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Mass Trapping Technique Using Pheromones: A Standalone Method for Management of Diamondback Moth, *Plutella Xylostella* (Linnaeus) (Plutellidae: Lepidoptera) in Cabbage

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Abstract: The diamondback moth (DBM), *Plutella xylostella*(Linnaeus) (Plutellidae: Lepidoptera) is found throughout the world and considered as the most destructive insect pest of cruciferous crops, particularly cabbage, broccoli and cauliflower. An attempt was made to evaluate the effectiveness of the pheromones in combination with need based insecticides under farmer's field conditions. Trap density study results indicated that the highest number of moths trapped with highest percent population reduction was recorded in both Bangalore and Kolar with trap density @ 40 traps/acre with a highest mean head weight and yield. The data on mass trapping as a standalone method in season-I revealed that highest number of moths was trapped (675 moths), resulted in 73.96 percent reduction in larva and pupal numbers over control compared to farmer's practice (46.11 percent). Highest number (Mean) of larvae and pupae (3.68) was observed in control plot compared to farmer's practice plot (1.67) and standalone plot (0.89). In season-II, highest number of moths was trapped (13935 moths) in mass trapping operated plot, which had resulted 51.42 percent reduction in larva and pupal numbers over control compared to farmer's practice with only 39.04 percent population reduction. Highest number of larvae and pupae (5.82) was observed in control plot compared to farmer's practice plot (3.16) and mass trapped plot (3.04). Highest percent population reduction of DBM over control was observed in mass trapping as a standalone method compared to farmer's practice. Pheromone deployed plots had significantly increased *Cotesia plutellae* population when compared to farmer's practice. The C: B ratio of pheromone installed plots in both the seasons was found to be higher compared to farmer's practice.

Keywords: Cabbage; *Plutella xylostella*; Sex pheromone; Water traps; Mass trapping technique; standalone method.

1. Introduction

Cruciferous vegetables are important crops throughout the world. Among them, cabbage and cauliflower are economically important vegetable crops in India. Cole crops are one of the most abundantly consumed vegetables all over the world and grown in temperate and tropical regions of the world. They belong to the genus Brassica of the family Brassicaceae. This group has a wide variety of vegetable crops including cabbage. In India, Cabbage is grown in an area of 3,72,000 ha with a production of 8.53 million t (NHPD, 2013). In a country like Taiwan crucifers are by far

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the most predominant group comprising up to 25 % of the land devoted to vegetable planting (Talekar et al., 1992) [1].

Although the cabbage crop has got huge domestic requirement, a number of limiting factors have been attributed for low productivity. Among them, the chief constraint in the production of cabbage is damage caused by pest complex right from germination till harvesting stage. Maison (1965) [2] listed 51 insect pests to damage cruciferous crops throughout the world. In India, a total of 37 insect pests have been reported to feed on cabbage (Lal, 1975) [3]. Of which, diamondback moth (DBM), *Plutella xylostella* (Linnaeus), cabbage butterfly, *Pieris brassicae* Linnaeus, cabbage semilooper, *Trichoplusia ni* Hubner, cabbage head borer, *Hellula undalis* Fabricius, tobacco caterpillar, *Spodoptera litura* (Fabricius), cabbage aphid, *Brevicoryne brassicae* Linnaeus and green peach aphid, *Myzus persicae* (Green) are the major insect pests. Among these, DBM is the most serious pest. Though, the moth was originated in the Mediterranean area, it has surpassed all the natural barriers and is believed to have become a cosmopolitan pest (Meyriche, 1928) [4].

The diamondback moth (DBM), *P. xylostella* (Linnaeus) (Plutellidae: Lepidoptera) is found throughout the world and considered as the most destructive insect pest of cruciferous crops, particularly cabbage, broccoli and cauliflower (Talekar and Shelton, 1993) [5]. The extent of damage on these crops by this pest alone was estimated to be 52 % in India (Sachan and Gangwar, 1990) [6]. The difficulty of controlling this pest has forced some growers to abandon the production of cruciferous crops (Talekar et al., 1992; Talekar and Shelton, 1993) [1, 5].

To control this pest, farmers use large quantities of insecticides. However, insecticidal effectiveness has been gradually declining following their widespread and continuous use. This intensive and frequently aimless utilization of chemicals coupled with rapid turnover of generations has brought about DBM getting to be impervious or resistant to practically all categories of insecticide used for its control. It has recently come to light that indiscriminate use of pesticides kill beneficial predators like spiders, ants, earwigs and others which in the absence of pesticides, help to reduce pest population. This side effect not only results in resurgence of DBM, but it is now held responsible for epidemics of other pests like whiteflies, leaf rollers and aphids. Now, it is very much essential to get out of this pesticide reliance treadmill because old pesticides do not work any longer and new chemicals are not coming into market fast enough specially to control DBM.

Significance of pheromones in integrated pest management is gaining attention basically due to decrease in the pesticide usage in vegetables which are consumed directly by human beings. Pheromones suppress the pests apart from reducing the hazards caused by chemical toxicants on the environment and human beings. Therefore, in this paper we discuss about the effectiveness of the pheromones in combination with timely used insecticides in different farmer’s fields.

Studies carried out by Bio-Control Research laboratories (BCRL) Bangalore, succeeded in development and use of sex pheromone traps as an effective tool for surveillance and monitoring of *P. xylostella*. However, the data available for recommending this pheromone based mass trapping technology for the management of *P. xylostella* is meager. Hence, the present study was conducted with the expectation of creating appropriate measures for the management of *P. xylostella*.

2. Materials and methods

Pheromone chemicals: Dilutions were made by using indigenously synthesized *Z*-11-hexadecenal, *Z*-11-hexadecenyl acetate and *Z*-11-hexadecenol (Ando et al. 1979) [7] in 10:10:0.1 ratio as standard formulation for EAG studies. The concentration of the dilution was prepared by using 2 µL of sample in 100 µL of solvent Hexane (2%). The same concentration was maintained for other semiochemicals viz., kairomone (Allyl isothiocyanate), plant volatile (*Z*-3,6-OAc) while preparing dilutions for EAG studies.

Pheromone Sample/lures & Traps

The pheromone lures used in standardization of pheromone dosage study were prepared using black rubber septa impregnated with 0.5mg, 0.75mg, 1mg, 2mg and 3mg of standard formulation consisting of three components *Z*-11-hexadecenal, *Z*-11-hexadecenyl acetate and *Z*-11-hexadecenol (Ando et al. 1979) [7] in the ratio 10: 10: 0.1 prepared by Bio-control Research Laboratories, PCI, Bangalore. Field studies were carried out with pheromone lures prepared by using 1mg of standard blend mentioned above in rubber septa (DBM lure) along with water trap. A half tea spoon of detergent powder was mixed in the water to retain and drown the trapped DBM moths. The trap height was maintained at 0.3 m above the canopy level. Total five treatments with four replications were installed in one-acre cabbage field distributed in uniform grid pattern. Weekly observations of moths trapped were recorded continuously for eight weeks.

The pheromone lures used in the other field studies were black rubber septa impregnated with 1 mg of a formulation of three components *Z*-11-hexadecenal, *Z*-11-hexadecenyl acetate and *Z*-11-hexadecenol in the ratio 10: 10: 0.1 with water traps installed as indicated above.

Trap density studies and observations:

In order to standardize the trap density per unit area for maximum moth catches, the experiment was carried out in five different isolated cabbage (Variety; Unnati) fields of one acre each in and around Rajanukunte, Bangalore rural (13.174475, 77.549865) and Kolar (42.706385, -87.840225) (i.e., two locations). The crop was planted at the same time in all five fields. The traps with different densities were set up in the farmers' fields on 15th day after transplantation to trap the adult males. The water traps baited with pheromone septa were set up by using wooden pegs. The trap height maintained at 0.3 m above the canopy level. The traps were installed randomly covering an acre area. Water was maintained and served about three fourth of the trap throughout the trapping period.

Observation on number of moths trapped was recorded at four days intervals. Besides, observation on number of larvae and pupae and its larval parasitoid, *Cotesia plutellae* per plant were also recorded at an interval of one week on randomly selected 50 plants from each of the field. The percent population reduction in different treatments over control was calculated using the modified Abbott's formula given by Flemming and Ratnakaran (1985) [8].

$$\text{Percent population reduction} = \left[1- \left(\frac{\text{Post-treatment population in the treatment}}{\text{Pre-treatment population in the treatment}} \text{ X } \frac{\text{Pre-treatment population in the control}}{\text{Post-treatment population in the control}} \right) \right] \times \mathbf{100}$$

Mass trapping of DBM using sex pheromone lures as a stand-alone method
Sriramanahalli (Season-I)

A study area of 2100 m^2 was selected at Sriramanahalli (13°12'01.29"N 77°33'33.76"E elev-2953 ft), Bangalore Rural District for mass trapping of DBM. Based on the results obtained from the trap density trials, trap installation was done @ 40 per acre. A total of 21 traps were installed at 0.3 m above the crop canopy level.

Comparison of the standalone technique was done with the farmers practice (conventional practice); an area of half acre cabbage field was selected nearer to the standalone field for the study. Information on the number of sprays deployed in the farmer's field for the management of DBM in cabbage ecosystem was obtained. 5 sprays were used by the farmer for the management of DBM throughout the cropping period. Details of spray number and chemicals are furnished in Table 1. Two traps were installed in the middle of the field for monitoring purpose. Cost benefit ratio was calculated to see the differences between the treatments and control plots.

Haniyuru (Season-II)

The second trial on mass trapping of DBM in cabbage ecosystem was carried out with a study area of 2400 m^2 at Haniyuru (13°12'32.62"N 77°31'06.53"E elev-2846 ft), Bangalore Rural District. In standalone method two sprays were given to manage DBM along with 24 traps whereas in farmers practice, a total of six sprays were provided to manage DBM (Table 1). Methods deployed in the earlier experiment were followed here also.

Table 1. Insecticides and trap details for mass trapping of *P. xylostella* as a standalone method comparison with farmer's practice.

Season	Treatments	Spray number	Insecticide name	Trap number
Season I (*Rabi* 2013-14)	**Standalone Method**	-	-	21 traps @ 40 traps/acre
	Farmer's practice	Spray I	Caldan (Cartap hydrochloride)	2 traps (Monitoring)
		Spray II	Avaunt (Indoxacarb)	
		Spray III	Coragen (Chlorantraniliprole)	
		Spray IV	Chlorpyriphos (Dursban)	
		Spray V	K-cobra (Organic product)	
Season II (*Winter* 2013-14)	**Standalone method**	Spray I	Coragen (Chlorantraniliprole)	24 traps @ 40 traps/acre
		Spray II	K-cobra (Organic product)	
	Farmer's practice	Spray I	Caldan (Cartap hydrochloride)	2 traps (Monitoring)
		Spray II	Caldan (Cartap Hydrochloride)+ Nuvan (DDVP)	
		Spray III	Coragen (Chlorantraniliprole)	
		Spray IV	Rocket (combi product)	
		Spray V	Avaunt (Indoxacarb)	
		Spray VI	K-cobra (Organic product)	

3. Results

Behaviour of diamondback moth in the presence of semiochemicals:

The DBM responds to a variety of plant odours, particularly those of *Brassica juncea* and *B. napus*. EAG study was carried out by using synthetic semiochemicals like pheromones, kairomones & plant volatiles to observe & compare the response of male DBM antennae to different volatiles.

EAG response of DBM male antenna to different blends:

The Electroantennogram (EAG) response for DBM male antennae to standard synthetic female pheromone (*Z*-11- hexadecenal, *Z*-11- hexadecenyl acetate and *Z*-11- hexadecenol in 10:10:0.1 ratio), kairomone (Allyl isothiocyanate), plant volatile (*Z*-3,6-OAc (100parts)), honey and hexane were determined. The results revealed that EAG response of DBM male antennae was statistically not significant to different blends (semiochemicals) and control. Though there was no significant difference but still there was a higher response of DBM male antennae to kairomone (1.63±0.61) followed by honey (1.18±0.28), standard synthetic formulation (1.03±0.23), *Z*-3,6-OAc (100parts) (0.89±0.35). Lowest response was recorded to Hexane (Control) (0.22±0.11) (Fig. 1).

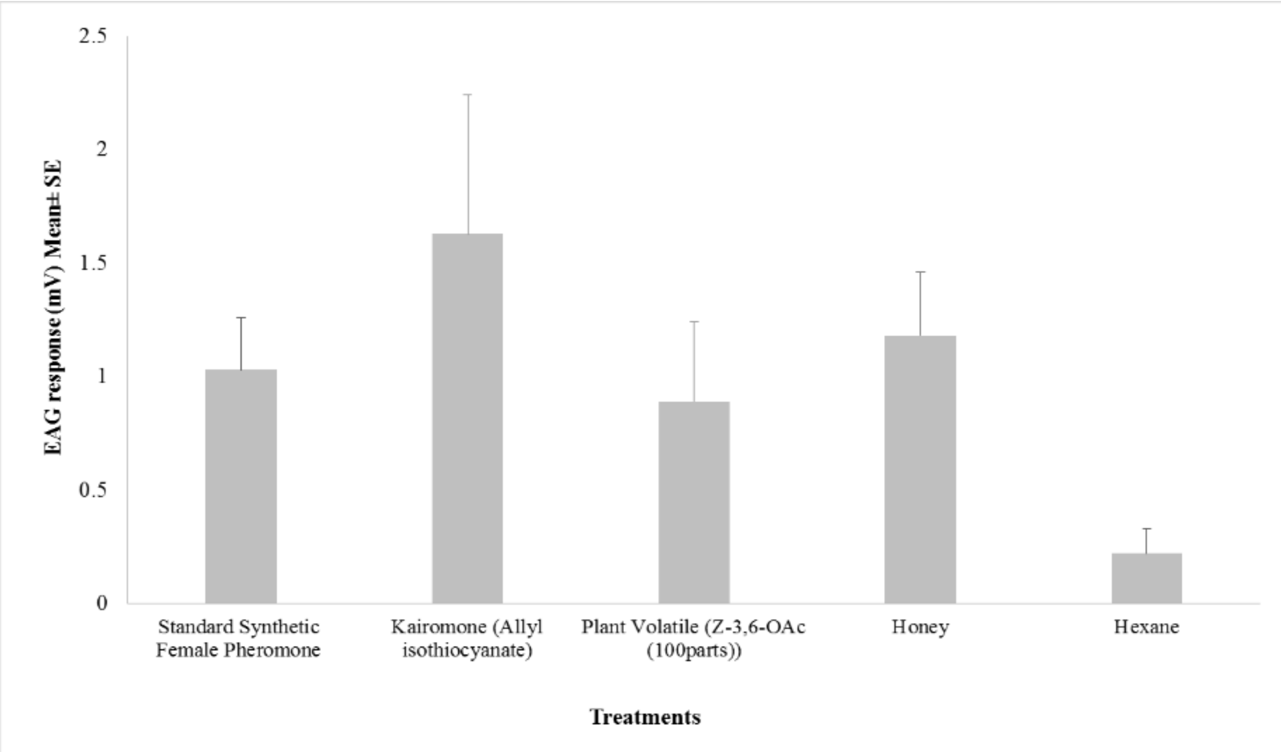

Figure 1. EAG response of DBM male antenna to different blends.

EAG response of DBM male antenna to different doses of standard formulation:

The EAG responses of DBM male antennae to different dose of synthetic sex pheromone blend were examined. The treatments were not statistically significant increasing dose of 2% solution of standard formulation (*Z*-11- hexadecenal, *Z*-11- hexadecenyl acetate and *Z*-11- hexadecenol) and control. The EAG response was initially increased with the increase in dose from 20 µL (0.841±0.67) to 30 µL (0.861±0.67) and then decreased from 40 µL (0.486±0.23) onwards viz., 80 µL (0.474±0.35) and 120 µL (0.472±0.31) of blend of *Z*-11- hexadecenal, *Z*-11- hexadecenyl acetate and *Z*-11- hexadecenol. Lowest response was recorded to Hexane (Control) (0.130±0.08) (Fig. 2).

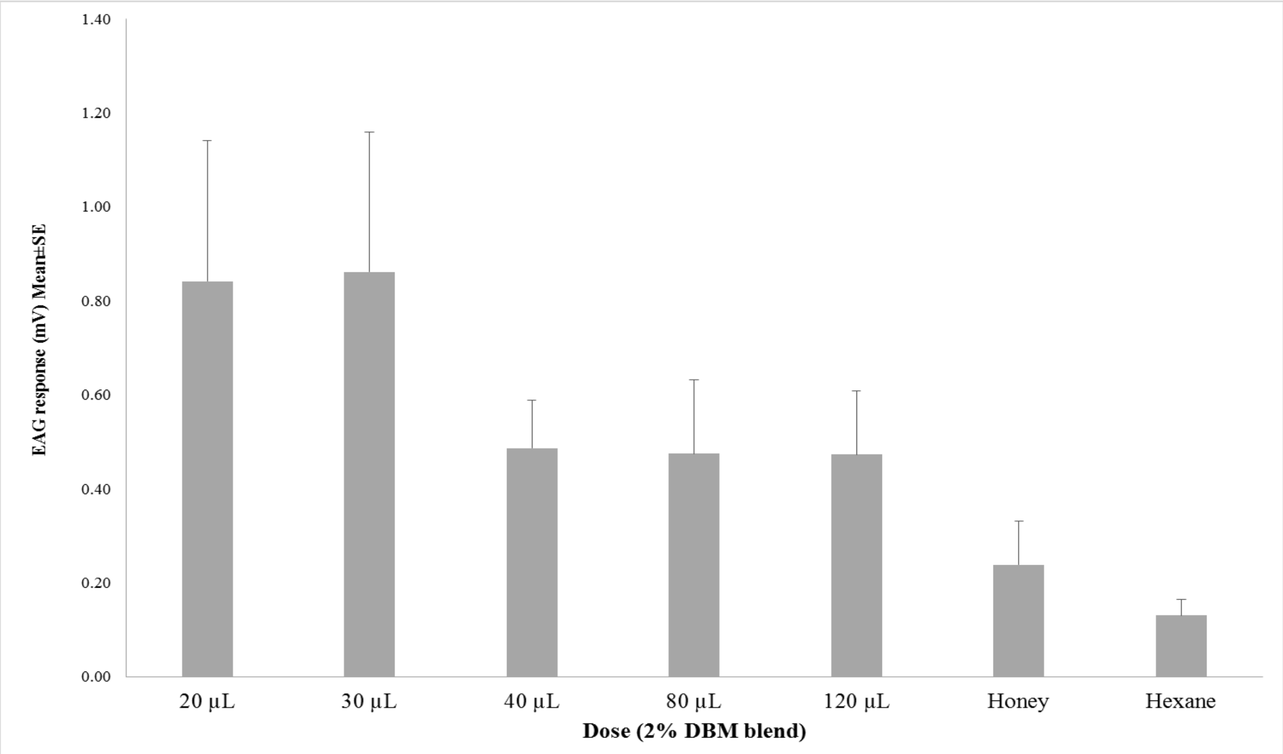

Figure 2. EAG response of DBM male antenna to 2% solution of standard formulation.

Field studies using different doses of standard synthetic pheromone:

Based on the results of EAG studies of increased doses of 2% of standard formulation, field studies were conducted with septa containing different doses of pheromone. The results revealed that there is similar pattern followed in field studies with different concentrations. The results suggest that though there was an increase initially the trap catches had not increased with increased concentration of standard formulation. The highest catches were collected (1115 ± 150.71) in a trap with 0.75 mg of dose and surprisingly, the highest dose (3 mg) trapped less number of moths (912 ± 99.81) than the lowest dose (0.5 mg) with 1076 ± 127.52 of trapped adults. Other treatments of different doses 1 mg and 2 mg had 1031 + 119.84 and 1015 ± 123.42 moth catches, respectively. Control trap caught the lowest moths (455 ± 62.75) when compared to all dosage treatments (Fig.3).

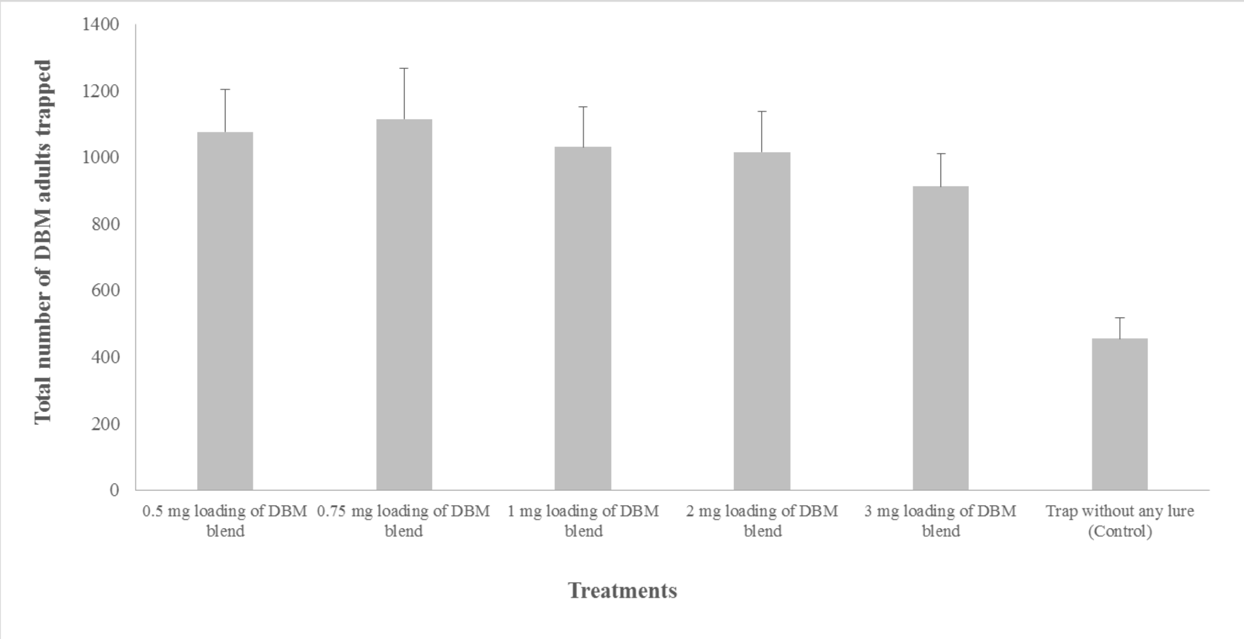

Figure 3. Number of *P. xylostella* adults trapped against different doses of standard synthetic pheromone.

Trap Density

Results on the trap density experiments (two places i.e., Bangalore and Kolar; and two season studies at each place) revealed that the moth catches per trap decreased as trap density per unit area increased which is an indication of reduction in population. The number of moths trapped in different traps and larval, pupal count across the fields varied with different treatments of trap densities.

In the trap density trial for moth catches per trap during kharif-2012 (July – October) at Kolar revealed that the effect of different trap densities on moth catches was statistically significant. The moth catches per trap varies with trap density per unit area. The highest number of (3995) moths with an average of 99.88 moths/trap was recorded in 40 traps/acre followed by 1267 moths trapped with an average of 42.23 moths/trap at 30 trap/acre and 981 moths trapped with an average of 81.75 moths/trap in 12 traps. The least number of 764 moths were trapped at 20 traps/acre field. In control (n=2 traps) where two traps were placed at centre of the cabbage field, 66 moths were trapped with an average of 33.00 moths/trap during the same moth emergence period.

The observations on larval and pupal reduction indicated that DBM population decreased with increase in trap density. Among the four trap densities tested, highest number of moths was trapped (3995 moths) at 40 traps/acre, resulted 31.65 % reduction in population over control. This was followed by 24.76 %, 22.46 % and 19.51 % reduction in larval and pupal number over control at 30, 20 and 12 traps/acre, respectively (Table 2).

Table 2. Relation between trap density, number of male moths and percent DBM population reduction in mass trapping experiments, Kolar during *kharif,* 2012.

Trap density (traps acre^{-1})	No. of traps	Total number of moths trapped	Number of moths trapped/trap (Mean ± SEM)	Number of moths trapped/trap/week (Mean ± SEM)	Percent population reduction over control
0 (Monitoring)	2	66	33.00±8.37	4.67±1.20	-
12	12	981	81.75±11.35	11.68±1.62	19.51
20	20	764	38.20±5.38	5.46±0.77	22.46
30	30	1267	42.23±6.45	6.03±0.97	24.76
40	40	3995	99.88±13.36	14.27±1.91	31.65
F value, df=4,99			11.54	**F value, df=3,196**	1.070E^3
p value			0.0005	**p value**	0.0005

Similar trend was observed in trap density experiment during rabi-2012 (October to March) at Kolar. Among the four trap densities tested, highest number of moths was trapped (3247 moths) at 40 traps/acre treatment, resulting in 24.59% reduction in larval numbers over control followed by 1380 moths with 16.06% reduction at 20 traps/acre treatment and 1598 moths with 13.11% at 30 traps/acre treatment. The least (5.92 %) reduction in larval number over control was recorded with only 809 moths trapped in 12 traps/acre treatment (Table 3).

However, results on trap density at Bangalore during rabi-2012 revealed that the highest number of (16121) moth catches were recorded at 40 traps/acre, with an average of trapping of 403.03 moths/trap. The next highest was 9102 moths trapped with an average of 758.50 moths/trap at 12 traps/acre followed by 8041 moths trapped with an average of 402.05 moths /trap at 20 traps. The least number of moths (2683) were trapped at 30 traps/acre treatment. In control (n=2 traps), 154 moths were trapped with an average of 77.00 moths/ trap during the same moth emergence period (Table 4).

Table 3. Relation between trap density, number of male moths and percent DBM population reduction in mass trapping experiments Kolar during *rabi,* 2012.

Trap density (traps acre^{-1})	No. of traps	Total number of moths trapped	Number of moths trapped/trap (Mean±SEM)	Number of moths trapped/trap/week (Mean±SEM)	Percent population reduction over control
0 (Monitoring)	2	118	59.00±11.00	8.42±2.61	-
12	12	809	67.42±6.05	9.63±0.86	5.92
20	20	1380	69.00±6.31	11.50±1.05	16.06
30	30	1598	53.27±3.40	10.65±0.68	13.11
40	40	3427	85.68±3.88	14.28±0.65	24.59
F value, df=4,99			5.68	**F value, df=3,196**	171.51
p value			0.0005	**p value**	0.0005

Table 4. Relation between trap density, number of male moths and percent DBM population reduction in mass trapping experiments, Bangalore during *rabi,* 2012.

Trap density (traps acre^{-1})	No. of traps	Total number of moths trapped	Number of moths trapped/trap (Mean±SEM)	Number of moths trapped/trap/week (Mean±SEM)	Percent population reduction over control
0 (Monitoring)	2	154	77.00±19.00	8.56±4.81	-
12	12	9102	758.50±50.79	84.28±5.64	20.01
20	20	8041	402.05±16.35	44.67±1.82	32.97
30	30	2683	89.43±7.44	9.94±0.83	44.33
40	40	16121	403.03±17.58	44.78±1.95	38.15
F value, df=4,99			142.05	**F value, df=3,196**	345.50
p value			0.0005	**p value**	0.0005

Among the four trap densities tested, highest percent population reduction (44.33) was recorded at 30 traps/acre followed by 38.15, 32.97 and 20.01 percent at 40, 20 and 12 traps / acre, respectively.

Similarly, during winter-2012 at Bangalore the highest number of (2927) moths were trapped in 40 traps/acre resulted in 28.26% of population reduction over control. The next highest was 1841 moths trapped with only 13.06% reduction of pest population at 20 trap/acre. The least number of 1510 and 596 moths were trapped at 30 and 12 traps/acre treatments with 16.18 and 10.96% reduction of DBM population, respectively. In control (n=2 traps) where two traps were placed at centre of the cabbage field, 98 moths were trapped during the same moth emergence period (Table 5).

Table 5. Relation between trap density, number of male moths and percent DBM population reduction in mass trapping experiments, Bangalore during *winter,* 2012-13.

Trap density (traps acre^{-1})	No. of traps	Total number of moths trapped	Number of moths trapped/trap (Mean±SEM)	Number of moths trapped/trap/week (Mean±SEM)	Percent population reduction over control
0 (Monitoring)	2	98	49.00±9.00	5.40±1.00	-
12	12	596	49.67±3.90	6.21±0.49	10.96
20	20	1841	92.05±9.30	10.23±1.03	13.06
30	30	1510	50.33±5.57	7.19±0.80	16.18
40	40	2927	73.18±5.88	8.13±0.65	28.26
F value, df=4,99			2.74	**F value, df=3,196**	792.73
p value			0.033	**p value**	0.0005

Effect of different trap densities on the yield of cabbage

The effect of different trap densities on the yield of cabbage was determined in two seasons at Bangalore and Kolar regions. The results on effect of different trap densities on yield of cabbage revealed that mean head weight and yield increases as trap density per unit area increased. In present study, the differences in trap density on the yield of cabbage were significant. The highest mean head weight at Bangalore, season-I 1.93 kg and season-II 1.99 with an average yield of 77.20 t/ha and 79.60 t/ha, respectively was recorded at 40 traps whereas the least mean head weight (season-I 1.46 kg and season-II 1.41 kg) and yield (season-I 58.4 t/ha and season-II 56.4 t/ha) were observed at 12 traps (Table 6). The mean head weight (season-I 1.67 kg and season II- 1.70 kg) and yield (season-I 66.80 t/ha and season-II 68.00 t/ha) at 20 traps which is less than the mean head (season-I 1.70 kg and season-II 1.74 kg) and yield (season-I 68.00 t/ha and season-II 69.60 t/ha) recorded at 30 traps. Whereas in a similar experiment carried out at Kolar for two seasons revealed that, 40 traps/acre has highest mean head weight (season I-1.98 kg and season-II 1.98 kg) and yield (season-I 79.20 t/ha and season-II 79.20 t/ha) followed by 30 traps (mean head weight =

season-I 1.33 kg, season-II 1.46 kg ; yield = season-I 53.20 t/ha, season-II 58.40 t/ha) and 20 traps (mean head weight = season-I 1.27 kg, season-II 1.23 kg ; yield = season- I 50.80 t/ha, season-II 49.20 t/ha) and the least mean head weight (season-I 1.24 kg and season-II 1.19 kg) and yield (season-I 49.60 t/ha and season-II 47.60 t/ha) was at 12 traps/acre. Over all, control recorded least mean head weight and yield compared to 12, 20, 30 and 40 traps/acre at both Bangalore and Kolar (Table 6).

Table 6. Effect of different trap densities on the yield of cabbage.

Trap density(traps acre^{-1})	**Bangalore**				**Kolar**			
	Season I (*Rabi* 2012)		**Season II (*Winter*2012-13)**		**Season I (*Kharif* 2012)**		**Season II (*Rabi* 2012)**	
	Mean Head Weight (kg)	**Yield (t/ha)**	**Mean Head Weight (kg)**	**Yield (t/ha)**	**Mean Head Weight (kg)**	**Yield (t/ha)**	**Mean Head Weight (kg)**	**Yield (t/ha)**
12	1.46	58.40	1.41	56.40	1.24	49.60	1.19	47.60
20	1.67	66.80	1.70	68.00	1.27	50.80	1.23	49.20
30	1.70	68.00	1.74	69.60	1.33	53.20	1.46	58.40
40	1.93	77.20	1.99	79.60	1.98	79.20	1.98	79.20
Control	1.46	58.40	1.37	54.80	1.21	48.40	1.09	43.60
F valuedf (4,95)	5.64*		10.13*		10.66*		10.96*	
p value	0.0005		0.0005		0.0005		0.0005	

Yield obtained based on mean head weight
16000 seedlings/acre
* -significant

Therefore, from the results of different trap densities i.e., 12 traps / acre, 20 traps/ acre, 30 traps / acre and 40 traps/ acre it was concluded that treatment with 40 traps per acre was appeared to be the most effective and convenient trap density to use in an integrated management program of DBM than the other densities. The lowest populations were observed at 40 traps / acre across all the seasons in two different localities followed by 30 traps/ acre and then the remaining two 20 and 12 traps/ acre. Hence, based on the results of trap density experiments, further investigations on evaluation of mass trapping technique as a standalone method were carried out and results of the same are presented in the following sections.

Mass trapping as a standalone method

The results of two seasons of mass trapping experiments i.e., *rabi* (October to March) (Season-I) and *winter* (December – February) (Season-II) 2013-14 are presented below.

Season I (Rabi 2013-14)

The observations on population reduction indicated that larval and pupal population decreased with increase in trap density. Highest number of moths was trapped (675 moths), resulting in 73.96 percent reduction in larva and pupal numbers over control in mass trapped plot compared to farmer's practice where only 46.11 percent population reduction was observed. Data on the mean number of larvae and pupae revealed that highest number of 3.68 was observed in control plot compared to farmer's practice plot (1.67) and mass trapping as a standalone method plot (0.89). Mean number of larvae and pupae were differed significantly in all the three plots (Fig. 4 and 5).

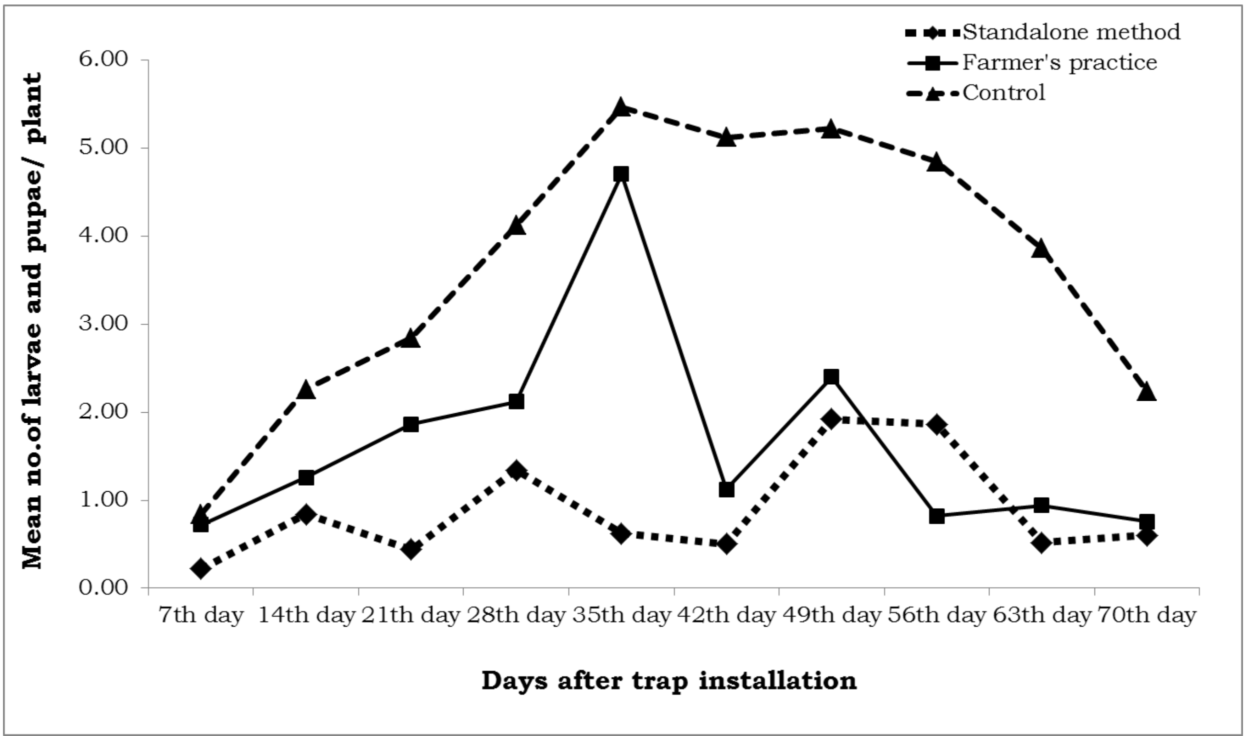

Figure 4. Mean number of *P. xylostella* per plant from 50 plants sampled weekly.

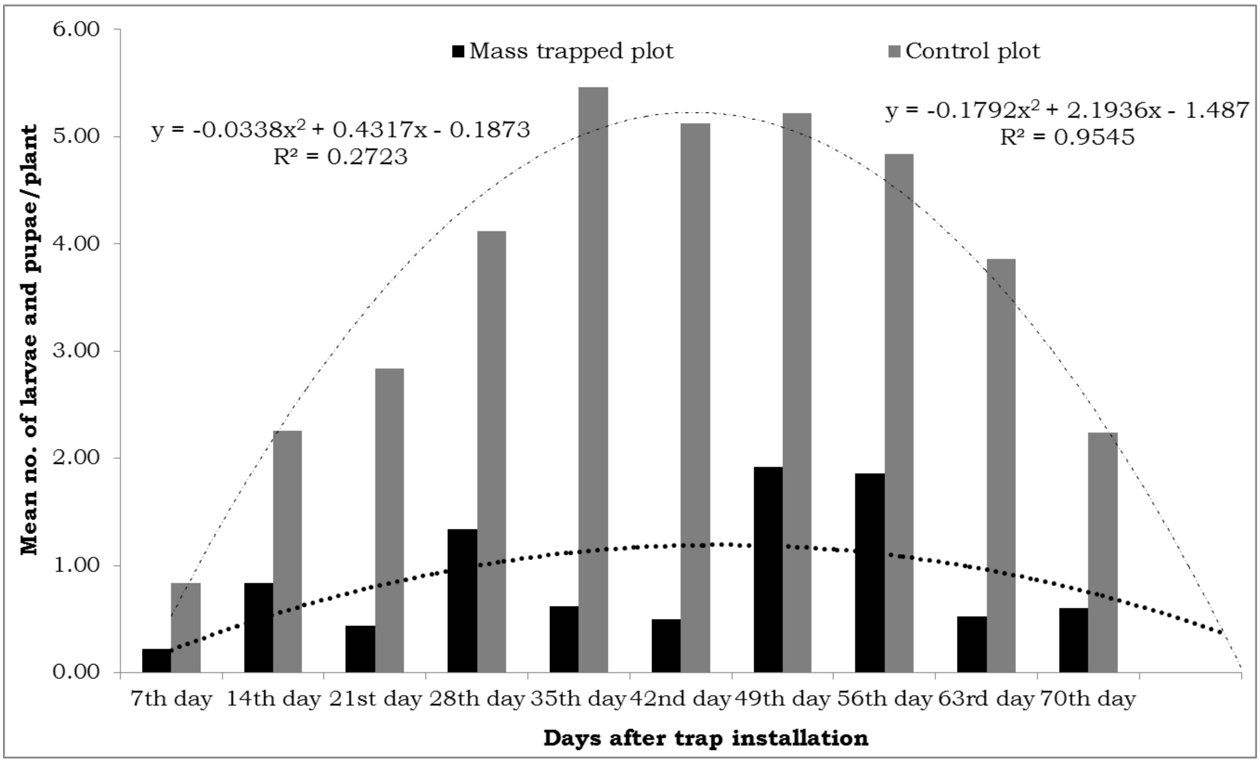

Figure 5. Polynomial relationship of larva and pupal numbers/plant between pheromone operated and control plots in Sriramanahalli.

The number of moths trapped in standalone deployed plot and farmer's practice differed and in alignment with the hypothesis. A total number of 675 moths with an average of 32.14 moths/trap was recorded in the standalone method treatment plot (21 traps placed @ 40 traps/acre). Whereas in farmer's practice plot (n=2 traps) the two traps placed at centre of the cabbage field, trapped 121 moths with an average of 60.50 during the same moth emergence period (Table 7).

Observations on the Cotesia population (larval parasitoid) revealed that pheromone installed plot had more number (0.82±0.26) of *C. plutellae* per plant when compared to farmer's practice (0.23±0.07) (Table 7) where chemical sprays were undertaken.

Table 7. Comparison between mass trapping as a standalone method and farmer's practice at Sriramanhalli, Bangalore during *rabi,* 2013-14.

Treatments	No. of traps	Total number of moths trapped	Number of moths trapped/trap (Mean±SEM)	*Number of larvae and pupae per plant (Mean±SEM)	Percent population reduction over control	*Number of *Cotesia* per plant (Mean±SEM)
Standalone Method	21	675	32.14±3.93	0.89±0.19	73.96	0.82±0.26
Farmer's Practice	2 (Monitoring)	121	60.50±1.50	1.67±0.39	46.11	0.23±0.07
Control	-	-	-	3.68±0.49	-	-
F value, df=1, 21			10.01	**F value, df=1, 98**	$1.172E^4$	-
p value			0.005	**p value**	0.0005	-

**Mean of 50 plants*

In all three *rabi* commercial cabbage crops, there were small outbreaks of DBM larvae. These required spray applications to reduce the pest population for minimizing the damage. A total of 5 sprays were applied during the cropping period in farmer's plot where as in mass trapped plot no application of insecticide was done to bring down the DBM population in cabbage (Fig. 6). In other words, 5 sprays were reduced in the mass trapped field of cabbage plot to manage *P. xylostella*. (Fig. 7).

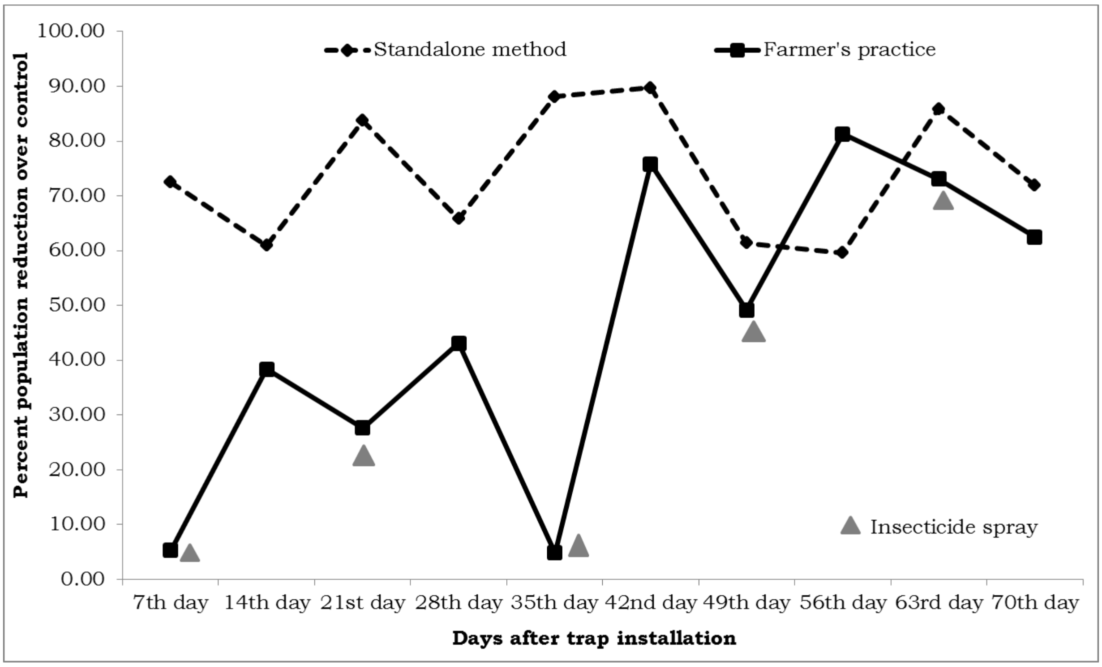

Figure 6. Percent population reduction of *P. xylostella* over control in pheromone operated plot and farmer's practice in cabbage, Sriramanhalli, Bangalore during rabi 2013-14.

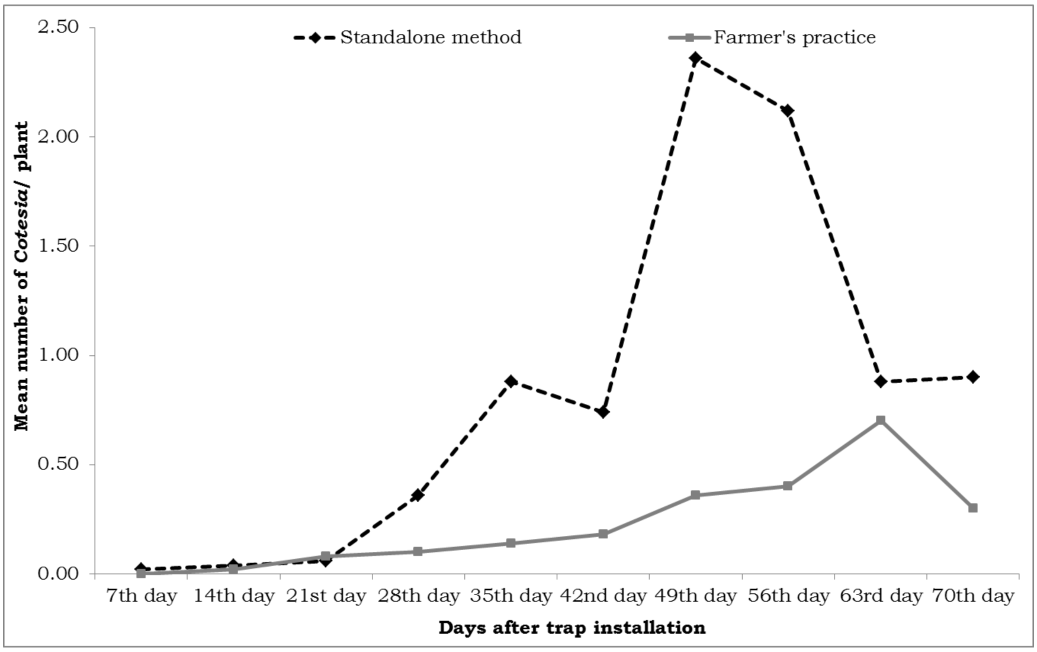

Figure 7. Mean numbers of *C. plutellae* per plant from 50 plants sampled weekly at Sriramanahalli.

Season II (Winter 2013-14)

The observations on population reduction indicated that mass trapping as a standalone method operated filed had maximum trapped moths with highest 51.42 percent of population reduction over control when compared to farmer's practice, with only 39.04 percent reduction of DBM infestation level. Data on the mean number of larvae and pupae revealed that highest number of 5.82 was observed in control plot compared to farmer's practice plot (3.16) and standalone method deployed plot (3.04). Mean number of larvae and pupae were differed significantly in all the three plots (Fig. 8 and 9).

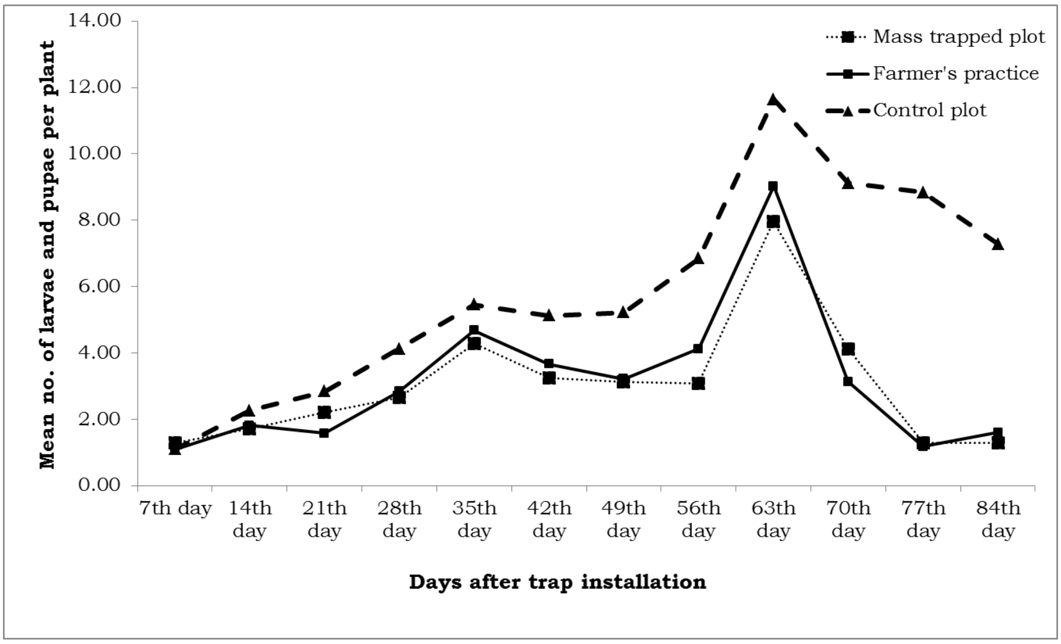

Figure 8. Mean numbers of *P. xylostella* per plant from 50 plants sampled weekly.

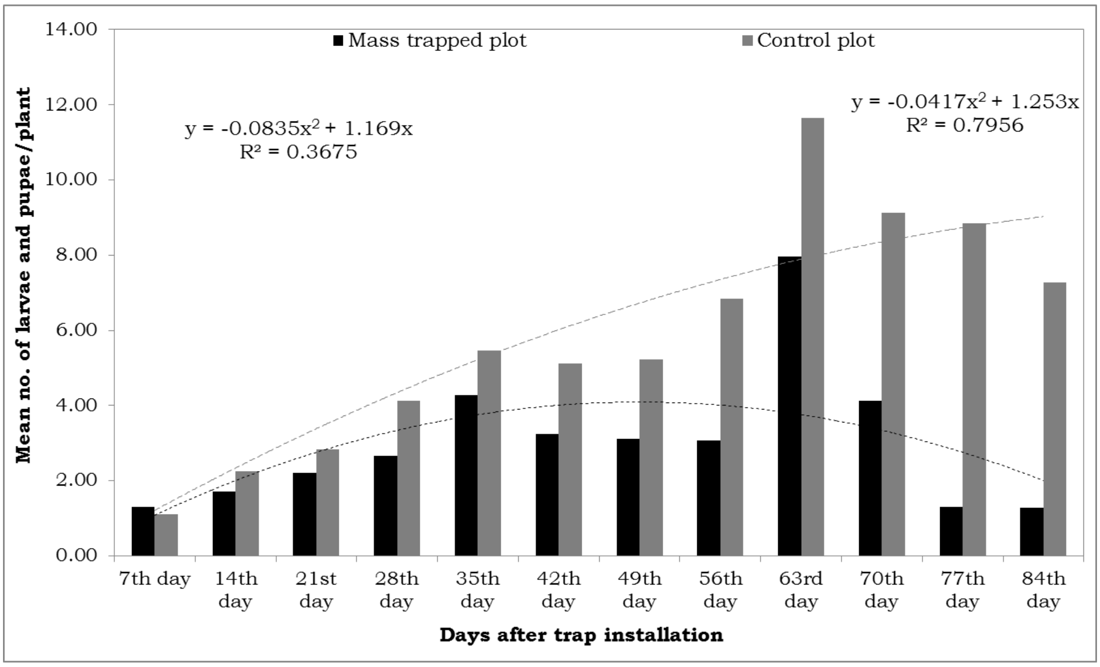

Figure 9. Polynomial relationship of larva and pupal numbers/plant between pheromone trap operated and control plots in Haniyuru.

The results on mass trapping as a standalone method conducted at Haniyuru during *winter* 2013-14 revealed that the number of moths trapped in standalone deployed plot and farmer's practice plot varied significantly. A total number of (13935) moths with an average of 580.60 moths/trap was recorded in the standalone method plot (24 traps @ 40 traps/acre). In farmer's practice plot (n=2 traps) where two traps were placed at centre of the cabbage field, 782 moths were trapped with an average of 391.00 during the same moth emergence period (Table 8).

Observations on the specific larval parasitoid revealed that pheromone installed plot had more number (0.28±0.08) of *C. plutellae* per plant when compared to farmer's practice (0.06±0.02) (Table 8).

Table 8. Comparison between mass trapping as a standalone method and farmer's practice at Haniyuru, Bangalore during *winter,* 2013-14.

Treatments	**No. of traps**	**Total number of moths trapped**	**Number of moths trapped/trap (Mean±SEM)**	***Number of larvae and pupae per plant (Mean±SEM)**	**Percent population reduction over control**	***Number of *Cotesia* per plant (Mean±SEM)**
Standalone Method	24	13935	580.60±53.87	3.04±0.52	51.42	0.28±0.08
Farmer's Practice	2 (Monitoring)	782	391.00±152.00	3.16±0.63	39.04	0.06±0.02
Control	-	-	-	5.82±0.89	-	-
F value, df=1,24			0.37	**F value, df=1,98**	$1.791E^3$	-
p value			NS	**p value**	0.0005	-

**Mean of 50 plants; NS-non-significant*

However, application of insecticide was required in all the three plots to reduce the damage of DBM from reaching the threshold level. A total of 6 sprays were applied during the cropping period in farmer's plot where as in mass trapped plot, application of 2 insecticide sprays required to bring down the DBM population in cabbage. In other words, 4 sprays were reduced in the mass trapped plots in cabbage ecosystem to manage *Plutella*. From the above study, it is evident that mass trapping as a standalone method needs to be supplemented with 2 sprays of insecticides to manage DBM in cabbage fields (Fig. 10). The study also revealed that pheromones supplemented with insecticide had more number of specialist parasitoid i.e., *C. plutellae* compared to only insecticide treated plot (farmer's practice) (Fig. 11).

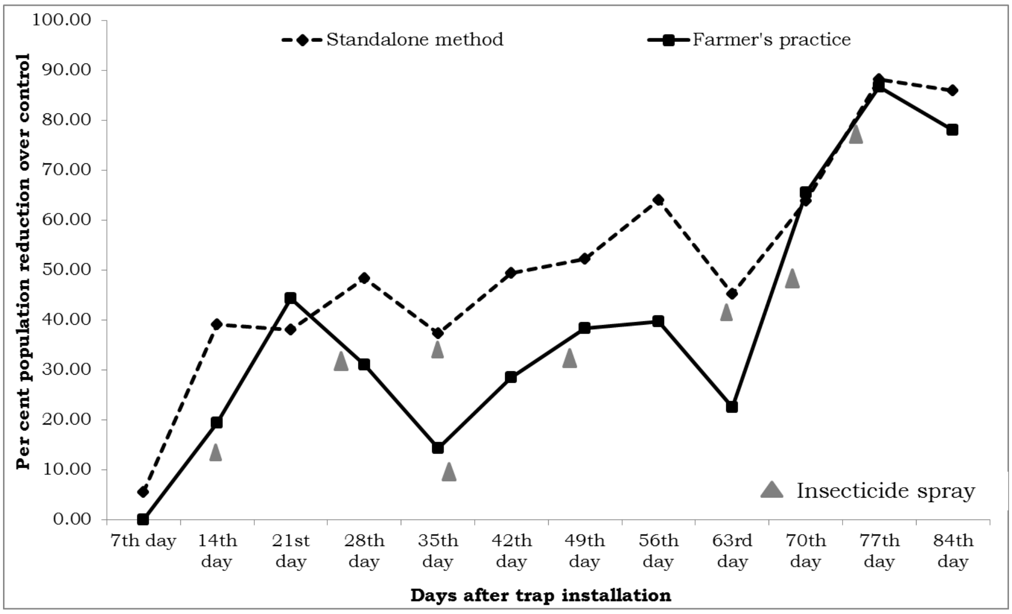

Figure 10. Percent population reduction of *P. xylostella* over control in pheromone operated plot and farmer's practice in cabbage, Haniyuru, Bangalore during winter 2013-14.

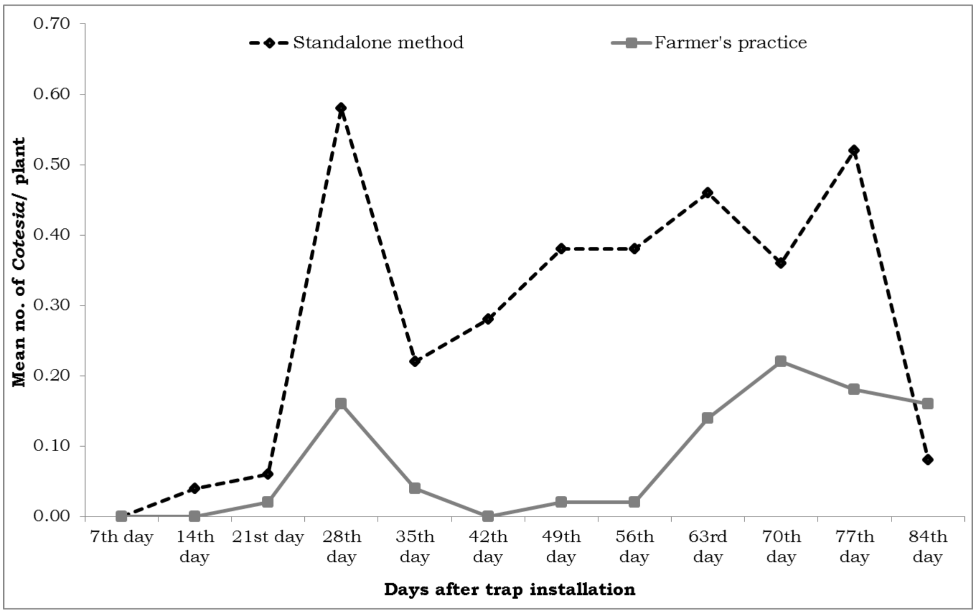

Figure 11. Mean numbers of *C. plutellae* per plant from 50 plants sampled weekly at Haniyuru.

Yield and Economics

The cost benefit ratio was estimated for mass trapping or treatment field and farmers practice for *rabi* and *winter* seasons of 2013-14. The results revealed that the C: B ratio was found to be higher in standalone method ((*rabi* 1: 8.17) and (*winter* 1: 7.23)) when compared to farmers practice with C: B ratio of 1: 7.28 and 1: 7.20 during *rabi* and *winter* seasons, respectively (Table 9 and 10).

Table 9. Economics of mass trapping as standalone method and farmer's practice at Sriramanhalli, Bangalore during *rabi,* 2013-14.

Sl. No.	Treatment	Yield (t/ha)	Gross income (Rs/ha)	Cost of cultivation (Rs/ha)	Cost of treatment (Rs/ha)	Net income (Rs/ha)	C:B ratio
1	Standalone Method	77	385000.00	35000.81	7000.00	342999.19	1: 8.17
2	Farmer's Practice	71	355000.00	35000.81	7863.33	312135.86	1: 7.28
3	Untreated Control	27	135000.00	35000.81	-	99999.19	1: 2.86

Yield obtained based on mean head weight; Trap Cost= Rs. 55 per trap; Lure cost=Rs. 15 per lure
16000 seedlings/acre
Price of Cabbage = Rs. 5000/t

Table 10. Economics of mass trapping as standalone method and farmer's practice at Haniyuru, Bangalore during *winter,* 2013-14.

Sl.No.	Treatment	Yield (t/ha)	Gross income (Rs/ha)	Cost of cultivation (Rs/ha)	Cost of treatment (Rs/ha)	Net income (Rs/ha)	C:B ratio
1	Standalone Method	79	395000.00	35000.81	13013.33	346985.86	1: 7.23
2	Farmer's Practice	73	365000.00	35000.81	9525.33	320473.86	1: 7.20
5	Untreated Control	31	155000.00	35000.81	-	119999.19	1: 3.43

Yield obtained based on mean head weight; Trap Cost= Rs. 55 per trap; Lure cost=Rs. 15 per lure
16000 seedlings/acre
Price of Cabbage = Rs. 5000/t

4. Discussion

Green leaf volatiles are highly abundant in the plant kingdom and play an important role in plant-insect interactions (Visser, 1986) [9]. In Brassica spp. a number of GLVs have been reported (Fischer, 1992; McEwan and Smith, 1998) [10~11], as well as glucosinolate breakdown products (isothiocyanates, nitriles, and sulfides) and benzenoids. In the present study, electroantennogram analysis of kairomone, honey, standard formulation, *Z*-3,6-OAc and synthetic female pheromone revealed the non-significant difference in treatments and control However, there was a slight variation in EAG response which showed higher to kairomone followed by honey, *Z*-3,6-OAc (100 parts) and synthetic female pheromone and lowest response to Hexane (Control). In contrast, relatively strong EAG responses have been recorded on antennae of male and female spruce bark beetle when exposed to 1-hexanol, (*Z*)- 3-hexen-1-ol, and (*E*)-2-hexen-1-ol. However, weak responses were elicited by (*E*)-3-hexen-1-ol and (*Z*)-2-hexen-1-ol, and no activity was caused by (*E*)-2-hexenal and (*Z*)-3-hexenyl acetate (Zhang et al., 1999) [12]. Low EAG responses on *M. brassicae* were recorded by Rojas (1999) [13] except for 1-hexanol. In fact, 1-hexanol has been used as standard in EAG studies (Dickens, 1989) [14]. But nowadays kairomone (Allyl isothiocyanate) is not being utilized for value addition purposes because of its toxic nature due to which the standard pheromone blend was considered for further studies.

The major components of the DBM pheromone are (*Z*)-11 hexadecenal (*Z*-11-16Ald) and (*Z*)-11-hexadecenyl acetate (*Z*-11-16Ac) (Chow et al., 1977). An 8:2 to 4:6 mixture of *Z*-11-16Ald and *Z*-11-16Ac is highly attractive to males in the field (Koshihara et al., 1978) [15], but addition of only 1 % of (*Z*)- 11-hexadecenol (*Z*-11-16: OH) to the bait significantly increased the capture of males (Koshihara and Yamada, 1980) [16]. Chilholm et al., (1983) [17] reported that lure specificity is improved by adding 10 % of (*Z*)-9-tetradecenol (*Z*-9-14OH) to the natural pheromone. The synthetic pheromone has been utilized in studies to monitor pest populations (Mottus et al., 1997) [18], in mass trapping experiments (Reddy and Urs, 1997) [19], and in an IPM programs (Reddy and Guerrero, 2000) [20].

The present study presumes that the kairomonal basis for selection, assessment, and acceptance of a plant as an appropriate host may not only be part of the female’s role but also and perhaps to a lower extent, to that of the male. Enhancement of the insect pheromone action by GLVs could have important practical applications due to the possibility of attracting females. Improvement of specific formulations by addition of a small amount of other minor components of the pheromone may be helpful based on the attraction in the fields. The use of inexpensive GLVs could increase the effectiveness of the pheromone especially by attracting not only males but also females to the traps and diminish the amount of pheromone needed per lure.

It is important to optimize the number of traps per unit area for the deployment of traps and also to maximize the moth catch per unit time for the mass trapping of DBM moths. Density of pheromone traps in the field is influenced by the size of pest population in the field. Rodriguez-Saona and Stelinski (2009) [21] reported that the utility of mass trapping as a practical application in IPM programs has been very limited given that the technique is density dependent.

The present findings are in conformity with Larraín et al. (2009) [22] who reported that larger numbers of male potato tuber moths were captured per trap with densities of 20 and 40 traps per hectare, resulting in a significant reduction of tuber damage in these treatments compared with the control which used conventional chemical insecticide sprays. 20 traps per hectare appeared to be the most effective and convenient trap density in a potato tuber moth integrated management program. In contrast, Cork et al. (2005) [23] who observed that in mass trapping trials 20 traps/ha were sufficient to reduce male rice yellow stem borer populations significantly. The difference in the trap density may be due to difference in the crop phenology and insect pests dependent on the crop.

The efficient trap density is the one which can cause good population reduction besides trapping. Therefore, the results suggest that traps have to be placed at right time before building up of population to catch maximum number of moths occurring in field. Timing and placement of trap in the field and phenology of crop are crucially important besides trap density.

Based on trap density studies, mass trapping (@ 40 traps/acre) as a standalone method was conducted at Sriramanahalli and Haniyuru during *rabi* 2012-13 and *winter* 2013-14, respectively revealed that the number of moths trapped in standalone deployed plot and farmer's practice plot varied in both seasons. Highest number of moths was trapped in mass trapped plot compared to farmer's practice over control. Data on the mean number of larvae and pupae revealed that highest number was observed in control plot compared to farmer's practice plot and standalone plot. Based on the pattern of trapped moths in mass trapping experiments, it is considered that the behavioural mechanism of competitive attraction was involved in mass trapping of DBM male moths. This competitive attraction results in an initial fast decrease in the number of males trapped in the pheromone traps with an asymptotic approach to zero as trap density increases. Based on Miller et al., (2006) [24] plots of catch vs. trap density resulted in linear relationships with positive and negative slopes, respectively.

During the cropping period of both rabi and winter seasons, there were small outbreaks of DBM larvae in cabbage fields and required insecticide spray applications to reduce the pest population for minimizing the infestation level/damage in the field. The studies on mass trapping as a standalone method during Season-I indicated "no insecticide sprays" because of no buildup of DBM population in the cabbage field. Whereas in season-II, mass trapping as a standalone method was supplemented with two need based application (2 sprays) of insecticides to manage heavy population of DBM, leading to IPM model.

The use of pheromone traps in pest management in the cabbage ecosystem is economical, environment friendly with the sustained activity of natural enemies. Together with these, cultural, mechanical and chemicals tools can also form an adjunct to IPM of DBM.

The cost benefit ratio was estimated for standalone method and farmers practice for two seasons *rabi* and *winter* 2013-14. The C: B ratio was found to be high in standalone method during both seasons. The least C: B ratio was recorded in farmers practice during both *rabi* and *winter* seasons.

The pheromone trap density is an important factor in mass trapping techniques and control of many insect pests. Evaluation of trap density per unit area indirectly shows the effect of trap catches on the reduction of DBM population. The results showed that optimum moth catches can be achieved with a trap density @ 40 traps/acre. The estimated C: B ratio suggest that the use of pheromone traps as a standalone method is best for low infestation level, where as in high infestation level pheromone traps @ 40 traps/acre supplemented with two sprays resulted in optimum moth catches, reduction in pest population with high yield.

5. Conclusion

In conclusion, the study indicated about the alternate management strategy for managing *P. xylostella* in cabbage ecosystem. The methodology confers that the DBM can effectively be managed through this ecofriendly approach by using pheromone traps @40 per acre and also with need based insecticidal spray. Mass trapping as a standalone method can be used effectively for the management of *P. xylostella* with timely placement of pheromone traps where the infestation is moderate without depending on any chemical sprays.

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References

[1] Talekar, N. S., Yang, J.C., and Lee, S. T. 1992. Introduction of Diadegma semiclausum to control diamondback moth in Taiwan. *In*: Diamondback moth and other crucifer pests. *In Proceedings of the 2nd International Workshop, Asian Vegetable Research and Development Center, Taipei, Taiwan*, pp. 263-270.

[2] Maison, B. L. 1965. Insect pest of crucifers and their control. *Annual Review of Entomology,* 10, 233-256.

[3] Lal, O. P. 1975. A compendium of insect pest of vegetables in India. *Bulletin of Entomology*, 16: 31-56.

[4] Meyriche, E. 1928. A revised handbook of British Lepidoptera, (London: Watkins and Doncaster Eds.), pp. 803.

[5] Talekar, N. T., Shelton, A. M. 1993. Biology, ecology and management of the diamondback moth. *Annual Review of Entomology,* 38: 275-301.

[6] Sachan, J. N. and Gangwar, S. K. 1990. Seasonal incidence of insect pests of cabbage, cauliflower and knol khol. *Indian Journal of Entomology*, 52: 111-124.

[7] Ando, T., Koshihara, T., Yamada, H., Vu, M. H., Takahashi, N., and Tamaki, Y. 1979. Electroantennogram activities of sex pheromone analogues and their synergistic effect on field attraction in the diamondback moth. Appl. Entomol. Zool. 14: 362-364.

[8] Flemming, R., and Ratnakaran, A. 1985. Evaluating single treatment data using Abbott's formula with reference to insecticides. *Journal of Economic Entomology,* 13: 1179-1181.

[9] Visser, J. H. 1986. Host odour perception in phytophagous insects. *Annual Review of Entomology,*31: 121-144.

[10] Fischer, J.1992. Sulfur- and nitrogen-containing volatile components of kohlrabi Brassica oleracea var. gongylodes. *Zeitschrift für Lebensmittel-Untersuchung und -Forschung NLM,* 194: 259-262.

[11] Mcewan, M., Smith, W. H. M. 1998. Identification of volatile organic compounds emitted in the field by oilseed rape (Brassicanapus ssp. oleifera) over the growing season. *Clinical and Experimental Allergy,* 28: 332-338.

[12] Zhang, Q. H., Schlyter, F. and Anderson, P. 1999. Green leaf volatiles interrupt pheromone response of spruce bark beetle, Ips typographus. *Journal of Chemical Ecology*, 25: 2847-2861.

[13] Rojas, J. C. 1999. Electrophysiological and behavioral responses of the cabbage moth to plant volatiles. *Journal of Chemical Ecology,* 25: 1867-1883.

[14] Dickens, J. C. 1989. Green leaf volatiles enhance aggregation pheromone of boll weevil, Anthonomus grandis. *Entomologia Experimentalis et Applicata,* 52: 191-203.

[15] Koshihara, T., Yamada, H., Tamaki, Y. and Ando, T. 1978. Field attractiveness of the synthetic sex pheromone of the diamondback moth, *Plutella xylostella* (L.). *Applied Entomology and Zoology,* 13 (2): 138-141.

[16] Koshihara, T. and Yamada, H. 1980. Activity of the female sex pheromone of diamondback moth, *Plutella xylostella* (L.) and analogue. *Japanese Journal of Applied Entomology and Zoology,* 24: 6-12.

[17] Chilholm, M. D., Steck, W. F., Underhill, E. W. and Palaniswamy, P. 1983. Field trapping of diamondback moth, Plutella xylostella using an improved four component sex attractant blend. *Journal of Chemical Ecology,* 9, 1: 113-118.

[18] Mottus, E., Nomm, V., Williams, I. H., and Liblikas, I. 1997. Optimization of pheromone dispensers for diamondback moth Plutella xylostella. *Journal of Chemical Ecology,* 23, 9: 2145-2159.

[19] Reddy, G. V. P. and Urs, K. C. D. 1997. Mass trapping of diamondback moth, *Plutella xylostella* in cabbage fields using synthetic sex pheromones. *International Pest Control,* 39, 4: 125-126.

[20] Reddy, G. V. P. and Guerrero, A. 2000. Behavioral responses of the diamondback moth, *Plutella xylostella*, to green leaf volatiles of Brassica oleracea subsp. capitata. *Journal of Agricultural and Food Chemistry,* 48, 12: 6025-6029.

[21] Rodriguez-Saona, C. R., Stelinski, L. L. 2009. "Behavior-modifying strategies in IPM: Theory and Practice". R. Peshin, A.K. Dhawan (eds.): *Integrated Pest Management: Innovation-Development Process.* Springer Science + Business Media B. V. 4: 261-312.

[22] Cork, A., Alam, S.N., Rouf, F.M.A., and Talekar, N.S. 2005. Development of mass trapping technique for control of brinjal shoot and fruit borer, Leucinodes orbonalis (Lepidoptera: Pyralidae). *Bulletin of Entomological Research*, 95: 589-596.

[23] Miller, J. R., Gut, L.J., De Lame, F.M., Stelinski, L. L. 2006. Differentiation of competitive vs. non-competitive mechanisms mediating disruption of moth sexual communication by point sources of sex pheromone. *Journal of Chemical Ecology,* 32: 2089–2114.