BIOPESTICIDES : GREEN ALTERNATIVE IN PEST MANAGEMENT: A REVIEW

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ABSTRACT

Till recent, chemical pesticides is the most frequent used tool for pest management. Indiscriminate use and sole reliance on eco-hazardous pesticides have created several environment related problems, which leads to search on eco-friendly approaches to tackle the noxious/ hazardous pests. With this backdrop of knowledge, the paper presents a review of biopesticides reported to be insecticidal against various insect pests in agriculture as well as forest, domestic and public health importance without any detrimental effect on beneficial fauna for sustainable agriculture.

KEY WORDS: Biopesticides, pest management

INTRODUCTION

Indian farmers are using wide range of chemical pesticides in which insecticides account for 78 per cent, herbicides for 14 per cent, fungicides for 16 per cent and others 4 per cent (Khan *et al*., 2014). Pesticides have contaminated different components of our environment and pose a potential health hazard to consumers. The indiscriminate use of pesticides has created several problems, which came to limelight with the publication of "Silent Spring" by Rachel Carson. Therefore, future pest problems will have to be tackled in an environmentally benign manner as a part of a sustainable crop production technology (Dhaliwal and Heinrichs, 1998; Koul *et al.*, 2004; Koul, 2008). Pest management should be ecologically based and undertaken within the context of integrated crop management. In fact, the use of biopesticides has gained a lot of importance that reduce the pests for longer time. The term 'biopesticide'embraced a wide diversity of both chemical and microbial active ingredients (Joseph *et al.*, 2012).

Botanicals as biopesticides

The use of plants has been practiced as pesticides since time immemorial. The Hindu book, the *Rig Veda*, mentioned the use of poisonous plants for pest control (Koul and Walia, 2009). The exploitation of the toxicological properties of plants had an even older history. Of the estimated 3,08,800 plant species, very few have been surveyed and most remained unexploited and un-utilized for pesticidally active principles. Till date, about 2400 plant species have been reported to possess pesticidal properties belonging to 189 families among which about 22 families contain more than 10 plant species in each family with insecticidal properties. With the development of agriculture, links between food production and pest control might have provided an opportunity for protection of crops against pests (Thacker, 2002). Approximately, more than 350 insecticidal compounds, more than 800 insect feeding deterrents and quite a good number of insect growth inhibitors and regulators had been isolated from various plant species, but apparently only few had achieved the commercial status. Among diverse array of plant chemicals, only about 10 per cent of these had been examined, indicating that there is enormous scope for further work (Benner, 1993).

Among the botanical pesticides, neem (*Azadirachta indica*) is being widely used as several formulations, because of its active component *Azadirachtin*. Jilani *et al.* (2003) tested neem seed oil from five localities of Pakistan against red flour beetle as growth inhibitor and found significant reduction in the progeny at 250 ppm or higher rate in all the samples. According to Phukon *et al*. (2014), neem oil was nearly as effective as cypermethrin in reducing fruit damage by *Helicoverpa armigera* leading to increased tomato yield. Mustafiz *et al.* (2015) reported that neem oil @ 3.0 ml/l of water at three days interval showed better performance to control *H. armigera* in tomato in respect to number of total fruits per plant, number of healthy fruits per plant with lowest number of infested fruit resulting highest yield and highest benefit cost ratio. Neem leaf extract and garlic extract also showed better performance in controlling fruit borer. Neem oil was more effective against jassids (20.4 to 42.5 % reduction) in cotton than that of neem seed kernel extract. However, both neem oil and neem seed kernel extract were found to reduce more than 50 per cent of whitefly population (Jat and Jeyakumar, 2006).

Neem seed kernel extract (NSKE) 5% was found to be effective against the sucking pests (leafhopper and aphids) of cotton followed by *Pongamia glabra* seed kernel extract 5%, neem oil 3% and *P. glabra* oil 3% and maximum population reduction was noticed on the 3rd day after treatment (Vinodhini and Malaikozhundan, 2011). Significant lower mean mortality of *H. armigera* larvae was observed when allowed to feed on square dipped in neem seed extract (2.5-10%) followed by *Carica papaya* seed extract (2.5%). However, *C. papaya* seed extract (2.5-10%) was proved to be most significant followed by *Acacia* bark extract (5-10%) during larval immersion method (Chauhan *et al*., 2013). The lowest tomato fruit infestation due to *H. armigera*, in terms of number and weight (27.15% and 22.29%, respectively) was observed in plots treated with NSKE 5% leading to highest infestation reduction (30.08%) over control, highest yield (18.14 t/ha) and highest MBCR (2.99), which was statistically similar to tobacco leaf extract and cypermethrin treated plots (Rahman *et al*., 2014). There is potential to use insecticide (Emamectin benzoate) in combination with the botanical insecticides (neem products) to maintain the population of *Plutella xylostella* below damage level in cauliflower (Akbar *et al.*, 2014). Stanikzi and Thakur (2016) obtained comparatively higher cabbage yield from the plots treated with botanicals treatments *viz*., NSKE, neem oil than untreated control. The highest yield, however, was recorded in the insecticidal treatment. Better performance exhibited by neem product may be due to repellency of the larvae of different instars on the leaves from the treated plants and secondly due to antifeedant effect on the larvae (Rajput *et al.*, 2003).

According to Ali *et al.* (2016), extract of neem (*A. indica*), tobacco (*Nicotiana tabacum*) and eucalyptus (*Eucalyptus globus*) showed its comparative superiority to combat sucking insect pests (white flies, jassid and mites) in brinjal. Noonari *et al.* (2016) recorded the highest reduction of thrips (67.65%) in the treatment neem seed extract followed by neem oil (60.00%), tobacco (63.59%) and hing (*Asafoetida*) (52.68%) after 96 hours of application on cotton. The highest reduction of jassid (71.97%) was recorded in neem seed extract followed by neem oil (70.06%), hing (*Asafoetida*) (68.15%) and tobacco (23.56%). With regards to reduction in whitefly population, the maximum reduction (60.18%) was recorded in hing (*Asafoetida*) followed by neem oil (59.78%), neem extract (59.38%) and tobacco (40.61%). Solangi *et al.* (2016) noted the higher efficacy of neem extract followed by tobacco, tooh (*Citrullus colocynthus* Schrad. L.), Akk (*Calotropis procera* Alton. F.) with 78.42%, 72.33%, 69.51% and 65.55% reduction in thrips population on cauliflower. In case of whitefly, tooh (83.81%) was highly effective, whereas population of diamondback moth was greatly reduced in the treatment neem (97.23%), tobacco (95.39%), tooh (92.19%) and dhatura (*Datura stramonium*) (89.79%).

Reddy *et al.* (2012) published the extracts of bitter olive, *Melia azadiracta* not only controlled *P. xylostella,* but also enhanced the activity of parasitoid against diamondback moth and hence, can be widely used in integrated management (Razmjoo *et al.*, 2013). Basavaraj *et al*. (2014) reported comparative lower population of *H. armigera* infesting sunflower and the highest benefit: cost ratio in the treatment *Parthenium* leaf extract treatment (37.29) followed by NSKE (20.17) and Pongamia seed kernel extract (12.54).

Uma and Kumar (2009) explored certain plants of Euphorbiaceae family for their insecticidal property against *P. xylostella* by using leaf dip method as bioassay technique and found that of the 15 plants tested, potentially insecticidal against *P. xylostella* were *viz*., *Euphorbia antiquorum*, *E. pulcherrima*, *Croton bonplandianum*, *Jatropa curcas*, *J. gossypifolia*, *Breynia officinalis* and *Ricinuscommunis*.

Sundararaj *et al.* (2004) reported toxic and repellent properties of sugarcane bagasse-based lignin against some stored grain insect pests including *Tribolium castaneum.* Jeyasankar *et al*. (2010) reported antifeedant and growth inhibitory activities of *Syzygium lineare* Wall against *Spodoptera litura*. The efficacy of two botanical formulations, mixtures of *Piper retrofractum* with *Annonasquamosa* (RS) extracts and *Aglaia odorata* with *A. squamosa* (OS) extracts at 0.05 and 0.1% was compared with deltamethrin 0.04% and *Bt* 0.15% and the results revealed that both the formulations of RS and OS at 0.1% was more effective than synthetic pyrethroid without hampering the activity of natural enemies (Dadang *et al*., 2011).

Sahayaraj (2011) reported that population of *S. litura* and *H. armigera* was reduced when field was treated with *Ipomea carnea* and *Vitex negundo*. Mishra and Singh (2014) revealed that the module having plant extract comprising of dhatura, neem, dhark (*Melia azadirach* L.), Lantana

(*Lantana camera* L.), Mehandi (*Lawsonia inermis* L.) and recommended check (three sprays of methyl demeton 25 EC at 1250 ml/ha) gave significantly superior control of *P. xylostella* in cabbage over the untreated check (45.16 larvae / 5 plants). Similar kinds of results were also reported by Moorthy and Kumar (2000) and Liang *et al*. (2003).

According to Odewole and Adebayo (2014), *Zingiber officinales* extract effectively control the *P. xylostella* larvae at all concentrations with 25 % w/v and gave the highest cabbage yield, while *Tephrosia vogelii* and *L. camara* extracts were as effective as Deltamethrin at different concentrations and hours on adult of diamondback moth. Anosom® 1 EC (liquid formulation of Anonin from *Annona squamosa*) was found to be most effective against *P. xylostella* among botanicals *viz*., *Deris indica and A. Indica*, as evidenced from the lowest LC_{50} value of only 0.1 ppm (Sontakke *et al.*, 2014). Tuan *et al.* (2014) reported that combo-solution of Garlic and Chilli effectively reduced cabbage insect pests. On the other hand, the solution not only reduced the number of days required for the cabbage growth, but also enhanced the leaf number, head diameter, head weight and quality of cabbage greatly.

Botanical treatments *viz*., neem; lantana; Chilli, *Capsicum annuum* and Turmeric, *Curcuma longa* reduced the number of diamondback moth larval and pupal population significantly and increased marketable yield of cabbage. However, neem was the best treatment, as it gave the highest yield and also maximum economic return in cabbage (Begna and Damtew, 2015). *Allium sativum*, *A. indica* and *Momordica balsamina* extracts significantly reduced *P. xylostella* populations, leaf and head damage of cabbage, also increased the plant height and yield. The botanical insecticides were at par with the synthetic insecticide Lambda cyhalothrin 2.5 EC due to their pungent and repellent mode of action (Degri and Zakaria, 2015). Antifeedant activity and toxicity of commercial formulations of Anosom® (*A. squamosa*), Derisom® (*P. glabra*), Margosom® (*A. indica*) and ethanolic extract of *Argemone mexicana*, *Nerium oleander*, *Parthenium hysterophorus* were evaluated by Khan and Qamar (2015) and reported that the highest concentration Derisom exhibited 83.24% starvation of household pest, *Periplaneta americana* after 24 hrs of treatment. Percent mortalities showed by Populus (*Populus euphratica*) and Sea buckthorns (*Hippophae rhamnoids*) plant extracts at 3% was, however, low as compared to the synthetic insecticides, but theses biopesticides were helpful to some extent for control of tomato fruit borer (Rizvi and Jaffar, 2015).

Amongst the all tested extracts of botanicals (rhizome of *Acorus calamus*, leaves of *Vitexnegundo*, *Adhatoda vasica* and tuber of *Dioscorea deltoidea*, higher mortality of *H. armigera* (48.91%) was noted in the treatment with hexane extract of *A. calamus* (Matharu and Mehta, 2016).

Based on the literature discussed above, it is clearly evident that botanical insecticides having insecticidal property *viz*., neem, pongam, custard apple, *Parthenium* etc. has tackled various crop pests effectively. Among botanicals, neem is widely used not only because of its insecticidal properties, but also for its synergistic action with microbial pesticides (Reddy *et al.*, 2012), which can be an effective tool in IPM.

Microbial pesticides

Entomopathogenic fungi

Entomopathogenic fungi have a significant role among all the biocontrol agents because of its mode of pathogenicity, broad host range etc. Therefore, these have been received a lot of attention due to their prospective as biocontrol agents against insect pests and can be incorporated in IPM systems (Reddy *et al*., 2013). Major entomopathogenic fungal formulations developed against insect pests available in market are *Beauveria bassiana*, *Metarhizium anisopliae* and *Verticillium* (*Lecanicillium*) *lecanii*. Pathogenesis is occurred by mechanical force, enzymatic processes and perhaps certain metabolites. Insect cuticle mainly composed of chitin and protein. Various enzymes produced by entomopathogenic fungi have significant role for degradation of insect cuticle, saprophytic growth of fungi and activation of prophenoloxidase (Khachatourians and Qazi, 2008).

The bio-agent, *B. bassiana* was found to reduce 39.7 to 72.6 per cent of white fly population in cotton. However, it was ineffective against jassids, as it could reduced only 10–14 per cent of population (Jat and Jeyakumar, 2006). As per the report of Karthikeyan and Selvanarayanan (2011), *B. bassiana* 0.25% recorded the highest mortality of *H. armigera* (86.67 %), *S. litura* (86.67 %) and *Earias vittella* (73.33 %) and found most effective against chewing pests *in vitro*, whereas sucking pest complex *viz*., *Aphis gossypii* (100.00 %), *Bemisia tabaci* (100.00 %) and *Amrasca devastans* (93.33 %) were effectively managed by *V. lecanii* at the same concentration *i.e*. 0.25%.

Beauveria bassiana was used to evaluate its pathogenecity against adults of different aphid species *i.e*., *Schizaphis graminum*, *Rhopalosiphum padi*, *Brevicoryne brassicae* and *Lipaphis erysimi* and their natural enemy *Coccinella septempunctata*. The fungus was found effective at all concentrations *i.e*., 1×10^6, 1×10^7 and 1×10^8 spores/ml on all aphid species, but the uppermost concentration (1×10^8 spores/ml) provided the maximum control within short period of time ($P < 0.0001$), while the LT_{50} values were in range of 2.19-3.73 days for different aphid species treated at various concentrations. *B. bassiana* showed little or no detrimental effects to *C. septempunctata*. Hence, this entomopathogenic fungus can be used as potential biocontrol agent for the management of aphids (Akmal *et al*., 2013).

Zafar *et al.* (2016) studied the application of different isolates of *B. bassiana* against different life stages of *B. tabaci* on different host plants *i.e.Gossypium hirsutum*, *Lycopersicum esculentum*, *Solanum melongena* and *Capsicum annum*. The results showed *B. bassiana* isolate (Bb-01) to be the most effective with LC_{50} value (2.4×10^7 spores/ml), which caused the highest mortality of eggs (65.30%) and nymphs (88.82%) with LC_{50} value (2.7×10^6 spores/ml).

Isolates of *M. anisopliae* and *B. bassiana* from naturally infected insects were found to be pathogenic to the tested rice ear head bug, *Leptocorisa acuta* in both greenhouse (up to 87% and 77.7% mortality, respectively) and field (86.6% and 74.9%, respectively) condition at 10 days after treatment. Among 12 selected isolates of *M. anisopliae* and *B. bassiana* tested, *M. anisopliae* (OM3-BD), *M. anisopliae* (HG3-B) and *M. anisopliae* (HG5-BD) exhibited higher pathogenicity to *L. acuta* as compared to the rest. *M. anisopliae* showed better efficacy against *L. acuta* as compared to *B.bassiana* (Loc and Chi, 2005). Naik and Shekharappa (2009) studied the bioefficacy of different formulation (crude, wettable powder and oil based formulation) of entomopathogenic fungi *viz*., *B. bassiana*, *M. anisopliae* and *V. lecanii* against sucking pests of okra and concluded that oil based formulation of all the fungal pathogens effectively managed the sucking pests. Minimum number of leafhopper (5.25 / 3 leaves) and mites (9.75 /3 leaves) was recorded in plots treated with oil based *M. anisopliae,* whereas oil based *B. bassiana* was most effective against thrips (2.58 /3 leaves) and *V. lecanii* against aphid (7.75 /3 leaves) and whitefly (2.70 /3 leaves). The yield of okra was significantly higher in oil based formulation of *M. anisopliae* (38.80 q/ha) and *V. lecanii* (38.50 q/ha). Similarly, among three formulations (liquid, talc and lignite) of *M. anisopliae* $3x10^{12}$ conidia/ha, liquid formulation was found to be efficient for the control of sugarcane white grub, *Holotrichia serrata* (Chelvi *et al*., 2011). In another study by Manisegaran *et al*. (2011), application of *M. anisopliae* at 4 $x10^9$ conidia/ha was found effective next to chlorpyriphos and registered 92 per cent reduction in *H. serrata* population on sugarcane at 60^{th} DAT leading to higher cane yield and incremental benefit cost ratio (IBCR) (7.58). As per the report of Mohammadbeigi and Port (2013), *B. bassiana* and *M. anisopliae* caused significant mortality of *Uvarovistia zebra* (Orthoptera: Tettigoniidae) by both contact and ingestion. The highest concentrations of *B. bassiana* (1.5×10^8 spores/ml) and *M. anisopliae* (2×10^7 spores/ml) caused 100 per cent and 53.3 per cent mortality, respectively, when applied topically on the nymphs, whereas ingestion by insects using lettuce baits inoculated with different conidial concentrations, the mortality caused by *B. bassiana* and *M. anisopliae* at concentration of 5×10^6 conidia/ml was 30 per cent and 43 per cent, respectively. The entomopathogenic fungi *B. bassiana* and *M. anisopliae* could be effectively used as pest management option in production of organic tomato to reduce the pest population below economic threshold level and increased yield (Phukon *et al*., 2014).

Liquid formulation of *V. lecanii* showed significantly higher efficacy in controlling aphids irrespective of dosage and registered up to 96.70 per cent kill of the pest (Chavan *et al*., 2008). It suppressed 62 per cent of *Aphis craccivora* population at 39 days after seedling emergence. During the same period, *B. bassiana* reduced 72 per cent of *S. litura* larval population (0.73 larvae). The infestation of *S. litura* and *Aproaerema modicella* were greatly reduced after the treatment of *B. bassiana*; subsequently the yield (1721.31 kg/ha) and cost benefit ratio (1: 1.93) were increased (Sahayaraj and Namachivayam, 2011). The LC_{50} values of *V. lecanii* for *Toxoptera citricida* and its parasitoid, *Lysiphlebus testaceipes* were 2.26×10^{10} spores/ml and 1.09×10^9 spores/ml, respectively and they are statistically at par with each other indicating limitation in integration of biocontrol agent, *L. testaceipes* in a pest management program to control *T. citricida* while using *V. lecanii* in citrus (Balfour and Khan, 2012). Kulkarni and Patil (2013) mentioned about the efficacy of *V. lecanii* to control three species of mealybug *viz*., *Maconellicocus hirsutus*, *Planococcus citri* and *Ferrisia virgata* on custard apple. Neem oil 1.0%, *V. lecanii* @ 2.5 kg/ha and azadirachtin 0.0009 per cent were found moderate effective against major sucking pests of *Bt* cotton. In case of toxicity of insecticides on predators (Coccinellids and *Chrysoperla*) of sucking pests, all the biopesticides were found safer to predators (Ghelani *et al*., 2014). As per the report of Janghel *et al.* (2015), *V. lecanii* was most effective biopesticide against aphid on okra, which was at par with the insecticidal check *i.e.* acetamiprid. Application of *L. lecanii* at conidial density of 10^9 conidia/ml per week significantly decreased *B. tabaci* population on soybean (Rakhmad *et al*., 2015).

Conidia of *M. anisopliae* in stored wheat along with dust carriers gave significantly higher adult mortality of *Tribolium castaneum* and less grain infestation (Batta and Safieh, 2005). Samodra and Ibrahim (2006) reported that *B. bassiana* formulated in kaolin showed the highest mortality of *Sitophilus oryzae* and lowest grain weight loss in stored rice followed by talc and tapioca flour. Similarly, Shafighi *et al*. (2014) reported that the addition of the diatomaceous earth (DE) to the fungal isolates of *B. bassiana* and *M. anisopliae* increased the pathogenicity especially at the highest exposure interval and provided satisfactory control of the insect pests of stored products. According to Dhuyo and Ahmed (2007), first and second instar larvae of larger grain borer, *Prostephanus truncates* were more susceptible to *B. bassiana* in stored maize than the third instar, while pupal stage was found significantly more susceptible than other stages.

Bacterial pathogen

The most successful insect pathogen used for insect control is the soil bacterium, *Bacillus thuringiensis* (*Bt*), which occupies about 2 per cent of the total insecticidal market (Bravo *et al*., 2011). Each *Bt* strains produces different mix of toxins and specifically kills one or a few related species of insects (*Bt* subspecies *kurstaki* and *aizawai* for lepidopteran larvae) and (*Bt* subspecies *tenebrionis* for coleopteran larvae). Some of these strains are specific to mosquitoes (*Bt* subspecies *israelensis*).

Cry, Cyt and Vip proteins are stomach poisons and must be ingested for toxicity. The cry genes code for proteins with a range of molecular masses from 50 to 140 kDa. Upon ingestion by the susceptible insect larvae, protoxins are solubilized in the high alkaline pH of midgut and proteolytically digested by midgut proteinases to release the toxic fragments of approximately 55-68 kDa. Action of Cry toxin is a multistage process (Bravo *et al*., 2011), which includes:

- The activated toxin binds to receptors located on the apical microvillus membrane of epithelial midgut cells. Two important insect proteins have been identified as receptors for Cry toxins *viz*., aminopeptidase N (APN) and Cadherins. Insect glycolipids were additionally suggested as a receptor in nematodes.
- Binding of the toxin to the receptor leads to change in the toxin's conformation, allowing toxin insertion into the membrane.
- Oligomerization of the toxin follows and this oligomer then forms a pore that leads to osmotic cell lysis and larval death.

McGaughey (1978) noticed good control (92%) of *Plodia interpunctella* and *Ephesti acautella* in bulk wheat and corn by treating the surface layers with dust or aqueous suspension of *Bt*. Ahmedani *et al.*

(2008) evaluated three commercial formulations of *Bt* against *T. castaneum* and reported Ecotech Pro as more effective than Dipel ES and Bactospeine in suppressing the pest. Effect of *Bt* var *kurstaki* on 3rd instar larvae of *Hyposidra infixaria* was studied. On 7th day after treatment, the lowest (50.00%) and the highest (96.43%) mortality were provided by *Bt kurstaki* @ 0.5 g/lit and 2 g/lit, respectively. On 10th ay after treatment *Bt kurstaki* @ 2 g/lit provided cent percent mortality (Nair *et al*., 2011). According to Vanlaldiki *et al.* (2013), *Bt* formulation (dipel) recorded the lowest larval population (0.21/plant) with highest cabbage yield (22.73t/ ha) and proved to be the most effective treatment followed by *Bt* (delfin) and nuvan with larval populations of 0.45 and 1.50/plant, respectively, as against 8.88/plant in untreated control. Regarding the safety of natural enemies, agrineem and delfin proved to be the safest insecticide to the predatory beetle, *C. septempunctata* with the highest population of 1.20/plant each against 1.28/plant in untreated control. Basavaraj *et al*. (2014) recorded comparatively lower population of *H. armigera* in the treatment V-*Bt* leading to the highest sunflower seed yield (3528 kg/ha), volume weight (55.14 g/100 ml) and oil content (37.78 %). Sontakke *et al.* (2014) reported microbial pesticide Lipel® (*Bt* subsp. *kurstaki*) was found to be very effective than MVP II (Cry1Ac) and XenTari® (*Bt* subsp. aizawai) against *P. xylostella* on cabbage.

Insect viruses

Among the insect viruses baculoviruses (Nuclear polyhedrosis virus, NPV and Granulosis virus, GV) are the most promising for insect control particularly of Lepidoptera and Diptera because of their specificity. NPVs have been successfully used for management of devastating lepidopteran pests like *Heliothis* spp. and *Spodoptera* spp. on cotton, fruit and vegetable crops in several countries (Rosell *et al*., 2008).

The virus particles are attached to the peritrophic membrane of the midgut. The lipoprotein membrane surrounding the virus fuses with plasma membrane of the gut wall cells and liberates nucleocapsids into the cytoplasm. The nucleotide transports virus DNA into the nucleus of the cell and virus gene expression begins. The virus multiplies rapidly and eventually fills the body of the host with virus particles. The infected larvae are extremely fragile to the touch, rupturing to release fluid filled with infective virus particles. This tendency to remain attached to foliage and then rupture is an important aspect of the virus life-cycle (Ramanujam *et al*., 2014).

A nuclear polyhedrosis and a granulosis virus have been isolated from *E. cautella*. Both the viruses infect *P. interpunctella*, whereas granulosis virus from *P. interpunctella* does not cross-infect *E. cautella* (Hunter *et al*., 1973). Another nuclear polyhedrosis virus has been isolated from *Corcyra cephalonica* (Rabindra and Subramaniam, 1975); but it is not known whether it will cross-infect other moths or not. Among the *Ha*NPV isolates, CBE I (Coimbatore) and NEG (Negamum) applied at 3.0×10^{12} POB/ha on cotton and 1.5×10^{12} POB/ha on chickpea with crude sugar as an adjuvant significantly reduced the *H. armigera* larval population and increased the yield with higher cost/benefit ratios (Jeyarani *et al*., 2010). Among the three treatments, NPV 500 LE/ha treatment significantly reduced the both larval population and boll damage than the chemical treatment Cypermethrin 25% EC. Whereas, the combination treatment NPV 500 LE/ha + Cypermethrin 25% EC + Quinalphos 25% EC significantly reduced the pest population and boll damage than the individual treatments. Pugalenthi *et al*. (2013) reported that *Nuclear Polyhedrosis Virus* (NPV) may be a good potent source of Microbial pesticides against selected important agricultural lepidopteran field pests and boll damage.

Nematodes

Entomopathogenic nematodes in the genus *Steinernema* and *Heterorhabditis* have been successfully commercialized as biological control agents for a variety of insect pests species (Sharifi *et al*., 2014). The free-living infective juveniles (IJ) have to locate a potential host, penetrate through its cuticle or natural openings and establish in the host's body cavity (Koppenhöfer *et al*., 2007). In the insect haemocoel, the nematode releases its symbiotic bacteria from its intestine. The bacteria proliferate, producing toxins and metabolites that kill the insect host and prevent invasion by secondary organisms. The nematodes feed on the lysed tissues of the host and bacterial colonies (Griffin *et al*., 2005).

Species and strains of *Steinernema* is more effective than *heterorhabditis* and *Steinernema riobrave* was the best performing nematode, producing earlier and greater mortality of squash vine borer, *Melittia cucurbitae* both in laboratory as well as field conditions in South Carolina than the other strains (Canhilal and Carner, 2006). Strain Hawaii of *Steinernema feltiae* and strain USA/SC were found most virulent against *Tribolium confusum* and *Ephestia kuehniella* larvae, respectively (Athanassiou *et al*., 2008). The efficacy of three strains of *S. feltiae* against *S. oryzae* at five different concentrations and four different temperatures was tested by Laznik and Trdan (2010). They found all the strains as most effective at 25°C and highest concentration of nematode. The efficacy of the infective juveniles (IJs) of four native entomopathogenic nematode (EPN) species *viz*., *Steinernema affine* (Bovien) (isolate 46), *S. carpocapsae* (Weiser) (isolate 1133), *S. feltiae* (Filipjev) (isolate 879) and *Heterorhabditis bacteriophora* (Poinar) (isolate 1144) were investigated against the larvae of American pinworm, *Tuta absoluta* (Meyrick) on tomato in Turkey. The results showed that *S. feltiae* (isolate 879) was the most effective nematode species against *T. absoluta* with up to 94.3 per cent mortality. Hence, it was clear from the study that EPNs can also be potential candidates to control insect pests and can be integrated into the management programme (Gözel and Kasap, 2015).

CONCLUSION

Biopesticides offers effective alternatives for the control of many insect pests (Isman, 2006; Khaman *et al*., 2006; Krischik and Davidson, 2007) due to their strength as being eco-friendly, economic, target specific, biodegradable and essentially non-toxic and non-pathogenic to animals and humans. Biopesticides are likely to play an important role in IPM in modern agriculture as well as pests of forest, domestic and public health importance. The only drawback, slow active nature, have to be tackled by developing effective strategies for using them in agriculture and by creating awareness in extension workers and farmers regarding the use of biopesticides. The price of the commercial biopesticides has to be competitive with synthetic chemical pesticides or alternately the government has to provide subsidies for encouraging their use in agriculture to safeguard human health.

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