Biorational versus conventional insecticides – Comparative field study for managing red spider mite and fruit borer on tomato

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ABSTRACT

Tomato, *Lycopersicum esculentum* L. (Solanaceae), is an important crop worldwide that is grown both outdoors and under protected structures, for fresh market consumption and for processing. In the Mariana Islands, tomato is grown as an outdoor crop throughout the year. Tomatoes are attacked by a variety of pests, including the tomato fruitworm, *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae), and, in Pacific islands, the red spider mite *Tetranychus marianae* McGregor. These pests cause scarring, tissue damage, and aberrations in fruit shape or color, making the tomatoes undesirable for fresh market. Also, insect bodies, excretia or parts in fruits reduce their market suitability. Field trials aimed at improving management of these pests were undertaken at two locations in Guam (Yigo and Inarajan), USA in 2012 and 2013, assessing the efficacy of different biorational and conventional insecticides against *T. marianae* and *H. armigera* on tomato. At both locations, the mean percentage of mite-infested leaves and the population density of *T. marianae* were higher in control than in treated plots. An integrated pest management (IPM) program comprising sprays of selective insecticides (Petroleum spray oil, *Beauveria bassiana*, azadirachtin, and *Bacillus thuringiensis*), evaluated at 15, 30, 45 and 60 days after transplantation of tomato seedlings, significantly reduced the number of *T. marianae*-infested leaves and the density of *T. marianae* over plots treated with carbaryl, malathion, six applications of *B. bassiana* or *B. thuringiensis* and over both controls at both locations. Similarly, significantly lower fruit damage by *H. armigera* was recorded in the plots treated with the IPM program than in plots treated with carbaryl, malathion, or the control treatments at both locations. Marketable tomato yields from the plots which received with the IPM program were significantly greater at both locations than were those in the other treatments.

1. Introduction

Our recent survey on the Mariana Islands found *Helicoverpa armigera* Hübner (Lepidoptera: Noctuidae) and the red spider mite *Tetranychus marianae* McGregor (Acari: Tetranychidae) to be the most serious pests on tomato (*Solanum lycopersicum* L.) (Reddy et al., 2011; Reddy and Tangtrakulwanich, 2013). Rates of tomato damage caused by these pests are typically 60%, and sometimes reach 88% in severely infested fields in Guam. Infestations on tomato plants on farms in the Commonwealth of the Northern Mariana Islands (CNMI) by these pests can reach 100%. While other pests such as cutworms or armyworms (e.g. *Spodoptera litura* [F.]) (Lepidoptera: Noctuidae) can be found causing damage to tomatoes at the later stage of the crop, *H. armigera* was by far the most

common species observed in the field, requiring careful monitoring and control to avoid high (40–50%) yield losses (Reddy and Tangtrakulwanich, 2013).

Processing and fresh market tomato acreage has been progressively increasing in the Mariana Islands during the preceding few years. Tomato has been widely grown in Guam as a new crop which regularly means dealing with a diverse pest complex. At present, *S. litura* is not damaging enough to require control. In addition, both adults and larvae of the Philippine lady beetle, *Epilachna viginsexpunctata* (Boisduval) (Coleoptera: Coccinellidae) feed on the leaves of tomato, leaving distinctive parallel brown scrape marks on the leaves. However, a parasitic wasp, *Pediobius foveolatus* (Crawford) (Hymenoptera: Eulophidae) has been introduced to Guam and the Commonwealth of the Northern Mariana Islands (CNMI) that attacks the pupal stage of the beetle efficiently, so that it is rarely damaging in these areas (Vargo and Schreiner, 2000). Another minor pest of tomato in the region is the silverleaf white fly (*Bemisia tabaci* strain B Bellows & Perring (Hemiptera:

Aleyrodidae), which has been frequently found on tomato, eggplant, cucumber, and other vegetables, at times heavily infesting leaves. However, natural enemies often maintain this whitefly below damaging levels if key parasitoids are not killed by use of pesticides. Other direct pests of tomato such as thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) and stink bugs, *Euschistus variolarius* (Palisot de Beauvois) (Hemiptera: Pentatomidae) are not generally a problem in this region.

Many tomato growers in Guam and other Pacific Islands buy and spray conventional chemical pesticides without consultation or guidance. The majority of growers in the region use carbaryl or malathion to control *T. marianae* and *H. armigera* on tomato (Reddy and Tangtrakulwanich, 2013, 2014). As many as 13—15 applications may be applied to each tomato crop, which can greatly increases costs and exposure to pesticide residues. Also, carbaryl is known to make mite problems worse (by destruction of predatory mites) and resistance to the miticide Dicofol: 1, 1-bis (chlorophenyl)-2,2,2-trichloroethanol) (dicofol 4E®) can develop rapidly. Consequently, the current pest management program used by growers in the region for spider mites on tomato is unsatisfactory (Goyal, 1982; Reddy et al., 2013). In particular, carbaryl induces mite problems physiologically (Martinez-Rocha et al., 2008; Reddy and Bautista, 2012) and malathion, while somewhat effective against caterpillars, provides little control of mites. Many farmers in Guam often resort to repeated applications because of the ineffectiveness of these chemicals and resultant increases in mite and fruitworm populations (Reddy, 2001; Reddy and Tangtrakulwanich, 2013).

Recently, farmers have been encouraged to increase vegetable production, including tomato, to reduce the importation of vegetables to the region. Production of cherry tomatoes has expanded on commercial farms and in home gardens (Schulub and Yudin, 2002), but have been extensively damaged by *T. marianae* and *H. armigera*. The rationale in selecting some of the control measures to these pests are based on earliest tests were carried out in farmer's tomato fields, in which *Beauveria bassiana*, azadirachtin, *Bacillus thuringiensis* were used. The biorational chemicals was applied (as a spray) up to 6 times during the cropping period. The insect damage in the plot treated with *B. bassiana*, azadirachtin, *B. thuringiensis* was low compared with that in fields treated with traditional insecticides such as carbaryl and malathion, and a 35% higher yield of marketable tomatoes was obtained there.

The objective of the current study was to compare the efficacies of different management approaches of biorational and conventional-based pest management programs for these pests on tomato to replace conventional chemical pesticides used by growers.

2. Materials and methods

2.1. Seedling production and plot design

Seeds of the cherry tomato variety 'Season Red' were sown in trays (40 × 30 cm) and seedlings were grown for 40 days in a nursery in a shade house (30—32 °C, 60—80% RH, and 14:10 h L:D photoperiod) using the standard agronomic practices of the area (Schulub and Yudin, 2002).

Experiments were conducted at the University of Guam Agricultural Experiment Station at Yigo (N 13° 31.930' E 144° 52.351') in northern Guam and at the Inarajan Experiment Station (N 13° 61.963′ E 144° 45.353′) in southern Guam. Treatment plots (8 × 8 m) were arranged in a randomized block design and separated from other plots by 1.0 m buffer zones to prevent contamination from pesticide drift. Identical trials were conducted from June—September 2012 at Yigo and August—November 2013 at Inarajan. Thirty five tomato seedlings per plot that were 40 days old were transplanted with 75 cm spacing between rows and an average of 91.4 cm between plants within rows. Three replicates of each of the 11 treatments resulted in a total of 33 plots for each experiment. Each plot consisted of 5 rows of 12 tomato plants, for a total of 60 plants per plot. The total area of the experimental tomato field was 480 m^2 at each site. Fertilizer applications followed those of Schulub and Yudin (2002).

2.2. Treatment procedures

Nine chemical application treatments consisting of single products or combinations of products, a water spray control and a no spray control were applied to plots (Table 1). Carbaryl and malathion applications were made at the set time intervals normally practiced by Guam farmers (Table 2). The amount of spray solution per application was 95 L/ha for small plants (up to 45 days after transplanting/DAT) and 190.0 L/ha for larger ones (45 DAT until harvest). All the chemicals were applied with motorized backpack sprayers (Solo Brand; Forestry Suppliers, Jackson, Mississippi) equipped with an adjustable, flat spray, hollow cone, jet stream nozzle, with pressure (45 psi = 310 kPa) calibrated to deliver desired quantity of spray per hectare.

2.3. Arthropod sampling and tomato yields

To determine *T. marianae* population levels, 10 plants were selected randomly per plot and for each plant, three leaves were checked, one from the top, middle and bottom of the plant (Reddy et al., 2013). On the underside of each leaf, mites were counted using a magnifying lens. Leaf counts were repeated weekly, and in addition the number of leaves (mite-infested leaves) infested by *T. marianae* of the 30 leaves examined per plot was also recorded. The term "mite-infested leaves" means a leaf is characterized as "infested" when one or more mite individuals of any developmental stage was recorded on the underside. In practice such a leaf (with only 1-2 mites) may not be regarded as "infested" by tomato growers.

Larval infestation levels were estimated by randomly examining 60 unripe fruit per plot (one fruit per plant) and recording the

Table 1
Biological and conventional insecticides used in the present study.

Treatment	Active ingredient	Dose	Source
Aza-Direct® spray	1.2% Azadirachtin and other ingredients 98.8%	10 ml/1 L of water	Azadirachtin, Gowan Company, Yuma, AZ
Volck oil spray®	Petroleum Oil 97%, other ingredients 3%	20 ml/1 L of water	The Ortho Group, Marysville, OH
BotaniGard® 22WP	*Beauveria bassiana* Strain GHA 22%, inert ingredients 78%	2.4 g/1 L of water	Laverlam International Corporation, Butte, MT
DiPel® DF	*Bacillus thuringiensis*, subsp. *kurstaki*, strain ABTS-351, fermentation solids, spores, and insecticidal toxins 54%; Other ingredients 46%	15 g/1 L of water	Valent USA, Libertyville, IL
Carbaryl 50 WP	1-Naphthyl N-methylcarbamate 50%, Inert Ingredients 50%	43 g/l L of water	AllPro, St. Joseph, MO
Malathion (Prentox®)	Malathion 0,0-dimethyl phosphorodithioate of diethyl mercaptosuccinate 57%, other ingredients 43%	5 ml/1 L of water	Prentiss Incorporated, Floral Park, NY

Table 2
Treatments used for control of pests on tomatoes in trial.

Treatment code	Type of agent used	Number of applications	Timing of treatment application (days after transplanting)
T1	Control (no applications)	–	–
T2	Control (water spray)	–	–
T3	Petroleum spray oil (PSO) + *Beauveria bassiana* + azadirachtin + *Bacillus thuringiensis* (the IPM package)	4	15, 30, 45 and 60
T4	Two applications of PSO followed by azadirachtin	4	15, 30 and 45, 60
T5	Two applications of *Beauveria bassiana* followed by *Bacillus thuringiensis*	4	15, 30 and 45, 60
T6	PSO, 6 applications	6	15, 30, 45, 60, 75 and 90
T7	azadirachtin, 6 applications	6	15, 30, 45, 60, 75 and 90
T8	*Beauveria bassiana*, 6 applications	6	15, 30, 45, 60, 75 and 90
T9	*Bacillus thuringiensis*, 6 applications	6	15, 30, 45, 60, 75, and 90
T10	Malathion, 15 applications (the growers practice)	13	10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120 and 130
T11	Carbaryl, 15 applications (the growers practice)	13	10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120 and 130

number of *H. armigera* larvae and damaged fruit (Kuhar et al., 2006). The plots were harvested when ready and the yield was recorded for each plot. Both undamaged (marketable) and damaged fruits were graded using a commercial tomato grader. Cherry tomatoes variety of Season Red, "2−16/32", and "2−24/32" (diameter cm) fruit sizes were considered marketable, and anything smaller or misshapen were culled. The marketable fruits were those that were mature, not overripe or soft, clean, well developed, well formed, smooth, and free from decay, sunscald, or damage by any other cause (USDA, 1991). The data were averaged and expressed as the number of mites per leaf, the percent of infested leaves, and yield per hectare.

2.4. Statistical analysis

Data for the number of mite-infested leaves per plot, the proportion of damaged fruit, and overall yield in different treatment were analyzed using repeated measures ANOVA ($P < 0.05$) over multiple dates, and differences between treatments means were compared using the Tukey HSD test. Proportion data were square-root transformed prior to analysis in order to stabilize variances. All statistical analyses were carried out using SAS Version 9.3 (SAS Institute, 2009). 5% levels of significance were used for comparing means.

3. Results

3.1. Damage assessment

The mean percentage of mite-infested leaves and the population density of *T. marianae* at both locations were higher in control plots than in the treated plots ($F_{7, 17} = 14.25$, $P < 0.05$) (Table 3). In plots treated with the IPM package (Petroleum spray oil (PSO), *B. bassiana*, azadirachtin and *B. thuringiensis*) at 15, 30, 45 and 60 DAT, the number of *T. marianae*-infested leaves ($F_{7, 23} = 26.5$, $P < 0.05$; Table 3) and the number of mites per leaf ($F_{7, 32} = 31.4$, $P < 0.05$; Table 3) were both significantly lower than in plots treated with carbaryl, malathion, six applications of *B. bassiana*, or *B. thuringiensis* at both locations. Significantly lower fruit damage (5%) by *H. armigera* was recorded in plots treated with the IPM package compared to the carbaryl, malathion treated plots and to both controls at both locations where recorded on an average of 50% and 65% damage, correspondingly ($F_{7, 18} = 24.7$, $P < 0.05$; Fig. 1). Fruit damage in the plots that received two applications each of PSO and azadirachtin (T4) and *B. bassiana* and *B. thuringiensis* (T5) was significantly ($F_{7, 13} = 31.4$, $P < 0.05$; Fig. 1) lower than in the control treatments.

3.2. Yield assessment

Both control plots suffered the greatest damage from *T. marianae* and *H. armigera* and had the lowest marketable yield. The marketable tomato yields from the plots managed with the IPM package were significantly greater at both locations than those in other treatments ($F_{7, 17} = 9.31$, $P < 0.05$; Fig. 2). The treatment with six applications of *B. bassiana* and *B. thuringiensis*, malathion, and carbaryl did not differ significantly from each other but did produce higher marketable yields than in either of the control plots ($F_{7, 21} = 12.7$, $P < 0.05$; Fig. 2).

4. Discussion

According to our previous research (Reddy and Tangtrakulwanich, 2013), the plots treated with horticultural oil (Sun-spray 6E®) at 8−12 mites/leaf in the dry season and 8−14 mites/leaf during the wet season had significantly lower leaf damage and *T. marianae* densities compared to plots treated at a higher mite threshold, or plots treated with regularly scheduled sprays, or in control plots. Likewise, an initial spray with azadirachtin (Aza-Direct®) when two *H. armigera* eggs were detected in 10 of the plant samples, followed by an additional spray only if two damaged fruits or *H. armigera* larvae were detected per 50 immature fruit, resulted in lower percent fruit damage and higher marketable yield compared to other threshold levels or a regular spray schedule. Although a pest management based threshold level

Table 3
Percentage of mite-damaged leaves and mean number of *Tetranychus marianae* in different treatments imposed on tomato.

Treatment code	Mean ± SE percent mite infested leaves		Mean ± SE number of mites/ leaf	
	Inarajan	Yigo	Inarajan	Yigo
T1	84.5 ± 2.1a	48.2 ± 1.3a	746.4 ± 2.6a	326.4 ± 2.6a
T2	83.3 ± 3.9a	45.3 ± 2.9a	722.0 ± 4.9a	297.0 ± 1.4a
T3	7.2 ± 1.3e	2.1 ± 0.2d	4.3 ± 1.1e	0.8 ± 0.2e
T4	22.1 ± 1.7d	16.2 ± 1.4c	36.2 ± 2.6d	21.8 ± 1.2c
T5	37.3 ± 0.2c	28.1 ± 1.7b	86.4 ± 3.5c	22.3 ± 0.8c
T6	24.2 ± 2.2d	18.6 ± 1.4c	38.5 ± 1.3d	15.7 ± 1.2d
T7	23.8 ± 1.7d	15.2 ± 0.9c	42.4 ± 2.7d	14.2 ± 0.6d
T8	73.6 ± 2.5b	33.2 ± 1.4b	170.1 ± 4.6b	108 ± 1.6b
T9	72.1 ± 3.6b	31.4 ± 2.2b	168.4 ± 3.2b	99.7 ± 3.2b
T10	70.3 ± 3.6b	28.3 ± 2.1b	174.2 ± 2.7b	102.5 ± 2.4b
T11	68.3 ± 1.3b	30.8 ± 2.4b	180.8 ± 4.3b	98.3 ± 1.2b

Means within the same column followed by the same letter are not significantly different $P > 0.05$ (Repeated measure ANOVA, Tukey HSD). Each value represents the mean (±SE) of three replications. The mean number of infested leaves and mean number of *T. marianae* per plot was recorded on the 30 leaves in each plot.
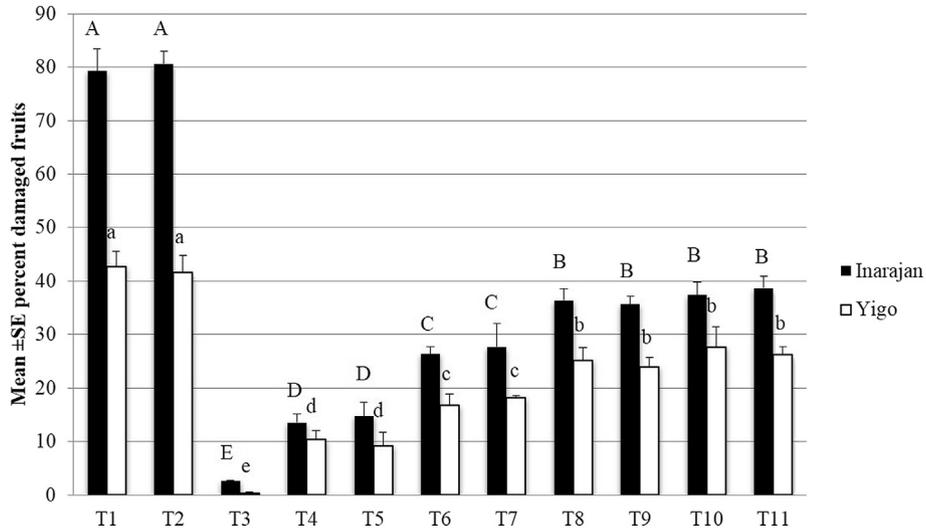
Fig. 1. Percentage of fruit damage of tomatoes in different treatments for *Helicoverpa armigera*. Different letters above the bars indicate significant differences, *P* > 0.05 (Repeated measure ANOVA, Tukey HSD). Each value represents the mean (±SE) of 3 replications. T1: Control (no applications); T2: Control (water spray); T3: Petroleum spray oil (PSO), *Beauveria bassiana*, azadirachtin, *Bacillus thuringiensis* (the IPM package); T4: Two applications of each, PSO and azadirachtin; T5: Two applications of each, *Beauveria bassiana* and *Bacillus thuringiensis*; T6: PSO, 6 applications; T7: azadirachtin, 6 applications; T8: *Beauveria bassiana*, 6 applications; T9: *Bacillus thuringiensis*, 6 applications; T10: Malathion, 15 applications (the growers' practice); T11: Carbaryl, 15 applications (the growers' practice). Different capital and lower-case letters above the bars indicate significant differences among treatments (repeated measures ANOVA followed by LSD test, $\alpha = 0.05$).

is always better than calendar based sprays, we did not have the results for threshold levels ready when we initiated this study. In addition, there was urgency to develop an effective control method for *T. marianae* and *H. armigera* to replace the conventional sprays in the Pacific Islands. Not all growers want to follow threshold-based sprays since it is labor intensive and difficult to schedule for work. Although a binominal sampling scheme (presence: absence) would be ideal, many growers do not want to count mites and assess fruit damage in the field.

Integrated pest management strategies for spider mites and fruit borer favor botanical pesticides over conventional broad-spectrum chemical pesticides due to the former's lower toxicity, and higher safety to the environment and beneficial arthropods (Yang et al., 2010). Presently, conventional insecticides (carbaryl and malathion) are the only pesticides used by growers in this region on tomato. However, repeated use of broad-spectrum insecticides is often expensive and harmful to natural enemies, and can lead to insecticide resistance, environmental pollution and secondary pest outbreaks (Mallet, 1989). More broadly, biorational insecticides include botanical extracts, pathogens (bacteria, viruses, fungi, protozoa and entomopathogenic nematodes), semi-ochemicals, and insect growth regulators, and they have been used
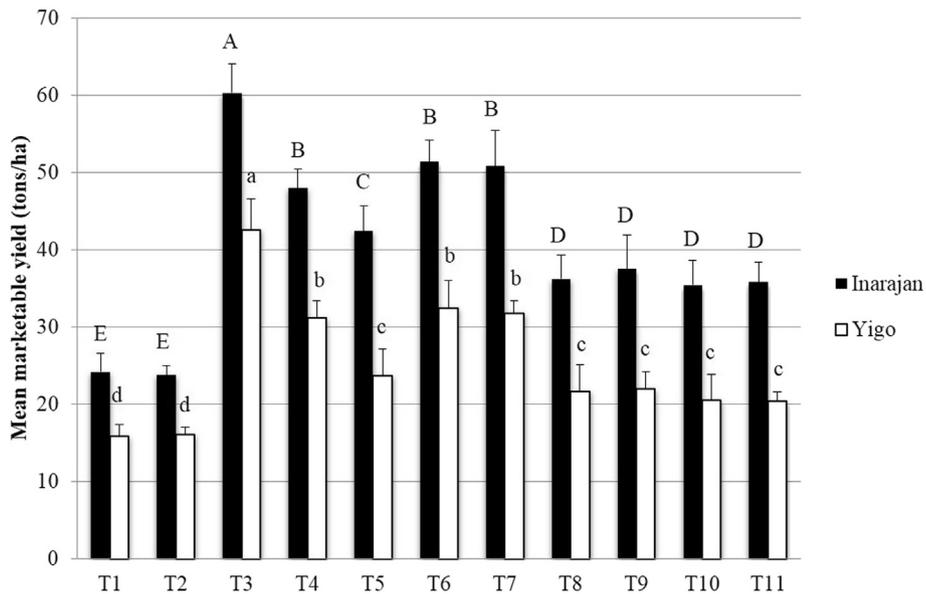

Fig. 2. Marketable yield of tomatoes in different treatments. Different letters above the bars indicate significant differences, *P* > 0.05 (Repeated measure ANOVA, Tukey HSD). Each value represents the mean (±SE) of 3 replications. T1: Control (no applications); T2: Control (water spray); T3: Petroleum spray oil (PSO), *Beauveria bassiana*, azadirachtin, *Bacillus thuringiensis* (the IPM package); T4: Two applications of each, PSO and azadirachtin; T5: Two applications of each, *Beauveria bassiana* and *Bacillus thuringiensis*; T6: PSO, 6 applications; T7: azadirachtin, 6 applications; T8: *Beauveria bassiana*, 6 applications; T9: *Bacillus thuringiensis*, 6 applications; T10: Malathion, 15 applications (the growers' practice); T11: Carbaryl, 15 applications (the growers' practice). Different capital and lower-case letters above the bars indicate significant differences among treatments (repeated measures ANOVA followed by LSD test, $\alpha = 0.05$).

to control many species of pest insects (Djerassi et al., 1974; Schmutterer, 1990, 1995; Davidson et al., 1991; Trdan et al., 2007; Leng and Reddy, 2012). Insecticidal oils, including those of botanical or mineral origin, are also biorational pesticides that are used against many pest insects (Trdan et al., 2006; Yang et al., 2010). On the other hand, most of the treatments used in the present study are cost effective and affordable by the growers (Reddy and Tangtrakulwanich, 2014).

In this study, the IPM package (PSO, *B. bassiana*, azadirachtin and *B. thuringiensis*) at 15, 30, 45 and 60 DAT was the most effective treatment in reducing the damage by *T. marianae* and *H. armigera* and significantly increasing the marketable yield of tomatoes. The integrated control starting with PSO is justifiable because the mite attacks occur particularly at the early stage of crop growth, and PSO has been shown to be effective against various spider mites. For example, Nicetic et al. (2001) reported that 0.5% PSO applied fortnightly to roses gave excellent protection from *Tetranychus urticae* Koch (Acarina: Tetranychidae) but did not affect the predatory mite *Phytoseiulus persimilis* Athias-Henriot (Acarina: Phytoseiidae). Reddy and Bautista (2012) reported that either PSO alone or a combination of the predatory mite *Neoseiulus californicus* (McGregor) (Acarina: Phytoseiidae) with PSOs produced significant control of *T. marianae* and did not affect the survival of *N. californicus*. Similarly, the severity of *H. armigera* attack seems to be high during the flower and pod stage of the crop. Application of *B. bassiana*, azadirachtin, and *B. thuringiensis* was therefore appropriate at 30, 45 and 60 DAT. Our results agree with Kumar et al. (2011) who reported that the treatment with biorational insecticides (*B. thuringiensis*, *B. bassiana*, azadirachtin and nuclear polyhedrosis virus) significantly reduced pod damage by *H. armigera* and increased the yield levels in chick pea (*Cicer arietinum* L.). Meanwhile, Sudharani and Rath (2011) reported that neem-based products are generally effective against *H. armigera*. Similarly, Nahar et al. (2004) reported that oils and entomopathogens are effective against *H. armigera*, and applications in pigeon pea (*Cajanus cajan* (L.) Millsp.) fields reduced pod damage and increased yield levels compared to insecticide treatments and control plots.

Acknowledgments

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