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Research Article

Development and validation of integrated pest management modules against spotted pod borer *Maruca vitrata* Fabricius on garden bean *Lablab purpureus var. typicus* (L.)

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Abstract
To reduce the detrimental effect of insecticides, an effective Integrated Pest Management (IPM) module is necessary for the eco-friendly management of *Maruca vitrata* in garden bean ecosystem. Two field trials were carried out to evaluate the efficacy of different insecticides and botanicals against *M. vitrata* on *Lablab purpureus var. typicus.* Two seasons field evaluation of insecticides revealed that chlorantraniliprole 18.5 SC was the most effective treatment to control the pest recorded 0.11 and 0.36 larva/plant in two seasons, respectively after two rounds of spray followed by flubendiamide 20 WG (0.46 and 0.92 larva/ plant) and emamectin benzoate 5 SG (0.50 and 0.95 larva/plant). Among botanicals tested, commercial neem formulation and 5% *Ageratina adenophora* recorded the least larval count of 1.64 & 1.05 larva/plant and 2.24 & 1.45 larva/plant in two seasons, respectively. IPM modules were developed with three effective insecticides (chlorantraniliprole 18.5 SC, flubendiamide 20 WG and emamectin benzoate 5 SG), two effective botanicals (commercial neem formulation 1500 ppm and 5% *A. adenophora*) along with the pheromone trap for validation. All the IPM modules were equally effective in managing *M. vitrata* population on *L. purpureus* and recorded a significantly (at 5 %) lower larval population than the farmer's practice. The residues of chlorantraniliprole, flubendiamide and emamectin benzoate reached below the detectable level at the time of harvest. The population reduction of predatory coccinellids and spiders was also lower in IPM modules than in farmer's practice. An increased benefit cost (1.95 to 1.99) ratio was observed in IPM modules.

Keywords: Bioefficacy, Garden bean, IPM module, *Maruca vitrata*, Residue

INTRODUCTION

Indian bean, *Lablab purpureus* var *typicus* (L.), habitually known as the garden bean belongs to the family Fabaceae is one of the important pulse crop that is grown in both fields as well as in kitchen gardens throughout the tropical regions in Asia and Africa. Soft edible pods of garden bean used as a vegetable are embraced with high nutritive value comprising 86 percent moisture, 2 percent fibre, 4 percent protein, 7.10 percent carbohydrate, 48 Kcal energy, 68mg phosphorus, 1mg iron, 210mg Ca, 668 IU vitamin-A, 0.08 mg

thiamine, 0.11 mg riboflavin, 0.75 mg niacin and 9.3 mg vitamin C (Gopalan *et al.*, 2004). Besides, the crop also provides silage, green manure and a magnificent source for soil nitrogen fixation (Bose *et al*., 1993). The cultivation of *L. purpureus* var. *typicus* in India is highly confined to the peninsular region to a large extent in Karnataka and adjoining districts of Tamil Nadu, Andhra Pradesh and Maharashtra (Choudhary *et al*., 2020).

Legume pod borer *Maruca vitrata* Fabricius (Crambidae – Lepidoptera also known as spotted pod borer is the major devastating pest of garden bean, which is mainly attributed to the poor yield of the crop. The spotted pod borer is an oligophagous pest that outspreads to various legumes viz., cowpea, green gram, black gram, red gram, yam bean, field bean etc. The serious consequence of this pest in grain legumes is due to its ample host range, distribution and destructiveness (Mahalakshmi *et al*., 2016). The damage by *M. vitrata* is caused by larval webbing of flowers, flower buds, and pods (Singh and Jackai, 1988). Third to fifth instar larvae are capable of boring into the pods and occasionally into the peduncle and stem. A single larva can consume up to 4 to 5 flowers before its development (Taylor, 1967). Due to its destructiveness at critical stages of crop growth *viz,* flowering and pod development stages especially to the economic plant parts such as flower buds, flowers and pods, it becomes a significant constraint to attain the maximum productivity from grain legumes. Varying yield loss has been reported viz. 20-60 per cent in cowpea (Singh and Alen, 1980), 9-84 per cent in pigeon pea (Ganapathy, 1996), 9.14- 34.95 per cent in Dolichos bean (Rekha and Mallapur, 2007). Since, insecticides are the only option farmers rely on for quick suppression of the pest, the heavy usage of chemicals leads to resistance, residues and environmental pollution. So there is a need to evaluate and develop an effective integrated pest management module for the management of *M. vitrata* in the garden bean ecosystem.

MATERIALS AND METHODS

Bioefficacy study

Two field experiments were conducted to assess the efficacy of different insecticides and botanicals (Tables 1 and 2) against *M. vitrata* on garden bean at the farmers holding located at Kupepalayam (11.18'25°N, 77.02'19°E) and Madampatti village (10.96'98°N, 76.85'98°E), Coimbatore district, Tamil Nadu during February to March 2021 and November to December 2021, respectively. The crop was maintained by adapting all the standard agronomic practices as per the recommendations of Tamil Nadu Agricultural University and ensuring no previous insecticide treatment was given. The trial was carried out in Randomized Block Design in a plot size of 5 × 5 m and was replicated thrice. Two rounds of spraying were given starting from 50 % flowering stage and repeated at 15 days interval, using a hand-operated knapsack sprayer with the following treatments. The insecticides used in the present experiment were, T_1 - Chlorantraniliprole 18.5 SC @ 30 g a.i ha^{-1}, T_2 - Chlorpyriphos 20 EC @ 600 g a.i ha^{-1}, T_3 - Emamectin benzoate 5 SG @ 11 g a.i ha^{-1}, T_4 - Flubendiamide 20 WG @ 50 g a.i ha^{-1}, T_5 - Novaluron 10 EC @ 75 g a.i ha^{-1}, T_6 - Spinosad 45 SC @ 67.5 g a.i ha^{-1} and T_7 – Untreated check. The botanicals used in the investigation were T_1 – Neem oil @ 2%, T_2 – NSKE @ 5%, T_3 - Commercial formulation of neem 1500 ppm (Azadirachtin 0.15 EC), T_4 - Ginger, Garlic and Green chilli (3G) extract @ 2%, T_5 - *Ruta graveolens* @ 5%, T_6 – *Ageratina adenophora* @ 5% and T_7 – Untreated check. Water was sprayed to the untreated control plots. Synthetic pheromone lures of *M.vitrata* were purchased from Sonkul Agro Industries Pvt. Ltd., Nashik, Maharashtra. The lures were also evaluated by suspending it in the middle of delta sticky traps that were hung to a wooden stakes at the rate of eight per acre.

Preparation of botanicals

Fresh leaves of *A. adenophora* and *R. graveolens* were collected from the Horticultural Research Station, Udhagamandalam, Nilgiris and identity were confirmed by the Botanical Survey of India (Regional centre), Coimbatore. The leaves were completely washed in running water, shade dried, pulverized to fine powder and stored for future use. The required quantity of powder was soaked in water overnight and the spray volume was made up before spraying. Dried neem seed kernels were also pulverized to a powder and 500 g of it was soaked overnight in 1 litre of water. The next morning it was filtered through a muslin fabric and the volume was made to 10 litres, to which 1 % detergent was added. To prepare 3G extract, ginger, garlic and green chilli (340 g each) were taken in the ratio of 1:1:1, ground to a fine paste, tied loosely in a '*khada*' cloth and soaked in 1 litre of cow's urine for 10 days. The extract was sprayed at the rate of 20 ml per litre of water.

Evaluation of Integrated pest management module

Module evaluation trial was carried out in the farmers' field at Kuppanur village (10.94'78°N & 76.86'27°E), Coimbatore, Tamil Nadu, from February to March 2022. Six IPM modules were developed from the results of the bioefficacy study and evaluated in comparison with farmers' practice and control. The trial was laid out in a Randomized block design with three replications. The details of the modules were M_1 - *M.vitrata* sex pheromone trap + 5 % *A.adenophora* @ 50 % flowering stage + Chlorantraniliprole 18.5 SC @ 30 g a.i ha^{-1} at 15 days after first spray, M_2- *M.vitrata* sex pheromone trap + Commercial neem formulation 1500 ppm

(Azadirachtin 0.15 EC) @ 50 % flowering stage + Chlorantraniliprole 18.5 SC @ 30 g a.i ha^{-1} at 15 days after first spray, M_3- *M.vitrata* sex pheromone trap + 5 % *A. adenophora* @ 50 % flowering stage + Flubendiamide 20 WG @ 50 g a.i ha^{-1} at 15 days after first spray , M_4- *M.vitrata* sex pheromone trap + Commercial neem formulation 1500 ppm (Azadirachtin 0.15 EC) @ 50 % flowering stage + Flubendiamide 20 WG @ 50 g a.i ha^{-1} at 15 days after first spray, M_5- *M.vitrata* sex pheromone trap + 5 % *A.adenophora* @ 50 % flowering stage + Emamectin benzoate 5 SG @ 11 g a.i ha^{-1} at 15 days after first spray, M_6- *M.vitrata* sex pheromone trap + Commercial neem formulation 1500 ppm (Azadirachtin 0.15 EC) @ 50 % flowering stage + Emamectin benzoate 5 SG @ 11 g a.i ha^{-1} at 15 days after first spray, M_7- Farmer's Practice (Insecticide Spray 4 rounds) – @ 12 days interval starting from 50 % flowering stage and M_8-.Untreated control. The performance of different modules was compared by Benefit-Cost ratio (B: C), calculated by the following formula, B: C ratio = Net return (Rs/ha) / Cost of cultivation (Rs/ha).

Observations

Observations on the number of alive larvae and natural enemies from five randomly selected plants in each plot were made one day before spraying and at 3, 7 and 14 days after the first and second sprays. The trap counts were made once a week. The pooled replication data were transformed into $\sqrt{X+0.5}$ and analysed using AGRES software. The means with a significant difference were differentiated using Duncan's multiple range test (DMRT) at 0.05 % significance level.

Residue analysis

The garden bean pod samples of 2 kg were collected from the IPM evaluation plots to analyse the insecticidal residues at the time of harvest. The collected samples were immediately transferred to the laboratory, chopped into pieces and about 500 g of sub sample was taken. The sub sample was homogenized using a high speed mixer grinder and stored in a wide mouthed glass bottle at -20°C until further use. The reference standards of chlorantraniliprole (99%), flubendiamide (98.9%) and emamectin benzoate (99.4%) were obtained from M/S Sigma Aldrich, Bangalore, India. HPLC grade acetonitrile, sodium chloride (NaCl) and anhydrous magnesium sulphate ($MgSo_4$) of analytical grade were purchased from Merck India Ltd., (Mumbai). NaCl and MgSo4 were activated by heating at 650°C for 4 h and kept in a desiccator until use. Primary Secondary Amine (PSA) (Bondesil 40 µm) and Graphitized Carbon Black (GCB) were purchased from M/s. Agilent technologies, USA. Type 1 water (or HPLC grade water) was harvested from Millipore water purification system.

The residues of chlorantraniliprole, flubendiamide and emamectin benzoate were extracted from the pods of the garden bean by following the modified QuEChERS (Quick, Easy, Cheap, Effective, Rugged and Safe) method (Anastassiades *et al.,* 2003). A representative homogenized sample of 10 g were taken in a 50 mL poly-propylene centrifuge tube and 20 mL of acetonitrile was added to it and the mixture was hand shaken vigorously, followed by vortexing for one minute. Subsequently, 1g of NaCl and 4 g of anhydrous $MgSO_4$ were added to the sample mixture and vortexed for 2 min followed by centrifugation at 6000 rpm for 10 min. The supernatant (9 mL) aliquot was transferred into a test tube containing 4 g of $NaSo_4$. From this 6 mL of aliquot was transferred to a 15 mL prefilled centrifuge tube with 10 mg GCB, 100 mg PSA sorbent and 600 mg anhydrous $MgSO_4$. The mixture was vortexed for one minute and then centrifuged at 3000 rpm for 10 min and 4 mL of supernatant aliquot was transferred into a turbovap tube concentrated to dryness under a gentle stream of nitrogen by using the Turbovap LV set at 40ºC. The residue was redissolved using acetonitrile (1 mL), filtered by a 0.2 µm membrane syringe filter, and transferred into 1.5 mL UHPLC (Ultra High Performance Liquid Chromatography) autosampler glass vials for analysis.

Primary stock solution of 400µg mL^{-1} for all three standards was prepared in a 25 ml volumetric flask. An intermediate stock solution of 10µg mL^{-1} was prepared from the primary stock solution and the working standards were prepared from intermediate stock. All the stock and working standards were stored at -20 °C until further use. Linearity was observed by injecting five different concentrations (0.05 to 0.8 µg mL^{-1}) with three replications of all three standards. LOD and LOQ were computed from the linear regression model. Recovery studies were carried out on a blank matrix of garden bean (10 g) by spiking them with known quantities of standards at three different concentrations (0.05, 0.25 and 0.5 µg g^{-1}) with three replications. The precision of the method was performed in terms of repeatability (Relative Standard Deviation) for each spiked level of 0.05, 0.25 and 0.5 µg g^{-1} of the matrix.

The estimation of chlorantraniliprole, flubendiamide and emamectin benzoate residues were performed by UHPLC (Shimadzu, i series 2020) equipped with diode array detector (SPD-M30A) and an autosampler. Chromatographic separation was achieved with a reverse phase - C18 (Agilent) column, 250 mm length x 4.6 mm id x 5 µ particle size in a column oven at 40˚C. The low -pressure gradient condition was employed with a mobile phase of acetonitrile and water (70:30) with a flow rate of 0.8 ml min^{-1} for flubendiamide and 1 ml min^{-1} for chlorantraniliprole and emamectin benzoate. The injection volume of 10 µl with an absorbance of 230 nm for flubendiamide, 260 nm for chlorantraniliprole and 246 nm for emamectin benzoate was fixed with a total run time of 10 minutes.

RESULTS AND DISCUSSION

Bioefficacy of insecticides and botanicals at location 1: Kupepalayam, Coimbatore

The pre-treatment population of *M. vitrata* larva in insecticide-treated plots ranged from 4.07 to 4.27 in different experimental plots (Table 1). Chlorantraniliprole 18.5 SC (T_1) @ 30 g a.i. ha^{-1} recorded the least larval population after the first (0.21 larva/plant) and second spray (0.11 larva/plant). Flubendiamide 20 WG (T_4) @ 50 g a.i. ha^{-1} and emamectin benzoate 5 SG (T_3) @ 11 g a.i. ha^{-1} recorded the second least population, which was on par at first (0.72 and 0.76 larva / plant) and second spray (0.46 and 0.50 larva/plant). Chlorpyriphos 20 EC (T_2) @ 500 g a.i. ha^{-1}, spinosad 45 SC (T_6) @ 73 g a.i. ha^{-1} and novaluron 10 EC (T_5) @ 67.5 g a.i. ha^{-1} recorded a relatively highest population in comparison with other treated insecticides. The post-treatment population of all the treatments were significantly lower than the control at both sprays.

The larval population ranged from 4.20 to 4.40 in different botanical-treated plots one day before spraying (Table 2). Application of commercial neem formulation 1500 ppm (T_3) reduced the larval population significantly (at 5 %), with a mean population of 2.00 larva/plant at the first spray and 1.64 larva/plant after the second spray. The next best treatment was NSKE 5% (T_2) that resulted in 2.50 and 2.25 larva/plant after the first and second sprays, respectively, which was on par with 5% *A. adenophora* (T_6) (2.33 and 2.24 larva/plant), followed by 2% neem oil (T_1) (2.85 and 2.80 larva/plant), 2% 3G extract (T_4) (3.18 and 2.91 larva/plant) and 5% *R. graveolens* (T_5) (3.91 and 3.68 larva/plant) during the first and second sprays, respectively.

Bioefficacy of insecticides and botanicals at location 2: Madampatti, Coimbatore

The spotted pod borer population before the spraying of insecticides ranged from 3.27 to 3.48 (Table 3). The mean larval population after two sprayings inferred that chlorantraniliprole 18.5 SC (T_1) @ 30 g a.i. ha^{-1} was the most effective treatment with the least population (1.23 and 0.36 larva/plant). Flubendiamide 20 WG (T_4) @ 50 g a.i. ha^{-1} (1.65 and 0.92 larva/plant) and emamectin benzoate 5 SG (T_3) @ 11 g a.i. ha^{-1} (1.76and 0.95 larva/plant) was the next best treatment and was found to be on par with one another after both sprayings. Following this, comparatively less effective treatments were chlorpyriphos 20 EC (T_2) @ 500 g a.i. ha^{-1} (1.97 and 1.57 larva/plant), spinosad 45 SC (T_6) @ 73 g a.i. ha^{-1} (1.98 and 1.56 larva/plant) and novaluron 10 EC (T_5) @ 67.5 g a.i. ha^{-1} (1.98 and 1.57 larva/plant) were all on par with each other.

Population of *M.vitrata* larvae before the spraying of botanicals ranged from 3.63 to 3.97 (Table 4) a day before spraying with no significant difference. Spraying of commercial neem formulation 1500 ppm (T_3) was found to be the best treatment with the least larval population of 1.71 larva/plant and 1.05 larva/plant after first and second spraying, respectively. NSKE 5% (T_2) (1.92 and 1.44 larva/plant) and *A. adenophora* 5 % (T_6) (1.94 and 1.45 larva/plant) were the next best treatments that were on par, followed by 2 % neem oil (T_1) (2.30 and 1.77 larva/plant), 2% 3G extract (T_4) (2.34 and 2.05 larva/plant) and 5% *R. graveolens* (T_5) (2.49 and 2.11 larva/plant).

The present results of insecticide bioefficacy were comparable with Aryal *et al*. (2021). They reported that the floral damage caused by *M. vitrata* in cowpea was lowest in flubendiamide treated plots (1.07 floral damage/ plant), followed by emamectin benzoate (1.35 floral damage/plant), chlorantraniliprole (1.45 floral damage/ plant) and spinosad (1.57 floral damage/plant) which were all on par with one another. The effectiveness of the insecticidal mixture chlorantraniliprole 9.3% + lamdacyhalothrin 4.6 % with the lowest pod damage (7.04%), followed by chlorantraniliprole 18.5 SC (72.04%) and flubendiamide 39.35 SC (67.30%) was reported by Swathi *et al.* (2019). Profenophos 50 EC + DDVP 76 EC recorded the lowest larval population (0.80 larva/ plant) and the lowest pod damage (7.13 %) in black gram (Naik *et al*., 2019). The insecticidal combination of imidachloprid 17.8 SL @ 0.005 % + spinosad 45 SC @ 0.009 % recorded the lowest number (1.18 larva / plant) of larval population of spotted pod borer in cowpea (Kattula *et al., 2018*).

Reddy and Hampaiah (2018) reported that the insecticidal mixture, lamda cyhalothrin 4.6 % + chlorantraniliprole 9.3 % ZC was superior in reducing the larval population of *M. vitrata* in cowpea even after 15 days of spraying. Chlorpyriphos (0.60 larva/plant), teflubenzuron (0.80 larva/plant), chlorantraniliprole + lamda cyhalothrin (1.00 larva/plant), and flubendiamide (1.00 larva/plant) were equally effective in reducing the mean larval population of *M. vitrata* in soyabean (Grigolli *et al*., 2015). Similarly, in pigeon pea the per cent inflorescence damage was found least with chlorantraniliprole 18.5 SC (2.08%) treated plots, followed by flubendiamide 39.35 SC (3.64%) and spinosad 45 SC (6.21%) (Sreekanth *et al.,* 2015). Kolarath *et al*. (2015) inferred that novaluron 10 EC (0.88 larva/ plant) and emamectin benzoate 5 SG (0.88 larva/plant) recorded the lowest population of field bean pod borer at 10 days after the second spray. Yadav and Singh (2014) reported spinosad 45 SC and indoxacarb 14.5 SC as the most effective insecticides in reducing the larval population with the per cent reduction of 80.7 and 79.2, respectively, over control.

Earlier studies with botanicals confirmed the predominance of neem-based management practices. As ob-

Table 1. Efficacy of insecticides on *M. vitrata* in garden bean at Kupepalayam

Treatments	PTC	Post treatment population No. / Plant *	
		Mean after 1st spray	Mean after 2nd spray
T_1- Chlorantraniliprole 18.5 SC	4.07 (2.02)	0.21 (0.46)[a]	0.11 (0.32)[a]
T_2- Chlorpyriphos 20 EC	4.27 (2.07)	2.30 (1.52)[e]	1.45 (1.20)[e]
T_3- Emamectin benzoate 5 SG	4.25 (2.06)	0.76 (0.87)[b]	0.50 (0.71)[b]
T_4- Flubendiamide 20 WG	4.20 (2.05)	0.72 (0.85)[b]	0.46 (0.68)[b]
T_5- Novaluron 10 EC	4.27 (2.07)	2.30 (1.52)[d]	1.46 (1.21)[d]
T_6- Spinosad 45 SC	4.25 (2.06)	2.27 (1.51)[c]	1.47 (1.21)[c]
T_7- Untreated check	4.20 (2.05)	4.46 (2.11)[f]	4.63 (2.15)[f]
SE(d)	0.017	1.148	0.011
CD	0.038	0.034	0.024

*-Mean of three replications; PTC – Pre Treatment Count; Values in parentheses are $\sqrt{X+0.5}$ transformed value; Means followed by same letter in a column are not significantly different by DMRT (P=0.05)

Table 2. Efficacy of botanicals on *M.vitrata* in garden bean at Kupepalayam

Treatments	PTC	Post treatment population No. / Plant *	
		Mean after 1st spray	Mean after 2nd spray
T_1- Neem oil	4.4 (2.10)	2.85 (1.69)[d]	2.80 (1.67)[c]
T_2- NSKE	4.20(2.05)	2.50 (1.58)[c]	2.25 (1.50)[b]
T_3- Commercial formulation of neem 1500 ppm (Azadirachtin 0.15 EC)	4.33 (2.08)	2.00 (1.42)[a]	1.64 (1.28)[a]
T_4- Ginger, Garlic and Green chilli (3G) extract	4.37 (2.09)	3.18 (1.78)[e]	2.91 (1.70)[d]
T_5- *Ruta graveolens*	4.33 (2.08)	3.91 (1.98)[f]	3.68 (1.92)[e]
T_6- *Ageratina adenophora*	4.40 (2.10)	2.33 (1.53)[b]	2.24 (1.50)[b]
T_7- Untreated check	4.27 (2.07)	4.41 (2.10)[g]	4.58 (2.14)[f]
SE(d)	0.014	0.012	0.006
CD	N/A	0.026	0.013

*-Mean of three replications; PTC – Pre Treatment Count; Values in parentheses are $\sqrt{X+0.5}$ transformed value; Means followed by same letter in a column are not significantly different by DMRT (P=0.05)

served in our studies, the application of neem 1500 ppm resulted in 26 % reduction of pod damage in pigeonpea (Sreekanth and Sesha Mahalakshmi, 2018) and 53 % reduction of pod damage in cowpea (Chandrayudu *et al.,* 2006) and 0.001 % azadirachtin reduced 36 % of pod damage over control (Kanhere *et al.,* 2012). Treatment of NSKE 5 % resulted in the reduction of pod damage by 40 % in cowpea (Kanhere *et al*., 2012), 46 % (Pillai *et al.,* 2013) and 54 % (Sambath Kumar *et al*., 2015) in pigeon pea and 10 – 15 % neem seed extract reduced 22.13 – 62.89 % pod damage in *Lablab purpureus* (Rouf and Sardar, 2011). Application of neem oil resulted in pod damage reduction of about 44 – 57 % in *Lablab purpureus* (Ahmed *et al.,* 2015) and 0.25 % neem oil emulsion reduced 32 – 41 % of damage in cowpea (Sokame *et al.,* 2015). Chilli extract of 2% resulted in 48 – 51 % (Ahmed *et al.,* 2015) and garlic bulb extract resulted in a 23 – 33 % reduction in pod borer damage (Rouf and Sardar, 2011) in garden bean. Other botanicals, including Jatropha oil (Pillai *et al.,* 2013), Mahogany oil (Rouf and Sardar, 2011; Ahmed *et al.,* 2015) and Pungamia oil (Sambathkumar *et al*., 2015) were also found to be effective in pod borer management.

IPM module evaluation

The pre-treatment mean larval population in IPM trial plots ranged from 2.33 to 2.56 larva/plant (Table 5). The results of the IPM module evaluation trial inferred that the larval population was the least in the farmer's practice (Module VII) with 0.48 larva/plant. All the other evaluated modules were equally effective, with the mean larval population of 0.82, 0.81, 0.82, 0.82, 0.80 and 0.83 larva/plant in modules I, II, III, IV, V and VI, respectively. The mean larval population in all the modules, including farmers' practice, were significantly (at 5%) lower than the untreated control plot (2.58 larva/plant).

Jacob and Revathi (2019) have observed that adopting an IPM package with an emphasis on monitoring population, spraying one botanical (NSKE or neem oil) and the insecticide has resulted in 9.48% reduction in pod

Table 3. Efficacy of insecticides on *M.vitrata* in garden bean at Madampatti

Treatments	PTC	Post treatment population No. / Plant *	
		Mean after 1st spray	Mean after 2nd spray
T_1- Chlorantraniliprole 18.5 SC	3.40 (1.84)	1.23 (1.11)[a]	0.36 (0.60)[a]
T_2- Chlorpyriphos 20 EC	3.33 (1.83)	1.97 (1.40)[d]	1.57 (1.25)[c]
T_3- Emamectin benzoate 5 SG	3.46 (1.86)	1.76 (1.33)[c]	0.95 (0.98)[b]
T_4- Flubendiamide 20 WG	3.48 (1.87)	1.65 (1.28)[b]	0.92 (0.96)[b]
T_5- Novaluron 10 EC	3.27 (1.81)	1.98 (1.41)[d]	1.57 (1.25)[c]
T_6- Spinosad 45 SC	3.37 (1.83)	1.98 (1.41)[d]	1.56 (1.25)[c]
T_7- Untreated check	3.33 (1.83)	4.51 (2.12)[e]	4.55 (2.13)[d]
SE(d)	0.017	0.009	0.007
CD	0.037	0.020	0.016

*-Mean of three replications; PTC – Pre Treatment Count; Values in parentheses are $\sqrt{X+0.5}$ transformed value; Means followed by same letter in a column are not significantly different by DMRT (P=0.05)

Table 4. Efficacy of botanicals on *M.vitrata* in garden bean at Madampatti

Treatments	PTC	Post treatment population No. / Plant *	
		Mean after 1st spray	Mean after 2nd spray
T_1- Neem oil	3.97 (1.99)	2.30 (1.52)[c]	1.77 (1.33)[c]
T_2- NSKE	3.63 (1.91)	1.92 (1.39)[b]	1.44 (1.20)[b]
T_3- Commercial formulation of neem 1500 ppm (Azadirachtin 0.15 EC)	3.78 (1.94)	1.71 (1.31)[a]	1.05 (1.03)[a]
T_4- Ginger, Garlic and Green chilli (3G) extract	3.93 (1.98)	2.34 (1.53)[c]	2.05 (1.43)[d]
T_5- *Ruta graveolens*	3.69 (1.92)	2.49 (1.58)[d]	2.11 (1.45)[e]
T_6- *Ageratina adenophora*	3.68 (1.92)	1.94 (1.39)[b]	1.45 (1.20)[b]
T_7- Untreated check	3.77 (1.94)	4.19 (2.05)[e]	4.45 (2.11)[f]
SE(d)	0.037	0.021	0.007
CD	0.017	0.009	0.014

*-Mean of three replications; PTC – Pre Treatment Count; Values in parentheses are $\sqrt{X+0.5}$ transformed value; Means followed by same letter in a column are not significantly different by DMRT (P=0.05)

borer damage in blackgram compared to farmers practice (17.08%) which is in accordance with our work. The pod damage by *M. vitrata* in yard-long bean was reduced significantly by 23 – 85 % in IPM package that included *Bacillus thuringiensis* in combination with cypermethrin (Yule and Srinivasan, 2014).

Natural enemy

Spinosad 45 SC @ 67.5 g a.i. ha^{-1} and novaluron 10 EC @ 75 g a.i. ha^{-1} recorded the lowest reduction in both predatory coccinellids and spider populations at both locations, indicating their less toxic effect on natural enemies, while chlorpyriphos 20 EC @ 500 g a.i. ha^{-1} recorded the highest reduction of natural enemies. The order of toxic effect of selected insecticides on natural enemies was chlorpyriphos 20 EC > chlorantraniliprole 18.5 SC > emamectin benzoate 5SG > flubendiamide 20 WG > novaluron 10 EC > spinosad 45 SC (Table 6). The population of natural enemies in IPM module plots were significantly higher in comparison with farmers' practice (Table 7). The population of natural enemies in all the treatment plots were lower than the untreated control plots. The results of this study are also in accordance with the observations of Sharma and Kaushik (2010) and Ghosh and Chatterjee (2009). They reported that spinosad 45 SC was safer for natural enemies in the eggplant and tomato ecosystem. Similarly, Chatterjee and Roy (2004) reported that novaluron caused fewer adverse effects on predators and parasitoids.

Residue analysis

An efficient analytical method was developed with several preliminary studies and evaluated based on the linearity and recovery studies. Standard calibration curves of chlorantraniliprole, flubendiamide and emamectin benzoate were constructed by plotting concentrations against peak area in the range of 0.05 to

Table 5. Efficacy of IPM modules against *M.vitrata* in garden bean

Modules	PTC	Post treatment population No. / Plant*		
		Mean of first spray	Mean of second spray	Pooled mean of two sprays
M_1 - *M.vitrata* sex pheromone trap + 5 % *A.adenophora* @ 50 % flowering stage + Chlorantraniliprole 18.5 SC @ 15 days after first spray	2.33 (1.53)	1.22 (1.10)^{bc}	0.43 (0.66)^{c}	0.82 (0.91)^{c}
M_2- *M.vitrata* sex pheromone trap + Commercial neem formulation @ 50 % flowering stage + Chlorantraniliprole 18.5 SC @ 15 days after first spray	2.56 (1.60)	1.21 (1.10)^{bc}	0.41 (0.64)^{b}	0.81 (0.90)^{bc}
M_3- *M.vitrata* sex pheromone trap + 5 % *A. adenophora* @ 50 % flowering stage + Flubendiamide 20 WG @ 15 days after first spray	2.41 (1.55)	1.22 (1.10)^{bc}	0.42 (0.65)^{bc}	0.82 (0.90)^{bc}
M_4- *M.vitrata* sex pheromone trap + Commercial neem formulation @ 50 % flowering stage + Flubendiamide 20 WG @ 15 days after first spray	2.47 (1.57)	1.23 (1.11)^{c}	0.41 (0.64)^{b}	0.82 (0.91)^{bc}
M_5- *M.vitrata* sex pheromone trap + 5 % *A.adenophora* @ 50 % flowering stage + Emamectin benzoate 5 SG @15 days after first spray	2.36 (1.54)	1.19 (1.09)^{b}	0.42 (0.65)^{bc}	0.80 (0.90)^{b}
M_6- *M.vitrata* sex pheromone trap + Commercial neem formulation @ 50 % flowering stage + Emamectin benzoate 5 SG @15 days after first spray	2.48 (1.57)	1.23 (1.11)^{c}	0.43 (0.65)^{bc}	0.83 (0.91)^{c}
M_7- Farmer's Practice (Insecticide Spray 4 rounds) – @ 12 days interval starting from 50 % flowering stage	2.33 (1.53)	0.70 (0.84)^{a}	0.25 (0.50)^{a}	0.48 (0.69)^{a}
M_8- Untreated control.	2.47 (1.57)	2.60 (1.61)^{d}	2.55 (1.60)^{d}	2.58 (1.61)^{d}
SE(d)	0.010	0.006	0.002	0.003
CD	0.022	0.013	0.005	0.007

*-Mean of three replications; PTC – Pre Treatment Count; Values in parentheses are $\sqrt{X+0.5}$ transformed value; Means followed by same letter in a column are not significantly different by DMRT (P=0.05)

Table 6. Effect of insecticides on predatory coccinellids and spiders

Treatments	Coccinellids				Spiders			
	Location 1		Location 2		Location 1		Location 2	
	Mean *	PRC	Mean *	PRC	Mean *	PRC	Mean *	PRC
T_1 -Chlorantraniliprole 18.5 SC	1.66(129)^{b}	36.24	1.67(1.29)^{b}	35.39	1.21 (1.10)^{b}	35.89	1.19 (1.10)^{b}	35.27
T_2-Chlorpyriphos 20 EC	1.27 (1.13)^{a}	51.31	1.36 (1.17)^{a}	47.25	1.02 (1.01)^{a}	45.74	0.97 (0.98)^{a}	47.60
T_3-Emamectin benzoate 5 SG	1.74 (1.32)^{c}	33.23	1.68 (1.29)^{b}	35.11	1.24 (1.11)^{b}	34.31	1.18 (1.09)^{b}	35.96
T_4-Flubendiamide 20 WG	1.74 (1.32)^{c}	33.02	1.76 (1.33)^{c}	31.93	1.22 (1.10)^{b}	35.21	1.24 (1.11)^{c}	32.55
T_5-Novaluron 10 EC	1.88 (1.37)^{d}	27.74	1.89 (1.37)^{d}	26.95	1.45 (1.20)^{c}	23.26	1.37 (1.17)^{d}	25.82
T_6-Spinosad 45 EC	1.93 (1.39)^{e}	25.70	1.89 (1.38)^{d}	26.72	1.41 (1.19)^{c}	25.36	1.38 (1.18)^{d}	24.98
T_7-Control	2.60 (1.61)^{f}	-	2.58 (1.61)^{e}	-	1.88 (1.37)^{d}	-	1.84 (1.36)^{e}	-
SE(d)	0.004	-	0.006	-	0.005	-	0.004	-
CD	0.010	-	0.013	-	0.010	-	0.010	-

*-Mean of three replications; PRC – Per cent reduction over control; Values in parentheses are $\sqrt{X+0.5}$ transformed value; Means followed by same letter in a column are not significantly different by DMRT (P=0.05)

Table 7. Effect of IPM modules on predatory coccinellids and spiders

Modules	Coccinellids		Spiders	
	Mean *	PRC	Mean *	PRC
M_1 - *M.vitrata* sex pheromone trap + 5 % *A.adenophora* @ 50 % flowering stage + Chlorantraniliprole 18.5 SC @ 15 days after first spray	2.07 (1.44)^{c}	17.13	1.54 (1.24)^{bc}	15.69
M_2- *M.vitrata* sex pheromone trap + Commercial neem formulation @ 50 % flowering stage + Chlorantraniliprole 18.5 SC @ 15 days after first spray	2.04 (1.43)^{bc}	18.34	1.55 (1.24)^{c}	15.26
M_3- *M.vitrata* sex pheromone trap + 5 % *A. adenophora* @ 50 % flowering stage + Flubendiamide 20 WG @ 15 days after first spray	2.15 (1.47)^{d}	13.78	1.53 (1.24)^{bc}	16.25
M_4- *M.vitrata* sex pheromone trap + Commercial neem formulation @ 50 % flowering stage + Flubendiamide 20 WG @ 15 days after first spray	2.14 (1.46)^{d}	14.22	1.53 (1.24)^{bc}	16.18
M_5- *M.vitrata* sex pheromone trap + 5 % *A.adenophora* @ 50 % flowering stage + Emamectin benzoate 5 SG @15 days after first spray	2.05 (1.43)^{bc}	17.85	1.52 (1.23)^{b}	16.73
M_6- *M.vitrata* sex pheromone trap + Commercial neem formulation @ 50 % flowering stage + Emamectin benzoate 5 SG @15 days after first spray	1.98 (1.41)^{b}	20.87	1.55 (1.24)^{c}	15.23
M_7- Farmer's Practice (Insecticide Spray 4 rounds) – @ 12 days interval starting from 50 % flowering stage	1.87 (1.37)^{a}	24.94	1.24 (1.12)^{a}	31.83
M_8- Untreated control.	2.50 (1.58)^{e}	-	1.82 (1.35)^{f}	-
SE(d)	0.006	-	0.003	-
CD	0.013	-	0.008	-

*-Mean of three replications; PRC – Per cent reduction over control; Values in parentheses are $\sqrt{X+0.5}$ transformed value; Means followed by same letter in a column are not significantly different by DMRT (P=0.05)

Table 8. Recovery percentage of chlorantraniliprole, flubendiamide and emamectin benzoate in/on garden bean

Spiked concentration (µg/g)	Chlorantraniliprole		Flubendiamide		Emamectin benzoate	
	Recovery (%) ± SD	RSD (%)	Recovery (%) ± SD	RSD (%)	Recovery (%) ± SD	RSD (%)
0.05	97.91± 2.46	2.47	91.88±1.30	1.42	97.21±1.11	1.14
0.25	93.81±2.71	2.93	91.26±1.38	1.52	95.77±3.22	3.36
0.50	93.30±2.62	2.83	96.25±2.96	3.07	96.74±3.27	3.38

SD – Standard Deviation, RSD- Relative Standard Deviation

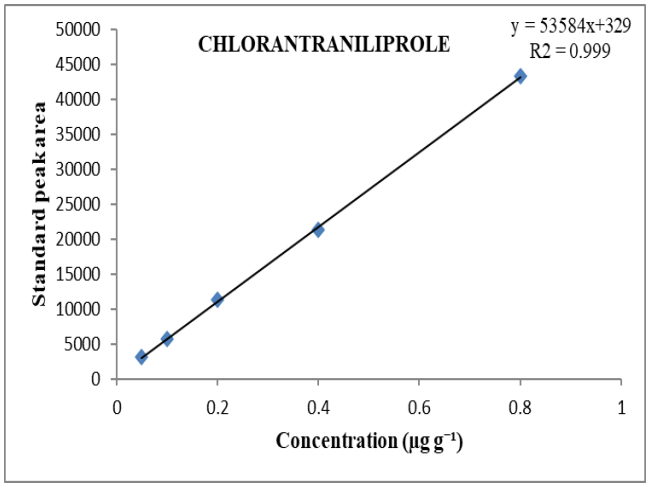

Fig. 1. *Calibration curve of chlorantraniliprole in UHPLC*

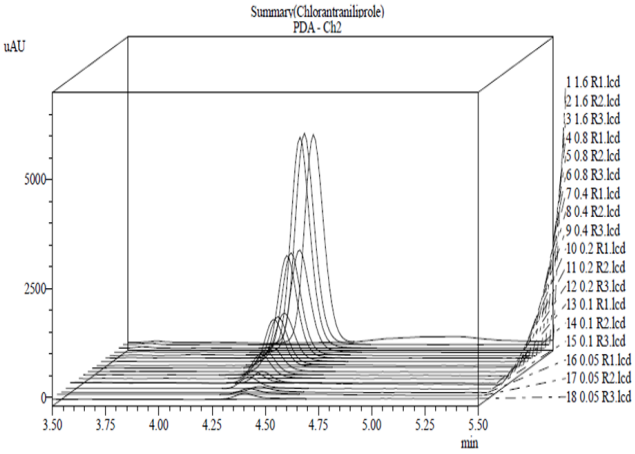

Fig. 2. *Linearity curve of chlorantraniliprole in UHPLC*

Table 9. Economics of IPM module for management of *M.vitrata* in garden bean

Modules	Pod yield (t/ha)	Total cost of cultivation (Rs/ha)	Gross return (Rs/ha)	Net return (Rs/ha)	B: C ratio
M_1 - *M.vitrata* sex pheromone trap + 5 % *A.adenophora* @ 50 % flowering stage + Chlorantraniliprole 18.5 SC @ 15 days after first spray	7.58	76,500	151600	75,100	1.98
M_2- *M.vitrata* sex pheromone trap + Commercial neem formulation @ 50 % flowering stage + Chlorantraniliprole 18.5 SC @ 15 days after first spray	7.57	77,500	151400	73,900	1.95
M_3- *M.vitrata* sex pheromone trap + 5 % *A. adenophora* @ 50 % flowering stage + Flubendiamide 20 WG @ 15 days after first spray	7.61	76,500	152200	75,700	1.99
M_4- *M.vitrata* sex pheromone trap + Commercial neem formulation @ 50 % flowering stage + Flubendiamide 20 WG @ 15 days after first spray	7.60	77,500	152000	74,500	1.96
M_5- *M.vitrata* sex pheromone trap + 5 % *A.adenophora* @ 50 % flowering stage + Emamectin benzoate 5 SG @15 days after first spray	7.58	76,500	151600	75,100	1.98
M_6- *M.vitrata* sex pheromone trap + Commercial neem formulation @ 50 % flowering stage + Emamectin benzoate 5 SG @15 days after first spray	7.61	76,500	152200	75,700	1.99
M_7- Farmer's Practice (Insecticide Spray 4 rounds) – @ 12 days interval starting from 50 % flowering stage	7.62	89,500	152000	59,500	1.70
M_8- Untreated control.	3.62	60,000	72400	12,400	1.21

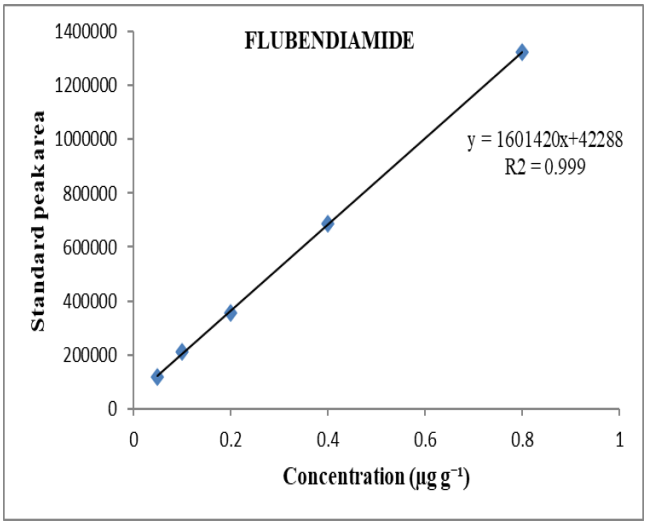

Fig. 3. *Calibration curve of flubendiamide in UHPLC*

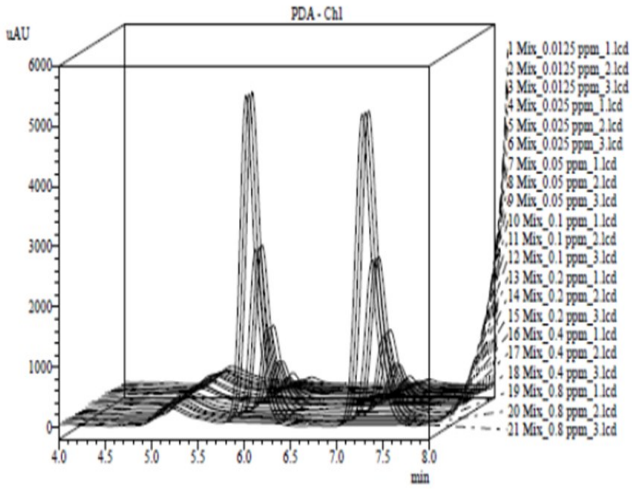

Fig. 4. *Linearity curve of flubendiamide in UHPLC*

0.8 µg g^{-1}. A good linearity was observed with the R^2 of 0.999 for chlorantraniliprole (Figure 1&2), flubendiamide (Figure3&4) and emamectin benzoate (Figure 5&6). The limit of detection (LOD) and limit of quantification (LOQ) of all the three standards were 0.015 and 0.05 µg g^{-1}. The recoveries of chlorantraniliprole, flubendiamide and emamectin benzoate were between the acceptable limit of 80 and 120 %, with the relative standard deviation less than 5% (SANTE 2017) (Table 8). The residues in garden bean samples collected at the time of harvest were below the detectable level (BDL) for all three insecticides. Since the preharvest interval was 8 to 10 days, the insecticide residues reached BDL at the time of harvest. Similarly, Vijayasree *et al.* (2014) reported a safe waiting period of 2.99 and 6.12 days when emamectin benzoate was

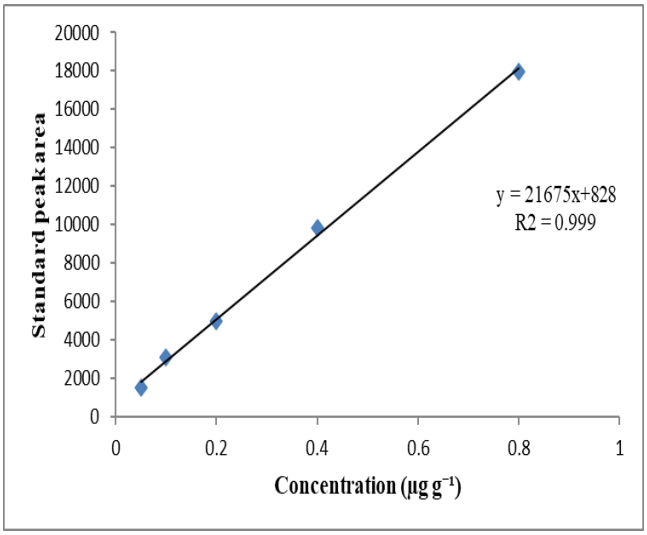

Fig. 5. *Calibration curve of emamectin benzoate in UHPLC*

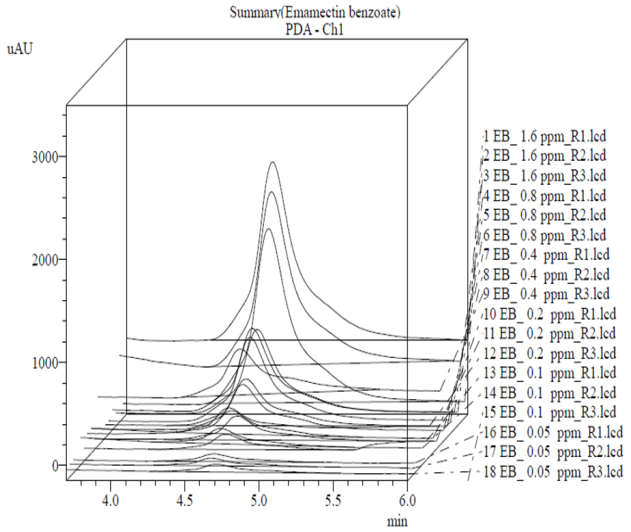

Fig. 6. *Linearity curve of emamectin benzoate in UHPLC*

sprayed at 11 and 22 g a.i. ha^{-1}. The residues of emamectin benzoate reached BDL on 3rd (8.5 g a.i. ha^{-1}) and 5th day (17 g a.i. ha^{-}1) after spraying on cabbage (Singh *et al*., 2013). A waiting period of 8 days was proposed for chlorantraniliprole in tomato (Malhat *et al.,* 2012), 0.62 days in cowpea (Vijayasree *et al.,* 2013), 1 day in cauliflower curds (Kar *et al.,* 2013) and 6 days in pigeonpea pods (Chawan *et al.*, 2020). Reddy *et al*. (2020) reported a waiting period of 10 days for flubendiamide in dolichos bean, 4.19 days in okra (Deepak *et al.,* 2017) and 1.63 days in cabbage (Paramasivam and Banerjee, 2013).

The economics of different IPM modules for garden bean is presented in table 9. The yield of garden bean pods varied from 5.3 to 7.6 t/ha. The cost of cultivation was higher in farmers' practice compared to IPM modules due to the cost involved in the increased application of insecticides. The gross return of IPM modules was similar to farmers' practice, with an increased benefit-cost ratio (1.95 to 1.99) in all the IPM modules.

Conclusion

The present study concluded that chlorantraniliprole 18.5 SC, flubendiamide 20 WG and emamectin benzoate 5 SG were the best treatments in managing the *M. vitrata* population in garden bean with two rounds of spraying at 15 days interval. Similarly, the botanicals, including commercial neem formulation and *A. adenophora* were found to be effective in reducing the larval population. So all these three insecticides and two botanicals can be combined in addition with *M. vitrata* pheromone traps @ 8/ acre that can be developed into a practical IPM module for the spotted pod borer management in garden bean ecosystem. The natural enemy population was comparatively high in IPM plots than in the farmers practice. When sprayed on the garden bean, pesticide residues of chlorantraniliprole, flubendiamide and emamectin benzoate reached BDL at the time of harvest. Since the effectiveness of the developed IPM module was slightly lower than the farmers' practice, the major problems like the residue build-up and toxic effect on the natural enemy population will be lower in the IPM modules. Similarly, the benefit-cost ratio of farmer's practice was lower than all the evaluated IPM modules.

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Conflict of interest

The authors declare that they have no conflict of interest.

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