Lindl at different stages of growth. *Journal of Agricultural Science and Technology*, **14**, 349-356.

Rodriguez-Saona, C., B. R. Blaauw and R. Isaacs (2012). Manipulation of natural enemies in agro ecosystems: habitat and semiochemicals for sustainable insect pest control. pp. 89-126, In: S. Soloneski (ed.). *Integrated Pest Management and Pest Control-Current and Future Tactics*, In Tech Publisher, Croatia.

Romeis, J., D. Babendreier, F. L. Wäckers and G. Shanower (2005). Habitat and plant specificity of *Trichogramma* egg parasitoids-Underlying mechanisms and implications. *Basic and Applied Ecology*, **3**, 215-236.

Singh, S., A. V. N. Paul, P. Dureja and A. K. Singh (2002). Kairomones of two host insects and their impact on the egg parasitoids, *Trichogramma brasiliensis* (Ashmead) and *Trichogramma exiguum* Pinto, Platner and Oatmen. *Indian Journal of Entomology*, **64**, 96-106.

Sreekumar, K. M. and A. V. N. Paul (2000). Labour efficient technology for the mass production of rice meal moth *Corcyra cephalonica*. *Indian Journal of Entomology*, **62**, 304-311.

Srivastava, M., A. K. Singh, S. G. Parihar and R. D. Gautam (2017). Comparative effect of formulated kairomonal dusts on parasitization efficiency of *Trichogramma* spp. *Journal of Environmental Biology*, **38**, 641-648.

Tang, R., D. Babendreier, F. Zhang, M. Kang, K. Song and M. L. Hou (2017). Assessment of *Trichogramma japonicum* and *Trichogramma chilonis* as potential biological control agents of yellow stem borer in rice. *Insects*, **8**, **doi:** 10.3390/insects8010019.

Van Lenteren, J. C. (2000). Success in biological control of arthropods by augmentation of natural enemies, pp. 77-103, In : Gurr G. and S. Wratten (eds.), *Biological Control: Measures of Success*, Springer, Dordrecht.

Yadav, B., A. V. N. Paul and R. K. Gautam (2001). Synomonal effect of some potato varieties on *Trichogramma exiguum* Pinto, Platner and Oatman. *Proceedings of Symposium on Biocontrol based Pest Management for Quality Crop Protection in the Current Millennium* (eds. Singh, D., M. S. Mahal, A. S. Sohi, V. K. Dilawari, K. S. Brar and S. P. Singh), Punjab Agricultural University, Ludhiana, pp. 16-17.

Yonggen, L., H. Xiaoyan, T. C. J. Turlings, J. Cheng, X. Chen and G. Ye (2006). Differences in induced volatile emissions among rice varieties result in differential attraction and parasitism of *Nilaparvata lugens* eggs by the parasitoid *Anagrus nilaparvatae* in the field. *Journal of Chemical Ecology*, **32**, 2375-2387.

Yousuf, M., M. Ikram and M. Faisal (2015). Current status of Indian *Trichogramma spp.* along with their distributional record and host range. *Indian Forester*, **141**, 806-812.