ECO-FRIENDLY MANAGEMENT STRATEGIES AGAINST POD BORER COMPLEX OF COWPEA, *Vigna unguiculata* var. *sesquipedalis* (L.) Verdcourt

By

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THESIS

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requirement for the degree of

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DECLARATION

I, hereby declare that this thesis entitled "Eco-friendly management strategies against pod borer complex of cowpea, *Vigna unguiculata* var. *sesquipedalis* (L.) Verdcourt" is a bona-fide record of research done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis, entitled **"Eco-friendly management strategies against pod borer complex of cowpea, *Vigna unguiculata* var. *sesquipedalis* (L.) Verdcourt"** is a record of research work done independently by **Ms. Subhasree, S.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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I believe, the green tinge of my eye
is a reflection of yours...

Dedicated to those green eyes which
have always loved nature...

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"When you want something the whole universe conspires in helping you realize your dream"

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Introduction

I. INTRODUCTION

Food legumes play an important and diverse role in the farming systems and in the diets of people around the world. Cowpea, *Vigna unguiculata* var. *sesquipedalis* (L.), a native crop of West Africa, is one of the most important food legumes, now grown in Asia, Africa, Southern Europe and Central and South America. Cowpea is well adapted to the drier regions of the tropics because of its drought tolerance. In terms of area, it is the second most important food legume crop in the world (Akibode and Maredia, 2011).

Production of cowpea is limited by large number of biotic and abiotic constraints and the productivity remains very low in India. The main reason attributed for the low productivity is the extensive damage caused by insect pests. Among these, pod borers damaging the reproductive parts cause maximum reduction in yield. In cowpea, the damage was as high as 94.67 and 78.93 per cent on pods and seeds (Kumar, 1978). Gubbaiah *et al.* (1975) observed 42 to 56 per cent damage to cowpea pods around Dharwad.

The pod borer complex includes *Maruca vitrata* (Fabricius), *Lampides boeticus* (L.), *Helicoverpa armigera* (Hubner), *Etiella zinckenella* Treitsche, *Adisura atkinsoni* Moore and *Exelastis atomosa* (Walsingham). Among these pod borers, *M. vitrata* was found to be the predominant one in South India (Kolarath, 2010).

The larvae of pod borers web the leaves and inflorescence and feed inside flowers, flower buds, and pods. This concealed feeding habit protects the larvae from natural enemies and other adverse factors including insecticides. The flower bud stage is preferred most for oviposition by the adult moth. The young larvae bore into the flower buds, and cause flower shedding by destroying the young flower parts enclosed in the sepals (Sharma *et al.*, 1999). The later instar larvae bore in to the pods and feed on developing grains. Excretory material is often seen at the entrance of bore holes. The damage caused by the pod borers drastically reduces the visual appeal and marketable yield of cowpea pods resulting in less consumer preference.

On account of the continuous flowering nature of cowpea plant, application of chemical insecticides belonging to the group of organochlorines, organophosphates and carbamates at short intervals become necessary to protect the flowers and pods from pod borer infestation. It leads to many deleterious effects such as residual toxicity, insecticide resistance, pest resurgence, destruction of natural enemies and environmental pollution. So it is high time for us to think of other strategies which are eco-friendly and environmentally safe as well as to control the pests bypassing all the ill effects caused by the toxic chemical insecticides. In this context, the relevance of the use of botanicals, entomopathogenic fungi and green labelled newer chemicals for managing pod borer complex assumes greater significance.

Neem based formulations act as a prophylactic measure and are very effective against lepidopteran larvae. When used in combination with *Bacillus thuringiensis* properly, the effectiveness of neem products could be increased (Dhaliwal and Arora, 2004). Azadirachtin containing formulations are effective in reducing the larval population of pod borers and contribute to a higher yield (Singh and Yadav, 2006).

Biopesticides like *Beauveria bassiana* and *Metarhizium anisopliae* have been reported to cause pathogenicity to legume pod borers. Foliar application of *B. bassiana* has resulted in less pod damage by pod borers (NBAII, 2010). *M. anisopliae* was found to cause 66.7 per cent mortality to *H. armigera* and recorded the lowest pod borer damage in chick pea (Kulkarni *et al.,* 2005).

The crystal inclusions derived from *Bacillus thuringiensis* var. *kurstaki* is generally lepidopteran specific and its effectiveness against the larvae of *H. armigera* was reported by (Dhaliwal and Arora, 1996) and against *M. vitrata* by Chandrayudu *et al.* (2006).

Flubendiamide is a novel green labelled insecticide with selective toxicity to lepidopterans. Application of flubendiamide at ten days interval starting from flowering stage has been suggested for the effective management of pod borer complex of pigeonpea (Ameta *et al.*, 2011; Dey *et al.*, 2012)

The present study entitled "Eco-friendly management strategies against pod borer complex of cowpea, *Vigna unguiculata* var. *sesquipedalis* (L.) Verdcourt" aims at, evaluating the efficacy of a botanical *viz.*, azadirachtin, bioagents *viz.*, *Beauveria bassiana*, *Metarhizium anisopliae*, *Bacillus thuringiensis* along with their sequential application (azadirachtin followed by *B. bassiana*, azadirachtin followed by *M. anisopliae*, azadirachtin followed by *B. thuringiensis*) and a safer chemical *viz.*, flubendiamide against pod borer complex of cowpea under field conditions, studying the species composition of pod borer complex and the natural enemies associated with them.

Review of Literature

II. REVIEW OF LITERATURE

A comprehensive review of research work done in India and abroad on the management of pod borer complex of pulses by eco-friendly management strategies including botanicals, bioagents and safer chemicals, species composition of pod borer complex and the natural enemies associated with them are summarized below.

2.1 MANAGEMENT OF POD BORER COMPLEX OF PULSES AND OTHER PESTS USING BOTANICALS

2.1.1 Azadirachtin

With increasing awareness towards environment-friendly and non-toxic pesticides, azadirachtin obtained from neem tree (*Azadirachta indica* A. Juss.) is gaining more and more importance (Prakash *et al.*, 2002). Neem seed contains many complex compounds that are effective against pests of various crops. Among these compounds azadirachtin is the most active tetranortriterpenoid which has been extensively studied as it modifies the insect behavior and influences their biological processes. Azadirachtin displays an array of effects such as phago- oviposition deterrent, repellant, growth retardant, molt inhibitor and fecundity and fitness reducing properties (Schmutterer, 1990). Feeding is affected through azadirachtin's interference with phagostimulants, which play a major role in normal feeding behavior of insects and related arthropods. Growth retarding effects are very much significant as such effects regulate the survival, longevity, molting process and other physiological processes of insects (Koul, 1996). Azadirachtin is slow acting and takes more than seven days for causing mortality of the larvae (Simmonds *et al.*, 2000). Azadirachtin interferes with synthesis of PTTH (Pro Thoracico Tropic Hormone), an important insect development hormone and affects insect development by altering the level of ecdysone. Also it mimics the juvenilising property of juvenile hormone to produce larval- pupal intermediates. Azadirachtin only affects the insects that consume it. Thus other friendly insects, predators and parasitoids and species which may help in pollination and other plant functions are not harmed. It quickly biodegrades by sunlight and hence does not accumulate in nature. Further the possibilities for insects to develop resistance are less likely because of its varying modes of action (Prakash *et al.*, 2002).

2.1.1.1. Pod borer complex of pulses

2.1.1.1.1 Work done in India

Dhaliwal and Arora (2004) reported that if the neem spray is synchronized with egg hatching, the newly emerging larvae will be controlled. Neem based formulations act best as a preventive or prophylactic measure. They are very effective against early instar larvae or at low level of pest population. Even though pests have not developed resistance to neem based formulations so far, it would be advisable not to use it continuously. The studies revealed that when neem based formulations are used in combination with selective insecticides and *B. thuringiensis* based formulations properly, the dosage and number of application of insecticides could be reduced and effectiveness of neem products can be increased in management of insect pests of pulse crop.

Singh and Yadav (2006) conducted studies on pigeon pea to assess the efficacy of newer insecticides along with bioinsecticides and neem based formulations against *Helicoverpa armigera* (Hubner) in order to evolve optimal need based insecticidal schedule without causing any deleterious effect on the ecosystem. Among neem based formulations, Nimbecidine gave highest per cent yield increase over control *i.e.* 85.88 per cent followed by Achook (64.63%) and Neemarin (28.39%). Also best result was observed in Nimbecidine treated plots *i.e.* 21.88 per cent, 11.38 per cent, 9.02 per cent and 637.95 kg ha^{-1} with respect to pod damage, seed damage, seed loss and yield, respectively.

Sunitha *et al.* (2008) evaluated six insecticides, at Acharya NG Ranga Agricultural University and observed that neem fruit extract (azadirachtin 5%) was least effective against pigeon pea pod borer, *M. vitrata*. There was no mortality of the treated larvae even after 24h and 48h of treatment. The mortality was also less (40%) even at higher concentrations (6% and 7%) after 72h of treatment showing its inefficacy against *M. vitrata.*

An experiment was conducted at Anand Agricultural University, Gujarat, to evaluate the efficacy of eleven biocides against two pod borers, *H. armigera* and *M. vitrata* infesting black gram. Of the eleven biocides, neem based formulations; Neemazal F (0.1%) and neem seed kernel extract (5%) were found effective against *H. armigera* and *M. vitrata.* Grain yield was highest in Neemazal treated plots (11q ha^{-1}) followed by NSKE 5 per cent (10.73 q ha^{-1}), Azadex 0.4 per cent (9.91 q ha^{-1}), Econeem 0.2 per cent (9.66 q ha^{-1}) and Vanguard 0.4 per cent (9.43 q ha^{-1}) (Krishna *et al.*, 2011).

Kanhere *et al.* (2012) tested nine insecticides for its efficacy against *Maruca testulalis* (=*M. vitrata*) infesting cowpea. They observed that the efficacy of botanicals *i.e.* NSKE 5 per cent (83-85% mortality) and azadirachtin 0.001 per cent (82-84% mortality) were statistically on par with endosulfan 0.07 per cent (87-89% mortality). They recommended two sprays of endosulfan (0.07 per cent), NSKE (5%) or azadirachtin (0.001%) at fifty per cent flowering stage for effective management of *M. testulalis.*

2.1.1.1.2 Work done outside India

Efficacy of some synthetic chemicals and biopesticides against pod borers *H. armigera* damage in chick pea was studied at the Regional Agricultural Research Station, Bangladesh, during *rabi* cropping season 2004-05. Synthetic chemicals and biopesticides reduced pod borer damage significantly. The biocontrol agent *Ha*NPV showed equally best performance like synthetic insecticides and also showed higher efficacy than neem based insecticides like Nimbecidin (AZ 0.03EC). Reduction in pod damage by synthetic insecticides ranged from 50.53 to 64.08 per cent while 24.98 to 63.40 per cent in biopesticides (Hossain, 2007).

2.1.1.2 Other pests

2.1.1.2.1 Work done in India

In the study conducted at Indian Agricultural Research Station, New Delhi, various neem products and insecticides were evaluated for the management of maize stalk borer, *Chilo partellus* (Swinhoe) during *Kharif* 1998 and 1999. They reported that, Neem Azal F 5EC and Neem Azal- T/s 1 EC were potential enough to reduce infestation including dead heart due to maize stalk borer but were inferior to endosulfan 35EC. Leaf injury and tunnel length recorded after releasing insects artificially, one day after pesticidal application showed that endosulfan was effective followed by Neemazal- F and Neemazal- T/s. Significantly higher grain yields were realized with application of endosulfan and neem products over control. The effectiveness of neem products was pronounced in terms of higher grain yield in relation to control but was not comparable with endosulfan (Bhanukiran and Panwar, 2005).

Laboratory studies conducted at Bidhan Chandra Krishi Viswavidyalaya (BCKV), Mohanpur indicated that mortality with neem insecticide Nimbecidine (0.03%) was 79.12-87.5 per cent, 95.75-100 per cent, 100 per cent and 34.2-48.16 per cent in *H. armigera*, two and seven days old grubs of *Epilachna* beetle and *Coccidohystrix insolita* (Green), respectively (Haque and Ghosh, 2007).

Mehta *et al.* (2010) conducted studies to observe the effect of Nimbecidine, Neemazal and role of birds in the suppression of *H. armigera* larval population in tomato fields. Nimbecidine was sprayed at 0.30 and 0.60 ppm azadirachtin concentrations whereas Neemazal was sprayed at 10 and 20 ppm azadirachtin concentrations. The maximum larval reduction after three sprays was recorded at 20 ppm concentration of Neemazal (71.29%) with higher fruit yield (20.42 kg) and lowest infestation (7.18%).

On farm and laboratory experiments were carried out at the Krishi Vigyan Kendra, Pechiparai, Tamil Nadu, India to assess the bio-efficacy of *Beauveria bassiana,* azadirachtin 10000 ppm and monocrotophos (spray and injection) against pseudostem weevil, *Odoiporus longicollis* Oliver in red banana. Injection of monocrotophos @ 4ml/plant registered the highest per cent reduction in infestation (76.07%) followed by the injection of azadirachtin 2ml/plant (70.0%), application of *B. bassiana* @ 25g on the pseudostem trap (56.75%) and monocrotophos spray (38.39%). Stem injection of monocrotophos, azadirachtin and the application of *B. bassiana* recorded high per cent mortality of weevils, 96.15, 84.74 and 75.36 per cent respectively, after 96h of application (Irulandi *et al.*, 2012).

Ghosh and Chakraborty (2012) studied the efficacy of botanicals against *Epilachna* beetle (*Henosepilachna vigintioctopunctata* Fab.) of potato and reported that, azadirachtin 1500 ppm brought about more than 60 per cent mortality within four days after spraying.

2.1.1.2.2 Work done outside India

A commercially available neem seed extract Neemix 4.5 per cent containing AZA was assessed for the biological activity against the root weevil, *Diaprepes abbreviates* (L.) an important exotic pest of citrus, at U.S. Horticultural Research Laboratory, Fort Pierce. Laboratory bioassay against neonates and three weeks old larvae fed sliced carrot treated with Neemix produced dose dependent mortality and reduced fresh weight among survivors of treatment. Reproductive effects were also observed when adult weevils were fed on foliage treated with Neemix. The number of larvae hatched per egg mass was reduced by 27 per cent and 68 per cent at 30 and 90 mg/ litre AZA respectively. These results suggest that Neemix should be further evaluated for its use in IPM (Weathersbee and Tang, 2002).

Abdulai *et al.* (2003) field tested the effectiveness of neem based formulations in the protection of cowpea against *Nezara viridula* (L.) at United States of America. They reported that densities of *N. viridula* declined in Neemix (210g azadirachtin per ha) treated plots (0.2 bugs/2m row) 10 days after the first spray compared to control (1.1 bugs/2m row) and suggested that neem can be effectively used in the management of *N. viridula* in cowpea. Kraiss and Cullen (2008) evaluated direct spray treatments of two neem formulations *viz*., azadirachtin (Neemix® 4.5 EC @ 23 g a.i. ha^{-1}) and neem seed oil (1% emulsion), under controlled conditions for effects on survivorship, development time and fecundity in *Aphis glycine* Matsumura and its key biological control agent *Harmonia axyridis* Pallas, at University of Wisconsin-Madison, USA. Both azadirachtin and neem oil significantly increased aphid nymphal mortality (80% and 77% respectively), while significantly increasing the development time of those surviving to adulthood. Neither neem formulations affected the fecundity of *A. glycine* and *H. axyridis*. The botanicals and the bioagents require more time for action and leads to a slow control of the larvae of black vine weevil, *Otiorhynchus sulcatus* Fabricius (Kowalska, 2008)

2.2 MANAGEMENT OF POD BORER COMPLEX OF PULSES AND OTHER PESTS USING ENTOMOPATHOGENIC FUNGI

Entomopathogenic fungi are known to infect a broader range of insects including Lepidoptera, Hemiptera, Hymenoptera, Coleoptera and Diptera. Although there are hundreds of species of entomogenous fungi in some 35 genera, very few have been studied in detail. Most research on fungi have been directed to *Beauveria bassiana* (Balsamo) Vuillemin and *Metarhizium anisopliae* (Metchnikoff) Sorokin (Whitten and Oakeshott, 1991). The anamorphic entomopathogenic fungi, *B. bassiana* and *M. anisopliae* are natural enemies of a wide range of insects and arachnids and both fungi have a cosmopolitan distribution (Roberts and St. Leger, 2004; Rehner *et al.*, 2006).

2.2.1 *Beauveria bassiana*

Entomopathogenic deuteromycete fungus *B. bassiana* grows naturally in soils through out the world and act as a parasite on various arthropod species. It is named after the Italian entomologist Agostino Bassi who discovered it in 1835. It is a promising and extensively researched pathogenic fungus that can suppress a variety of economically important insect pests (Prasad and Syed, 2010). When used as a biological insecticide, a white mould develops on the cadaver of the attacked insect and hence the name, white muscardine fungus.

2.2.1.1 Pod borer complex of pulses

2.2.1.1.1 Work done in India

Beauveria bassiana was pathogenic to all stages of *H. armigera* causing 60-100 per cent mortality of larvae and 100 per cent mortality of eggs when dipped into a suspension of 1.0×10^7 conidia/ml (Gopalakrishnan and Narayanan, 1990). *B. bassiana* tested under field conditions in India to control *H. armigera* infesting chickpea showed an average pod damage of six per cent and yield of 2377 kg ha^{-1} at a concentration of 2.68×10^7 spores/ml. The untreated control recorded 16.3 per cent pod damage with a yield level of 1844 kg ha^{-1} (Saxena and Ahmad, 1998).

Second and third instars of *H. armigera* were more susceptible to *B. bassiana* than other larval stages (IV and V). This susceptibility decreased with age and the fungus was pathogenic to all stages of the pest (2-72%) at 1.18×10^{10} conidia per ml (Rathod, 2002).

When the fourth instar larvae of *H. armigera* was sprayed with four different concentrations (0.1, 0.125, 0.2 and 0.25×10^8 spores/ml) of *B. bassiana*, dose dependent mortality was observed that went up to 76.7 per cent with highest dose of 0.25×10^8 spores/ml. The treated larvae died mainly due to spread of fungal infections into different body parts. Severity of infection was evident by the development abnormal body parts, fragile skin, entire body covered by fungal mycelia, and formation of inter mediate stages indicating that chitin is the main target of fungal attack (Prasad *et al.*, 2010).

A field experiment was conducted at Jawaharlal Nehru Krishi Vishwavidyalaya (JNKVV), Jabalpur for evaluating *B. bassiana* against pod borer complex of pigeon pea. The treatments included *B. bassiana* SC @ 250 and 300mg/l, *B. bassiana* WP @ 1.0 and 1.5 kg/ha, *B. thuringiensis* @ 1.5 kg/ha, spinosad 45 per cent SC @ 73 g a.i. /ha. The results revealed that *B. bassiana* WP @1.5 kg/ha recorded significantly less grain damage by *H. armigera* and *Exelastis atomosa* (Walsingham) and also recorded higher grain yield compared to *B. bassiana* SC formulation or *B. thuringiensis* but was inferior to spinosad (NBAII, 2010).

Soudararajan and Chithra (2011) at National Pulses Research Centre, Tamil Nadu, tested the effectiveness of bioinoculants on sucking pests and pod borer complex of urd bean for two years and found that foliar application of *B. bassiana* two times during flowering stage of the crop was effective on the pod borers.

Sreekanth and Seshamahalakshmi (2012) conducted studies to assess the relative toxicity of biopesticides to *H. armigera* and *M. vitrata* on pigeon pea (*Cajanus cajan* L.) at Regional Agricultural research Station, Guntur and reported that, the per cent inflorescence damage due to legume pod borer was lowest in spinosad 45 per cent SC @ 73 g a. i /ha (4.74%), followed by *Bacillus thuringiensis*-1 @ 1.5 kg/ha (10.52%) and *B. bassiana* SC formulation @ 300mg/l (14.15%) with 80.9, 57.6 and 42.9 per cent reduction over control respectively.

2.2.1.1.2 Work done outside India

The respiratory rate of the larvae of *H. armigera* infected by *B. bassiana*, (treated with high concentration *i.e.* 1 × 10^8 conidial/ml), decreased slowly in the first three days compared with the control, however, it decreased drastically from the fourth day. For the low concentration (1 × 10^6 conidia/ml) treatment, the respiratory rate increased in the first two days, then decreased gradually. In general, the larvae of cotton bollworm tended to speed up respiration in the beginning and then decreased in the course of infection (Sun *et al.*, 2000).

In an experiment conducted at Nigeria by Ekesi *et al.* (2002) showed that, at a concentration of 1×10^8 conidia ml^{-1}, four isolates (*B. bassiana* CPD 3 and 10, and *M. anisopliae* CPD 5 and 12) were found to be highly pathogenic to eggs (89-100% mortality) as well as larvae (94–100%) of *M. vitrata.*

Rijal *et al.* (2008) field tested the efficacy of two most virulent native isolates of insect pathogenic fungi (*M. anisopliae* and *B. bassiana* @ 1 × 10^7 conidia/ml) in comparison with four commercial pesticides (*Ha*NPV, *B. thuringiensis* var. *kurstaki,* azadirachtin and cypermethrin) against chickpea pod borer (*H. armigera*) at Chitwan, Nepal. The population of *H. armigera* larvae was significantly lesser in plots treated with *B. bassiana* (B3) and *M. anisopliae* (M1) compared to control plots during vegetative, flowering and pod setting stages of chick pea resulting in higher yield, however lesser than NPV and *B. thuringiensis* treated plots.

2.2.1.2 Other pests

2.2.1.2.1 Work done in India

Second and third instar larvae of *Chilo infuscatellus* Snellen were more susceptible (51.47% to 65.2%) to the fungus *B. bassiana* even at a low dosage (10^5 or 10^6 spores/ml) while 10^7 spores/ml concentration, the mortality observed was 68.53-75.93 per cent (Sivasankaran *et al.*, 1990).

High coffee berry borer mortality caused by the fungus *B. bassiana* has been reported in Indian coffee plantations (Haraprasad *et al.*, 2001).

An aqueous suspension of *B. bassiana* and *M. anisopliae* at 5 × 10^6 and 5 × 10^7 conidia ml^{-1} sprayed on eggs and pupae of *S. litura, Spilosoma obliqua and H. armigera* at the lower rate (5 × 10^6 conidia ml^{-1}) resulted in egg mortality values of 40-44 per cent and 32.3-40 per cent, respectively while the same caused mean egg mortalities of 51.6, 51 and 44 per cent, and 49.5, 44.0 and 38.1 per cent, and pupal mortalities of 48.8, 44 and 32.1 per cent, and 41.8, 40.8 and 22.5 per cent, on *S. litura, S. obliqua and H. armigera,* respectively (Pandey, 2003). Laboratory studies conducted at BCKV, Mohanpur, indicated that *B. bassiana,* causes 25.0-45.75, 91.62-100, 52.28-90.42 and 33.42-42.92 per cent mortality in

10 days old larvae of *H. armigera*, in two and seven days old grubs of *Epilachna*, and in females of *Coccidohystrix insolita* (Green), respectively (Haque and Ghosh, 2007). Laboratory bioassays made by Gulati *et al.* (2008) to study the virulence of *B. bassiana* against *H. armigera* and *S. litura* revealed that the highest concentration (2×10^{12} conidia/ml) caused maximum mortality (100%) of second and fourth instars of *H. armigera* and *S. litura* compared to the lowest concentration (2×10^{3} conidia/ml) with 0 to 23.33 per cent mortality. The mortality in treated larvae decreased with the increase in larval stage.

Field trial conducted at Regional Agricultural Research Station, Pattambi, Kerala Agricultural University to find out the bioefficacy of *B. bassiana* against rice blue beetle, *Leptispa pigmaea* Baly indicated that *B. bassiana* at 10^{7} spores/ml brought about 61 to 72 per cent reduction of damage over untreated control. The persistent toxicity of *B. bassiana* was on par with other eco-friendly insecticides, azadirachtin 1 per cent (Econeem) and neem oil 2 per cent (Karthikeyan and Jacob, 2010).

Based on a field study conducted at Marathwada Agricultural University, Parbhani, Shirale *et al.* (2010) reported that *B. thuringiensis* @ 1000 ml ha^{-1} and *B. bassiana* @ 1000g ha^{-1} were at par with triazophos 800ml ha^{-1} in controlling soyabean leaf miner (*Aproaerema modicella* (Deventer)).

Malarvannan *et al.* (2010) reported that, lowest pupation was observed in *S. litura* larvae treated with the highest spore concentration (2.7×10^{7}) of *B. bassiana* under laboratory conditions.

2.2.1.2.2 Work done outside India

A study conducted at USDA, Subtropical Agricultural Research Centre located at Southern Texas showed that multiple applications of one isolate of *Paecilomyces fumosoroseus* and four isolates of *B. bassiana* at 5×10^{13} conidia in 180 l water per ha at four to five days intervals provided more than 90 per cent control of large whitefly nymphs (third and fourth-instar) on cucumbers and cantaloupe melons indicating strong potential for microbial control of nymphal whiteflies infesting cucurbit crops (Wraight *et al.*, 2000).

Nymphal stages of *Bemisia tabaci* (Gennadius) are highly susceptible to infection by a number of fungi including *B. bassiana* (Vincentini *et al.*, 2001). Khan *et al.* (2005) reported the pathogenicity of *B. bassiana* against *Mylabris pustulata* (Thunberg). Sabbour and Sahib (2005) observed that *B. bassiana* was highly effective against *Plutella xylostella* (L.), *Pieris rapae* (L.) and *Spodoptera exigua* (Hubner) and infection reached to 20 and 21 per cent after nine days of treatment, when these were allowed to feed on artificial diet contaminated with 3×10^3 or 4.5×10^3 spores.

In Columbian coffee ecosystem, *B. bassiana* is a natural control agent of coffee berry borer, *Hypothenemus hampei* Ferrari (Bustillo, 2006). The natural control caused by the fungus in the Columbian coffee zone has been calculated around ten per cent. If *B. bassiana* has not been present, the economic losses in the Columbian coffee industry will be much higher. *B. bassiana* is a part of the coffee berry borer IPM strategy in Columbia (Gongora *et al.*, 2009).

Pinto *et al.* (2013) reported that one application of Actara 250WG (thiomethoxam 0.1g a. i. 200ml^{-1}) and Neemesto (azadirachtin 1%) achieved similar control of cotton aphids, *Aphis gossypii* Glover at 72h after treatment followed by cotton seed oil, where as the aphid populations on plants treated with Boveril (*B. bassiana* at 5×10^8 conidia per g) and untreated plants were similar.

2.2.2 *Metarhizium anisopliae*

Metarhizium anisopliae formerly known as *Entomophthora anisopliae* Metchn., is a fungus that grows naturally in soils through out the world and causes disease in various insects. The scientist, Ilya Mechnikoff named it after the insect species from which it was originally isolated, the beetle *Anisoplia austriaca* Hbst. The disease caused by the fungus is called as green muscardine disease because of the green colour of the spores. It has gained significant attention as a biocontrol agent due to its wide geographic distribution, high virulence, and vast spectrum of infectivity to wide range of insect pests (Ypsilos and Magnan, 2005).

The conidia of *M. anisopliae* usually enter in to insect mainly through the integument by adhesion, penetration into haemocoel and development of fungal infection (McCoy *et al.*, 1988). The process of fungal penetration through integument by a hyphal germination from a spore involves chemical and physical forces. *In vitro* studies indicated that the digestion of the integument follows a sequential lipase- protease chitin process of digestion (Nahar *et al.*, 2004).

2.2.2.1 Pod borer complex of pulses

2.2.2.1.1 Work done in India

Gopalakrishnan and Narayanan (1988) found that *M. anisopliae* caused 80-100 per cent mortality in all five larval instars of *H. armigera* at 1.8×10^9 conidia per ml. *M. anisopliae* var. *anisopliae* have been found to be pathogenic to larval instars, pre pupae and pupae of *H. armigera*. None of the adults and eggs treated with conidial suspension showed any mortality. However the eggs laid by the treated female were found to be sterile. Nahar *et al.* (2004) observed 66.74 per cent of mortality of third instar larvae of *H. armigera* when treated with *M. anisopliae*.

Among different biopesticides like *B. bassiana* (0.5, 1.0 and 1.5 g/litre), *B. thuringiensis*, *Nomuraea rileyi (*0.5, 1.0 and 1.5 g/litre), *M. anisopliae* and Nucleo Polyhedro Virus (NPV), evaluated at University of Agricultural Sciences, Dharwad, against *H. armigera* on chickpea, NPV resulted in the highest grain yield (8.25 q ha^{-1}), followed by *N. rileyi* (7.44 q ha^{-1}) and *M. anisopliae* (7.42 q ha^{-1}), while *M. anisopliae* recorded the lowest pod damage (18.06%), followed by *N. rileyi* (18.64%) and NPV (20.07%) (Kulkarni *et al.*, 2005). Further the experiment conducted under laboratory conditions by Gundannavar *et al.* (2007) to study the dose mortality response between *H. armigera and M. anisopliae* showed that *M. anisopliae* was more virulent to the first instar larvae of *H.*

armigera, killing 72.50 per cent of the larvae at highest concentration of 10^8 spores/ml in a minimum period of five days after inoculation and hundred per cent in the next two days.

In vitro bioassay conducted by Sahayaraj and Borgio (2010) to evaluate the virulence of *M. anisopliae* on seven insect pests of Tamil Nadu exhibited more than 50 per cent mortality after 48h of treatment in *Aphis craccivora* Koch, *Dysdercus cingulatus* Fabr., *Oxycarenus hyalinipennis* Costa, *Pericallia ricini* Fab., *S. litura* and *H. armigera* at 1.6×10^7 spores/ml. 93.33 per cent mortality was observed against third and fourth instar larvae of *H. armigera* in 96h after the treatment with *M. anisopliae.*

2.2.2.2 Other pests

2.2.2.2.1 Work done in India

Laboratory studies were conducted at Jaipur on the pathogenicity of *M. anisopliae* and it was showed that the fungus was strongly pathogenic to all three instars of *P. xylostella* larvae. Within four days of the treatment, *M. anisopliae* at 4×10^8 conidia/ml caused a mortality of 95, 86.66, and 86.66 per cent to the second, penultimate and final instar larvae respectively (Mahla *et al.*, 2005).

2.2.2.2.2 Work done outside India

Miranpuri and Khachatourians (1996) reported the pathogenicity of *M. anisopliae* against aphids. Shanda *et al.* (1996) indicated that *M. anisopliae* was strongly pathogenic upon Coleoptera and Lepidoptera and reported that mortality of *P. xylostella* larvae to be 90 per cent three days after inoculation at a concentration of 10^7 conidia /ml.

Laboratory results at USDA, University of Minnesota, suggested that *M. anisopliae* (5.4×10^{13} to 9×10^{13} spores/ha) have potential as a biocontrol agent of sugar beet root maggot, *Tetanops myopaeformis* Von Roder. Four year average recoverable sugar yield at Minnesota were 7160 kg ha^{-1} when no insecticide was applied, 8120 kg ha^{-1} when a chemical insecticide was used and 8622 kg ha^{-1} when *M. anisopliae* was used in spring and fall seasons (Campbell *et al.*, 2000).

The sugarcane spittlebug, *Mahanarva posticata* (Stal) (Homoptera: Cercopidae) causing serious losses in sugarcane crops was successfully controlled in Northeastern Brazil by *M. anisopliae* (Onofre *et al.*, 2002).

Krutmuang and Mekchay (2005) observed that termites apparently died two days after inoculation with the fungus, *M. anisopliae*. After seven days, the white mycelia developed and green conidia appeared around the cadavers. Per cent mortality of termites depends upon concentration of conidial suspension and varieties of *M. anisopliae*.

Gindin *et al.* (2006) while testing the susceptibility of red palm weevil to two entomopathogenic fungi, *M. anisopliae* and *B. bassiana*, found that *M. anisopliae* strains were more virulent than *B. bassiana* achieving hundred per cent mortality within six to seven days. The most virulent strains of *M. anisopliae* were then tested on eggs and adults of red palm weevil. Incubation in a substrate treated with *M. anisopliae* spores increased egg mortality and reduced their hatchability. The total per cent mortality of eggs and hatched larvae was 80.82 per cent, compared with 34 per cent in the control.

Nimbecidine (0.03% azadirachtin) and Bio-Magic (*M. anisopliae* at 1×10^8 CFU/ml) caused 69.9 and 68.9 per cent reduction in live larval population of *Liriomyza trifolii* (Burgess) after two applications and achieved 14.7 and 10.0 kg dry weight faba bean seeds/100 plants respectively, compared to 5.7 kg dry weight seeds/100 plants in control plots. Nimbecidine and Bio-Magic were considered promising compounds in controlling *L. trifolii* and it could be exploitation in the integrated pest management programme of faba bean crop (El-Salam *et al.*, 2013).

Experiment conducted to study the effect of entomopathogenic fungi, *B. bassiana* (isolate Bb.5335) and *M. anisopliae* (isolate Ma.7965) on non target insects, such as natural enemies, *Coccinella septempunctata* L., *Chrysoperla carnea* (Stephens) and *Dicyphus tamaninii* Wagner at a concentration of 1 × 10^8 conidia/ml revealed that, *B. bassiana* was non-pathogenic to natural enemies and beneficial soil insect while *M. anisopliae* had pathogenicity to *D. tamaninii* than *C. carnea* with corrected mortalities of 10 and 4 per cent, respectively (Thungrabeab and Tongma, 2007).

2.3 MANAGEMENT OF POD BORER COMPLEX OF PULSES AND OTHER PESTS USING ENTOMOPATHOGENIC BACTERIA

2.3.1 *Bacillus thuringiensis* var. *kurstaki*

Bacillus thuringiensis Berliner is an entomopathogenic bacterium which produces parasporal, proteinaceous, crystal inclusion bodies during sporulation. Upon ingestion, these are insecticidal to larvae of the order Lepidoptera, Diptera and to both larvae and adults of a few Coleoptera. Once inside the insect, the crystal proteins are solubilised and the insect gut proteases convert the original protoxin in to a combination of up to four smaller toxins. These hydrolyzed toxins bind to the insect's midgut cells at high-affinity, specific receptor binding sites where they interfere with the potassium-ion dependent active amino acid symport mechanism. This disruption causes the formation of large pores that increase the water permeability of the cell membrane. A large uptake of water causes cell swelling and eventual rupture, disintegrating the midgut lining. Different toxins bind to different receptors in different insect species and with varying intensities and this explains the specificity.

The crystal inclusions derived from *B. thuringiensis* var. *kurstaki* are generally lepidopteran specific and are often slow acting (2-48h in comparison to conventional insecticides) because they have to be ingested and then processed within insects gut. The toxin results in starvation leading to death. Insects not killed by direct action of the toxin may die from bacterial infection over a longer period. Different toxins have different spectra of activity (NCIPM, 2013). The main problem with *B. thuringiensis* products are their narrow activity spectrum and high sensitivity to ultra violet rays. The lower efficacy of *B. thuringiensis* in the field conditions may be due to the sunlight mediated inactivation of *B. thuringiensis* crystals (Pusztai *et al*., 1991).

2.3.1.1 Pod borer complex of pulses

2.3.1.1.1 Work done in India

Dhaliwal and Arora (1996) opined that three days old larvae of *H. armigera* were most susceptible to *B. thuringiensis* with lowest LC_{50} value of 803.37 IU. Early instars were relatively more susceptible than older ones. The decreased susceptibility of larvae of *H. armigera* to Biolep formulation with increase in age of the larvae may be related to increased size and malnutrition immunity.

Bacillus thuringiensis sub sp. *kurstaki* based insecticides (Dipel 82, Biolep, Halt, Bioasp) all at 1.5 kg ha^{-1} were as effective as quinalphos at 2 l ha^{-1} against young larvae (2-3 instar) of *H. armigera* on chickpea (Dhawan and Simwat, 1998). Kulat and Nimbalkar (2000) reported that *Btk, Btk* alternated with endosulfan, and endosulfan alone were the most effective in the reduction of larval population (49.48, 49.01 and 45.02% respectively). Mohapatra and Srivasthava (2002) reported that *B. thuringiensis* provided good protection and registered significantly lesser incidence of *M. vitrata* larvae and higher yield over control.

New insecticides evaluated against *M. vitrata*, in cowpea at Department of Entomology, Sri Venkateswara Agricultural College, Andhra Pradesh indicated that *B. thuringiensis* (Delfin 5 WG, 0.0025%) and fipronil (Regent 5 SC, 0.016%), exhibited superior control efficacy at two (54.1 and 48.7%), five (59.5 and 56.9%), nine (62.3 and 60.9%) and 14 (88.9 and 84.7%) days after spraying. At harvest, pod damage was significantly lower with *B. thuringiensis*, fipronil, and azadirachtin (15.8, 18.4, and 24.7% respectively) (Chandrayudu *et al*., 2006). Thilagam and Kennedy (2007) reported that *B. thuringiensis* var. *kurstaki* based product (Spic-Bio Reg.) @ 2.5 l/ha was the best treatment, recording lesser *H. armigera* larval population (0.7/plant) in pigeon pea.

A field trial conducted at Dharwad in the year 2009 to evaluate the efficacy of biorationals in the management of pod borer complex in field bean indicated that the treatment with *B. thuringiensis* spray was significantly superior (1.20 larvae/plant) over all the treatments and was followed by endosulfan spray (1.30 larvae/plant) which were on par with each other in reducing the larval population. Though *B. thuringiensis* (1 g/l), NSKE (5%) and *Pongamia glabra* seed extract (5%) were best among the biorationals offering least per cent damage, but were inferior to chemical insecticide (endosulfan 35EC). Highest yield of field bean was obtained in *B. thuringiensis* (1 g/l) treated plots followed by NSKE 5 per cent and *Pongamia glabra* seed extract (5%). In terms of cost benefit ratio (CBR), the best and most economical treatments among biorationals were *B. thuringiensis* (1 g/l) and NSKE 5 per cent. In case of *B. thuringiensis* treated plot, two sprays gave a return of Rs. 3.13 for every rupee invested whereas it was Rs. 2.54 for endosulfan 35EC (Kolarath, 2010).

Evaluation of Directorate of Oilseed Research (DOR) *B. thuringiensis* against pod borers of pigeon pea conducted at Anand Agricultural University revealed that DOR *B. thuringiensis* at 2 and 1 kg ha^{-1} were significantly superior to NSKE (5%) and were at par with other treatments in reducing the population of *M. testulalis* seven days after spray in pigeon pea. Similar trend was observed in the control of *H. armigera* (NBAII, 2009). Mortality of *H. armigera* in all age group larvae (2, 4, 6, 8 & 12 days old) was recorded with four doses (1×10^9, 1×10^8, 1×10^7 & 1×10^6) of *B. thuringiensis*, NPV and *B. bassiana.* Maximum mortality was observed with *B. thuringiensis* followed by NPV. *B. bassiana* was found least effective in reducing larval population of *H. armigera* under laboratory conditions (Tyagi *et al.*, 2010).

In a field trial conducted at Acharya N. G. Ranga Agricultural University, Hyderabad, application of *B. thuringiensis* @1 kg/ha recorded lesser populations of *Adisura atkinsoni* (Moore) (11 larvae/10 plants) and pod damage (1.35%) compared to control (29 larvae/10 plants and 14.79% pod damage) with better yield (3650 kg per ha) compared to all other treatments and was on par with *M. anisopliae* (3750 kg per ha). Control plots had only 550 kg per ha (NBAII, 2010).

Sreekanth and Seshamahalakshmi (2012) while evaluating the efficacy of biopesticides against *H. armigera* and legume pod borer, *M. vitrata* during *kharif*, 2010 at Regional Agricultural Research Station, Guntur, found that per cent inflorescence damage due to legume pod borer was lowest in spinosad 45SC @ 73g a. i. ha^{-1} (4.74%) followed by *B. thuringiensis* @ 1.5 kg ha^{-1} (10.52%). They also concluded that new generation insecticides when alternated with biopesticides, effectively managed pod borer complex and avoided the development of resistance.

2.3.1.1.2 Work done outside India

Two commercial formulations of microbial pesticides (*B. thuringiensis* var. *kurstaki* and *B. bassiana*) and a botanical (azadirachtin) bioassayed against *M. vitrata* larvae at University of Mauritius, indicated that *B. thuringiensis* var. *kurstaki* induced more than 80 per cent mortality in four days old larvae at 1.5 and 2.0 g/l and 50.3 per cent and 70.6 per cent mortality respectively in seven days old larvae (Unmole, 2011).

2.3.1.2 Other pests

2.3.1.2.1 Work done in India

Field experiment carried out in College of Agriculture, Nagpur, Maharashtra, to evaluate the effect of different biopesticides on the control of *H. armigera* on cotton revealed that *B. thuringiensis* at 2×10^8 spores ml^{-1} was found the most effective, bringing about 62.10 per cent larval mortality on seventh day after spraying (Nandanwar *et al.*, 2004).

Karabhantanal and Awaknavar (2005) investigated the effect of environmental parameters on the persistence of biological control agents, on tomato for managing *H. armigera* population and reported that the persistence had positive but non-significant correlation with minimum temperature but highly significant negative correlation with maximum temperature and highly significant positive correlation with evening relative humidity in the case of *Btk*, *Ha*NPV and *N. rileyi.*

Kale and Men (2008) carried out field trial to find out the performance of microbial insecticides alone or in combination against *H. armigera* and reported that effective microbial insecticides were *Ha*NPV (250 LE ha^{-1}) and *B. thuringiensis* (750 ml ha^{-1}), which stood only next to endosulfan (0.06%). *M. anisopliae* (2.5 kg ha^{-1}) and *B. bassiana* (2.5 kg ha^{-1}) were less effective, but performed better than their combinations with either *Ha*NPV or *B. thuringiensis* and combination of *Ha*NPV with *B. thuringiensis* at reduced doses.

The efficacy of *B. thuringiensis* var. *kurstaki* (*Btk* @ 55000 and 32000 IU mg^{-1}), avermectin (1.8 per cent w/v) at 1000 ppm, and *B. bassiana* (1.0×10^7 spores ml^{-1}) was evaluated against second instar larvae of *Leucinodes orbonalis* Guenee, *Earias vittella* (Fab.), *S. litura and H. armigera* under laboratory conditions. The biopesticides were effective against the pests except *B. bassiana. Btk* at 55 000 IU mg^{-1} recorded 86.49 and 68.59 per cent mortality of *S. litura and H. armigera.* The level of toxicity of the biopesticides decreased with time, and in most cases, mortality was reduced to less than 10 per cent within five days (Chatterjee, 2008).

2.4 MANAGEMENT OF POD BORER COMPLEX BY SEQUENTIAL APPLICATION OF BOTANICALS AND BIOAGENTS

2.4.1 Work done in India

Bhattacharya *et al.* (2004) tested the compatibility of *B. bassiana, B. subtilis and B. thuringiensis* with azadirachtin under laboratory conditions by inhibition zone method. No inhibition zones were recorded on entomopathogen inoculated agar plates for azadirachtin (1000, 2500 and 5000 ppm) at all concentrations. The result suggested that azadirachtin is compatible with *B. subtilis, B. thuringiensis and B. bassiana* and, thus, may be used with these biological control agents for integrated pest management.

Ravi *et al.* (2008) carried out an experiment in farmer's holdings of Coimbatore district to find out the efficiency of different sequential applications of microbial insecticides against *H. armigera* in comparison with sequential application of synthetic insecticides, on tomato F1 hybrid, Ruchi. Results showed that different sequential application of microbials and Neemazal were equally effective as that of sequential application of synthetic chemical insecticides. Highest fruit yield was recorded in endosulfan- quinalphos- indoxacarb treated plots which were on par with azadirachtin -*Btk*- spinosad, *Ha*NPV-*Btk*- spinosad and *Btk*- *Ha*NPV- spinosad treated plots. Highest number of predatory mirids and spiders were recorded in untreated control, but was comparable to that of *Ha*NPV, *Btk*, azadirachtin and spinosad treated plots (sequential application) where as endosulfan-quinalphos-indoxacarb treated plots had the lowest number of natural enemies which differed significantly from untreated check.

2.5 MANAGEMENT OF POD BORER COMPLEX OF PULSES AND OTHER CROPS USING NEW GENERATION CHEMICALS

2.5.1 Flubendiamide

Flubendiamide is a novel green labelled insecticide, which belongs to chemical class benzenedicarboxamides. It acts as a potent ryanodine receptor modulator. It activates insect's ryanodine receptors and subsequently induces calcium release leading to uncoordinated muscular contraction. Characteristic symptoms induced by flubendiamide include, gradual contraction, and thickening and shortening of the insect body without convulsions. Flubendiamide is inactive against beneficial arthropods (except silkworm) and natural enemies, which suggests that flubendiamide is valuable for integrated pest management (IPM) programs (Tohnishi *et al.*, 2005).

Flubendiamide shows extremely strong insecticidal activity especially against lepidopterous pests. The specificity of flubendiamide to Lepidoptera is due to the structure of ryanodine receptors (RyR). Flubendiamide only can bind with RyR of Lepidoptera and is inactive with mammalian RyR. The compound is highly active on insecticide- susceptible and resistant larvae of all instars of *Spodoptera exigua* (Hubner), *H. armigera* or *H. virescens* (F.) and shows no cross resistance to other chemical classes of insecticides such as pyrethroids, carbamates, organo - phosphates, chlorinated hydrocarbons, benzoylphenyl ureas or compounds such as indoxacarb (Nauen *et al.*, 2007).

According to pesticide fact sheet, flubendiamide is available as Water Dispersible Granule (WDG) and Soluble Concentrate (SC) (EPA, 2008). Fame 480SC, Takumi 20WDG, Fenos 24WDG, Belt 480SC, and Belt 240WDG are some of the formulations of flubendiamide available in the market.

A field experiment conducted at Anand Agricultural University, Anand studied the rate of degradation of flubendiamide in/on brinjal fruits following foliar application of Fame 480SC at 90 (standard dose) and 180 (double dose) g a.i. ha^{-1}. The residues estimated using HPLC (High Performance Liquid Chromatography) revealed persistence of flubendiamide in/on brinjal till third and seventh day after the last spray at standard and double dose, respectively. The residues of flubendiamide were reported as parent compound, and no metabolite was detected. The initial deposits of 0.17 and 0.42 $\mu g\ g^{-1}$ in/on brinjal fruits reached below determination level of 0.05 $\mu g\ g^{-1}$ on the fifth and tenth day at standard and double dose, respectively. The half life of flubendiamide on brinjal fruits ranged from 2.68 to 2.55 days. Soil samples analyzed on the 15th day after the last spray revealed residues at below detectable level (0.05 $\mu g\ g^{-1}$) at either dose of application (Chawla *et al.*, 2011).

2.5.1.1 Pod borer complex of pulses

2.5.1.1.1 Work done in India

An experiment was conducted at U. A. S., Bengaluru to evaluate the efficacy of indigenous materials and newer insecticide molecules against pod borers of dolichos bean. Among the newer insecticidal molecules, the total yield was highest in emamectin benzoate 5SG @ 0.2 g/l (14.94 q ha^{-1}), followed by indoxacarb 14.5 SC @ 0.3 ml/l (14.57 q ha^{-1}), flubendiamide 480SC @ 1 ml/l (14.26 q ha^{-1}), spinosad 45SC @ 0.2 ml/l (13.69 q ha^{-1}), fenvalerate 20EC @ 0.5 ml/l (11.73 q ha^{-1}) and endosulfan 35EC @ 2 ml/l (7.15 q ha^{-1}). Flubendiamide was found to be on par with indoxacarb and emamectin benzoate (Mallikarjuna *et al.*, 2009).

Among the newer insecticide molecules evaluated against pod borers of black gram (*H. armigera* and *Etiella zinckenella* Treit), larvin 75WP (Thiodicarb) @ 468.75 and @ 562.5 g a.i/ha, flubendiamide 480SC @ 36 and @ 48 g a.i./ha were superior by recording less larval populations of both the pod borers, followed by indoxacarb 14.5SC @ 75 g a.i./ha. Further, flubendiamide @ 48 g a.i./ha (6.04%), larvin @ 562.5 g a.i./ha (6.47%), flubendiamide @ 36 g a.i./ha (7.62%) and larvin @ 468.75 g a.i./ha (8.25%) were superior by recording less pod damage by *H. armigera* and were on par; but differed significantly from the rest of the treatments. The total yield was high in larvin @ 562.5 g a.i./ha (11.27 q/ha) followed by larvin @ 468.5 g a.i./ha (10.12 q/ha), flubendiamide @ 48 g a.i./ha (9.28 q/ha), flubendiamide @ 36 g a.i./ha (9.07 q/ha), indoxacarb (8.14 q/ha) chlorpyriphos (7.23 q/ha), quinalphos (7.10 q/ha), spinosad (6.93 q/ha) and endosulfan (6.86 q/ha) (Kumar and Shivaraju, 2009).

Ameta *et al.* (2011) carried out a field trial at Agronomy Farm, Maharana Pratap University of Agriculture and Technology, Udaipur, to test the efficacy of flubendiamide 480SC against the pod borers of pigeonpea and observed that flubendiamide at 100 ml ha^{-1} caused significantly high reduction in larvae of *H. armigera* and *M. testulalis* resulting in minimum flower and pod damage and significantly high seed yield in pigeon pea. Babar *et al.* (2012) studied the bioefficacy of ten different newer chemical insecticides against *H. armigera* and observed that flubendiamide at 0.01 per cent effected highest ovicidal and larvicidal action in the laboratory; highest reduction in larval population (97.02%), pod damage at green pod stage (90.24%) and maturity stage (87.96%); highest increase in yield over control (92.31%); and highest net incremental cost: benefit ratio.

Dey *et al.* (2012) field tested the bioefficacy of flubendiamide 480SC against lepidopteran pod borers of pigeon pea in an institutional trial at Gayeshpur, Nadia, West Bengal. The results of two seasons experiments revealed that flubendiamide @ 48 or 36 g a. i. ha^{-1} were most effective in reducing larval population of *H. armigera* and flower damage by *M. testulalis* suggesting the application of flubendiamide @ 48 or 36 g a.i. ha^{-1} at ten days interval starting from flowering stage for effective management of pod borer complex.

2.5.1.2 Other pests

2.5.1.2.1 Work done in India

Ameta and Bunker (2007) tested the efficacy of flubendiamide 480SC and observed that a dosage of 50 ml/ha caused significantly higher reduction of the population of diamond back moth.

Latif *et al.* (2009) reported that the application of flubendiamide reduced the infestation by *L. orbonalis* by 80.63 per cent and produced higher fruit yield in brinjal.

Field experiments were conducted at the Horticultural Research Station, Devihosur, Haveri, during 2007-08 and 2008-09 to test the bioefficacy of flubendiamide 20WG against chilli fruit borers, *H. armigera* and *S. litura.* The results indicated that among various dosages, flubendiamide @ 60 g a.i. /ha recorded highest yield of 7.48 q/ha with lowest fruit damage of 3.45 per cent followed by flubendiamide 20WG @ 40 g a.i./ ha (6.72 q/ha), emamectin benzoate 5SG @ 11 g a.i./ha (7.22 q/ha) and spinosad 45SC @ 75 g a.i./ha (7.32q/ha). However, standard check carbaryl 50WP @ 1000 g a.i./ha (6.46 q/ha) was least effective in reducing the incidence of fruit borers (Tatagar *et al.*, 2009).

Jagginavar *et al.* (2009) reported that flubendiamide 480 SC @ 90 and 72 g a.i. /ha were significantly superior over other treatments and on par with each other in recording less shoot damage by shoot and fruit borer of brinjal (11.43% and 16.21%) at seven days after first spray. Flubendiamide 480SC @ 90 g a.i./ha resulted in the lowest fruit damage of 0.78 per cent which was on par with flubendiamide 480 SC @ 72 g a.i./ha (1.04%) at seven days after first spray.

Two field trials conducted to evaluate the bioefficacy of flubendiamide 480SC in cotton against *H. armigera* at 60g a.i.ha^{-1} showed marked reduction in the larval population and recorded up to 96.0 per cent reduction in damage (Thilagam *et al.*, 2010). The bioefficacy of new insecticide, NNI 0001 480SC (Flubendiamide) was tested against the diamondback moth, *P. xylostella* under field conditions (Jalandhar, Punjab) on cabbage and it was found that medium and higher doses of NNI 0001 480SC (37.5 and 50.0 ml/ha) significantly reduced the larval population and hence increased the marketable yield. The lower dose of 25.0 ml/ha and Padan 50SP were at par in reducing population and increasing the yield (Gill *et al.*, 2010).

Flubendiamide 20 WDG (125g/ha) is recommended against major pests of rice *viz.*, yellow stem borer (*Scirpophaga incertulas* (Walker)), whorl maggot (*Hydrellia philippina* Ferino) and leaf folder (*Cnaphalocrocis medinalis* (Guenee)) (KAU, 2011).

Chatterjee and Mondal (2012) reported that the overall mean fruit infestation caused by *L. orbonalis* on brinjal was lowest in spinosad 45SC @ 50 g.a.i./ha (12.48%) followed by flubendiamide 20WDG @ 60 g ai/ha (13.37%) treated plots; whereas in untreated plot the fruit damage was 38.69 per cent. Also, spinosad recorded the highest good fruit yield of 16 t/ha followed by flubendiamide (14.96 t/ha).

Experiment conducted on okra for managing *Earias fabia* stoll., showed that all the insecticides were found to be significantly superior over the control. Among them spinosad 45SC @ 50 g ai/ha recorded the lowest infestation (4.33%) followed by flubendiamide 20WDG @ 60 g a.i./ha (4.83%), novaluron 10EC @ 50 g.a.i./ha (5.51%). Similarly the highest yield of okra was recorded in spinosad (7. 21 t/ha) followed by flubendiamide and novaluron (6.67 and 6.6 t/ha) (Chatterjee and Mondal, 2012).

Application of flubendiamide 20WDG @ 60 g a.i. /ha resulted in lower mean fruit damage by *H. armigera* (3.52%) and the highest yield (8.15 t/ha) in tomato, followed by spinosad 45SC @ 50 g ai/ha (5.21% fruit damage and yield of 7.69 t/ha) (Chatterjee and Mondal, 2012).

An experiment conducted on cabbage for managing diamond back moth indicated that flubendiamide 20WDG @ 60 g ai/ha performed exceedingly well both in reducing DBM population (91.0%) as well as increasing the yield (24.15 t/ha) closely followed by spinosad 45SC @ 50 g ai/ha and novaluron 10EC @ 50 g.a.i./ha (Chatterjee and Mondal, 2012).

Shivanna *et al.* (2012) studied the impact of biopesticides on budworm incidence and its effect on yield in FCV tobacco at Shimoga, Karnataka.The lowest number of larvae per plant was recorded in plots treated with flubendiamide 0.25 ml/l (0.33 & 0.00), novaluran 1 ml/l (1.00 and 0.00) and spinosad 0.5 ml/l (1.33 and 0.33) at three and seven days after treatment, respectively. Green and cured leaf yield were highest in flubendiamide (9364.0 and 1085.1 kg ha^{-1}) closely followed by spinosad (8749.91 and 1075.55 kg ha^{-1}) treatments. Highest total grade equivalent was recorded in spinosad (874.94 kg ha^{-1}), flubendiamide (803.70 kg ha^{-1}) and novaluron (661.72 kg ha^{-1}) treatments. These chemicals could be used in IPM programme against *H. armigera* in tobacco.

2.5.1.2.2 Work done outside India

Hirooka *et al.* (2007) reported that Phoenix (Flubendiamide 20% WG), at 100 mg a.i./ha, achieved complete control of *P. xylostella* and *Pieris rapae* (L.), 28 DAT on cabbage when the population of the larvae continued to increase. Flubendiamide at 25 and 50 g a.i./ha respectively, was extremely effective on the pests tested, including the population of *P. xylostella* normally resistant to conventional insecticides such as spinosad, indoxacarb and fipronil in Thailand.

Among the different IPM packages evaluated for the management of brinjal shoot and fruit borer, *L. orbonalis.* at Sher-e-Bangla Agricultural University, Bangladesh, package 6 (mechanical control + potash @100 kg ha $^{-1}$ + field sanitation in combination with flubendiamide 24WG applied at 5 per cent level of shoot and fruit infestation) showed better performance by reducing 80.63 per cent fruit infestation over control and produced the highest number of healthy and total fruits/plant (25.0 and 27.20 respectively) (Latif *et al.*, 2009).

2.6 MANAGEMENT OF POD BORER COMPLEX USING QUINALPHOS

2.6.1 On pod borer complex of pulses

2.6.1.1 Work done in India

Bhat *et al.* (1988) evaluated the efficiency of various insecticidal formulations and neem seed extract for the control of *M. testulalis* and cowpea seed moth, (*Cydia ptychora* (Meyr.) Perrin) on cowpea. The pest incidence was lowest in plots treated with monocrotophos at 250 ml/ha (29.27%) and grain yield was highest (5.75 q/ha) followed by neem seed extract at 25 kg/ha (42.34%), phosalone at 250 ml/ha (43.06%) and quinalphos at 250 ml/ha (44.83%), with grain yields of 4.79, 4.70 and 4.14 q/ha, respectively.

Senapati *et al.* (1992) field tested the efficacy of endosulfan (35EC) monocrotophos (36WSC) and quinalphos (25EC) to control *E. zinckenella* on pigeonpea, in Orissa. Endosulfan (three sprays at 0.14% at 20 days intervals) recorded the best yield (1891kg/ha), while monocrotophos (three sprays at 0.08% at 20 days intervals) gave a yield of 1739 kg/ha and quinalphos (three applications of at 0.10% at 20 days intervals), resulted in the yield of 1502 kg/ha. It was also reported that the application of quinalphos and monocrotophos leads to the accumulation of residues in the husk and grain.

The effectiveness of 12 insecticides against pod borer complex in pea (*Pisum sativum* L.) studied by Yadav *et al.* (2000) at Hisar, Haryana found that all insecticides were effective in controlling the pod borers and reduced pod damage from 19.73 to 10.28 per cent compared with 41.48 per cent in control. Fenvalerate 0.006 per cent, treated plots registered the highest yield (25.34 q/ha) followed by cypermethrin 0.002 per cent (24.07 q/ha). The synthetic pyrethroids were better than the other treatments in controlling yield loss due to insect pests and were at par with endosulfan and quinalphos 0.05 per cent.

Aslam *et al.*, (2004) tested ten insecticides including quinalphos 25EC (1250 ml per acre) under field conditions against *Earias insulana* (Boisd.), *E. vitella* and *H. armigera* and found that all the insecticides were effective against these pests only up to seven days after treatment.

Carbaryl (0.2%), fenthion (0.05%), quinalphos (0.05%) and neem kernel suspension (5%) are being recommended against cowpea pod borers in Kerala (KAU, 2007).

Patel *et al.* (2012) evaluated the efficacy of newer molecules against *M. vitrata* at Centre of Excellence for Research on Pulses, S. D. Agricultural University, Sardarkrushinagar. Emamectin benzoate 5SG was found to be significantly better in reducing the spotted pod borer damage (2.70%) which was equally effective as indoxacarb 14.5 SC (2.98%) and spinosad 45 SC (3.58%). Higher Cost: Benefit Ratio was obtained in the treatment of bifenthrin 10 EC (1:2.69) followed by indoxacarb 14.5 SC (1:2.36), chlorpyriphos (1:1.60), quinalphos (1:1.48), spinosad (1:1.29) and emamectin benzoate (1:1.10).

2.6.2 On other pests

2.6.2.1 Work done in India

Investigation conducted at the farm of Entomology section, College of Agriculture, Nagpur, Maharashtra, revealed that all the biological control treatments and quinalphos were significantly superior over control in reducing the larval population of *P. xylostella*. Quinalphos 25EC at 0.05 per cent was found to be an effective treatment and recorded 69.56 per cent reduction in the larval population. This was followed by *B. thuringiensis* @ 1000 ml/ha and *B. bassiana* @ 1×10^8 conidia per ml which exhibited 43.10 and 41.39 per cent reduction of larval population, respectively. The treatment with quinalphos 0.05 per cent achieved the highest yield (228.39 q/ha) followed by *B. thuringiensis* and *B. bassiana* which resulted in 197.73 and 182.63 q/ha yield, respectively (Gavhane *et al.*, 2008).

2.7 SPECIES COMPOSITION OF POD BORER COMPLEX

2.7.1 Work done in India

Mallikarjunappa (1989) conducted studies on the pod borer complex of field bean (*Vicia faba* L.) at University of Agricultural Sciences, Bengaluru and recorded pod borers like *A. atkinsoni, H. armigera, Sphenarches caffer* (Zeller.), *E. zinkenella, M. testulalis, L. boeticus, Cydia ptychora* (Meyrick), *Melanagromyza obtusa* (Malloch) and *Callosobruchus theobromae* (L.).

Species composition of pod borers in field bean was assessed at University of Agricultural Sciences, Dharwad. Among the four species of pod borers (*M. vitrata, L. boeticus, H. armigera* and *C. ptychora*) attacking the seed, *M. vitrata* was found to be the predominant one followed by *C. ptychora*. However the population of *H. armigera* and *L. boeticus* were negligible followed by *C. ptychora* (Kolarath, 2010).

2.7.2 Work done outside India

Karel (1985) reported from Tanzania that *M. testulalis* was more abundant and injurious (31% damage) to pods than *H. armigera* (13% damage) on common beans (*Phaseolus vulgaris* L.) and seed damage by both species averaged at 16.0 per cent.

Project surveys conducted on country bean, *Lablab purpureus* (L.) Sweet, at Joydebpur and Jessore, Bangladesh confirmed *M. vitrata* as the major pest of *Lablab*. Two other species of pod and flower feeding pests, *H. armigera* and plume moth, *Sphenarches anisodactylus* (Walker) were also reported. Infestation status of the different borer species was found to be location specific and changed over the three study years. During 2002-03 and 2004-05 three species of borer were observed at Joydebpur but during 2003-04, *H. armigera* was completely absent. In Jessore *H. armigera* represented 18 to 28 per cent of the borer population in flowers and comparable levels in pods. The infestation of *S. anisodactylus* was high in flowers during 2002-03 at Joydebpur but decreased in the two subsequent years and was not present at all in Jessore, with similar results observed in pods. The predominant species at both locations studied over all seasons was *M. vitrata* with infestations ranging between 71 and 99 per cent in pods. Infestations were found to be lowest in cool months, January, and highest in September and October when temperatures are high (Anonymous, 2006).

2.8 NATURAL ENEMIES ASSOCIATED WITH POD BORER COMPLEX

2.8.1 Work done in India

A survey conducted in Andhra Pradesh, India during 1975-76 reported a maximum of 13.8 per cent parasitism of *M. testulalis* by the braconid, *Phanerotoma hendecasisella* Cameron and of larvae of *E. atomosa* by *P. hendecasisella,* the braconid, *Apanteles paludicolae* Cam., the ichneumonid, *Diadegma* sp. and the chalcidid, *Tropimeris monodon* Boucek (Lateef and Reddy, 1984).

Nair (1986) reported that larva of *M. testulalis* is parasitized by *Bracon greeni* Ashm. and *P. hendecasisella* and the larvae of *Etiella zinckenella Treit.* by *Bracon* sp., *Tetrastichus* sp., *B. hebector* Say., *Phanerotoma* sp. and *P. hendecasisella.*

A survey of parasitoids of *M. testulalis* was conducted in various parts of the Central Brahmaputra Valley Zone of Assam, India, during 2002/03. The larvae and pupae of *M. testulalis* were collected from mung bean and urd bean fields during the summer and *kharif* seasons and reared in the laboratory for the emergence of adult parasitoids. The survey revealed the presence of *Caenopimpla* sp., *Phanerotoma* sp., *Temelucha* sp. and *B. greeni.* Parasitism ranged from 1.72 to 23.44 per cent in 2002 and 0.83 to 20.56 per cent in 2003. Total parasitism by the parasitoid complex reached 69.94 and 60.83 per cent in 2002 and 2003, respectively. *Caenopimpla* sp., followed by *Phanerotoma* sp., exerted a significant biotic pressure on the host (Borah and Sarma, 2004).

The natural enemies of pod borers and the extent and period of parasitization of *M. vitrata* in pigeon pea were studied in the laboratory at Bhubaneswar, Orissa. In the field, the maximum abundance of predators was recorded during the last week of September which coincided with high population of pod borers. Spiders, praying mantis and hymenopterous wasps (*Delta* spp.) predated larvae of *M. vitrata.* The braconid, *Apanteles taragamae* Viereck parasitized larvae of *M. vitrata* and *Grapholita critica* Meyr during mid-September to late December. *Microdes* sp., a larval-pupal braconid parasitoid, parasitized *M. vitrata* from September to December (Sahoo and Senapati, 2000b).

Gupta *et al.* (2013) recorded three larval parasitoids of *M. vitrata* from South India viz., *Bassus relatives* (Bhat & Gupta), *P. hendecasisella* and *Trathala flavoorbitalis* (Cam.).

2.8.2 Work done outside India

A two year survey was carried out in Sri Lanka by Fellowes and Amarasena (1977) on the parasitoids of some pests of grain legumes. They reported that *M. testulalis* was attacked in the larval stage by *P. hendecasisella* (6-7%) and in the pupal stage by *Antrocephalus* sp. (Kohl) (12-30%).

The parasitoids recorded from *M. testulalis* (=*M. vitrata*) in Nigeria, were *Tetrastichus* sp., *Phanerotoma* sp., *Braunsia* sp., the tachinids *Thelairosoma palposum* Villen. and *Pseudoperichaeta laevis* Villen. (Usua and Singh, 1978).

Natural enemies of *M. vitrata* feeding on *Sesbania cannabina*, were monitored by Chi-Chung *et al.* (2003) during the 1996 and 1997 summer seasons in Taiwan. A braconid, *A. taragamae*, a solitary endoparasitoid accounted for an average of 92 per cent of all parasitoid specimens reared from *M. vitrata* larvae and pupae. Its parasitism reached as high as 63 per cent. The parasitism was higher during June to August and reduced during September to November when other parasitoid species were more active.

The larval parasitoid guild of the cowpea pod borer, *M. vitrata* explored on wild and cultivated host plants in Southern and Central Benin, West Africa revealed two most important parasitoids *viz., Phanerotoma leucobasis* Kriechbaumer and *Braunsia kriegeri* Enderlein observed all year round parasitising the host larvae collected from wild host plants (*Pterocarpus santalinoides* L'Her, *Lonchocarpus sericeus* (Poir.) and *L. cyanescens* Stubbe to the tune of 30.2 and 4.2 per cent) and *Vigna unguiculata* (5.6 and 4.9% respectively) (Arodokoun *et al.*, 2006).

The per cent parasitism of two days old larvae of *M. vitrata* was positively correlated with host density indicating a good functional response of *A. taragamae*. A host plant odour was requisite for the parasitoid to discriminate uninfested flowers from infested ones (Dannon, 2011).

Materials & Methods

III.MATERIALS AND METHODS

A field trial on "Eco-friendly management strategies against pod borer complex of cowpea, *Vigna unguiculata* var. *sesquipedalis* (L.) Verdcourt," was carried out in the seed production unit of Department of Olericulture, College of Horticulture, Kerala Agricultural University, Thrissur (10°31'N latitude and 76°17'E longitude and at an elevation of 40 m above mean sea level) during the *rabi* season of 2012 (October 2012 to January 2013). The experimental site had a well-drained sandy loam soil and experienced a warm humid tropical climate.

3.1 FIELD EVALUATION ON THE EFFICACY OF BIOPESTICIDES, A BOTANICAL AND A SAFER CHEMICAL AGAINST POD BORER COMPLEX OF COWPEA

3.1.1 Treatments

The efficacy of selected eco-friendly management strategies including a botanical *viz.,* azadirachtin, bioagents *viz., Beauveria bassiana, Metarhizium anisopliae, Bacillus thuringiensis* along with their sequential application (azadirachtin followed by *B. bassiana,* azadirachtin followed by *M. anisopliae,* azadirachtin followed by *B. thuringiensis*) and a safer chemical *viz.,* flubendiamide were evaluated against pod borer complex of cowpea under field conditions (Table 1a). The experiment was laid out in Randomized Complete Block Design (RCBD) with ten treatments and three replications (Plates 1). A short duration (75 days) bushy vegetable cowpea variety *Bhagyalakshmi* which is susceptible to pod borers was used for the experiment. The land was prepared by ploughing and removal of weeds and stubbles. Lime was applied at the time of first ploughing. The experimental plots measured 3m × 3m. The seeds (@2/pit) were dibbled on 2nd October at a spacing of 60cm × 30cm in trenches, to conserve moisture and gap filled by re-sowing in places where the seeds did not sprout. Each plot consisted of five rows and 50 plants. All the agronomic practices were followed as per Package of Practices Recommendation

Plate 1. Field view of the experimental plot

Plate 1a. Before flowering

Plate 1b. At pod setting stage

Table 1a. Details of eco-friendly insecticides used in field experiment

Tr. No.	Treatments	Trade name	Formulation	Dose	Manufacturing company/ Source
T1	Azadirachtin 0.005% (Az)	Econeem	EC (10000ppm/1%)	5ml/l	PJ Margo Private Limited, Bangalore
T2	*Beauveria bassiana* 1% (*Bb*)		WP (Talc based)	10g/l	KAU formulation containing $1x10^9$ CFU/g
T3	*Metarhizium anisopliae* 1% (*Ma*)		WP (Talc based)	10g/l	KAU formulation containing $1x10^9$ CFU/g
T4	*Bacillus thuringiensis* var. *kurstaki* 0.2% (*Bt*)	Abtec *Btk*	Liquid formulation	2ml/l	Agro Bio Tech Research Centre, Kottayam
T5	Azadirachtin 0.005% f.b. *B. bassiana* 1% (Az- *Bb*)				
T6	Azadirachtin 0.005% f.b. *M. anisopliae* 1% (Az-*Ma*)				
T7	Azadirachtin 0.005% f.b. *B. thuringiensis* 0.2% (Az- *Bt*)				
T8	Quinalphos 0.05%	Ekalux	25 EC	2ml/l	Syngenta Crop protection Chemicals, Coimbatore
T9	Flubendiamide 0.008%	Fame	480 SC	0.2ml/l	Bayer Crop Science Private Limited Maharashtra
T10	Control (No treatments)				

*Treatments started at flowering

of Kerala Agricultural University (KAU, 2011) except for plant protection measures. At flowering stage the field was protected by installation of plastic nets in order to secure cowpea pods from parakeet, rabbit and peacock attack. Ten plants were tagged in each plot for taking observations on pod borer incidence.

3.1.2 Schedule of treatment application

Application of all treatments was started 48 days after sowing (at 50% flowering stage of the crop) when pod borer incidence was above economic threshold level (1 larva per two plants of pigeonpea (*H. armigera and M. vitrata*) (Pal and Gupta, 1994)). Spraying was repeated at fortnightly intervals. Schedule of spraying is presented in Table 1b.

a. First spray : 20/11/2012, 48 days after sowing
b. Second spray : 5/12/2012, 15 days after 1st spray (64 days after sowing)
c. Third spray : 20/12/2012, 15 days after 2nd spray (79 days after sowing)

3.1.3 Method of application of botanicals, bioagents, and chemical insecticides

Spray solution was prepared by thorough mixing of measured quantity of the insecticide and required amount of water to form a uniform emulsion. The treatments were applied using a hand operated high volume knapsack sprayer (15 l). Sprayer was cleaned properly after each treatment. In the case of bioagents, teepol was added at 1 ml/l and thoroughly mixed, to enhance the spreading quality and stickiness of spray solution. The bioagents were sprayed in the evening hours to enhance their efficacy by protecting them from ultra violet rays.

3.1.4 Field observations

3.1.4.1 Larval population of pod borers

Density of pod borers was estimated by counting the number of live larvae on pods and flowers on 10 tagged plants in each plot. Observations on larval

Table 1b. Schedule of application of treatments

Tr. No.	Treatments	First spray (At 50% flowering)	Second spray (15 days after first spray)	Third spray (15 days after second spray)
T1	Azadirachtin 0.005% (Az)	Azadirachtin	Azadirachtin	Azadirachtin
T2	*Beauveria bassiana* 1% (*Bb*)	*B. bassiana*	*B. bassiana*	*B. bassiana*
T3	*Metarhizium anisopliae* 1% (*Ma*)	*M. anisopliae*	*M. anisopliae*	*M. anisopliae*
T4	*Bacillus thuringiensis* var. *kurstaki* 0.2% (*Bt*)	*B. thuringiensis*	*B. thuringiensis*	*B. thuringiensis*
T5	Azadirachtin 0.005% f.b. *B. bassiana* 1% (Az- *Bb*)	Azadirachtin	*B. bassiana*	*B. bassiana*
T6	Azadirachtin 0.005% f.b. *M. anisopliae* 1% (Az-*Ma*)	Azadirachtin	*M. anisopliae*	*M. anisopliae*
T7	Azadirachtin 0.005% f.b. *B. thuringiensis* 0.2% (Az- *Bt*)	Azadirachtin	*B. thuringiensis*	*B. thuringiensis*
T8	Quinalphos 0.05%	Quinalphos	Quinalphos	Quinalphos
T9	Flubendiamide 0.008%	Flubendiamide	Flubendiamide	Flubendiamide

f.b. - followed by

population were taken one day prior to treatment application and at five, seven and 14 days after treatment (DAT). The infested flowers and pods were carefully opened and examined on the spot for live larvae of pod borers. Presence of larvae in flower and pods was used as index of infestation. The larvae counted during observation were retained on the cowpea plants. Per cent reduction in the larval population of pod borers in different treatments over control was worked out during each spray.

3.1.4.2 Pod damage

The matured pods were harvested plot wise on 26/11/2012, 4/12/2012 and 28/12/2012. Presence of bore holes and larval frass on pods were used as an indication of pod borer damage. Based on this, the pods were sorted and observations were made on number and weight of pod borer infested and uninfested pods. Per cent infestation by number and weight basis was worked out.

$$\text{Per cent pod infestation} = \frac{\text{Number/ weight of damaged pods}}{\text{Number/ weight of pods}} \times 100$$

3.1.4.3 Yield

Observations on total yield and marketable yield were made and per cent marketable yield was worked out.

3.1.4.4 Benefit: Cost Ratio (BCR)

Benefit: Cost Ratio was worked out for each treatment including bioagents, botanicals and chemical insecticides taking into consideration the cost of agronomic practices, plant protection measures adopted and market value of produce, using the formula

$$\text{Benefit: Cost Ratio (BCR)} = \frac{\text{Total benefit (Rs.)}}{\text{Total cost (Rs.)}}$$

3.1.5 Statistical analysis and interpretation of data

3.1.5.1 Larval population

Data on larval counts were transformed using square root transformation. Population differences on five, seven and 14 days after each application were first tested by one way ANOVA. Subsequently the transformed data were analyzed by analysis of covariance (ANOCOVA), taking population density prior to the first application as covariate. In the case of first spraying larval count one day prior to application was taken as covariate and ANOCOVA was done for fifth, seventh, and fourteenth day observations. For second spraying, the larval count taken on 14th day after first spraying was fixed as covariate and so on. The result obtained was subjected to DMRT (Duncan's Multiple Range Test).

3.1.5.2 Pod damage

Per cent pod damage was subjected to logit transformation and transformed data was analyzed by ANOVA and the means were separated by DMRT.

3.1.6 Meteorological data

Maximum and minimum temperature, relative humidity and rainfall during the period from flowering (November 2012) till the end of the crop (January 2013) were recorded. The mean weekly values of the meteorological parameters were found out and details are presented in Appendix 1.

3.2 SPECIES COMPOSITION OF POD BORER COMPLEX OF COWPEA

In order to study the species composition of pod borer complex and to find the dominant species attacking cowpea, larval population of pod borers was estimated by counting the number of each species of larvae on the pods and flowers of 10 tagged plants in the control plot. Larvae were identified by colour, shape and other identification features (Sharma *et al.*, 1999; Vijayachander and Arivudainambi, 2007). The per cent incidence of each species was worked out.

3.3 PARASITOIDS ASSOCIATED WITH POD BORERS

Observations were made on the parasitoids of cowpea pod borers. Infested pods were collected from control plots and larvae of each species were reared separately up to adult stage to study the parasitisation, if any. The natural enemies collected were identified by Dr. T. C. Narendran, Coordinator, All India Coordinated Project on Taxonomy and Capacity Building, Zoological Survey of India, Kozhikode.

Results

IV. RESULTS

The results of the investigation on "Eco-friendly management strategies against pod borer complex of cowpea, *Vigna unguiculata* var. *sesquipedalis* (L.) Verdcourt" are presented here.

4.1 FIELD EVALUATION ON THE EFFICACY OF A BOTANICAL, BIOAGENTS AND A SAFER CHEMICAL AGAINST THE LARVAL POPULATION OF POD BORERS

The mean population of pod borer larvae, one day prior to treatment application (pre treatment count) and five, seven and fourteen days after treatment are presented separately for each spraying.

4.1.1 Larval population of pod borers

4.1.1.1 First spraying- Pre treatment count

The larval population recorded one day before imposition of treatments was uniform in all the treatments as indicated by the non-significant difference in the mean larval population among the various treatments. The mean population ranged from 1.50 to 3.15. All the plots showed a pest infestation above the economic threshold level for pod borers, 1 larva per two plants (Table 2).

4.1.1.2 First spraying- Post treatment counts

Five days after the first spraying, the treatments showed significant variation with respect to mean larval population per plant. The mean larval population varied from 0.55 in flubendiamide (T9) to 3.70 in azadirachtin f.b. *B. thuringiensis* (T7) while 2.60 per plant in control (T10). Flubendiamide (T9) was found to be significantly superior over all other treatments. The next best treatment was quinalphos (T8) with a mean larval population of 1.45 per plant and this was found to be on par with *B. thuringiensis* (T4), *B. bassiana* (T2), *M. anisopliae* (T3), azadirachtin (T1) and control (T10) with mean larval count per plant being 3.30, 3.05, 2.50, 1.90 and 2.60 respectively. Among the bioagents

Table 2. Larval population of pod borer complex in different treatments after the first spray

Tr. No.	Treatments	Number of larvae per plant			
		† PTC	†† 5 DAT	†† 7 DAT	†† 14 DAT
T1	Azadirachtin 0.005% (Az)	1.70 (1.45)^{a}	1.90 (1.71)^{abc}	1.25 (1.46)^{a}	0.30 (0.92)^{a}
T2	*Beauveria bassiana* 1% (*Bb*)	2.95 (1.85)^{a}	3.05 (1.64)^{bc}	1.00 (0.95)^{a}	0.10 (0.72)^{a}
T3	*Metarhizium anisopliae* 1% (*Ma*)	2.45 (1.71)^{a}	2.50 (1.66)^{abc}	1.20 (1.19)^{a}	0.50 (0.98)^{a}
T4	*Bacillus thuringiensis* var. *kurstaki* 0.2% (*Bt*)	2.60 (1.76)^{a}	3.30 (1.82)^{abc}	1.40 (1.15)^{a}	0.15 (0.77)^{a}
T5	Azadirachtin 0.005% f.b. *B. bassiana* 1% (Az- *Bb*)	1.50 (1.38)^{a}	2.50 (1.98)^{ab}	1.10 (1.48)^{a}	0.30 (0.95)^{a}
T6	Azadirachtin 0.005% f.b. *M. anisopliae* 1% (Az-*Ma*)	1.80 (1.47)^{a}	2.50 (1.88)^{ab}	0.50 (1.16)^{a}	0.20 (0.88)^{a}
T7	Azadirachtin 0.005% f.b. *B. thuringiensis* 0.2% (Az- *Bt*)	1.75 (1.50)^{a}	3.70 (2.19)^{a}	1.05 (1.39)^{a}	0.10 (0.81)^{a}
T8	Quinalphos 0.05%	2.35 (1.69)^{a}	1.45 (1.40)^{c}	1.30 (1.26)^{a}	1.40 (1.25)^{a}
T9	Flubendiamide 0.008%	3.15 (1.91)^{a}	0.55 (0.75)^{d}	0.10 (0.47)^{a}	0.01 (0.64)^{a}
T10	Control (No treatments)	2.35 (1.65)^{a}	2.60 (1.72)^{abc}	1.60 (1.32)^{a}	0.60 (1.05)^{a}

DAT- Days After Treatment, PTC- Pre Treatment Count, f.b. - followed by

In a column mean followed by a common letter are not significantly different by DMRT (P= 0.05)

†- Values in the parenthesis are square root transformed values, ††- Values in the parenthesis are adjusted means of square root transformed values based on ANOCOVA

and botanicals, azadirachtin (T1) showed the lowest mean larval population followed by *M. anisopliae* (T3), and these treatments were found to be statistically on par.

On the seventh day after spraying all the treatments showed a reduction in the larval population and the mean values varied from 0.10 larvae per plant in flubendiamide (T9) to 1.6 larvae per plant in the control (T10). The values were equal to or greater than the ETL except in flubendiamide (T9). Among the bioagents, T6 (azadirachtin f.b. *M. anisopliae*) showed the lowest mean population of 0.50 larvae per plant followed by *B. bassiana* (T2) (1.0). All the treatments were statistically on par with untreated control (Table 2).

On the fourteenth day after spraying the larval population showed further reduction in numbers and recorded values below ETL except in quinalphos (T8) (1.40) and control (T10) (0.60). The highest population of pod borers was recorded in quinalphos (T8) and lowest was in flubendiamide (T9) (0.01). All the treatments were found to be statistically on par (Table 2).

4.1.1.3 Second spraying- Post treatment counts

All the treatments were statistically on par on the fifth and seventh day also with respect to mean larval population (Table 3).

On the fourteenth day after spraying the mean larval population increased above ETL in four treatments, namely azadirachtin f.b. *B. bassiana* (T5) (0.60), *B. bassiana* (T2) (0.70), azadirachtin f.b. *B. thuringiensis* (T7) (0.95), and control (T10) (1.65). Flubendiamide (T9) recorded the lowest mean larval population (0.1). This was found to be on par with *B. thuringiensis* (T4) (0.30), azadirachtin (T1) (0.30), *M. anisopliae* (T3) (0.45), azadirachtin f.b. *M. anisopliae* (T6) (0.50), quinalphos (T8) (0.50), azadirachtin f.b. *B. bassiana* (T5) (0.60) and *B. bassiana* (T2) (0.70). The highest infestation was recorded in control (T10) (1.65). Among the bioagents, azadirachtin f.b. *B. thuringiensis* (T7) (0.95) recorded the highest population followed by *B. bassiana* (T2) (0.70), azadirachtin f.b. *B. bassiana* (T5)

Table 3. Larval population of pod borer complex in different treatments after the second spray

Tr. No.	Treatments	Number of larvae per plant			
		† PTC	†† 5 DAT	†† 7 DAT	†† 14 DAT
T1	Azadirachtin 0.005% (Az)	0.30 (0.878)^{a}	0.05 (0.74)^{a}	0.00 (0.71)^{a}	0.30 (0.89)^{bc}
T2	*Beauveria bassiana* 1% (*Bb*)	0.10 (0.772)^{a}	0.00 (0.71)^{a}	0.05 (0.75)^{a}	0.70 (1.08)^{bc}
T3	*Metarhizium anisopliae* 1% (*Ma*)	0.50 (1.000)^{a}	0.00 (0.71)^{a}	0.00 (0.70)^{a}	0.45 (0.99)^{bc}
T4	*Bacillus thuringiensis* var. *kurstaki* 0.2% (*Bt*)	0.15 (0.801)^{a}	0.05 (0.74)^{a}	0.05 (0.75)^{a}	0.30 (0.88)^{bc}
T5	Azadirachtin 0.005% f.b. *B. bassiana* 1% (Az- *Bb*)	0.30 (0.887)^{a}	0.10 (0.77)^{a}	0.10 (0.77)^{a}	0.60 (1.04)^{bc}
T6	Azadirachtin 0.005% f.b. *M. anisopliae* 1% (Az-*Ma*)	0.20 (0.837)^{a}	0.00 (0.71)^{a}	0.05 (0.74)^{a}	0.50 (0.99)^{bc}
T7	Azadirachtin 0.005% f.b. *B. thuringiensis* 0.2% (Az- *Bt*)	0.10 (0.772)^{a}	0.10 (0.78)^{a}	0.15 (0.81)^{a}	0.95 (1.19)^{ab}
T8	Quinalphos 0.05%	1.40 (1.262)^{a}	0.05 (0.73)^{a}	0.00 (0.69)^{a}	0.50 (1.04)^{bc}
T9	Flubendiamide 0.008%	0.01 (0.707)^{a}	0.00 (0.71)^{a}	0.00 (0.71)^{a}	0.10 (0.75)^{c}
T10	Control (No treatments)	0.60 (1.049)^{a}	0.20 (0.83)^{a}	0.25 (0.86)^{a}	1.65 (1.48)^{a}

DAT- Days After Treatment, PTC- Pre Treatment Count, f.b. - followed by

In a column mean followed by a common letter are not significantly different by DMRT (P= 0.05)

†- Values in the parenthesis are square root transformed values, ††- Values in the parenthesis are adjusted means of square root transformed values based on ANOCOVA

(0.60), azadirachtin f.b. *M. anisopliae* (T6) (0.50) and *M. anisopliae* (T3) (0.45). But these treatments were found to be statistically on par with respect to mean larval population and were significantly superior over control. Azadirachtin f.b. *B. thuringiensis* (T7) (0.95) and control (T10) (1.65) recorded higher mean larval count/plant and were statistically on par (Table 3).

4.1.1.4 Third spraying- Post treatment counts

On the fifth day after third spraying *B. bassiana* (T2) (0.60), azadirachtin f.b. *M. anisopliae* (T6) (0.55) and control (T10) (0.60) showed an infestation above economic threshold level. Lowest mean larval population of zero larva per plant was observed in flubendiamide (T9). All the treatments were statistically on par with untreated control (Table 4).

Similar trend was observed on seventh day also and all the treatments were on par with respect to mean larval population. All the treatments except azadirachtin f. b. *B. thuringiensis* (T7) (0.50 larvae per plant) recorded infestation below economic threshold level. Quinalphos (T8) and flubendiamide (T9) showed zero mean larval population of pod borers (Table 4).

The pod borer infestation was very low in the treatments and control after third application of the treatments. Influence of treatments could not be visualized as the difference between control and the treatments compared showed no significant difference (Table 4).

Considering the three consecutive sprays, the mean larval population per plant remained below ETL in treatments like azadirachtin (T1), *M. anisopliae* (T3), and *B. thuringiensis* (T4) from 14th day after the first spray. Flubendiamide consistently recorded lowest population of pod borer larvae from fifth day after the first spray. Control (T10) though showed larval population below ETL at five and seven days after the second spray, exhibited borer infestation above ETL during other observations.

Table 4. Larval population of pod borer complex in different treatments after the third spray

Tr. No.	Treatments	Number of larvae per plant		
		† PTC	†† 5 DAT	†† 7 DAT
T1	Azadirachtin 0.005% (Az)	0.30 (0.89)^{cd}	0.10 (0.80)^{a}	0.10 (0.79)^{a}
T2	*Beauveria bassiana* 1% (*Bb*)	0.70 (1.09)^{bc}	0.60 (1.03)^{a}	0.40 (0.92)^{a}
T3	*Metarhizium anisopliae* 1% (*Ma*)	0.45 (0.97)^{bcd}	0.30 (0.92)^{a}	0.25 (0.88)^{a}
T4	*Bacillus thuringiensis* var. *kurstaki* 0.2% (*Bt*)	0.30 (0.89)^{cd}	0.25 (0.91)^{a}	0.15 (0.83)^{a}
T5	Azadirachtin 0.005% f.b. *B. bassiana* 1% (Az- *Bb*)	0.60 (1.04)^{bcd}	0.45 (0.97)^{a}	0.35 (0.92)^{a}
T6	Azadirachtin 0.005% f.b. *M. anisopliae* 1% (Az-*Ma*)	0.50 (1.00)^{bcd}	0.55 (1.03)^{a}	0.45 (0.97)^{a}
T7	Azadirachtin 0.005% f.b. *B. thuringiensis* 0.2% (Az- *Bt*)	0.95 (1.20)^{ab}	0.50 (0.95)^{a}	0.50 (0.97)^{a}
T8	Quinalphos 0.05%	0.50 (1.00)^{bcd}	0.10 (0.79)^{a}	0.00 (0.72)^{a}
T9	Flubendiamide 0.008%	0.10 (0.78)^{d}	0.00 (0.79)^{a}	0.00 (0.76)^{a}
T10	Control (No treatments)	1.65 (1.46)^{a}	0.60 (0.91)^{a}	0.45 (0.89)^{a}

DAT- Days After Treatment, PTC- Pre Treatment Count, f.b. - followed by

In a column mean followed by a common letter are not significantly different by DMRT (P= 0.05)

†- Values in the parenthesis are square root transformed values, ††- Values in the parenthesis are adjusted means of square root transformed values based on ANOCOVA

4.1.2 Per cent reduction in the larval population of pod borers in different treatments over control

The per cent reduction in the larval population of pod borers in different treatments over control during each spraying is given in Table 5.

4.1.2.1 First spraying

Highest per cent reduction (86.46%) in the population of pod borer larvae was observed in flubendiamide (T9). The next best treatment with respect to per cent reduction was azadirachtin f.b. *M. anisopliae* (T6) (33.33%). There was an increase in the population of pod borer larvae in *B. thuringiensis* (T4) (-1.04%).

4.1.2.2 Second spraying

After second spraying, the per cent reduction in the population of pod borers was highest in flubendiamide (T9) (95.65%) when compared to other treatments. The next best treatments with respect to per cent reduction were azadirachtin (T1) (84.78%) and *B. thuringiensis* (T4) (82.61%), and *M. anisopliae* (T3) (80.43%). *B. thuringiensis* application took considerable time to be effective.

4.1.3 Effect of botanicals, bioagents and synthetic insecticides on the damage by pod borers

The mean number and per cent of pods infested (in terms of number and weight) by borers during the three harvests are given below.

4.1.3.1 Infestation (On number basis)

4.1.3.1.1 First harvest

The first harvest was made six days after the first spray. The number of pods damaged by pod borers varied significantly in the different treatments. The lowest number of pods infested was observed in flubendiamide (T9) (35.50) followed by azadirachtin f. b. *B. bassiana* (T5) (79.50) and quinalphos (T8) (83.50 pods) and these treatments were on par. The highest number of infested pods was recorded in *B. bassiana* (T2) with 208 pods and this was found to be

Table 5. Per cent reduction in the larval population of pod borers in different treatments over control

Tr. No.	Treatments	Per cent reduction in larval population	
		First spray	Second spray
T1	Azadirachtin 0.005% (Az)	28.13	84.78
T2	*Beauveria bassiana* 1% (*Bb*)	13.54	65.22
T3	*Metarhizium anisopliae* 1% (*Ma*)	12.50	80.43
T4	*Bacillus thuringiensis* var. *kurstaki* 0.2% (*Bt*)	-1.04	82.61
T5	Azadirachtin 0.005% f.b. *B. bassiana* 1% (Az- *Bb*)	18.75	63.04
T6	Azadirachtin 0.005% f.b. *M. anisopliae* 1% (Az-*Ma*)	33.33	71.74
T7	Azadirachtin 0.005% f.b. *B. thuringiensis* 0.2% (Az- *Bt*)	-2.08	43.48
T8	Quinalphos 0.05%	13.54	76.09
T9	Flubendiamide 0.008%	86.46	95.65

statistically on par with *B. thuringiensis* (T4) (177.5), *M. anisopliae* (T3) (162.50), azadirachtin f.b. *M. anisopliae* (T6) (157), azadirachtin f.b. *B. thuringiensis* (T7) (138), azadirachtin (T1) (126) and control (T10) (118.50). Flubendiamide (T9) (35.50) was significantly superior to majority of the treatments except quinalphos (T8) (83.50) and azadirachtin f.b. *B. bassiana* (T5) (79.50) (Table 6).

4.1.3.1.2 Second harvest

In the second harvest done 14 days after the first spray, all the treatments were statistically on par and the number of damaged pods varied from three in flubendiamide (T9) to 133 in *B. thuringiensis* (T4) (Table 6).

4.1.3.1.3 Third harvest

In the third harvest done eight days after third spray also, there was no significant difference between the treatments for the number of borer damaged pods. The mean values varied from 10 in azadirachtin f.b. *M. anisopliae* (T6) to 33.5 in *B. bassiana* (T2). Control (T10) also recorded 33 damaged pods (Table 6).

4.1.3.2 Per cent infestation (On number basis)

4.1.3.2.1 First harvest

With respect to per cent infestation by number of borer damaged pods, all the treatments were found to be statistically on par and the lowest damage was in flubendiamide (T9) (4.62%). *M. anisopliae* (T3) recorded the highest damage (34.31%) (Table 7).

4.1.3.2.2 Second harvest

In the second harvest, the treatments varied significantly with respect to per cent infestation by number and flubendiamide (T9) (0.52%) was found to be superior over rest of the treatments. All other treatments were statistically on par.

Table 6. Effect of different treatments on pod borer infestation (On number basis)

Tr. No.	Treatments	Number of pods infested		
		First Harvest	Second Harvest	Third Harvest
T1	Azadirachtin 0.005% (Az)	126.00 (11.21)^{ab}	35.50 (5.49)^{a}	10.50 (3.32)^{a}
T2	*Beauveria bassiana* 1% (*Bb*)	208.00 (14.40)^{a}	43.50 (6.59)^{a}	33.50 (5.59)^{a}
T3	*Metarhizium anisopliae* 1% (*Ma*)	162.50 (12.72)^{ab}	84.50 (9.22)^{a}	12.00 (3.51)^{a}
T4	*Bacillus thuringiensis* var. *kurstaki* 0.2% (*Bt*)	177.50 (13.34)^{ab}	133.00 (11.09)^{a}	20.50 (4.48)^{a}
T5	Azadirachtin 0.005% f.b. *B. bassiana* 1% (Az- *Bb*)	79.50 (8.65)^{bc}	36.50 (6.06)^{a}	23.00 (4.78)^{a}
T6	Azadirachtin 0.005% f.b. *M. anisopliae* 1% (Az-*Ma*)	157.00 (12.33)^{ab}	48.00 (6.99)^{a}	10.00 (3.18)^{a}
T7	Azadirachtin 0.005% f.b. *B. thuringiensis* 0.2% (Az- *Bt*)	138.00 (11.75)^{ab}	56.00 (7.15)^{a}	16.50 (4.12)^{a}
T8	Quinalphos 0.05%	83.50 (9.13)^{bc}	129.50 (10.36)^{a}	30.00 (5.52)^{a}
T9	Flubendiamide 0.008%	35.50 (6.00)^{c}	3.00 (1.63)^{a}	15.00 (3.90)^{a}
T10	Control (No treatments)	118.50 (10.811)^{ab}	48.50 (6.545)^{a}	33.00 (5.77)^{a}

f.b. – followed by

In a column mean followed by a common letter are not significantly different by DMRT (P= 0.05)

Values in the parenthesis are square root transformed values

Table 7. Effect of different treatments on per cent pod borer infestation (On number basis)

Tr. No.	Treatments	Per cent infestation by number		
		First Harvest	Second Harvest	Third Harvest
T1	Azadirachtin 0.005% (Az)	23.36 (-1.21)^{a}	11.27 (-2.27)^{a}	4.01 (-3.18)^{d}
T2	*Beauveria bassiana* 1% (*Bb*)	31.98 (-0.76)^{a}	11.60 (-2.04)^{a}	8.22 (-2.41)^{bc}
T3	*Metarhizium anisopliae* 1% (*Ma*)	34.31 (-0.68)^{a}	22.32 (-1.27)^{a}	4.59 (-3.07)^{cd}
T4	*Bacillus thuringiensis* var. *kurstaki* 0.2% (*Bt*)	30.51 (-0.83)^{a}	25.37 (-1.08)^{a}	9.13 (-2.31)^{b}
T5	Azadirachtin 0.005% f.b. *B. bassiana* 1% (Az- *Bb*)	20.48 (-1.47)^{a}	16.05 (-1.66)^{a}	7.26 (-2.57)^{bcd}
T6	Azadirachtin 0.005% f.b. *M. anisopliae* 1% (Az-*Ma*)	29.98 (-0.90)^{a}	16.34 (-1.63)^{a}	5.37 (-2.92)^{bcd}
T7	Azadirachtin 0.005% f.b. *B. thuringiensis* 0.2% (Az- *Bt*)	20.87 (-1.38)^{a}	13.02 (-1.98)^{a}	6.30 (-2.76)^{bcd}
T8	Quinalphos 0.05%	16.41 (-1.69)^{a}	14.99 (-1.86)^{a}	9.67 (-2.33)^{b}
T9	Flubendiamide 0.008%	4.62 (-3.03)^{a}	0.52 (-6.89)^{b}	5.58 (-2.83)^{bcd}
T10	Control (No treatments)	23.91 (-1.23)^{a}	14.51 (-1.82)^{a}	16.93 (-1.59)^{a}

f.b. – followed by

In a column mean followed by a common letter are not significantly different by DMRT (P= 0.05)

Values in the parenthesis are logit transformed values

B. thuringiensis (T4) (25.37%) recorded the highest infestation followed by *M. anisopliae* (T3) (22.32%) and these treatments were on par (Table 7).

4.1.3.2.3 Third harvest

In the third harvest, all the treatments were significantly superior over control (T10) (16.93%) in reducing the damage by pod borers. Azadirachtin (T1) recorded the lowest damage (4.01%) and was statistically on par with treatments, *viz.*, *M. anisopliae* (T3) (4.59%), azadirachtin f.b. *M. anisopliae* (T6) (5.37%), flubendiamide (T9) (5.58%) azadirachtin f.b. *B. thuringiensis* (T7) (6.30) and azadirachtin f.b. *B. bassiana* (7.26) (Table 7).

4.1.3.3 Per cent infestation (On weight basis)

4.1.3.3.1 First harvest

With respect to per cent damage in terms of pod weight, all the treatments were statistically on par though the damage varied from 3.50 per cent in flubendiamide (T9) to 34.86 per cent in *B. thuringiensis* (T4). Control suffered a damage of 16.55 per cent (Table 8).

4.1.3.3.2 Second harvest

Flubendiamide (T9) (0.40%) was found to be statistically superior over all other treatments with respect to per cent pod damage (in terms of weight). All other treatments were statistically on par with highest damage in *B. thuringiensis* (T4) (18.50%) than in control (T10) having 14.60 per cent (Table 8).

4.1.3.3.3 Third harvest

In the third harvest, the per cent infestation did not vary significantly in different treatments. Control (T10) had the highest damage (12.12%) and the lowest damage was recorded in azadirachtin (T1) (2.83%) (Table 8).

Table 8. Effect of different treatments on per cent pod borer infestation by weight

Tr. No.	Treatments	Per cent infestation by weight		
		First Harvest	Second Harvest	Third Harvest
T1	Azadirachtin 0.005% (Az)	24.26 (-1.18)^{a}	10.26 (-2.34)^{a}	2.83 (-3.55)^{a}
T2	*Beauveria bassiana* 1% (*Bb*)	23.45 (-1.38)^{a}	18.38 (-1.55)^{a}	5.52 (-2.87)^{a}
T3	*Metarhizium anisopliae* 1% (*Ma*)	34.57 (-0.67)^{a}	14.65 (-1.78)^{a}	4.97 (-2.95)^{a}
T4	*Bacillus thuringiensis* var. *kurstaki* 0.2% (*Bt*)	34.86 (-0.63)^{a}	18.50 (-1.52)^{a}	7.01 (-2.67)^{a}
T5	Azadirachtin 0.005% f.b. *B. bassiana* 1% (Az- *Bb*)	19.22 (-1.57)^{a}	14.67 (-1.76)^{a}	6.42 (-2.70)^{a}
T6	Azadirachtin 0.005% f.b. *M. anisopliae* 1% (Az-*Ma*)	29.18 (-0.95)^{a}	14.04 (-1.81)^{a}	5.37 (-2.91)^{a}
T7	Azadirachtin 0.005% f.b. *B. thuringiensis* 0.2% (Az- *Bt*)	21.53 (-1.34)^{a}	18.70 (-1.47)^{a}	6.48 (-2.89)^{a}
T8	Quinalphos 0.05%	13.73 (-1.88)^{a}	14.17 (-1.96)^{a}	8.19 (-2.52)^{a}
T9	Flubendiamide 0.008%	3.50 (-3.33)^{a}	0.40 (-7.03)^{b}	5.87 (-2.87)^{a}
T10	Control (No treatments)	16.55 (-1.64)^{a}	14.60 (-1.80)^{a}	12.12 (-2.01)^{a}

f.b. – followed by

In a column mean followed by a common letter are not significantly different by DMRT (P= 0.05)

Values in the parenthesis are logit transformed values

4.1.4 Yield

4.1.4.1 Total yield

The total yield obtained in different treatments is presented in Table 9.

4.1.4.1.1 Pod number

The total number of pods varied from 1614.50 in quinalphos (T8) to 957 pods per plot in azadirachtin f.b. *B. bassiana* (T5). Control (T10) had a total yield of 1013.50 pods per plot. There was no significant difference among the treatments with respect to pod number.

4.1.4.1.2 Pod weight

The yield per plot did not vary significantly in different treatments. Quinalphos (T8) resulted in the highest yield of 5.86 kg pods per plot ($9m^2$) followed by flubendiamide (T9) which recorded a value of 5.71 kg. The lowest yield was in azadirachtin f.b. *M. anisopliae* (T6) (3.03 kg pods per plot) while control (T10) plot had a yield of 3.64 kg pods.

4.1.4.2 Marketable yield

The marketable yield obtained in different treatments is presented in Table 9.

4.1.4.2.1 Pod number

Application of flubendiamide (T9) resulted in the highest number of marketable pods (1463 pods per plot) followed by quinalphos (T8) (1371.5 pods per plot) and these two treatments were on par. Azadirachtin f. b. *B. thuringiensis* (T7) produced the next highest yield (1178 pods per plot) followed by *B. bassiana* (T2) (1141 pods per plot) and these were on par with the two chemical insecticides. The treatments T7 and T2 were also found to be on par with *B. thuringiensis* (T4), azadirachtin (T1), *M. anisopliae* (T3) azadirachtin f.b. *B.*

Table 9. Total yield, marketable yield and per cent marketable yield in different treatments (from 9m^{2})

Treatments	Total yield		Marketable yield		Per cent marketable yield	
	Pod number	Pod weight (kg)	Pod number	Pod weight (kg)	Pod number	Pod weight
Azadirachtin 0.005% (Az)	1081.50^{a}	3.90^{a}	909.50^{bc}	3.20^{a}	84.13^{b}	81.92^{a}
Beauveria bassiana 1% (*Bb*)	1426.00^{a}	4.97^{a}	1141.00^{abc}	3.96^{a}	80.02^{b}	79.66^{a}
Metarhizium anisopliae 1% (*Ma*)	1145.50^{a}	4.55^{a}	886.50^{bc}	3.56^{a}	77.37^{b}	78.13^{a}
Bacillus thuringiensis var. *kurstaki* 0.2% (*Bt*)	1307.00^{a}	5.34^{a}	976.00^{bc}	3.92^{a}	74.92^{b}	73.48^{a}
Azadirachtin 0.005% f.b. *B. bassiana* 1% (Az- *Bb*)	957.00^{a}	3.67^{a}	818.00^{bc}	3.09^{a}	86.03^{b}	84.06^{a}
Azadirachtin 0.005% f.b. *M. anisopliae* 1% (Az-*Ma*)	993.00^{a}	3.03^{a}	778.00^{c}	2.31^{a}	78.72^{b}	76.07^{a}
Azadirachtin 0.005% f.b. *B. thuringiensis* 0.2% (Az- *Bt*)	1388.50^{a}	4.47^{a}	1178.00^{ab}	3.66^{a}	84.36^{b}	81.97^{a}
Quinalphos 0.05%	1614.50^{a}	5.86^{a}	1371.50^{a}	4.99^{a}	85.79^{b}	85.23^{a}
Flubendiamide 0.008%	1516.50^{a}	5.71^{a}	1463.00^{a}	5.56^{a}	96.44^{a}	97.37^{a}
Control (No treatments)	1013.50^{a}	3.64^{a}	813.50^{bc}	3.05^{a}	80.76^{b}	83.79^{a}

f.b. – followed by

In a column mean followed by a common letter are not significantly different by DMRT (P= 0.05) *bassiana* (T5) and control (T10) which had a marketable yield of 813.5 pods per plot. Azadirachtin f.b. *M. anisopliae* (T6) resulted in the lowest marketable yield of 778 pods/plot.

4.1.4.2.2 Pod weight

The pod weight did not vary significantly between the treatments. There was no significant difference between the treatments with respect to pod weight. Highest marketable yield in weight was in flubendiamide (T9) (5.56 kg pods) followed by quinalphos (T8) (4.99 kg pods) and *B. bassiana* (T2) (3.96 kg pods). The lowest pod weight was recorded in azadirachtin f.b. *M. anisopliae* (T6) (2.31 kg pods).

4.1.4.3 Per cent marketable yield

Per cent marketable yield by pod number and pod weight obtained in different treatments is presented in Table 9.

4.1.4.3.1 Pod number

The treatments varied significantly with respect to per cent marketable yield by pod number. Flubendiamide (T9) (96.4) was significantly superior over rest of the treatments with highest per cent pod yield. Rests of the treatments were on par with each other.

4.1.4.3.2 Pod weight

Per cent marketable yield by weight did not vary significantly among the treatments. Highest value was recorded in flubendiamide (T9) (97.37) followed by quinalphos (T8) (85.23). The lowest per cent marketable yield by weight was recorded in *B. thuringiensis* (T4) (73.48).

4.1.5 Benefit: Cost Ratio (BCR)

Benefit: Cost Ratio was worked out for each treatment taking into consideration the agronomic practices, plant protection measures adopted and market value of produce and is presented in Table 10.

The treatment flubendiamide (T9) recorded the highest income (Rs. 987554.57ha $^{-1}$) followed by quinalphos (T8) (Rs. 887110.22 ha^{-1}). *B. bassiana* (T2) recorded a total return of Rs. 703110.41 ha^{-1} followed by *B. thuringiensis* (T4) (Rs. 696888.19 ha^{-1}), azadirachtin f.b. *B. thuringiensis* (T7) (Rs. 650666.02 ha^{-1}) and *M. anisopliae* (T3) (Rs. 631999.37 ha^{-1}). Azadirachtin (T1) and azadirachtin f.b. *B. bassiana* (T5) recorded a total return of Rs. 567999.43 ha^{-1} and Rs. 548443.90 ha^{-1} respectively. The lowest return was from azadirachtin f.b. *M. anisopliae* (T6) (Rs. 409777.37 ha^{-1}).

The result on Benefit: Cost Ratio indicated that the application of flubendiamide (T9) had the highest B: C Ratio (1.69) and was followed by quinalphos (T8) (1.53). Among the bioagents, *B. bassiana* (T2) resulted in the highest B: C Ratio (1.22) followed by *B. thuringiensis* (T4) (1.20), azadirachtin f.b. *B. thuringiensis* (T7) (1.12) and *M. anisopliae* (T3) (1.09).

4.2 SPECIES COMPOSITION OF POD BORER COMPLEX OF COWPEA

The species composition of pod borer complex is given in Table 11.

During the period of study two different pod borers were recorded on cowpea as given below (Plates 2 and 3).

1. Spotted pod borer : *Maruca vitrata* (Fabricius) (Crambidae)
2. Pea blue butterfly : *Lampides boeticus* (L.) (Lycaenidae)

Maruca vitrata was found to be the dominant species of pod borer infesting cowpea under Vellanikkara conditions. The per cent incidence of *M. vitrata* varied from 97.87 per cent observed at 50 per cent flowering (19/11/12) to

Table 10. Benefit: Cost Ratio for different treatments for the management of pod borer complex of cowpea

Tr. No.	Treatments	Return * (Rs. ha^{-1})	Total cost (Rs.)	Benefit Cost Ratio
T1	Azadirachtin 0.005% (Az)	567999.43	587722.27	0.97
T2	*Beauveria bassiana* 1% (*Bb*)	703110.41	577611.16	1.22
T3	*Metarhizium anisopliae* 1% (*Ma*)	631999.37	577611.16	1.09
T4	*Bacillus thuringiensis* var. *kurstaki* 0.2% (*Bt*)	696888.19	580500.04	1.20
T5	Azadirachtin 0.005% f.b. *B. bassiana* 1% (Az- *Bb*)	548443.90	580981.53	0.94
T6	Azadirachtin 0.005% f.b. *M. anisopliae* 1% (Az- *Ma*)	409777.37	580981.53	0.71
T7	Azadirachtin 0.005% f.b. *B. thuringiensis* 0.2% (Az- *Bt*)	650666.02	582907.45	1.12
T8	Quinalphos 0.05%	887110.22	578277.82	1.53
T9	Flubendiamide 0.008%	987554.57	583388.93	1.69
T10	Control	542221.68	548278.60	0.99

* The price of the produce is taken as Rs. 40 per kg

f.b. - followed by

Table 11. Species composition of pod borer complex of cowpea

Days After Sowing (DAS)	Larvae /10 plants		Infestation (%)	
	M. vitrata	*L. boeticus*	*M. vitrata*	*L. boeticus*
48 DAS (November 3rd week)	46	1	97.87	2.13
54 DAS (November 3rd week)	48	4	92.31	7.69
56 DAS (November 4th week)	31	1	96.88	3.13
63 DAS (December 1st week)	11	1	91.67	8.33
71 DAS (December 2nd week)	3	1	75.00	25.00
73 DAS (December 2nd week)	3	2	60.00	40.00
80 DAS (December 3rd week)	21	12	63.64	36.36
86 DAS (December 4th week)	9	3	75.00	25.00
88 DAS (December 4th week)	6	3	66.67	33.33
Mean	19.78	3.11	79.89 ±14.95	20.11 ±14.95

Plate 2. Spotted pod borer- *Maruca vitrata*

Plate 2a. Larva of *M. vitrata* on flower

Plate 2b. Larva inside the pod

Plate 2c. Damaged pods

Plate 2d. Adult of *M. vitrata*

Plate 3. Pea blue butterfly- *Lampides boeticus*

Plate 3a. Larva of *L. boeticus*

Plate 3b. Ant tending the larva

Plate 3c. Female laying eggs

Plate 3d. Damaged pods

60 per cent during the middle of December (14/12/2012). The larval count recorded at 50 per cent flowering (19/11/2012) showed 97.87 per cent incidence of *M. vitrata* and 2.13 per cent of *L. boeticus.* The per cent incidence of *L. boeticus* remained below ten per cent till 4/12/2012. Gradually the population of *L. boeticus* increased when there were more pods in the field compared to flowers and the highest incidence reported during the period of study was 40 per cent (14/12/2012).

4.3 PARASITOIDS ASSOCIATED WITH POD BORERS

Two species of parasitoids were recorded (Plate 4) on *M. vitrata* as given as given below.

Table 12. Parasitoids recorded on *M. vitrata*

Sl. No.	Scientific name	Family	Host stage attacked
1	*Apanteles* sp.	Braconidae	Larvae
2	*Phanerotoma* sp.	Braconidae	Larvae

Plate 4. Parasitoids of *Maruca vitrata*

Plate 4a. *Apanteles* sp.

Plate 4b. *Phanerotoma* sp.

Discussion

V. DISCUSSION

Cowpea is a protein rich pulse crop which is grown extensively in Kerala. Of the various factors responsible for reducing the yield of cowpea, pod borers are an important insect pest which causes substantial yield loss by destroying the developing flowers and the pods. Large quantities of highly toxic chemical insecticides are used by the farmers at short intervals for managing the pod borer complex. Indiscriminate and inappropriate use of insecticides poses high risk to biodiversity and leads to the accumulation of harmful residues in the pods. Hence to find out an eco-friendly strategy for managing the pod borer complex of cowpea, one botanical, three bioagents (along with their sequential applications) and a new generation safer chemical were evaluated under field conditions at College of Horticulture, Vellanikkara. *Bhagyalakshmi*, a short duration bushy cowpea variety with bold pods, released by Kerala Agricultural University was used for the study. The detailed discussion on the results is presented under the following headings.

5.1 FIELD EVALUATION ON THE EFFICACY OF BIOPESTICIDES, BOTANICALS AND SAFER CHEMICALS AGAINST POD BORER COMPLEX OF COWPEA

5.1.1 Larval population

Considering the three consecutive sprays, flubendiamide consistently recorded the lowest population of pod borer larvae from fifth day after the first spray till the end of cropping period. Five days after first spraying flubendiamide resulted in the lowest larval population and was significantly superior over all other treatments (Table 2, Fig. 1). On the fourteenth day after second spraying also, flubendiamide recorded lowest larval population and was significantly superior over control (Table 3). The population of pod borers remained below economic threshold level starting from seven days after first spray onwards (Tables 2, 3 and 4, Fig. 1, 2, and 3). Hence application of flubendiamide was found to be the best treatment compared to the botanical and bioagents in

Figure 1. Larval population of pod borer complex in different treatments after the first spray

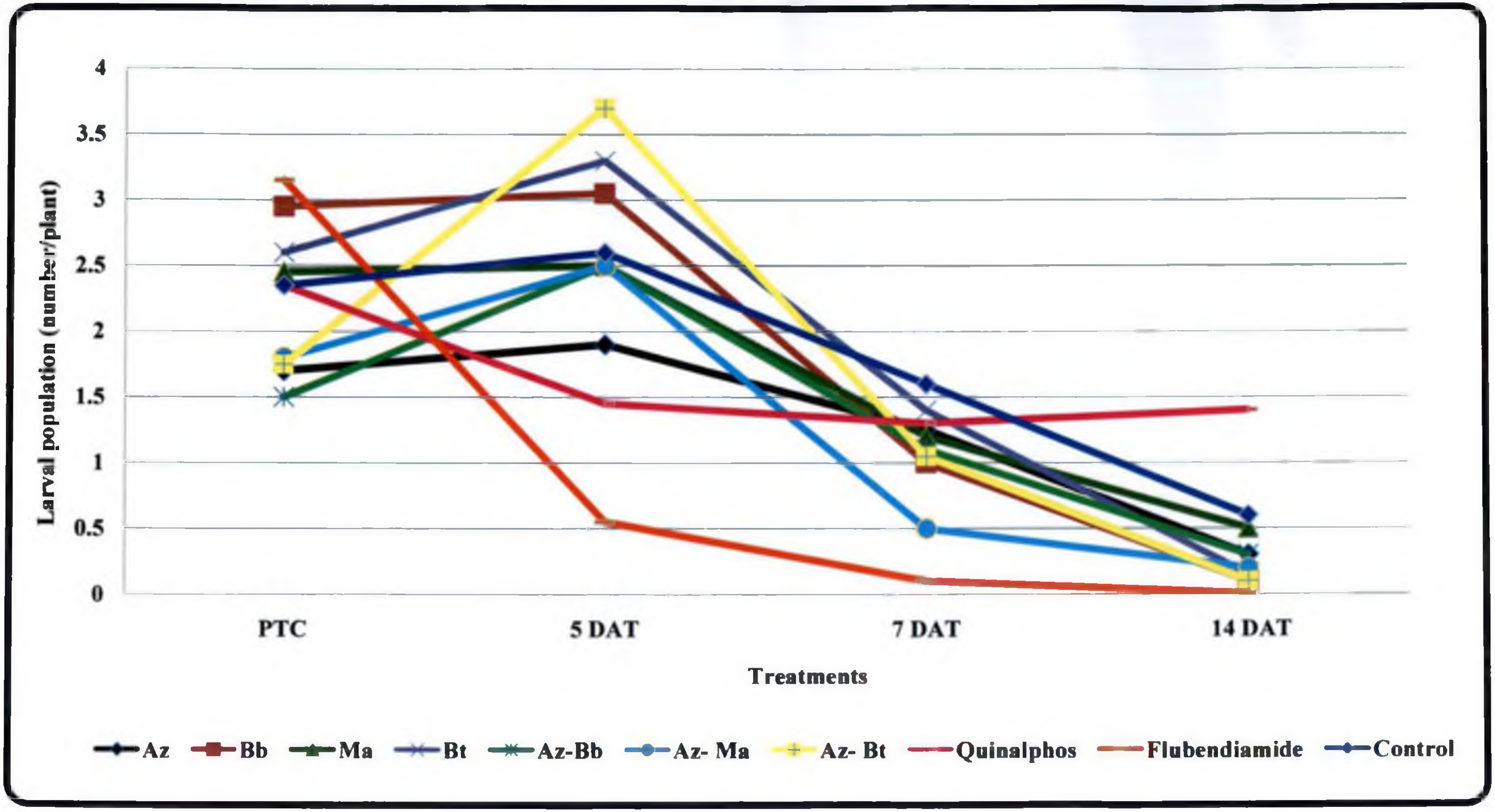


Figure 2. Larval population of pod borer complex in different treatments after the second spray

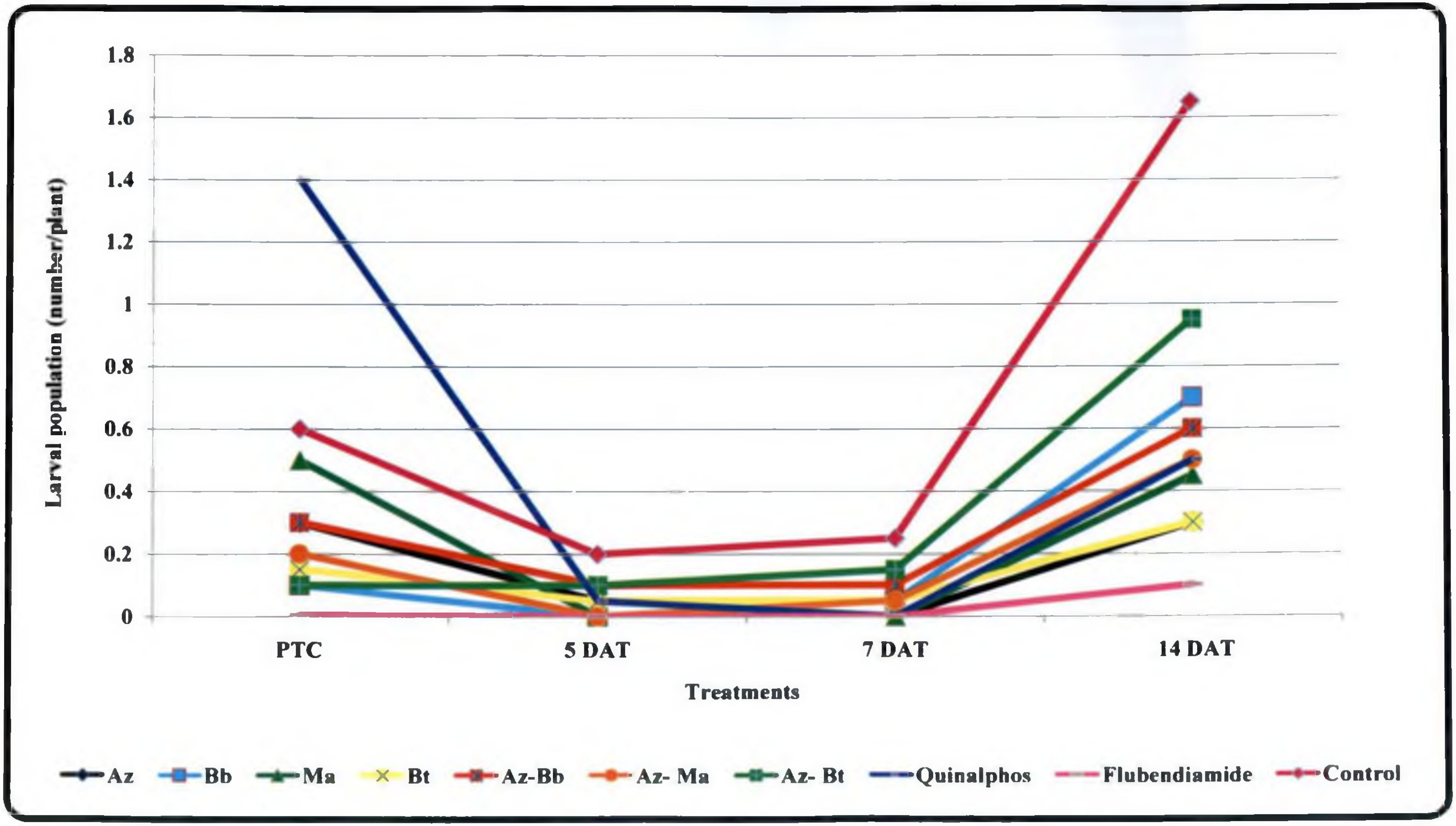
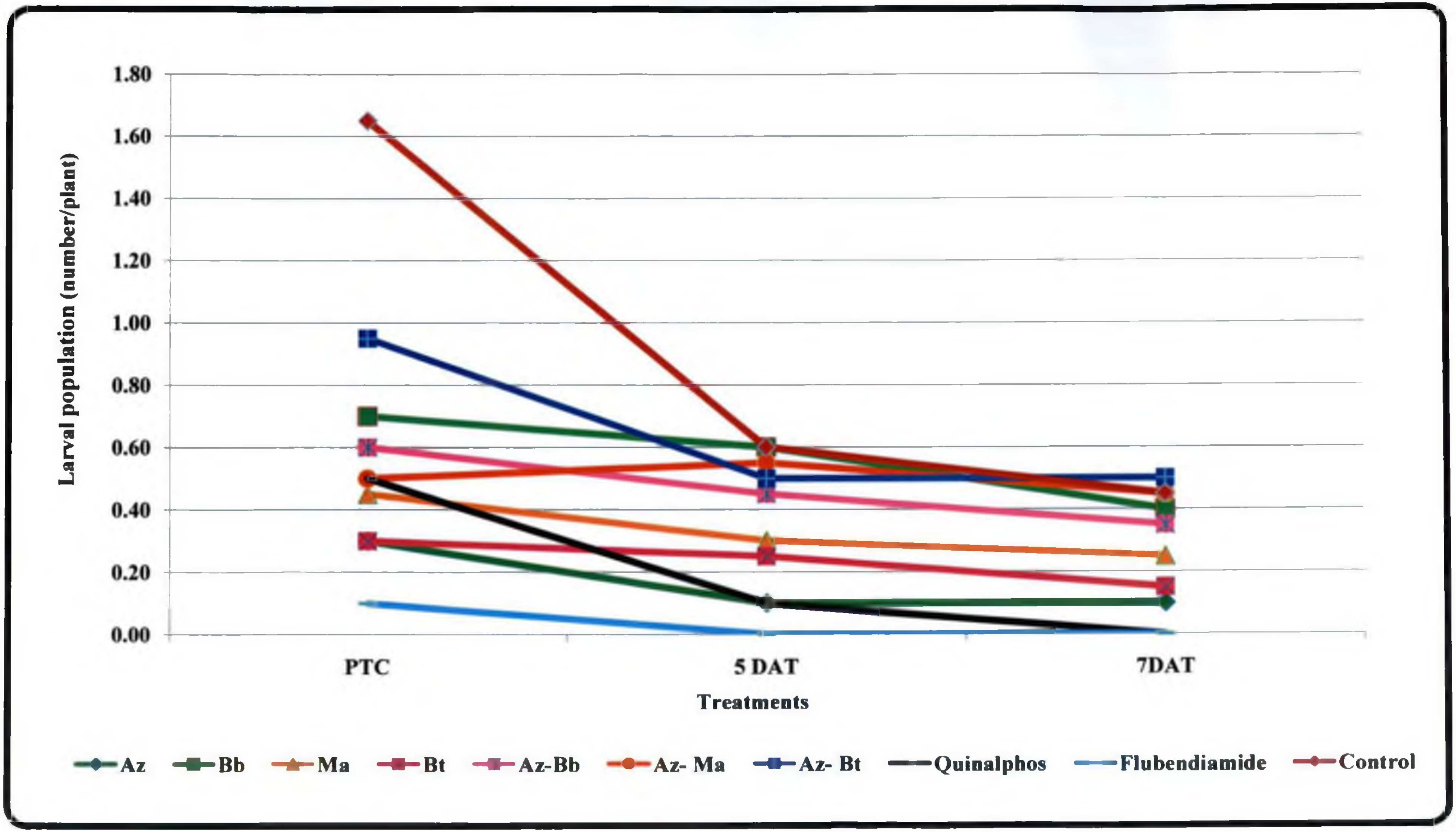


Figure 3. Larval population of pod borer complex in different treatments after the third spray



reducing the larval population of pod borers throughout the growing season of cowpea. Ameta and Bunker (2007) observed that flubendiamide at 50 ml/ha caused significantly higher reduction in the larval population of diamond back moth. The effectiveness of the same against pod borers of dolichos bean was reported by Mallikarjuna *et al.* (2009) where it rendered higher yield on par with indoxacarb and emamectin benzoate. Flubendiamide at 0.01 per cent recorded highest ovicidal and larvicidal action in the laboratory and highest reduction in larval population (97.02%) of *H. armigera* (Babar *et al.*, 2012).

Medium and higher doses of flubendiamide 480SC (37.5 and 50.0 ml/ha) significantly reduced the larval population of *Plutella xylostella* (Gill *et al.*, 2010). Flubendiamide was effective in reducing the population of diamond back moth in cabbage (Chatterjee and Mondal, 2012) and bud worm in tobacco (Shivanna *et al.* 2012).

Flubendiamide is a novel green labeled insecticide which shows strong insecticidal activity against lepidopterans. The specificity of flubendiamide to Lepidoptera is due to the structure of ryanodine receptors (RyR). Flubendiamide can only bind with RyR of Lepidoptera and is inactive with mammalian RyR forms (Nauen *et al.*, 2007). It is safe to beneficial arthropods and natural enemies which suggest that flubendiamide is valuable for integrated pest management programs (Tohnishi *et al.*, 2005).

In the case of quinalphos, the population of pod borers decreased from 2.35 to 1.30 larvae per plant on seven days after first spraying (Table 2, Fig. 1). Thereafter the population showed an increasing tendency. Similar trend was observed during the second and third spraying also (Tables 3 and 4, Fig. 2 and 3). As quinalphos is a contact insecticide with residual toxicity lasting up to seven days, the new flowers and pods developed on the plants after the application of treatments might not be having the active ingredient deposited on it. So the newly formed flowers and pods get fresh infestation. Hence repeated application of quinalphos at seven days interval can effectively manage pod borer complex.

Aslam *et al.* (2004) tested ten insecticides including quinalphos 25EC (1250 ml per acre) under field conditions against *Earias insulana, E. vitella* and *H. armigera* and found that all the insecticides were effective against these pests only up to seven days after treatment (DAT) in cotton. Bhat *et al.* (1988) recorded the lowest pest incidence and highest grain yield in plots treated with monocrotophos followed by neem seed extract, phosalone and quinalphos when tested against *M. testulalis.*

Five days after first spraying quinalphos recorded a larval population of 1.45 per plant and ranked next to flubendiamide (Table 2, Fig. 1). This was also on par with *B. thuringiensis, B. bassiana M. anisopliae* and azadirachtin. This result is in agreement with Gavhane *et al.* (2008) who found that quinalphos 25EC at 0.05 per cent was an effective treatment (69.56 per cent reduction in the larval population of *P. xylostella*) and was followed by *B. thuringiensis* @ 1000 ml/ha and *B. bassiana* @ 1×10^8 conidia per ml which exhibited 43.10 and 41.39 per cent reduction of larval population, respectively.

Azadirachtin brought down larval population below economic threshold level starting from 14th day after first spraying till the end of cropping period. On the fifth day after first spraying the population of pod borers in azadirachtin was found to be on par with quinalphos (Table 2, Fig. 1). On the fourteenth day after second spraying also, azadirachtin recorded a lower pod borer population and was on par with flubendiamide (Table 3, Fig. 2). This shows the efficacy of azadirachtin in managing the pod borers of cowpea. The time taken to attain a population below ETL is slightly high compared to the chemical insecticides. This delay in efficacy might be due the characteristic features of azadirachtin which possess antifeedant, fecundity reducing and egg sterility causing properties (Schmutterer, 1990). It is slow acting and takes more than seven days for causing mortality of the larvae (Simmonds *et al.*, 2000). Dhaliwal and Arora (2004) reported that, if the neem spray is synchronized with egg hatching, the newly emerging larvae will be controlled. Mehta *et al.* (2010) observed that Neemazal at 20ppm resulted in maximum reduction of *H. armigera* larvae after three sprays in tomato field. Kanhere *et al.* (2012) recommended two sprays of azadirachtin (0.001%) at 50 per cent flowering stage for effective management of *M. testulalis.*

Azadirachtin is also a good candidate in the IPM of vegetables as it controls insect pests and according to Prakash *et al.* (2002) the candidate spares the predators, parasitoids and pollinators.

Five days after the first spray, all the treatments except the chemical insecticides showed an increase in the population of pod borer larvae (Table 2, Fig. 1). This indicated that the time taken to cause mortality of the larvae was different in different treatments. The botanicals and the bioagents require more time for action and leads to a slow control of the larvae (Kowalska, 2008).

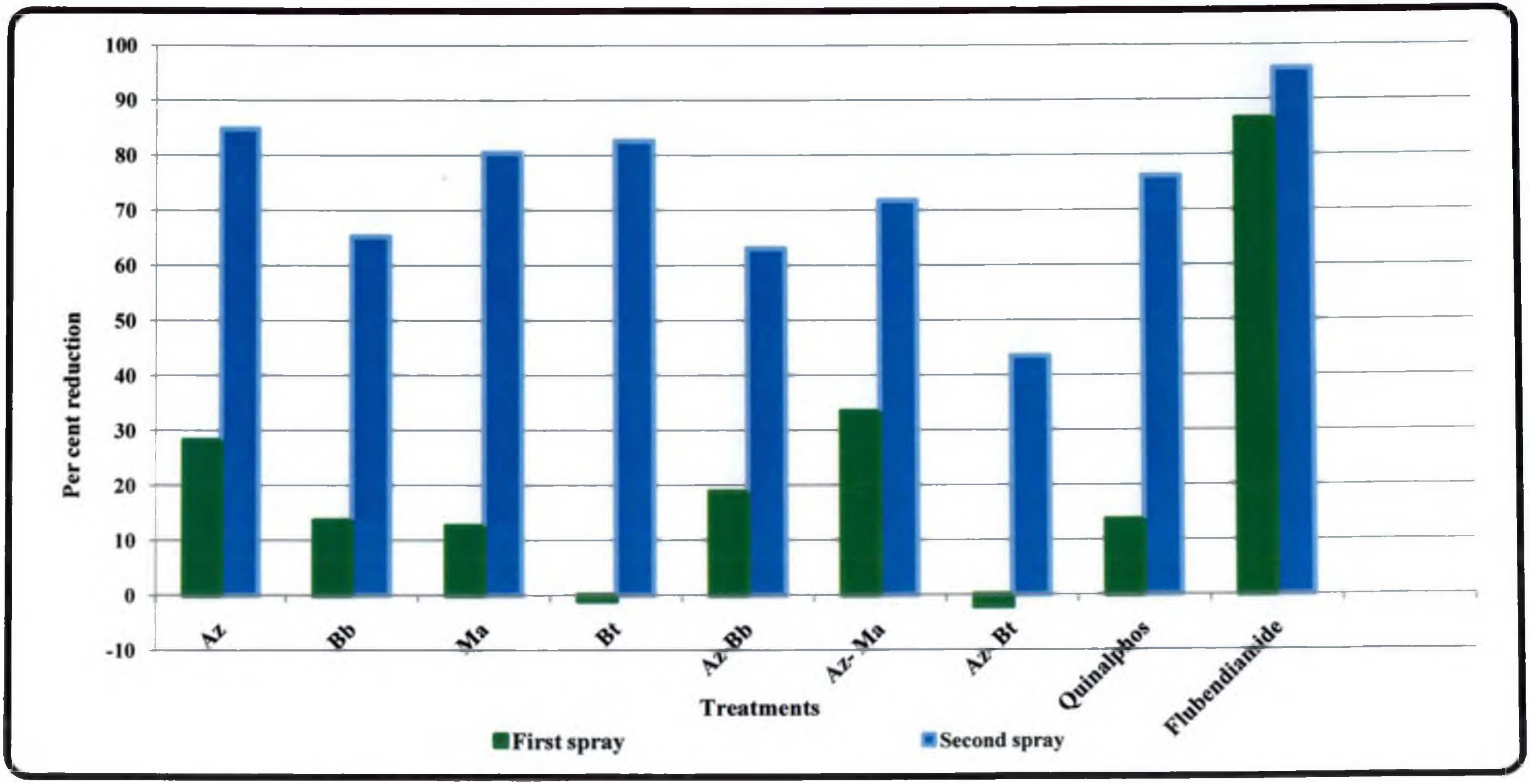
Bacillus thuringiensis treatment experienced a pod borer infestation lower than economic threshold level from 14th day after first spraying till seven days after third spraying (Table 2, 3 and 4, Fig. 1, 2 and 3). The larval population at five days after first spray was on par with quinalphos (Table 2). This result showed that *B. thuringiensis* can be sprayed repeatedly at 14 days interval for effective management of pod borers. Similar findings were reported by Kolarath (2010) who found that *B. thuringiensis* spray was significantly superior (1.20 larvae/plant) over NSKE, pongamia seed extract and enodsulfan in reducing the larval population of pod borer complex of field bean. Mortality of *H. armigera* in all age group larvae (2, 4, 6, 8 & 12 days old) was recorded with four doses (1×10^9, 1×10^8, 1×10^7 & 1×10^6) of *B. thuringiensis,* NPV and *B. bassiana* and maximum mortality was observed with *B. thuringiensis* (Tyagi *et al.,* 2010). Application of *B. thuringiensis* @1 kg/ha reduced the populations of *Adisura atkinsoni* (NBAII, 2010). Dipel induced more than 80 per cent mortality in four days old larvae of *M. vitrata* at 1.5 and 2.0 g/l and 50.3 per cent and 70.6 per cent mortality respectively in seven days old larvae (Unmole, 2011).

The population of *M. anisopliae* never exceeded economic threshold level starting from 14th day after first spraying to seven days after third spraying (Table 2, 3 and 4, Fig. 1, 2 and 3). Fourteen days after second spraying *M. anisopliae* resulted in a population of 0.45 larvae/plant and was on par with quinalphos, azadirachtin, *B. bassiana, B. thuringiensis,* azadirachtin f.b. *B. bassiana,* azadirachtin f.b. *M. anisopliae* and azadirachtin f.b. B. *thuringiensis* (Table 3). However it was significantly superior over control with respect to larval population. Similar results were reported by several scientists all over the world. Gopalakrishnan and Narayanan (1988) found that *M. anisopliae* caused 80-100 per cent mortality in all five larval instars of *H. armigera* at 1.8 × 10^9 conidia per ml. Nahar *et al.* (2004) observed 66.74 per cent of mortality of third instar larvae of *H. armigera* when treated with *M. anisopliae.* At the highest concentration of 10^8 spores/ml, 72.50 per cent of the larvae were killed in a minimum period of five days after inoculation, but in the next two days the mortality reached hundred per cent Gundannavar *et al.* (2007).

5.1.2 Per cent reduction in the larval population of pod borers in different treatments over control

During the first spray, highest per cent reduction (86.46%) in the population of pod borer larvae was observed in flubendiamide (Table 5 and Fig. 4). The next best treatment with respect to per cent reduction was azadirachtin f.b. *M. anisopliae* (33.33%). There was an increase in the population of pod borer larvae in *B. thuringiensis.* During second spraying also the per cent reduction in the population of pod borers was highest in flubendiamide (95.65%) when compared to other treatments (Table 5 and Fig. 4). The next best treatments were azadirachtin (86.46%) and *B. thuringiensis* (82.61%), and *M. anisopliae* (80.43%). From this result it is evident that, flubendiamide reduced the larval population by a single spray. Higher efficacy of flubendiamide in field situations may be attributed to the desirable qualities such as rainfastness and efficient uptake into the leaves, followed by acropetal translocation of the active substance to the new growing points of the plant. Even small quantities of the chemical are effective over a prolonged period, so that depending on the situation, repeated applications may be avoided. Babar *et al.* (2012) observed that flubendiamide at 0.01 per cent caused highest reduction in larval population (97.02%) of *H.*

Figure 4. Per cent reduction in the larval population of pod borers in different treatments over control



armigera. The effectiveness of neem products against *Chilo partellus* was pronounced in terms of higher grain yield in relation to control but was not comparable with endosulfan (Bhanukiran and Panwar, 2005).

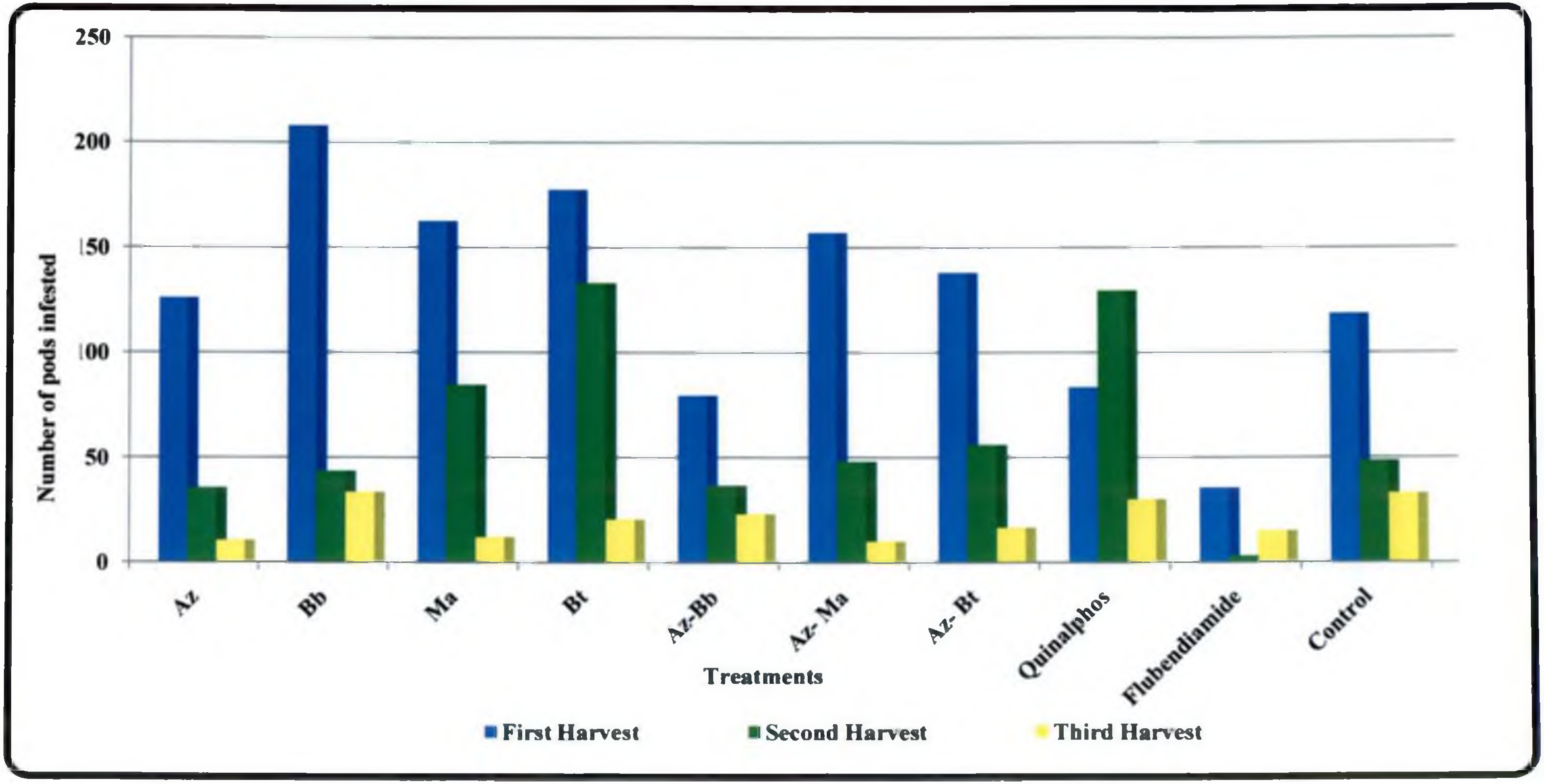
5.1.3 Pod damage

5.1.3.1 Infestation by number

The number of pods damaged by pod borers varied significantly among the different treatments during the first harvest. The lowest infestation by number (35.50) was observed in flubendiamide followed by azadirachtin f. b. *B. bassiana* (79.50) and quinalphos (83.50) and these treatments were on par (Table 6 and Fig. 5). Similar results were also reported by Bhat *et al.* (1988) who found that the incidence of *M. testulalis* was the lowest and grain yield was the highest in quinalphos @ 250 ml/ha. Kumar and Shivaraju (2009) found that flubendiamide @ 36 and 48 g a.i./ha was significantly superior over other treatments by recording less pod damage by *H. armigera.* Thilagam *et al.* (2010) reported up to 96 per cent reduction in damage by *H. armigera* in flubendiamide applied plots. Flubendiamide 480SC @ 72 and 90 g a. i. /ha were significantly superior over other treatments in recording less shoot damage by shoot and fruit borer of brinjal at seven days after first spray (Jagginavar *et al.*, 2009).

During the second harvest all the treatments were statistically on par and the number of damaged pods varied from three in flubendiamide to 133 in *B. thuringiensis.* The lower efficacy of *B. thuringiensis* in the field conditions may be attributed to the inability to reach the feeding sites of larvae which are internal feeders as well as sunlight mediated inactivation of *B. thuringiensis* crystals (Pusztai *et al.*, 1991). During the third harvest also, there was no significant difference between the treatments for the number of borer damaged pods. The mean values varied from 10 in azadirachtin f.b. *M. anisopliae* to 33.5 in *B. bassiana* (Table 6 and Fig. 5). The efficacy of *M. anisopliae* in managing insect pests was reported by Kulkarni *et al.* (2005) who recorded the lowest pod damage (18.06%) by *H. armigera* followed by *N. rileyi* (18.64%) and NPV (20.07%).

Figure 5. Effect of different treatments on pod borer infestation by number



5.1.3.2 Per cent infestation (On number basis)

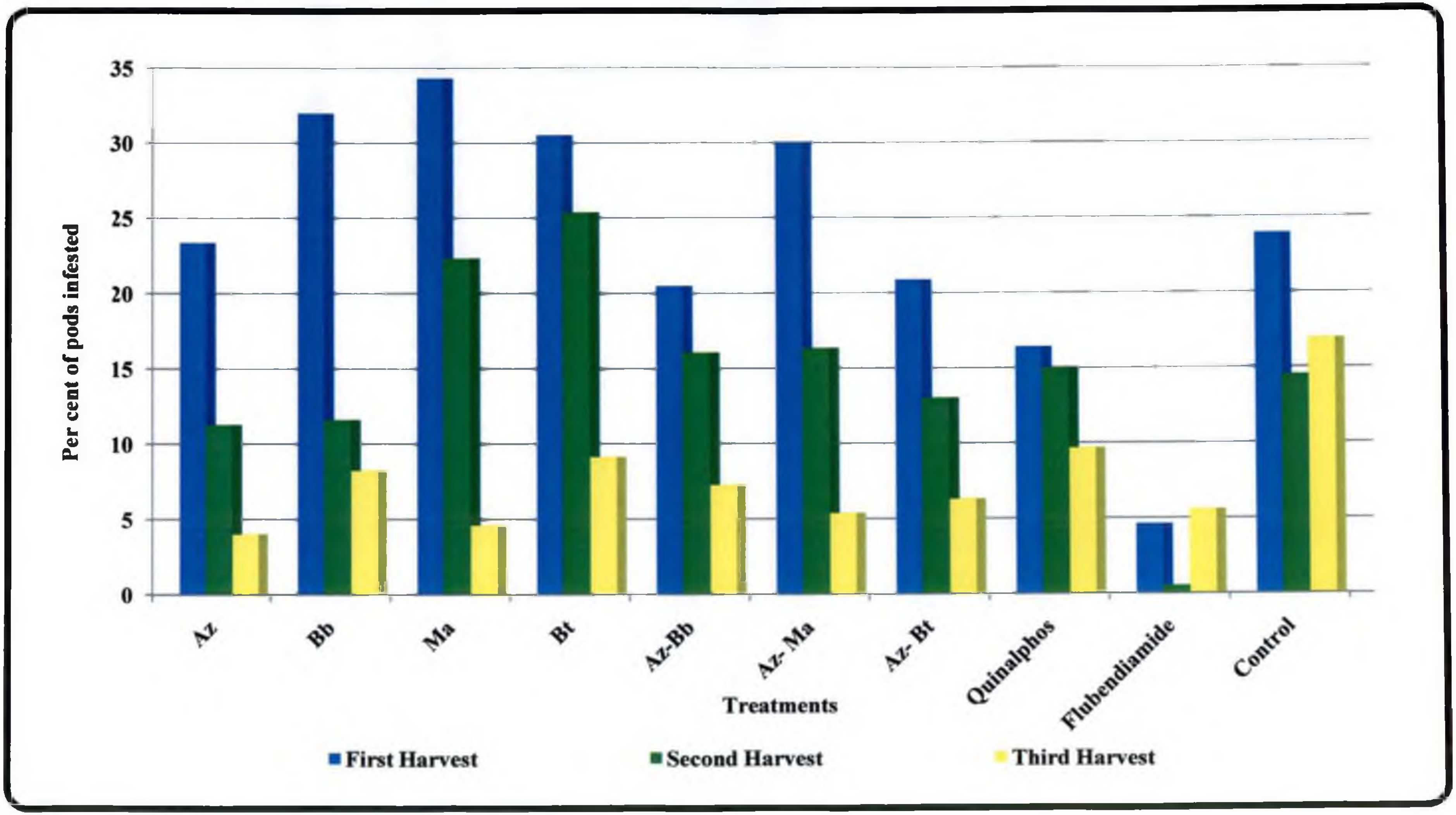
Though not statistically different, flubendiamide showed the lowest per cent infestation by number during first harvest (4.62%). In the second harvest, the treatments varied significantly and flubendiamide was found to be superior over rest of the treatments. *B. thuringiensis* (25.37%) recorded the highest infestation followed by *M. anisopliae* (22.32%) and these treatments were on par (Table 7 and Fig. 6). Several scientists have reported the efficacy of flubendiamide in managing lepidopteran pests. Ameta *et al.* (2011) reported that flubendiamide at 100 ml ha^{-1} recorded minimum flower and pod damage (by the larvae of *H. armigera* and *M. testulalis*) and significantly high seed yield in pigeon pea. Babar *et al.* (2012) also observed that flubendiamide at 0.01 per cent recorded highest reduction in pod damage at green pod stage and maturity stage when tested against *H. armigera.* Quinalphos was found to be on par with synthetic pyrethroids and endosulfan in controlling yield loss due to pod borer complex in pea (Yadav *et al.*, 2000).

At the third harvest, all the treatments were significantly superior over control in reducing the damage by pod borers. Azadirachtin had the lowest damage (4.01%) and was statistically on par with treatments, *viz.*, *M. anisopliae,* azadirachtin f.b. *M. anisopliae* and flubendiamide (Table 7 and Fig. 6). Among neem based formulations, Nimbecidine gave highest per cent yield increase over control followed by Achook and Neemarin, when treated against *H. armigera* (Singh and Yadav, 2006). Neemazal (20ppm) recorded lowest infestation of *H. armigera* and higher tomato yield (Mehta *et al.*, 2010). Of the eleven biocides tested, neem based formulations, Neemazal F (0.1%) and neem seed kernel extract (5%) were found effective against *H. armigera* and *M. vitrata* (Krishna *et al.*, 2011).

5.1.3.3 Per cent infestation (On weight basis)

All the treatments were statistically on par during the first harvest. The damage varied from 3.50 per cent in flubendiamide to 34.86 per cent in *B.*

Figure 6. Effect of different treatments on per cent pod borer infestation by number



thuringiensis and control showed a damage of 16.55 per cent. Flubendiamide was found to be statistically superior over all other treatments with respect to per cent pod damage during second harvest. All other treatments were statistically on par with highest damage recorded in *B. thuringiensis*. In the third harvest, the per cent infestation did not vary significantly in different treatments. Control showed the highest damage (12.12%) while the lowest was in azadirachtin (2.83%) (Table 8 and Fig. 7).

5.1.4 Yield

5.1.4.1 Total yield

The total yield per plot (in terms of number and weight) did not vary significantly in different treatments. Quinalphos application resulted in the highest yield both in terms of weight and number. Considering the pod number flubendiamide stood next to quinalphos. The total yield recorded in terms of weight was higher in *B. thuringiensis* than other bioagents (Table 9, Fig. 8 and 9).

Quinalphos 25EC at 0.05 per cent was found to be an effective treatment with 69.56 per cent reduction in the larval population of *P. xylostella* and achieved the highest yield (228.39 q/ha) followed by *B. thuringiensis* (Gavhane *et al*., 2008). The effectiveness of flubendiamide (1ml/l) against pod borers of dolichos bean was reported by Mallikarjuna *et al.* (2009) where it rendered higher yield on par with indoxacarb and emamectin benzoate. Latif *et al.* (2009) reported that the application of flubendiamide reduced the infestation by *L. orbonalis* by 80.63 per cent producing higher fruit yield in brinjal. Flubendiamide 20WG @ 60 g a.i. /ha resulted in the highest yield in chilli with lowest fruit damage by *H. armigera* and *S. litura* followed by flubendiamide 20WG @ 40 g a.i./ ha (Tatagar *et al*., 2009). Similarly, the highest yield of okra was recorded in spinosad followed by flubendiamide and novaluron when treated against *Earias fabia* (Chatterjee and Mondal, 2012).

Figure 7. Effect of different treatments on per cent pod borer infestation by weight

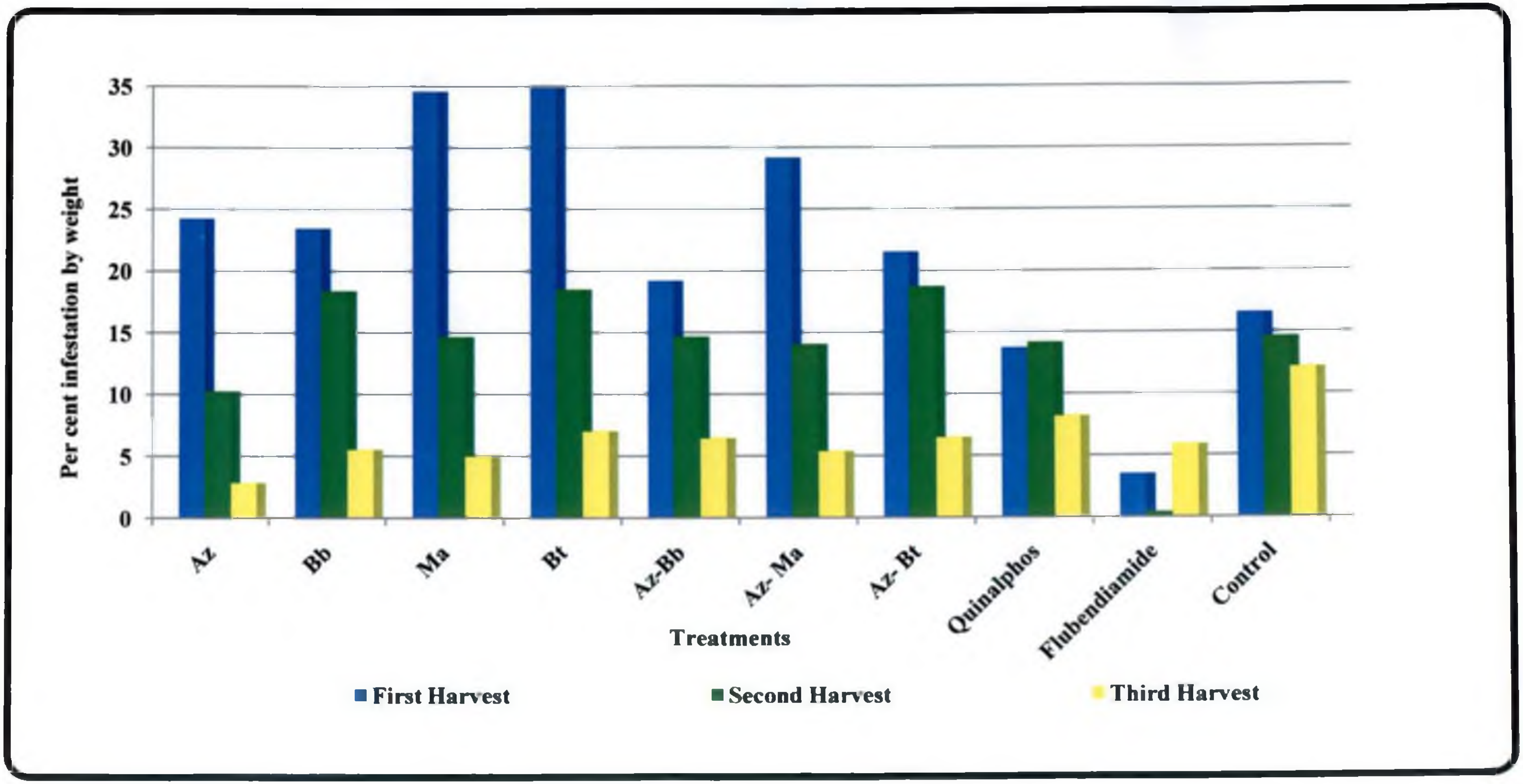


Figure 8. Total number of pods in different treatments

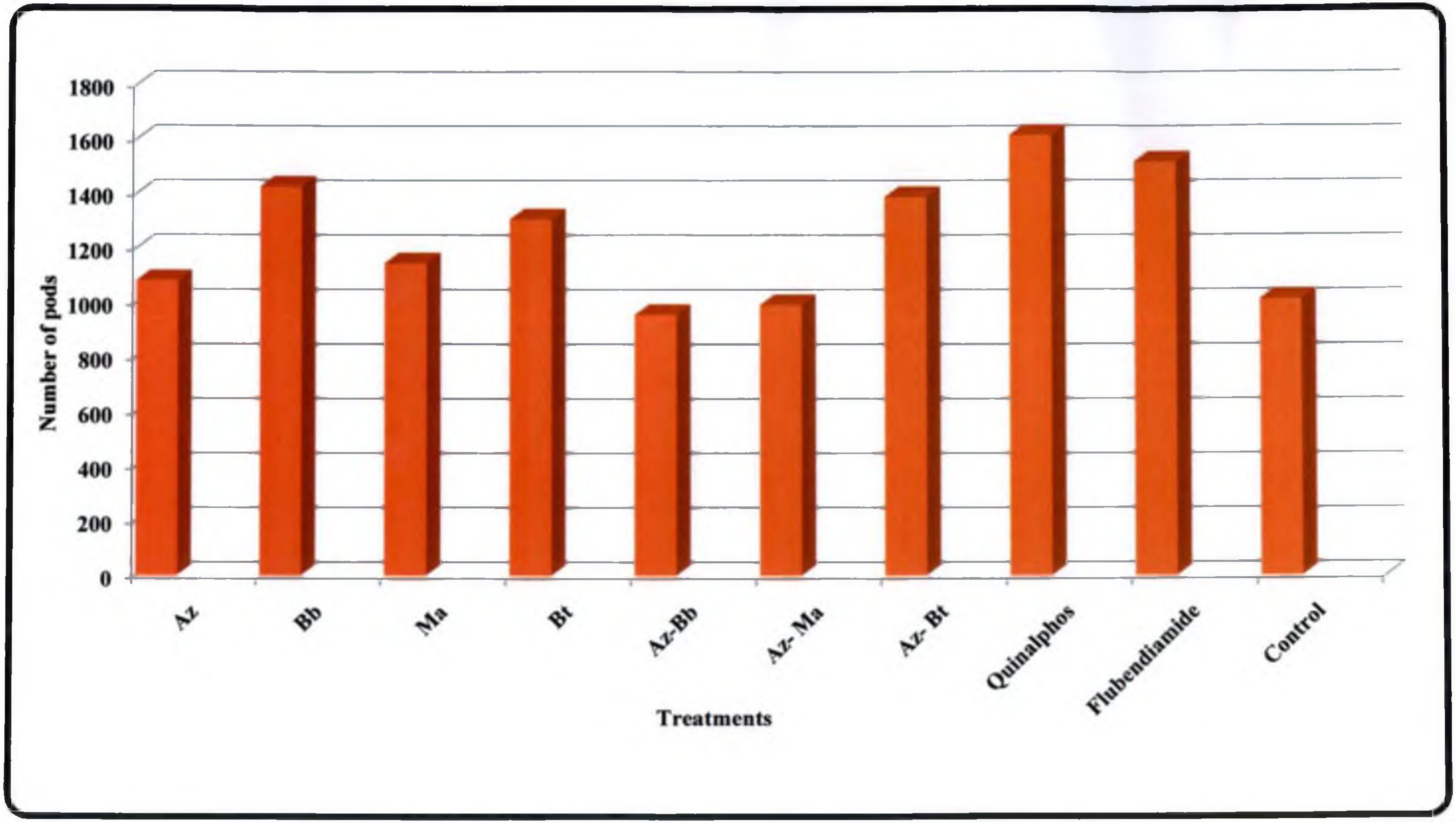
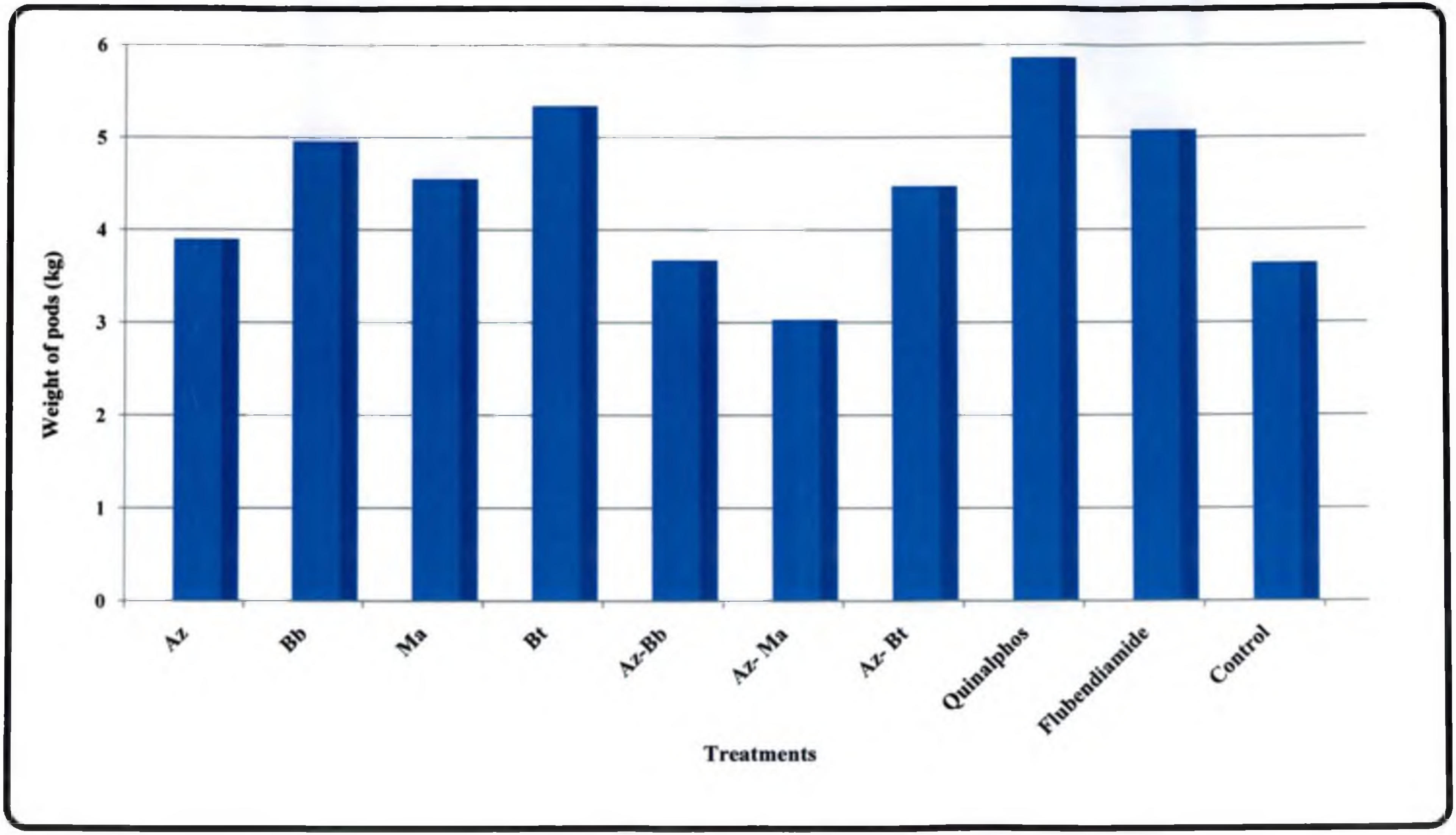


Figure 9. Total weight of pods in different treatments



5.1.4.2 Marketable yield

Application of flubendiamide resulted in the highest number of marketable pods (1463 pods/9m^2) followed by quinalphos and these two treatments were on par. Flubendiamide and quinalphos were significantly superior over control with respect to marketable yield in terms of number. Azadirachtin f. b. *B. thuringiensis* recorded the next highest yield followed by *B. bassiana* and these were on par with the two chemical insecticides and control. The treatments showed no significant difference with respect to marketable yield by weight. The chemical insecticides recorded a better marketable yield in terms of weight though not significantly different (Table 9). Gill *et al.* (2010) reported that medium and higher doses of flubendiamide significantly reduced the larval population of diamond back moth and hence increased the marketable yield. The highest tomato yield was recorded in endosulfan- quinalphos- indoxacarb treated plots which were on par with azadirachtin -*Btk*- spinosad (Ravi *et al.*, 2008). Foliar application of *B. bassiana* two times during flowering stage of the crop showed good results on the pod borer complex and recorded highest pod yield in pigeon pea followed by chemical treated plots. Per cent inflorescence damage due to legume pod borer was lowest in spinosad, followed by *Bacillus thuringiensis* and *B. bassiana* (Sreekanth and Seshamahalakshmi, 2012).

5.1.4.3 Per cent marketable yield

The treatments varied significantly with respect to per cent marketable yield by pod number and flubendiamide was significantly superior over rest of the treatments with highest per cent pod yield in terms of pod number. Rests of the treatments were on par with each other. Per cent marketable yield by weight did not vary significantly among the treatments and the highest value was recorded in flubendiamide followed by quinalphos. Among the biocontrol agents azadirachtin f.b. *B. bassiana* recorded the highest value closely followed by azadirachtin f.b. *B. thuringiensis* (Table 9, Fig. 10 and 11).

Figure 10. Per cent marketable yield in different treatments in terms of pod number

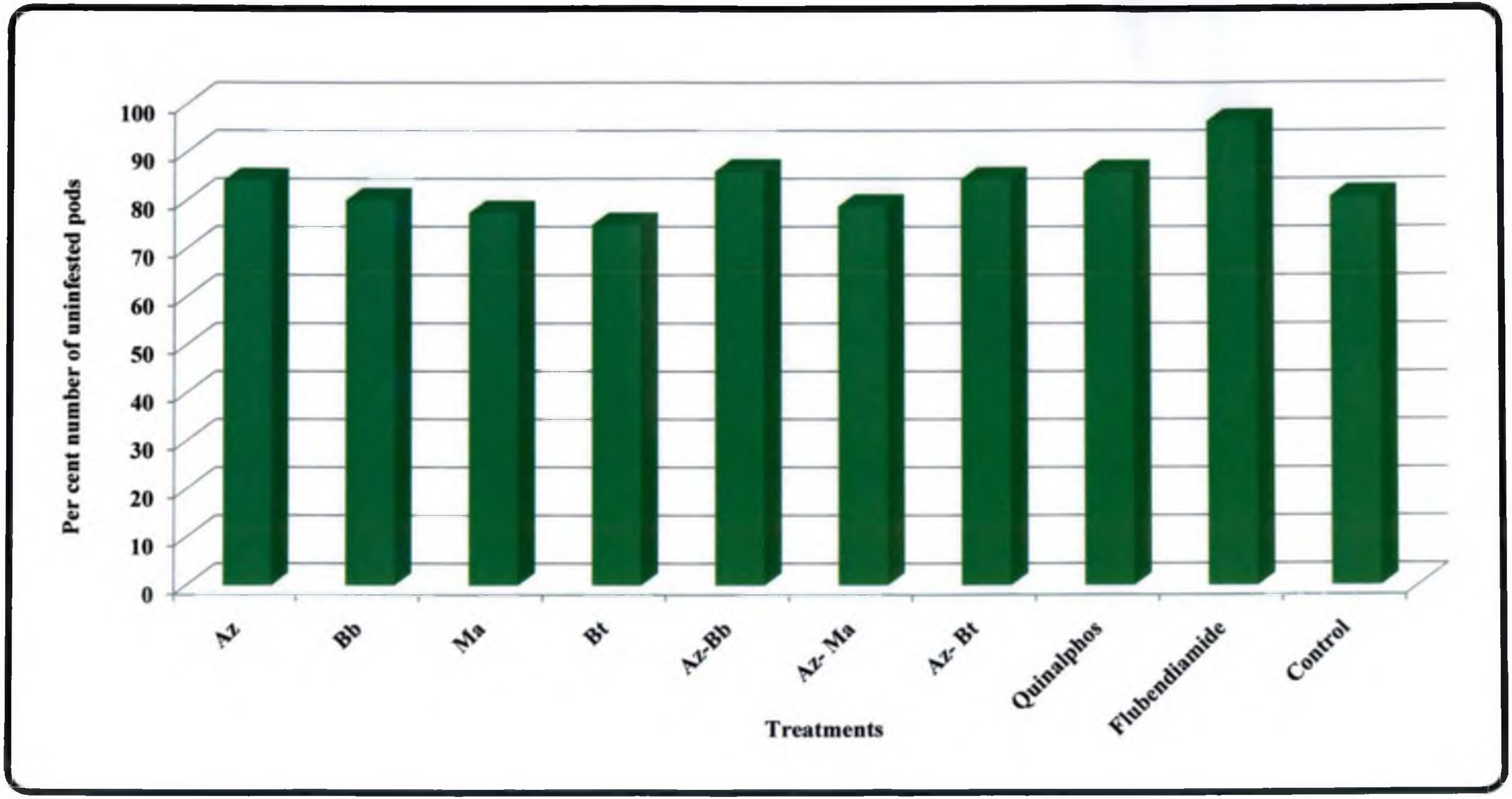
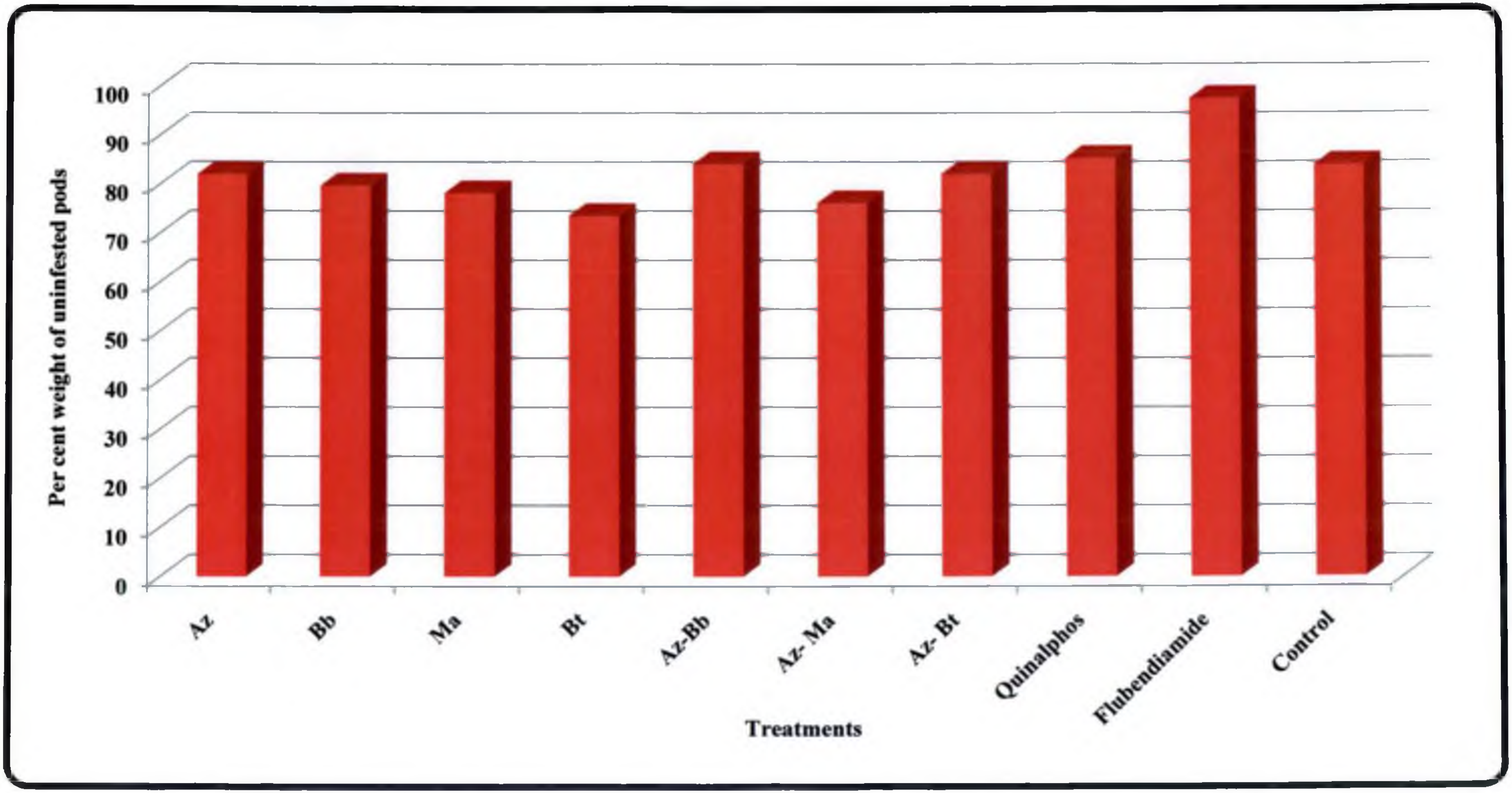


Figure 11. Per cent marketable yield in different treatments in terms of pod weight



5.1.5 Benefit: Cost Ratio (BCR)

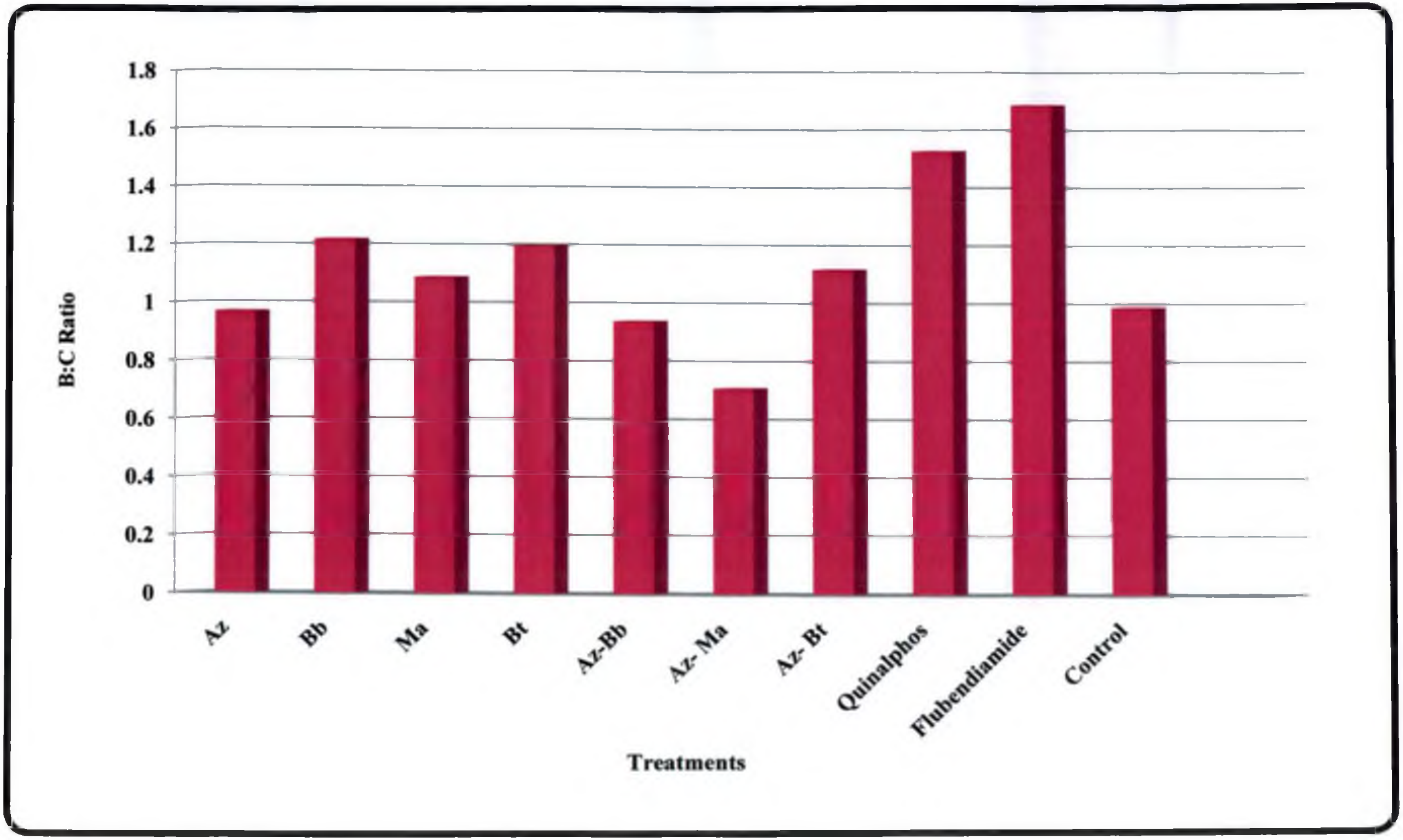
Among the different treatments, chemical insecticides (flubendiamide and quinalphos) showed a higher B: C ratio than the bioagents and botanical (Table 10 and Fig. 12). Flubendiamide recorded the highest B: C ratio (1.69) followed by quinalphos (1.53). Highest return (Rs. 987554.57/ha) obtained from flubendiamide balanced the high cost of the chemical (Rs. 35110.33/ha) needed to spray one hectare area and gave the highest B: C ratio (1.69). This result is in consonance with Babar *et al.* (2012) who reported that, flubendiamide at 0.01 per cent gave the highest increase in yield over control (92.31%) and the highest net Incremental Cost: Benefit Ratio (1:4.19) in *H. armigera* management.

The cost of chemical was comparatively low in the case of quinalphos which recorded a return of Rs. 887110.22/ha (Next to flubendiamide) (Table 10 and Fig. 12). These factors contributed to a B: C ratio of 1.53 for the same. Patel *et al.* (2012) observed a higher cost benefit ratio in treatments like bifenthrin 10 EC (1:2.69) followed by indoxacarb 14.5 SC (1:2.36), chlorpyriphos (1:1.60), quinalphos (1:1.48), spinosad (1:1.29) and emamectin benzoate (1:1.10) when treated against *M. vitrata*..

The cost of insecticides needed to apply in one hectare area was highest in the case of azadirachtin (Rs. 39443.67/ha) followed by flubendiamide (Rs. 35110.33/ha) (Table 10 and Fig. 12). So all the treatments with azadirachtin showed a B: C ratio less than one (except azadirachtin f.b. *B. thuringiensis*). *B. bassiana* and *M. anisopliae* recorded the lowest cost for plant protection (Rs. 29332.56/ha) and recorded a B: C ratio (1.22 and 1.09 respectively) higher than one.

Among the bioagents, *B. bassiana* recorded the highest B: C ratio of 1.22, next to quinalphos and was followed by *B. thuringiensis* (1.20) (Table 10 and Fig. 12). This is in agreement with the findings of Kolarath (2010) who reported that, *B. thuringiensis* treated plot (two sprays) gave a return of Rs. 3.13 for every rupee invested whereas it was Rs. 2.54 for endosulfan 35EC. The treatment with

Figure 12. Benefit: Cost Ratio for different treatments for the management of pod borer complex of cowpea



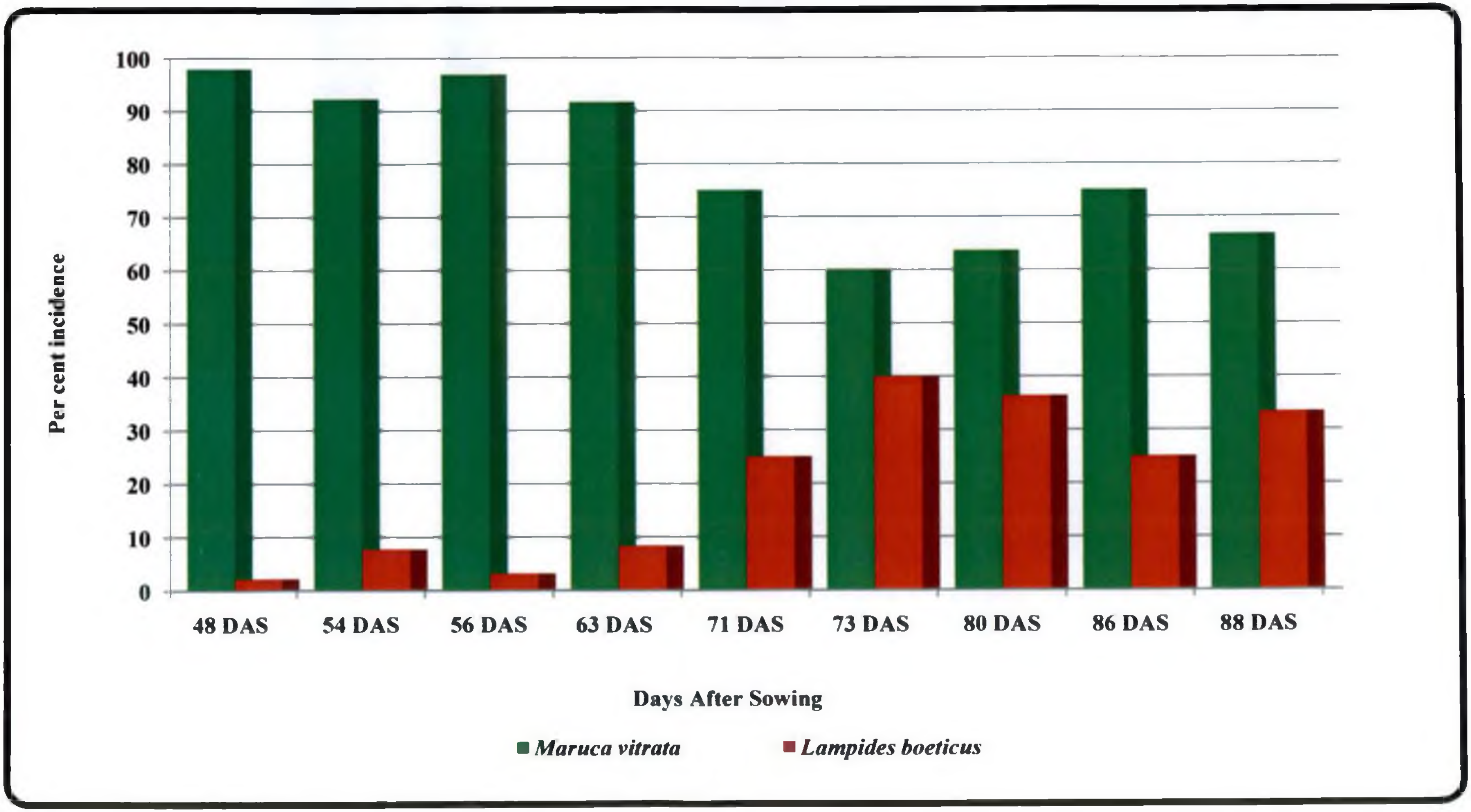
quinalphos 0.05 per cent achieved the highest yield (228.39 q/ha) followed by *B. thuringiensis* and *B. bassiana* which recorded 197.73 and 182.63 q/ha yield (Gavhane *et al.*, 2008).

5.2 SPECIES COMPOSITION OF POD BORER COMPLEX OF COWPEA

The investigations on the species composition of pod borer complex indicated *Maruca vitrata* as the dominant species of pod borer in cowpea compared to *Lampides boeticus*. The per cent incidence of *M. vitrata* varied from 97.87 per cent observed at 50 per cent flowering to 60 per cent during the middle of December. The larval count recorded at 50 per cent flowering showed 97.87 per cent incidence of *M. vitrata* and 2.13 per cent of *L. boeticus*. The per cent incidence of *L. boeticus* remained below ten per cent till the first week of December. Gradually the population of *L. boeticus* increased when there were more pods in the field compared to flowers and the highest incidence reported during the period of study was 40 per cent (Table 11 and Fig. 13).

Mallikarjunappa (1989) recorded pod borers like *A. atkinsoni, H. armigera, Sphenarches caffer, E. zinkenella, M. testulalis, L. boeticus, Cydia ptychora, Melanagromyza obtusa* and *Callosobruchus theobromae* on *Vicia faba* at Dharwad. Kolarath (2010) also reported that, among the four species of pod borers (*M. vitrata, L. boeticus, H. armigera* and *C. ptychora*) attacking the seed, *M. vitrata* was found to be the predominant one followed by *C. ptychora*. However the population of *H. armigera* and *L. boeticus* were negligible followed by *C. ptychora.* Karel (1985) from Tanzania also reported that *M. testulalis* was more abundant and injurious (31% damage) to pods than *H. armigera* (13% damage) on common beans (*Phaseolus vulgaris* L.). Project surveys conducted on country bean, *Lablab purpureus* (L.) Sweet, at Joydebpur and Jessore, Bangladesh confirmed *M. vitrata* as the major pest of Lablab (Anonymous, 2006).

Figure 13. Species composition of pod borer complex of cowpea



5.3 NATURAL ENEMY COMPLEX OF POD BORERS

Two different hymenopteran larval parasitoids belonging to the family Braconidae observed on *M. vitrata* were *Apanteles* sp. and *Phanerotoma* sp. (Table 12). These are being reported for the first time in Kerala. These two parasitoids were reported by several workers. *Phanerotoma* sp. was recorded from *M. testulalis* in Nigeria (Usua and Singh, 1978). The survey conducted in Andhra Pradesh, India during 1975-76 showed a maximum of 13.8 per cent parasitism of *M. testulalis* by the braconid, *P. hendecasisella* and of larvae of *Exelastis atomosa* by *P. hendecasisella, Apanteles paludicolae* Cam., the ichneumonid, *Diadegma* sp. and the chalcidid, *Tropimeris monodon* Boucek. (Lateef and Reddy, 1984). The braconid, *A. taragamae* parasitized larvae of *M. vitrata* during mid-September to late December (Sahoo and Senapati, 2000b). Chi-Chung *et al.* (2003) reported that *A. taragamae* accounted for an average of 92 per cent of all parasitoid specimens reared from *M. vitrata* larvae and pupae in Taiwan. They also observed that the parasitism was high during June to August and got reduced during September to November when other parasitoid species were more active. Borah and Sarma (2004) reported that the parasitoids *Caenopimpla* sp. followed by *Phanerotoma* sp. induced a significant biotic pressure on *M. testulalis.* Arodokoun *et al.* (2006) reported *P. leucobasis* Kriechbaumer as one of the two important parasitoids of *M. vitrata.* Gupta *et al.* (2013) recorded three larval parasitoids of *M. vitrata* from Karnataka, *viz., Bassus relativus, P. hendecasisella* and *Trathala flavoorbitalis.*

Summary

SUMMARY

Cowpea occupies a unique position in the vegetable scenario of Kerala, as a nutrient rich food source and a soil enriching legume. The yield of cowpea is severely limited due to the incidence of insect pests. Among these insect pests, the pod borers cause significant yield loss by feeding on flowers and pods and also reduce the visual appeal of the produce. Chemical pesticides are extensively used to protect the flowers and pods from pod borer attack. Inappropriate and extensive use of highly toxic pesticides has lead to the development of resistance to most of the classes of chemicals, deteriorated the quality of environment and posed severe health hazards. Government has responded to these problems with regulatory action and banned majority of the red labelled insecticides and has restricted the use of yellow labelled insecticides. These changes in the regulatory environment and the world wide concern over an eco-friendly living stressed the importance of developing alternative technologies for insect pest management. Under these circumstances the present study entitled "Eco-friendly management strategies against pod borer complex of cowpea, *Vigna unguiculata* var. *sesquipedalis* (L.) Verdcourt" was taken up at the Department of Agricultural Entomology, College of Horticulture, Vellanikkara during 2012-2013.

FIELD EVALUATION ON THE EFFICACY OF BIOPESTICIDES, BOTANICALS AND SAFER CHEMICALS AGAINST POD BORER COMPLEX OF COWPEA

The salient findings of the present investigation are summarized below.

- Considering the three consecutive sprays, flubendiamide consistently showed the lowest larval population and recorded values below ETL from seven days onwards after the first spray.

- In the case of quinalphos the population of pod borers exhibited a decreasing trend up to seven days after each spraying and an increasing trend thereafter.

- Azadirachtin, *Metarhizium anisopliae* and *Bacillus thuringiensis* recorded larval population below economic threshold level starting from 14th day after first spraying till the end of cropping period.

- A single application of flubendiamide reduced the population of pod borers significantly. So need based application can be recommended.

- Flubendiamide resulted in the highest per cent reduction (86.46 & 95.65%) in the population of pod borer larvae after each spraying.

- With respect to per cent pod damage (in terms of number and weight) flubendiamide was found to be significantly superior over control and all other treatments were on par.

- Quinalphos recorded the highest total yield both in terms of pod weight (5.86kg) and number (1614.5).

- Among the bioagents the total yield in terms of pod weight was the highest in *B. thuringiensis*. *Beauveria bassiana* recorded the highest B: C ratio (1.22) next to quinalphos and was followed by *B. thuringiensis*, azadirachtin f.b. *B. thuringiensis* and *M. anisopliae*.

- Application of flubendiamide resulted in the highest number of marketable pods followed by quinalphos.

- Flubendiamide was significantly superior over rest of the treatments with highest per cent marketable yield in terms of pod number.

- Among the different treatments, chemical insecticides (flubendiamide followed by quinalphos) showed a higher B: C ratio compared to the bioagents and azadirachtin.

- *Maruca vitrata* was the dominant species of pod borer infesting cowpea compared to *Lampides boeticus*. The population of *L. boeticus* increased when there were more pods in the field compared to flowers.

- Two different hymenopteran larval parasitoids *viz.*, *Apanteles* sp. and *Phanerotoma* sp. belonging to the family Braconidae were observed on *M. vitrata*.

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Appendix

Appendix I.

Weekly meteorological data recorded at College of Horticulture, Vellanikkara during 2012- 2013

Month/week	Temperature (° C)		Relative humidity (%)	Rainfall (mm)
	Maximum	Minimum		
2012				
November I (5/11/12-11/11/12)	32.8	23.4	75	1
November II (12/11/12-18/11/12)	32.7	21.9	63	0
November III (19/11//12-25/11/12)	32.7	23.0	75	1
November IV (26/11/12-2/12/12)	33.1	22.0	53	0
December I (3/12/12-9/12/12)	33.2	23.6	63	1
December II (10/12/12-16/12/12)	33.3	21.5	58	0
December III (17/12/12-23/12/12)	31.6	24.2	55	0
December IV (24/12/12-31/12/12)	33.2	23.6	59	1
2013				
January I (1/1/13-7/1/13)	34.4	23.0	61	0
January II (8/1/13-14/1/13)	33.9	23.0	52	0

ECO-FRIENDLY MANAGEMENT STRATEGIES AGAINST POD BORER COMPLEX OF COWPEA,

Vigna unguiculata var. *sesquipedalis* (L.) Verdcourt

By

SUBHASREE, S.

ABSTRACT OF THE THESIS

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requirement for the degree of

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DEPARTMENT OF AGRICULTURAL ENTOMOLOGY
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ABSTRACT

The investigations on "Eco-friendly management strategies against pod borer complex of cowpea, *Vigna unguiculata* var. *sesquipedalis* (L.) Verdcourt" was taken up at Department of Agricultural Entomology, College of Horticulture, Vellanikkara during October 2012 to January 2013. The short duration bushy variety of cowpea, *Bhagyalakshmi* susceptible to pod borers was used for the study. The experiment aimed at, evaluating the efficacy of a botanical *viz.*, azadirachtin (0.005%), bioagents *viz., Beauveria bassiana* (1%), *Metarhizium anisopliae* (1%), *Bacillus thuringiensis* (0.2%) along with their sequential application (azadirachtin followed by *B. bassiana,* azadirachtin followed by *M. anisopliae,* azadirachtin followed by *B. thuringiensis*), a safer chemical *viz.*, flubendiamide 480SC (0.008%) and a standard check (quinalphos 0.05%) against pod borer complex of cowpea under field conditions, studying the species composition of pod borer complex of cowpea and the natural enemies associated with them.

Considering the three consecutive sprays at fortnightly intervals starting from flowering, flubendiamide was found to be highly effective in managing the larval population of pod borers compared to azadirachtin and bioagents. A single application of the same reduced the population of pod borers significantly. In the case of quinalphos the population of pod borers showed a decreasing trend up to seven days after each spraying and increased thereafter. Azadirachtin, *M. anisopliae* and *B. thuringiensis* recorded larval population below economic threshold level starting from 14th day after first spraying till the end of cropping period. With respect to per cent pod damage (in terms of number and weight) flubendiamide was found to be significantly superior over control and all other treatments were on par. Though quinalphos recorded the highest total yield both in terms of weight and number, application of flubendiamide resulted in the highest number of marketable pods. The total yield recorded in terms of weight was higher in *B. thuringiensis* than other bioagents. Azadirachtin followed by *B. thuringiensis* application resulted in high marketable yield among bioagents and

botanical, followed by *B. bassiana* and were on par with the two chemical insecticides. Flubendiamide recorded the highest B: C ratio followed by quinalphos. Among the bioagents *B. bassiana* recorded a B: C ratio next to quinalphos and was followed by *B. thuringiensis*, azadirachtin followed by *B. thuringiensis* and *M. anisopliae*.

Two species of pod borers were recorded on cowpea *viz.,* spotted pod borer (*Maruca vitrata*) and pea blue butterfly (*Lampides boeticus*). *M. vitrata* was the major species of pod borer under Vellanikkara conditions compared to *L. boeticus.* The population of *L. boeticus* increased when there were more pods in the field compared to flowers. Two species of hymenopteran larval parasitoids belonging to the family Braconidae observed on *M. vitrata* were *Apanteles* sp. and *Phanerotoma* sp.