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Field efficacy of various entomopathogens against Fall Armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) infesting maize

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ABSTRACT: Farmers typically use chemical measures to combat fall armyworm, but their improper application has led to numerous issues. In such cases, it is necessary to make an efficient, low-risk plan for managing this pest. This study was conducted with the objective to evaluate the efficacy of different entomopathogens/microbial biopesticides on *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) infesting maize. A field trial experiment was conducted during *kharif*, 2019 and *rabi*, 2019-20 by using Randomized Block Design (RBD) with three replications at Biological control farm, Anand Agricultural University, Anand. *Bacillus thuringiensis* AAU Strain – 1% AS was found most effective among all the evaluated entomopathogens in both the seasons and that treatment was at par with *Bacillus thuringiensis* 3.5% ES (Commercial formulation)with recording the lowest population of larvae (1.11 larvae/10 plants and 1.22 larvae/10 plants), plant damage (11.47 % and 13.10 %) and cob damage (11.45 % and 13.01 %), respectively. The highest grain as well as stover yield was recorded from the plot treated with *Bacillus thuringiensis* AAU Strain – 1% AS (2868 and 4136 kg/ha) and followed by *Bacillus thuringiensis* 3.5% ES (Commercial formulation) (2829 and 4099 kg/ha), respectively. During the experiment period, all the evaluated entomopathogens/microbial biopesticides were found safe to the natural enemies *viz*., chrysopids, coccinellids and spiders.

Keywords: Fall armyworm, invasive pest, entomopathogens/microbial biopesticide, maize, yield, natural enemies.

INTRODUCTION

Maize (*Zea mays* L.) is the third most important crop grown in various agroclimatic zones around the world. It commonly known as corn and belongs to the Poaceae family. It is also called the "queen of cereals" due to its wider adaptability and highest yield potential among cereals (Jeyaraman, 2017).

In India, maize is grown all year round in different states of the country for various purposes such as grain, fodder, green corn on the cob, sweet corn, baby corn and popcorn. In terms of production volume, India ranks sixth in the world. It is mainly grown in Madhya Pradesh, Karnataka, Maharashtra, Rajasthan, Tamil Nadu, Andhra Pradesh, Bihar, Chhattisgarh, Gujarat, Himachal Pradesh and Uttar Pradesh. It is cultivated on an area of 9.47 million hectares with an annual production of 28.72 million tons and an average productivity of 3032 kg/ha. In Gujarat, it is cultivated on an area of 4.38 lakh hectares with a production of 7.93 lakh tonnes and a productivity of 1809 kg/ha (Anonymous, 2019). The fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) is a new invasive pest of maize. It is a major pest of maize having native of tropical and subtropical regions of the America (Sah *et al.*, 2019). It was first reported in West and Central Africa in early 2016 (Goergen *et al.*, 2016). Caterpillars wreaking havoc and feed voraciously not only on cereals (corn, wheat, sorghum, millet, rice) and grasses, but also on sugar cane, cotton, potatoes, yams, ginger, chrysanthemums, tomatoes, tobacco, spinach, cruciferous vegetables, gourds, cucumbers, cowpeas, kidney beans, soybeans, peanuts, bananas, etc. (Anonymous, 2018). It is therefore a highly polyphagous pest known to feed on 353 host crops worldwide, mainly belonging to 76 plant families, including the Poaceae (106), Asteraceae (31), and Leguminous (31) families. (Montezano *et al.*, 2018). In July 2018, fall armyworm was observed for the first time in Asia. Sharanabasappa *et al.* (2018) first reported an incidence of fall armyworm, an alien invasive pest infesting maize in Karnataka during June 2018. So far, this pest has been reported in maize from different states of the country. In Gujarat, Sisodiya *et al*. (2018) first reported the incidence of fall armyworm on sweet corn at Anklav taluka of Anand district.

The growing larvae feed on different parts of the host plant, depending upon the crop, the developmental stage of the crop, and the age of the larvae. In maize, young larvae feed on developing leaves by remain inside funnel, producing the characteristic window effect. Moist frass near the funnel are easily recognizable as signs of larval feeding. In the early stage infection, this feeding can kill the growing point of plants. On older plants, larger larvae can burrow into the corncob that cause reduce in yield quality and quantity. The larvae hide in the funnel during the day and come out at night to feed on the leaves. This special behaviour complicates its control by direct interventions such as pesticides, especially when efficacy is contact-based.

Chemical control is commonly used by farmers to increase their gains, but its indiscriminate use creates many problems. Relying solely on chemical control can lead not only to pest resistance problems, but also to pest resurgence and it pollute environment. Under these circumstances, it is necessary to provide effective, low-risk strategies to control this pest. Therefore, this experiment was conducted to assess the efficacy of various entomopathogenic/microbial biopesticides in controlling fall armyworm and their effects on natural enemy populations.

MATERIALS AND METHODS

To evaluate different entomopathogens/microbial biopesticides against the fall armyworm, *S. frugiperda* in maize, a field experiment was carried out during *Kharif*, 2019 and *rabi*, 2019-20 at Agronomy Farm, B. A. College of Agriculture, AAU, Anand in Randomized Block Design (RBD) with 10 treatments and 3 replications each having plot size of 6.0 × 4.8 m. Maize variety GAYMH-1 was sown at spacing of 60 × 20 cm on 17th July, 2019 (*Kharif*) and 13th November, 2019 (*rabi*). Maize crop was grown according to standard farming practices, with the exception of pest control measures. There were total 10 treatments containing different entomopathogens/microbial biopesticides (Table 1). All the respective strain/formulations of entomopathogens were collected from respective laboratories of Anand Agricultural University, Anand, ICAR-National Bureau of Agricultural Insect Resources (NBAIR), Bangalore and University of Agricultural Sciences (UAS), Dharwad. The first application was made after initial appearance of pest. The second and third sprays were applied at 10 days interval after first spray. The spray solution was applied with a knapsack sprayer until it easily ran off. Before as well as at 3rd, 5th, 7th and 10th days after each spray, the number of larva(e) and damaged plants, were counted from randomly selected ten maize plants in all treatments. The numbers of damaged cobs were recorded at harvest. Population of natural enemies namely coccinellids (grubs and adults), chrysopids (grubs and adults) and spiders (spiderlings and adults) were recorded for each treatment from randomly selected plants. After harvest, grain and stover yield were also recorded from each net plot and converted to kg/ha. After performing appropriate transformations, the data were subjected to statistical analysis and valid conclusions were drawn.

Table 1: Treatment details of evaluated different entomopathogens against fall armyworm.

Treatments		Concentration	Quantity (ml or g)/ 10 L
T_1	*Bacillus thuringiensis* – 1% AS (AAU Strain)	2 × 10^8 spores/ml	40
T_2	*Bacillus thuringiensis* 3.5% ES (Commercial Strain)	1 × 10^9 spores/ml	40
T_3	*Beauveria bassiana* – 1% WP (AAU Strain)	2 × 10^{8}cfu/g	40
T_4	*Beauveria bassiana* – 5% WP (Commercial Strain)	1× 10^{9}cfu/g	40
T_5	*Metarhizium anisopliae* – 1% WP (NBAIR Strain)	2 × 10^8 cfu/g	40
T_6	*Metarhizium anisopliae* – 1.15% WP (Commercial Strain)	1 × 10^{9}cfu/g	40
T_7	*Nomuraea rileyi* – 1% WP (AAU Strain)	2 × 10^{8}cfu/g	40
T_8	*Nomuraea rileyi* – 1% WP (UAS Dharwad Strain)	2 × 10^{8}cfu/g	40
T_9	*Sf*NPV– 1% AS(NBAIR Strain)	1 × 10^9 POBs/ml	30
T_{10}	Untreated control	-	-

RESULTS AND DISCUSSION

Bio-efficacy based on larval population. The population of fall armyworm was homogeneous before spray in all the treatments during both the seasons. All the evaluated entomopathogens were significantly superior to control up to ten days of each spray. The pooled data of larval population during *kharif*, 2019 (Table 2) clearly indicated that the treatment of *B. thuringiensis* (AAU Strain – 1% AS) (1.19 larvae/10 plants) and *B. thuringiensis* (Commercial Strain – 3.5% ES) (1.32 larvae/10 plants) were found significantly superior than all the evaluated entomopathogens. Whereas, the plots treated with *B. bassiana* (Commercial Strain – 5% WP) (4.79 larvae/10 plants) recorded the highest larval population, which was remained at par with *B. bassiana* (AAU Strain – 1% WP) (4.70 larvae/10 plants) and *Sf*NPV (NBAIR Strain – 1% AS) (4.61 larvae/10 plants) which were inferior in reducing the larval population. Similar trend was documented in the field experiment conducted during *rabi* season 2019-20. Based on these observations, it can be deduced that the *B. thuringiensis* (AAU Strain – 1% AS) and *B. thuringiensis* (Commercial Strain – 3.5% ES) are effective in reducing larval population of fall armyworm. The data of pooled over seasons is depicted in Fig. 1. In nutshell, fall armyworm, *S. frugiperda* can be effectively managed by spraying of *B. thuringiensis* (AAU Strain – 1% AS) and *B. thuringiensis* (Commercial Strain – 3.5% ES). In contrast to this, *Sf*NPV (NBAIR Strain – 1% AS), *B. bassiana* (AAU Strain – 1% WP), *B. bassiana* (Commercial Strain – 5% WP) are noticed as least effective entomopathogens against fall armyworm infesting maize.

Capalbo *et al*. (2001) reported 100 per cent mortality of neonate larvae of *S. frugiperda* within two days of spraying of *B. thuringiensis* (*Bt*) and all larvae were found dead on leaves. According to Molina-Ochoa *et al*. (2003), among evaluated the treatments, *B. thuringiensis* and *M. anisopliae* cause significant higher mortality in fall armyworm populations and help to reduce plant and cob damage in crops. Dhobi *et al.*

(2020) found higher efficacy of *N. rileyi* 1 % WP and *B. thuringiensis* 1 % WG (2.03 larvae/10 plants) against *S. frugiperda* in maize at Anand. These findings are more or less in agreement with the present study.

Bio-efficacy based on plant damage and cob damage. All the evaluated entomopathogens were found significantly superior to control up to 10 days of each spray. The data pertaining to plant damage and cob damage (Table 3) clearly indicated that *B. thuringiensis* (AAU Strain – 1% AS) (11.84%) and *B. thuringiensis* (Commercial Strain – 3.5% ES) (13.83%) were found significantly superior among all the evaluated entomopathogens. *M. anisopliae* (NBAIR Strain – 1% WP) (25.82%), *M. anisopliae* (Commercial Strain – 1.15% WP) (26.30%), *N. rileyi* (AAU Strain – 1% WP) (28.54%) and *N. rileyi* (UAS Dharwad Strain – 1% WP) (29.95%) were noticed as next effective treatments, followed by *Sf*NPV (NBAIR Strain – 1% AS) (42.07%), which was at par with *B. bassiana* (AAU Strain – 1% WP) (44.06%) and *B. bassiana* (Commercial Strain – 5% WP) (45.19%). In a field study done during the 2019–20 *rabi* season, a similar effect was observed. Thus, from the above result, it can be concluded that the treatments of *B. thuringiensis* (AAU Strain – 1% AS) and *B. thuringiensis* (Commercial Strain – 3.5% ES) are found to be more effective on the basis of plant damage caused by fall armyworm in maize. Similarly, efficacy of the various treatments in reducing cob damage documented the similar observations. Overall, it was deduced that maize cob damage caused by fall armyworm, *S. frugiperda* can be reduced by spraying of *B. thuringiensis* (AAU Strain – 1% AS) and *B. thuringiensis* (Commercial Strain – 3.5% ES).

Ramanujam *et al.* (2020) found that 69 % and 76 %, 68 % and 70 % of reduction of maize plant damage caused by fall armyworm in plots treated with *M. anisopliae* ICAR-NBAIR Ma-35 and *B. bassiana* ICAR-NBAIR Bb-45, respectively in 2018 and 2019, respectively. Dhobi *et al.* (2020) noticed lowest maize plant damage caused by fall armyworm in plots treated with *N. rileyi* 1 % WP (15.34%), followed by *B. thuringiensis* 1 % WG (17.70%). It was indicative from review of available literature that very few researcher have evaluated entomopathogens against cob damage by *S. frugiperda* under field condition. Dhobi *et al.* (2020) observed lowest cob damage in plots treated with *N. rileyi* 1 % WP (15.19%), which was at par with *B. thuringiensis* 1 % WG (15.19%).

Impact on yield. During *kharif*, 2019 (Table 4) the plots treated with *B. thuringiensis* (AAU Strain – 1% AS) (2811 kg/ha & 3991 kg/ha) and *B. thuringiensis* (Commercial Strain – 3.5% ES) (2773 kg/ha & 343 kg/ha) were recorded significantly higher grain and stover yield. The observations during the *rabi* season 2019-20 documented the similar effect. Dhobi *et al.* (2020) observed that the highest grain and stover yield was recorded in plots treated with *N. rileyi* 1 % WP (2957 kg/ha and 4069 kg/ha), which was at par with treatment of *B. thuringiensis* 1 % WG (2932 kg/ha and 4033 kg/ha). In present findings also *B. thuringiensis* (AAU Strain – 1% AS) treated plots recorded the highest yield.

Impact on population of natural enemies. The data on population of natural enemies revealed that there was no any impact of all the tested entomopathogens on the natural enemies (Table 5). Looking to the past literatures, scanty reports are available on effect of entomopathogens on population of natural enemies in maize. Meena *et al.* (2013) evaluated various biopesticides against mustard aphid, *Lipaphis erysimi* and natural enemies in mustard, they reported that treatment of *M. anisopliae* and *B. bassiana* @ 5 g per litre of water were found safer to coccinellids. Singh *et al.* (2015) evaluated different microbial insecticides against *Plutella xylostella* Linnaeus, *Pieris brassicae* Linnaeus and natural enemies in cabbage, they found that treatment of *B. thuringiensis* var. *kurstaki* @ 1000 g/ha and *B. bassiana* @ 500 ml/ha were proved safest to *Coccinella septempunctata*. Thus, these results are in conformity with present findings. Scanty information is available so far on the impact of various entomopathogens on population of spiders (spiderlings + adults) and chrysopids (grubs + adults) in maize ecosystem.

Table 2: Bio-efficacy of different entomopathogens against larvae of fall armyworm.

Treatments		*Kharif*, 2019	*Rabi*, 2019-20
		No. of larvae / 10 plants	
T_1	*Bacillus thuringiensis* – 1% AS	1.30a (1.19)	1.24a (1.04)
T_2	*Bacillus thuringiensis* 3.5% ES	1.35a (1.32)	1.28a (1.14)
T_3	*Beauveria bassiana* – 1% WP	2.28c (4.70)	2.20d (4.34)
T_4	*Beauveria bassiana* – 5% WP	2.30c (4.79)	2.24c (4.52)
T_5	*Metarhizium anisopliae* – 1% WP	1.74b (2.53)	1.66b (2.26)
T_6	*Metarhizium anisopliae* – 1.15% WP	1.77b (2.63)	1.69b (2.36)
T_7	*Nomuraea rileyi* – 1% WP (AAU Strain)	1.82b (2.81)	1.75b (2.56)
T_8	*Nomuraea rileyi* – 1% WP (UAS Dharwad Strain)	1.87b (3.00)	1.78b (2.67)
T_9	*Sf*NPV– 1% AS	2.26c (4.61)	2.17d (4.21)
T_{10}	Untreated control	2.75d (7.06)	2.63d (6.42)
S. Em. ±		0.04	0.04
C. D. at 5%		0.09	0.08
C. V. (%)		9.69	9.71

Note: 1. Figures in parenthesis are retransformed values and thoseoutside are $\sqrt{x-0.5}$ transformed values
2.Treatment mean(s) with the letter(s) in common are not significant by Duncan's New Multiple Range Test (DNMRT) at 5% level of significance

Table 3: Influence of different entomopathogens on plant and cob damage.

Treatments		*Kharif*, 2019		*Rabi*, 2019-20	
		Plant damage (%)	Cob damage at harvest (%)	Plant damage (%)	Cob damage at harvest (%)
T_1	*Bacillus thuringiensis* – 1% AS	20.13a (11.84)	21.14a (13.01)	19.44a (11.08)	18.42a (9.98)
T_2	*Bacillus thuringiensis* 3.5% ES	21.83a (13.83)	21.14a (13.01)	20.61a (12.39)	21.14a (13.01)
T_3	*Beauveria bassiana* – 1% WP	41.59c (44.06)	41.13d (43.27)	39.81c (40.99)	39.22d (39.98)
T_4	*Beauveria bassiana*– 5% WP	42.24c (45.19)	43.08d (46.65)	40.94c (42.94)	41.13d (43.27)
T_5	*Metarhizium anisopliae* – 1% WP	30.54b (25.82)	28.77ab (23.16)	29.05b (23.58)	28.27b (22.43)
T_6	*Metarhizium anisopliae* – 1.15% WP	30.85b (26.30)	30.77bc (26.17)	29.44b (24.16)	28.77b (23.16)
T_7	*Nomuraea rileyi* – 1% WP (AAU Strain)	32.29b (28.54)	30.98bc (26.50)	30.98b (26.50)	28.77b (23.16)
T_8	*Nomuraea rileyi* – 1% WP (UAS Dharwad Strain)	32.55b (29.95)	30.98bc (26.50)	31.15b (26.76)	30.98bc (26.50)
T_9	*Sf*NPV– 1% AS	40.44c (42.07)	39.21cd (39.96)	39.45c (40.37)	37.21cd (36.57)
T_{10}	Untreated control	51.62d (61.45)	48.82d (56.65)	50.91d (60.24)	46.90e (53.31)
S. Em. ±		0.64	2.10	0.70	2.08
C. D. at 5%		1.80	6.71	1.95	6.18
C. V. (%)		11.20	10.89	12.61	11.29

Note: 1. Figures in parenthesis are retransformed values; those outside are arc sine transformed values
2. Treatment mean(s) with the letter(s) in common are not significant by Duncan's New Multiple Range Test (DNMRT) at 5% level of significance

Table 4: Impact of different entomopathogens on yield of maize.

Treatments		*Kharif*, 2019				*Rabi*, 2019-20			
		Yield (kg/ha)		Increase in yield over control (%)		Yield (kg/ha)		Increase in yield over control (%)	
		Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover
T_1	*Bacillus thuringiensis* – 1% AS	2811a	3991a	84.09	76.98	2925a	4280a	83.50	81.05
T_2	*Bacillus thuringiensis* – 3.5% ES	2773ab	3943ab	81.60	74.86	2886ab	4255ab	81.05	79.99
T_3	*Beauveria bassiana* – 1% WP	1931de	2792de	26.46	23.81	2000e	2975ef	25.47	25.85
T_4	*Beauveria bassiana* – 5% WP	1919e	2770e	25.67	22.84	1986e	2957f	24.59	25.08
T_5	*Metarhizium anisopliae* – 1% WP	2386abc	3431abc	56.25	52.15	2494abc	3669abc	56.46	55.20
T_6	*Metarhizium anisopliae* – 1.15% WP	2358bcd	3407bc	54.42	51.09	2477bc	3645abcd	55.40	54.19
T_7	*Nomuraea rileyi* – 1% WP (AAU Strain)	2333cde	3361cd	52.78	49.05	2431cd	3604bcde	52.51	52.45
T_8	*Nomuraea rileyi* – 1% WP (UAS Dharwad Strain)	2302cde	3334cd	50.75	47.85	2403cde	3591cdef	50.75	51.90
T_9	*Sf*NPV – 1% AS	1945de	2819de	27.37	25.01	2015de	2994def	26.41	26.65
T_{10}	Untreated control	1527f	2255f	0	0	1594f	2364g	0	0
S. Em. ±		129.03	171.20	-	-	128.47	194.55	-	-
C. D. at 5%		Sig.	Sig.	-	-	Sig.	Sig.	-	-
C. V. (%)		10.03	9.24	-	-	9.59	9.81	-	-

Note: 1. Figures in parenthesis are retransformed values; those outside are arc sine transformed values
2. Treatment mean with the letter(s) in common are not significant by Duncan's New Multiple Range Test (DNMRT) at 5% level of significance

Table 5: Impact of different entomopathogens on natural enemies of maize.

Treatments		*Kharif*, 2019			*Rabi*, 2019-20		
		Natural enemies / 10 plants			**Natural enemies / 10 plants**		
		LBB	**GLW**	**Spider**	**LBB**	**GLW**	**Spider**
		Pooled over period over sprays	**Pooled over period over sprays**	**Pooled over period over sprays**	**Pooled over period over sprays**	**Pooled over period over sprays**	**Pooled over period over sprays**
T_1	*Bacillus thuringiensis* – 1% AS	1.23 (1.01)	0.92 (0.35)	1.05 (0.60)	1.19 (0.92)	0.90 (0.31)	1.06 (0.62)
T_2	*Bacillus thuringiensis* –3.5% ES	1.22 (0.99)	0.93 (0.26)	1.02 (0.54)	1.20 (0.94)	0.89 (0.29)	1.00 (0.50)
T_3	*Beauveria bassiana* – 1% WP	1.19 (0.92)	0.88 (0.27)	1.04 (0.58)	1.21 (0.96)	0.92 (0.35)	1.03 (0.56)
T_4	*Beauveria bassiana* – 5% WP	1.20 (0.94)	0.91 (0.33)	1.06 (0.62)	1.19 (0.92)	0.92 (0.35)	1.02 (0.54)
T_5	*Metarhizium anisopliae* – 1% WP	1.23 (1.01)	0.90 (0.31)	1.08 (0.67)	1.21 (0.96)	0.89 (0.29)	1.05 (0.60)
T_6	*Metarhizium anisopliae* – 1.15% WP	1.19 (0.92)	0.88 (0.27)	1.04 (0.58)	1.20 (0.94)	0.88 (0.27)	1.07 (0.64)
T_7	*Nomuraea rileyi* – 1% WP (AAU Strain)	1.22 (0.99)	0.88 (0.27)	1.07 (0.64)	1.18 (0.89)	0.89 (0.29)	1.09 (0.69)
T_8	*Nomuraea rileyi* – 1% WP (UAS Dharwad Strain)	1.21 (0.96)	0.92 (0.35)	1.01 (0.58)	1.17 (0.87)	0.91 (0.33)	1.04 (0.58)
T_9	*Sf*NPV – 1% AS	1.16 (0.85)	0.89 (0.29)	1.05 (0.60)	1.16 (0.85)	0.90 (0.31)	1.05 (0.60)
T_{10}	Untreated control	1.21 (0.96)	0.93 (0.36)	1.08 (0.67)	1.19 (0.92)	0.92 (0.35)	1.08 (0.67)
S. Em. ±		0.02	0.02	0.017	0.02	0.02	0.016
C. D. at 5%		NS	NS	NS	NS	NS	NS
C. V. (%)		9.56	9.85	9.80	9.59	9.89	9.38

Note: 1. Figures in parenthesis are retransformed values; those outside are arc sine transformed values
2. Treatment mean with the letter(s) in common are not significant by Duncan's New Multiple Range Test (DNMRT) at 5% level of significance; 3. NS: Non-significant 4. LBB: Lady Bird Beetle, GLW: Green Lace Wing

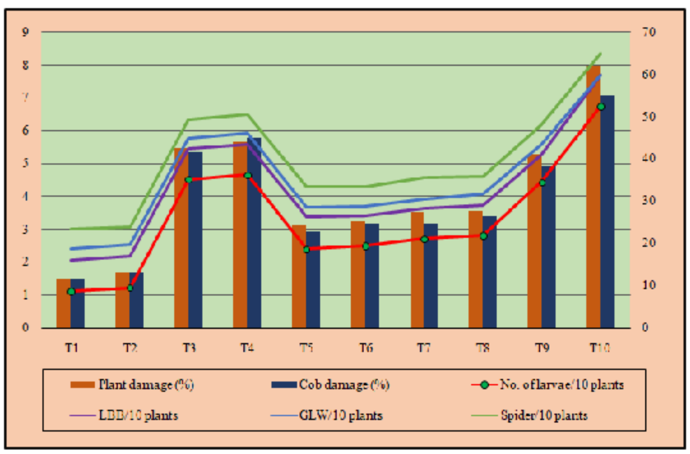

Fig. 1. Bio-efficacy of different entomopathogens against fall armyworm infesting maize (Pooled over seasons).

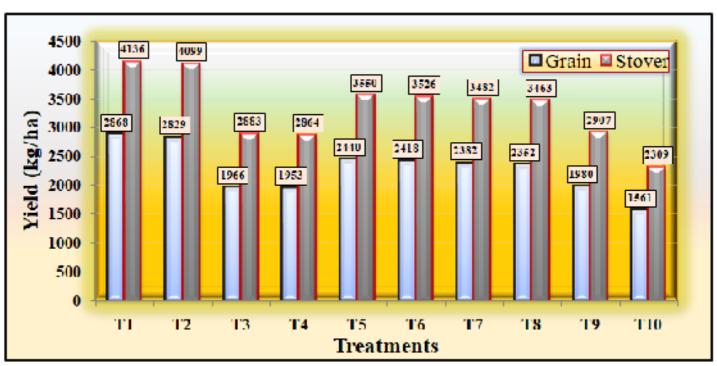

Fig. 2. Impact of different strains of entomopathogens on yield of maize (Pooled over seasons).

CONCLUSION

On basis of larval population, plant damage and cob damage percentage recorded it is concluded that treatment of *B. thuringiensis* (AAU Strain – 1% AS) @ 40 ml/10 litre of water was highly effective entomopathogen under field condition. Further, all the entomopathogens/microbial biopesticides were found safe to natural enemies *viz*., coccinellids (grubs and adults) and chrysopids (grubs and adults) and spiders (spiderlings and adults). The positive impact of treatment *B. thuringiensis* (AAU Strain – 1% AS) on grain yield and stover yield of maize is noticed. Since, *S. frugiperda* is an invasive pest of maize in Gujarat, India; hence, these findings may be useful to various stakeholders *viz*., farmers, researchers, students etc.

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Conflict of Interest None.

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