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Evaluation of Bio-pesticides against Fall Armyworm, *Spodoptera frugiperda* (J. E. Smith) in Maize

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A B S T R A C T

An experiment was conducted under field condition at three locations *viz.*, Entomology Farm, B. A. College of Agriculture, AAU, Anand, Agricultural Research Station, Sansoli and main maize research Station, Godhra during *Kharif*, 2019 to determine the efficacy of different biopesticides against the fall armyworm, *Spodoptera frugiperda* in maize (GAYMH-1) by using Randomized Block Design (RBD) with three replications. The lowest larval population (1.81 larvae /10 plants and 2.03 larvae /10 plants), minimum plant damage (15.34% and 17.70%) and cob damage (15.19 % and 15.19%) was observed in the plot treated with *Nomuraea rileyi* 1% WP @ 40 g/10 lit water and it was at par with *Bacillus thuringiensis var.kurstaki* 1 % WG @ 20 g/10 lit water, respectively. Of the tested biopesticides, the highest grain and fodder yield was recorded from the plot treated with *N. rileyi* 1% WP (2957 and 4069 kg/ha) and followed by *B. thuringiensis* (2932 and 4033 kg/ha).

Introduction

Maize is an emerging third most important cereal crop after rice and wheat in India. Andhra Pradesh, Tamil Nadu, Rajasthan, Maharashtra, Bihar, Uttar Pradesh, Madhya Pradesh and Gujarat account for 85 per cent of India's maize production. Recently, the occurrence of a new invasive exotic pest *Spodoptera frugiperda* (J.E. Smith), a lepidopteron insect has been suspected on maize crop in Karnataka (Shylesha *et al.*, 2018). This pest is highly polyphagous and migratory in behaviour that can colonize over 80 different plant species of which maize is not an exception. It also attacks crops such as alfalfa, soybean, sorghum (Bohnenblust *et al.*, 2014) cotton and other diverse pasture grasses (Murúa and Virla, 2004). The caterpillar feeds on all stages of the corn plant by consuming the foliage and mostly prefers the young plants (Ameida de Moraes *et al.*, 2015). Rows of perforations are produced in the leaves due to the feeding done in the whorls of the plant

and sometimes this can lead to extensive defoliation and a reduction in the growth potential of the plant. In conditions of heavy infestations, the caterpillar sometimes burrows into the corn ear through the husk and feeds on the kernel and this damage the quality of the corn. The densities of caterpillar finally reduced to one or two caterpillar per plant due to their cannibalistic behaviour (Capinera, 2008). Sisodiya *et al.,* (2018) reported the occurrence of invasive pest, fall armyworm, *S. frugiperda* in the maize field of Anklav taluka of Anand district of Gujarat. As *S. frugiperda* is polyphagous pest, as per the available literature, efforts are needed to manage the pest and to check its further spread and to attack other crops. For this purpose, insecticides are the main method to control *S. frugiperda* in corn in Brazil, however, it pollutes the environment when they are used indiscriminately. Another option is the biological control with several beneficial organisms acting as natural enemies, *viz.,* parasitoids, predators, fungi, virus, bacteria and nematodes (Cruz *et al.*, 2002). Hence, the present experiment was conducted to evaluate the effectiveness of some biopesticides for controlling FAW in maize.

Materials and Methods

In order to study the evaluation of different biopesticides against the fall armyworm, *S. frugiperda* in maize, a field experiment was carried out during *Kharif,* 2019 at three locations *viz.,* Entomology Farm, B. A. College of Agriculture, AAU, Anand, Agricultural Research Station, Sansoli and main maize research Station, Godhra in Randomized Block Design (RBD) with 10 treatments and 3 replications each having plot size of 6.0 x 3.6 m. Maize variety GAYMH-1 was sown at spacing of 60 x 20 cm on 15th, 22nd and 18th July, 2019 in different locations respectively. Maize crop was raised by following standard agronomical practices except pest control measures. Treatments were used: T_1 *Beauveria bassiana* 5 % WP ($1x10^9$ cfu/g), T_2 *Metarhizium anisopliae* 1.15% WP ($1x10^9$ cfu/g), T_3 *Bacillus thuringiensis* 1 % WG, T_4 *Nomuraea rileyi* 1% WP ($2x10^8$cfu/g), T_5 Azadirachtin 1500 ppm, T_6 Neem seed kernel extracts 5%, T_7 Tobacco decoction 2 % (cold method), T_8 *Lantana camara* leaf water extracts 10%, T_9 Green Chilli (chilli variety GVC- 111) water extracts 10% and T_{10} control. In the entire treatments sticker was added @ 0.15 %. The first spray was made at initiation of pest. The second and third sprays were applied after 10 days interval of first spray. Spray fluid was applied to the extent of slight run off using knapsack sprayer. The number of larva(e) and damaged plants were counted from randomly selected ten plants before as well as 5 and 10 days after each application. Numbers of damaged cobs were recorded at harvest. The grain and fodder yield were also recorded from each net plot and converted into kg/ha. The data obtained thus were, subjected to statistical analysis after appropriate transformation to draw valid conclusion.

Results and Discussion

The data on pooled over periods, sprays and locations of fall armyworm during 2019 are presented in Table 1 to 5, respectively. The efficacy of different biopesticides is adjudged based on pooled over periods.

Larval population (No. of larvae/10 plants)

The data on larval population pooled over three locations before spraying of biopesticides showed non significant differences which indicated homogeneous distribution of pest in the experimental plots at all locations *i.e.,* Anand, Sansoli and Godhra (Table 1 and 3). All the biopesticides treatments were found significantly superior

to control till 10 days of application in all the three sprays, pooled over periods as well as pooled over periods and sprays.

The data on pooled over periods of first spray differed significantly to each other. The lowest population of fall armyworm was recorded in plots treated with *Nomuraea rileyi* 1% WP (2.19 larvae/10 plants) and it was at par with *Bacillus thuringiensis* 1 % WG (2.32 larvae/10 plants). These two treatments significantly superior to rest of the bio-pesticides.

The treatment of azadirachtin 1500 ppm (2.78 larvae/10 plants) and *Beauveria bassiana* 5% WP (2.81 larvae/10 plants) remained next effective in controlling the pest. Remaining bio-pesticides performed equally against fall armyworm in maize. The *Lantana camara* leaf water extract recorded highest larval population (3.54 larvae/10 plants).

The data on pooled over periods of second spray revealed that *Nomuraea rileyi* 1%WP (1.84 larvae /10 plants) recorded the lowest larval population and it was at par with *B. thuringiensis* 1 % WG (2.03 larvae/10 plants). Azadirachtin 1500 ppm (2.32 larvae/10 plants) and *B. bassiana* 5% WP (2.42 larvae/10 plants) registered next best effective treatments in controlling the pest. Of the tested biopesticides, green chilli water extracts found least effective by recording the highest larval population (3.83 larvae /10 plants) and it was at par with *L. camara* leaf water extract (3.66 larvae /10 plants). More or less similar trend of effectiveness was observed in pooled over periods of third spray as noticed after pooled over periods of second spray.

Overall, the data on pooled over periods, sprays and locations showed the lowest larval population in *N. rileyi* 1% WP (1.81 larvae /10 plants) and it was at par with *B. thuringiensis* 1 % WG (2.03 larvae /10 plants). *B. bassiana* 5% WP (2.42 larvae/10 plants) and Azadirachtin 1500 ppm (2.46 larvae /10 plants) were at par and stood second in position.

Remaining bio-pesticides perform equally against fall armyworm in maize. The green chilli water extracts recorded the highest population (3.83 larvae /10 plants) and it was at par with the *L. camara* leaf water extract (3.66 larvae /10 plants) in maize.

Plant damage (%)

The data on plant damage pooled over three locations before spraying of biopesticides showed non significant differences which indicated homogeneous distribution of pest in the experimental plots at three locations *i.e.*, Anand, Sansoli and Godhra (Table 2 and 3). All the biopesticides treatments were found significantly superior to control till 10 days of application in all the three sprays, pooled over periods as well as pooled over periods and sprays.

The data on pooled over periods of first spray differed significantly to each other. Minimum plant damage caused by fall armyworm was found in plots treated with *N. rileyi* 1% WP (18.40%) and it was at par with *B. thuringiensis* 1 % WG (20.27%).

These two treatments were found significantly superior to rest of the bio-pesticides. *B. bassiana* 5% WP (24.89%), azadirachtin 1500 ppm (25.09%) and neem seed kernel extracts (26.51%) were found statically at par in reducing the maize plant damage due to fall armyworm.

The green chilli water extracts recorded maximum (32.87%) plant damage and it was at par with *L. camara* leaf water extracts (32.58%).

Table.1 Evaluation of bio-pesticides against fall armyworm, *S. frugiperda* infesting maize (Pooled over periods, sprays and locations)

Tr. No.	Treatments	No. of larva(e) /10 plants days after spray										
		Before spray	First			Second			Third			Pooled over periods and sprays
			5	10	Pooled	5	10	Pooled	5	10	Pooled	
1	*Beauveria bassiana* 5 % WP (40 g/10 lit water)	1.91 (3.15)	1.69^{ab} (2.36)	1.94^{ab} (3.26)	1.82^{bc} (2.81)	1.75^{ab} (2.56)	1.66^{bc} (2.26)	1.71^{bc} (2.42)	1.55^{bc} (1.90)	1.66^{bc} (2.26)	1.61^{bc} (2.09)	1.71^{b} (2.42)
2	*Metarhizium anisopliae*1.15% WP (40 g/10 lit water)	1.88 (3.03)	1.73^{abc} (2.49)	1.99^{abc} (3.46)	1.86^{cd} (2.96)	1.85^{bcd} (2.92)	1.76^{c} (2.60)	1.80^{cd} (2.78)	1.70^{c} (2.39)	1.80^{c} (2.74)	1.76^{c} (2.60)	1.81^{c} (2.78)
3	*Bacillus thuringiensis* 1 % WG (20 g/10 lit water)	1.91 (3.15)	1.62^{a} (2.12)	1.73^{a} (2.49)	1.68^{ab} (2.32)	1.58^{a} (2.00)	1.59^{ab} (2.03)	1.59^{ab} (2.03)	1.48^{ab} (1.69)	1.49^{ab} (1.72)	1.49^{ab} (1.72)	1.59^{a} (2.03)
4	*Nomuraea rileyi* 1%WP (40 g/10 lit water)	1.91 (3.15)	1.58^{a} (2.00)	1.69^{a} (2.36)	1.64^{a} (2.19)	1.58^{a} (2.00)	1.47^{a} (1.66)	1.52^{a} (1.84)	1.37^{a} (1.38)	1.39^{a} (1.43)	1.39^{a} (1.43)	1.52^{a} (1.81)
5	Azadirachtin 1500 ppm (40 ml/10 lit water)	2.01 (3.54)	1.73^{abc} (2.49)	1.88^{ab} (3.03)	1.81^{bc} (2.78)	1.72^{bc} (2.46)	1.62^{bc} (2.12)	1.67^{bc} (2.32)	1.62^{bc} (2.12)	1.72^{c} (2.46)	1.67^{c} (2.29)	1.72^{bc} (2.46)
6	Neem seed kernel extract 5% (500 g/10 lit water)	1.79 (2.70)	1.77^{abc} (2.63)	1.94^{ab} (3.26)	1.86^{cd} (2.96)	1.77^{bcd} (2.63)	1.72^{bc} (2.46)	1.75^{c} (2.56)	1.65^{c} (2.22)	1.72^{c} (2.46)	1.69^{c} (2.36)	1.77^{bc} (2.63)
7	Tobacco decoction 2% (cold method) (200 g/10 lit water)	1.83 (2.85)	1.79^{d} (2.70)	2.06^{bc} (3.74)	1.92^{cd} (3.19)	1.88^{cde} (3.03)	1.97^{d} (3.38)	1.93^{de} (3.22)	1.88^{d} (3.03)	2.03^{d} (3.62)	1.96^{d} (2.34)	1.94^{d} (3.26)
8	*Lantana camara* leaf water extract 10% (1000 g/10 lit water)	1.85 (2.92)	1.89^{cd} (3.07)	2.13^{cd} (4.04)	2.01^{d} (3.54)	1.99^{de} (3.46)	2.08^{d} (3.83)	2.03^{e} (3.66)	1.99^{de} (3.46)	2.12^{d} (3.99)	2.06^{de} (3.74)	2.04^{e} (3.66)
9	Green chilli water extract 10% (1000 g/10 lit water)	2.04 (3.66)	1.85^{bcd} (2.92)	2.08^{bc} (3.83)	1.97^{cd} (3.38)	2.02^{e} (3.58)	2.13^{d} (4.04)	2.08^{e} (3.83)	2.13^{e} (4.04)	2.25^{d} (4.56)	2.19^{e} (4.30)	2.08^{e} (3.83)
10	Control	1.75 (2.56)	2.36^{e} (5.07)	2.51^{e} (5.80)	2.44^{e} (5.45)	2.66^{f} (6.58)	2.77^{e} (7.17)	2.72^{f} (6.90)	2.88^{f} (7.79)	3.00^{e} (8.50)	2.95^{f} (8.20)	2.70^{f} (6.79)
S. Em.± Treatment (T)		0.06	0.06	0.06	0.05	0.07	0.05	0.05	0.05	0.07	0.05	0.03
Location (L)		0.03	0.04	0.03	0.03	0.04	0.03	0.03	0.03	0.04	0.03	0.02
T x L		0.11	0.12	0.12	0.09	0.14	0.11	0.09	0.11	0.14	0.09	0.05
C.D. at 0.05 %		NS	S	S	S	S	S	S	S	S	S	S
C. V. %		10.04	12.25	10.75	11.24	13.31	10.43	11.81	10.64	12.81	11.81	11.79

Note: 1. Figures in parenthesis are retransformed values; those outside are $\sqrt{x+0.5}$ transformed values

2. Treatment mean(s) with the letter(s) in common are not significant by DNMRT at 5% level of significance

3. Significant parameters and its interactions: T, P, L, T x S, P x S, where P= Period and S=Spray

Table2 Evaluation of bio-pesticides against plant damage caused by fall armyworm, *S. frugiperda* infesting maize (Pooled over periods, sprays and locations)

Tr. No.	Treatments	Plant damage (%) days after spray										
		Before spray	First			Second			Third			Pooled over periods and sprays
			5	10	Pooled	5	10	Pooled	5	10	Pooled	
1	*Beauveria bassiana* 5 % WP (40 g/10 lit water)	32.25 (28.47)	27.63^{abc} (21.51)	32.22^{cd} (28.43)	29.93^{b} (24.89)	29.03^{bcd} (23.55)	28.53^{bc} (22.81)	28.78^{b} (23.18)	25.08^{bc} (17.97)	28.37^{b} (22.58)	26.72^{b} (20.22)	28.48^{b} (22.74)
2	*Metarhizium anisopliae*1.15% WP (40 g/10 lit water)	30.01 (25.02)	29.20^{bc} (23.80)	35.10^{cde} (33.06)	32.15^{bc} (28.32)	31.32^{cd} (27.02)	30.84^{c} (26.41)	31.08^{b} (26.65)	28.53^{cd} (22.81)	30.84^{bc} (26.28)	29.68^{b} (24.52)	30.97^{bc} (26.48)
3	*Bacillus thuringiensis* 1 % WG (20 g/10 lit water)	32.98 (29.63)	25.48^{ab} (18.51)	28.03^{ab} (22.08)	26.76^{a} (20.27)	24.58^{ab} (17.30)	25.48^{ab} (18.51)	25.03^{a} (17.90)	22.03^{ab} (14.07)	23.68^{a} (16.13)	22.86^{a} (15.09)	24.88^{a} (17.70)
4	*Nomuraea rileyi* 1%WP (40 g/10 lit water)	32.32 (28.58)	23.68^{a} (16.13)	27.12^{a} (20.78)	25.40^{a} (18.40)	23.68^{a} (16.13)	22.94^{a} (15.19)	23.31^{a} (15.66)	18.18^{a} (9.73)	22.77^{a} (14.98)	20.48^{a} (12.24)	23.06^{a} (15.34)
5	Azadirachtin 1500 ppm (40 ml/10 lit water)	30.84 (26.28)	28.53^{bc} (22.81)	31.58^{bc} (27.42)	30.06^{b} (25.09)	28.53^{bc} (22.81)	28.53^{bc} (22.81)	28.54^{b} (22.83)	26.72^{c} (20.22)	29.94^{b} (24.91)	28.33^{b} (22.52)	28.97^{b} (23.46)
6	Neem seed kernel extract 5% (500 g/10 lit water)	31.34 (27.05)	28.37^{bc} (22.58)	33.63^{cd} (30.67)	30.99^{b} (26.51)	30.67^{cd} (26.02)	31.58^{cd} (27.42)	31.13^{b} (26.73)	28.53^{cd} (22.81)	30.84^{bc} (26.28)	29.68^{b} (24.52)	30.61^{bc} (25.93)
7	Tobacco decoction 2% (cold method) (200 g/10 lit water)	30.01 (25.02)	29.27^{bc} (23.90)	35.84^{de} (34.28)	32.55^{bc} (28.95)	33.69^{de} (30.77)	35.84^{de} (34.28)	34.77^{c} (32.52)	32.96^{de} (29.60)	35.10^{cd} (33.06)	34.03^{c} (31.32)	33.79^{cd} (30.93)
8	*Lantana camara* leaf water extract 10% (1000 g/10 lit water)	30.67 (26.02)	30.01^{c} (25.02)	38.36^{e} (38.51)	34.19^{c} (32.58)	37.05^{e} (36.30)	38.46^{ef} (38.68)	37.76^{cd} (37.50)	35.00^{ef} (32.90)	37.05^{de} (36.30)	36.03^{c} (34.60)	35.99^{de} (34.53)
9	Green chilli water extract 10% (1000 g/10 lit water)	32.98 (29.63)	31.58^{c} (27.42)	38.39^{e} (38.57)	34.98^{c} (32.87)	37.72^{e} (37.43)	40.44^{f} (42.07)	39.08^{d} (39.74)	38.36^{f} (38.51)	41.08^{e} (43.18)	39.72^{d} (40.84)	37.93^{e} (37.79)
10	Control	28.37 (22.58)	40.44^{d} (42.07)	46.93^{f} (53.37)	43.78^{d} (47.87)	50.28^{f} (59.16)	55.02^{g} (67.13)	52.66^{e} (63.21)	59.35^{g} (74.01)	65.38^{f} (82.64)	62.36^{e} (78.48)	52.90^{f} (63.61)
S. Em.± Treatment (T)		1.39	1.37	1.27	0.98	1.45	1.34	1.02	1.49	1.40	1.04	1.08
Location (L)		0.83	0.79	0.70	0.54	0.69	0.78	0.56	0.85	0.78	0.57	0.32
T x L		2.64	2.52	2.21	1.69	2.51	2.47	1.77	2.68	2.46	1.80	1.01
C.D. at 0.05 %		NS	S	S	S	S	S	S	S	S	S	S
C. V. %		14.67	14.84	11.05	12.96	13.34	12.70	13.09	14.78	12.39	13.40	13.80

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 DNMRT at 5% level of significance
3. Significant parameters and its interactions: T, P, L, T x S, P x S, T x L where P= Period and S=Spray

Table.3 Evaluation of bio-pesticide against fall armyworm, *S. frugiperda* and its plant damage in maize (Pooled over locations)

Tr. No.	Treatment	No. of larva(e)/10 plants				Plant damage (%)			
		Anand	Sansoli	Godhra	Pooled	Anand	Sansoli	Godhra	Pooled
1	*Beauveria bassiana* 5 % WP (40 g/10 lit water)	1.99 (3.46)*	1.63^{bc} (2.16)	1.52^{ab} (1.81)	1.71^{b} (2.42)	35.82^{b} (34.25)**	26.76^{cd} (20.27)	22.86^{bc} (15.09)	28.48^{b} (22.74)
2	*Metarhizium anisopliae*1.15% WP (40 g/10 lit water)	2.06 (3.74)	1.72^{cd} (2.46)	1.64^{b} (2.19)	1.81^{c} (2.78)	37.85^{bc} (37.65)	28.69^{de} (23.05)	26.39^{de} (19.76)	30.97^{bc} (26.48)
3	*Bacillus thuringiensis* 1 % WG (20 g/10 lit water)	1.82 (2.81)	1.44^{a} (1.57)	1.49^{ab} (1.72)	1.59^{a} (2.03)	25.31^{a} (18.28)	23.39^{ab} (15.76)	22.94cd (15.19)	24.88^{a} (17.70)
4	*Nomuraea rileyi* 1%WP (40 g/10 lit water)	1.78 (2.67)	1.40^{a} (1.46)	1.36^{a} (1.35)	1.52^{a} (1.81)	27.49^{a} (21.31)	22.04^{a} (14.08)	19.66^{a} (11.32)	23.06^{a} (15.34)
5	Azadirachtin 1500 ppm (40 ml/10 lit water)	2.00 (3.50)	1.56^{b} (1.93)	1.59^{b} (2.03)	1.72^{bc} (2.46)	35.87^{b} (37.33)	24.75^{bc} (17.53)	26.30^{de} (19.63)	28.97^{b} (23.46)
6	Neem seed kernel extract 5% (500 g/10 lit water)	2.01 (3.54)	1.61^{bc} (2.09)	1.67^{bc} (2.29)	1.77^{bc} (2.63)	36.86^{bc} (35.98)	26.02^{cd} (19.24)	28.93^{ef} (23.40)	30.61^{bc} (25.93)
7	Tobacco decoction 2% (cold method) (200 g/10 lit water)	2.15 (4.12)	1.82^{de} (2.81)	1.84^{cd} (2.89)	1.94^{d} (3.26)	39.48^{c} (40.43)	30.90^{ef} (26.37)	30.98^{fg} (26.50)	33.79^{cd} (30.93)
8	*Lantana camara* leaf water extract 10% (1000 g/10 lit water)	2.23 (4.47)	1.91^{ef} (3.15)	1.96^{d} (3.34)	2.04^{e} (3.66)	43.03^{d} (46.56)	32.98f^{g} (29.63)	31.97^{fg} (28.03)	35.99^{de} (34.53)
9	Green chilli water extract 10% (1000 g/10 lit water)	2.27 (4.65)	1.96^{f} (3.34)	2.01^{d} (3.54)	2.08^{e} (3.83)	44.96^{d} (49.93)	35.10^{g} (33.06)	33.72^{g} (30.82)	37.93^{e} (37.79)
10	Control	2.92 (8.03)	2.56^{g} (6.05)	2.61^{e} (6.31)	2.70^{f} (6.79)	56.14^{e} (68.96)	49.04^{h} (57.03)	53.52^{h} (64.65)	52.90^{f} (63.61)
S. Em.± Treatment (T)		0.05	0.04	0.05	0.03	1.05	0.83	1.11	1.08
Location (L)		-	-	-	0.02	-	-	-	0.32
T x L		-	-	-	0.05	-	-	-	1.01
C. V. %		11.83	9.27	13.64	11.76	11.63	11.76	15.91	13.80

Note:
1. *Figures in parenthesis are retransformed values; those outside are $\sqrt{x+0.5}$ transformed values
2.Figures in parenthesis are retransformed values; those outside are arc sine transformed values**
3. Treatment mean(s) with the letter(s) in common are not significant by DNMRT at 5% level of significance
4. Significant parameters and its interactions: T, P, L, T x S, P x S, where P= Period and S=Spray and
5. Significant parameters and its interactions: T, P, L, T x S, P x S, T x L (For plant damage)

Table.4 Evaluation of bio-pesticides against cob damage caused by fall armyworm, *S. frugiperda* in maize

Tr. No.	Treatments	Cob damage (%)			
		Anand	**Sansoli**	**Godhra**	**Pooled**
1	*Beauveria bassiana* 5 % WP (40 g/10 lit water)	32.98[b] (29.63)	32.99[b] (29.65)	30.98[b] (26.50)	32.32[b] (28.58)
2	*Metarhizium anisopliae*1.15% WP (40 g/10 lit water)	35.20[b] (33.23)	35.20[b] (33.23)	35.20[b] (33.23)	35.20[b] (33.23)
3	*Bacillus thuringiensis* 1 % WG (20 g/10 lit water)	23.84[a] (16.34)	23.84[a] (16.34)	21.13[a] (12.99)	22.94[a] (15.19)
4	*Nomuraea rileyi* 1%WP (40 g/10 lit water)	23.84[a] (16.34)	23.84[a] (16.34)	21.13[a] (12.99)	22.94[a] (15.19)
5	Azadirachtin 1500 ppm (40 ml/10 lit water)	32.98[b] (29.63)	32.99[b] (29.65)	30.98[b] (26.50)	32.32[b] (28.58)
6	Neem seed kernel extract 5% (500 g/10 lit water)	35.20[b] (33.23)	35.20[b] (33.23)	35.20[b] (33.23)	35.20[b] (33.23)
7	Tobacco decoction 2% (cold method) (200 g/10 lit water)	35.20[b] (33.23)	35.20[b] (33.23)	35.20[b] (33.23)	35.20[b] (33.23)
8	*Lantana camara* leaf water extract 10% (1000 g/10 lit water)	37.21[b] (36.57)	37.21[b] (36.57)	35.20[b] (33.23)	36.54[b] (35.45)
9	Green chilli water extract 10% (1000 g/10 lit water)	37.21[b] (36.27)	37.21[b] (36.57)	35.20[b] (33.23)	36.54[b] (35.45)
10	Control	50.83[c] (60.11)	48.83[c] (56.66)	46.90[c] (53.31)	48.85[c] (56.70)
S. Em.±	**Treatment (T)**	2.82	2.67	2.31	1.32
	Location (L)	-	-	-	0.82
	T x L	-	-		2.61
C. V. %		14.20	13.48	12.25	13.37

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 DNMRT at 5% level of significance
3. Significant parameters and its interactions: T and L

Table.5 Effect of bio-pesticides on grain and fodder yield of maize

Tr. No.	Treatments	Grain yield (kg/ha)				Fodder yield (kg/ha)			
		Anand	Sansoli	Godhra	Pooled	Anand	Sansoli	Godhra	Pooled
1	*Beauveria bassiana* 5 % WP (40 g/10 lit water)	2558^{c}	2710^{b}	2482^{b}	2584^{b}	3399^{b}	3532^{b}	3585^{ab}	3506^{bc}
2	*Metarhizium anisopliae*1.15% WP (40 g/10 lit water)	2412^{cd}	2589^{bc}	2147^{c}	2383^{c}	3255^{bc}	3395^{b}	3080^{cd}	3244^{c}
3	*Bacillus thuringiensis* 1 % WG (20 g/10 lit water)	2837^{ab}	3065^{a}	2895^{a}	2932^{a}	3970^{a}	4070^{a}	4058^{a}	4033^{a}
4	*Nomuraea rileyi* 1%WP (40 g/10 lit water)	2854^{a}	3112^{a}	2904^{a}	2957^{a}	4012^{a}	4102^{a}	4093^{a}	4069^{a}
5	Azadirachtin 1500 ppm (40 ml/10 lit water)	2618^{abc}	2676^{b}	2446^{b}	2580^{b}	3408^{b}	3548^{b}	3584^{ab}	3513^{b}
6	Neem seed kernel extract 5% (500 g/10 lit water)	2565^{bc}	2654^{b}	2117^{cd}	2446^{bc}	3266^{bc}	3410^{b}	3099^{bc}	3259^{bc}
7	Tobacco decoction 2% (cold method) (200 g/10 lit water)	2227de	2388^{c}	1978^{cd}	2198^{d}	3113^{bc}	2924^{c}	2613^{cd}	2884^{d}
8	*Lantana camara* leaf water extract 10% (1000 g/10 lit water)	2013^{ef}	2378^{c}	1877^{d}	2089^{d}	2977^{bc}	2904^{c}	2598^{d}	2827^{d}
9	Green chilli water extract 10% (1000 g/10 lit water)	1928^{f}	2351^{c}	1874^{d}	2051^{d}	2885^{c}	2892^{c}	2558^{d}	2779^{d}
10	Control	1617^{g}	2067^{d}	1576^{e}	1753^{e}	2313^{d}	2407^{d}	2069^{e}	2263^{e}
S. Em.± Treatment (T)		82.01	81.95	76.61	49.88	143.08	143.53	149.16	81.88
Location (L)		-	-	-	25.37	-	-	-	45.94
T x L		-	-	-	80.22	-	-	-	145.28
C. V. %		6.01	6.46	5.95	5.79	7.60	7.49	8.24	7.77

Note: 1. Treatment mean(s) with the letter(s) in common are not significant by DNMRT at 5% level of significance
2. Significant parameters and its interactions: T and L, T x L (Grain yield), T and L (Fodder yield)

The data on pooled over periods of second spray differed significantly to each other. The significantly minimum plant damage was noticed in plots treated with *N. rileyi* 1% WP (15.66%) and it was at par with *B. thuringiensis* 1 % WG (17.90%). These two treatments were found significantly superior to rest of the bio-pesticides. Azadirachtin 1500 ppm (22.83%), *B. bassiana* 5% WP (23.18%) and neem seed kernel extracts (26.73%) were found equally effective in reducing the plant damage caused by fall armyworm. The green chilli water extract recorded maximum plant damage (39.74%) and it was at par with *L. camara* leaf water extract (37.50%). More or less similar results were found after pooled over periods of third spray as observed after pooled over periods of second spray.

Overall, the data on pooled over periods, sprays and locations showed minimum plant damage in the treatment of *N. rileyi* 1%WP (15.34%) and it was at par with *B. thuringiensis* 1 % WG (17.70%). *B. bassiana* 5% WP (22.74%) and azadirachtin 1500 ppm (23.46%) were at par and next effective treatments against the pest. Of the tested bio-pesticides, green chilli water extract found least effective by recording the highest plant damage (37.79 %).

Cob damage (%)

The data on cob damage pooled over the locations showed significant difference among the various biopesticides tested (Table 4). The lowest cob damage was recorded in plots treated with *N. rileyi* 1% WP (15.19 %) and *B. thuringiensis* (15.19%). The treatments of *B. bassiana* 5% WP and azadirachtin 1500 ppm found mediocre in their effectiveness against the pest. The highest cob damage recorded in green chilli water extract (35.45 %) and proved least effective in controlling the FAW in maize.

Grain yield (Kg/ha)

The highest grain yield recorded in the treatment of *N. rileyi* 1% WP (2957 kg/ha) among all the treated biopesticides and it was at par with *B. thuringiensis* (2932 kg/ha). *B. bassiana* 5% WP (2584 kg/ha), Azadirachtin (2580 kg/ha) and neem seed kernel extract (2446 kg/ha) were found equal in registering grain yield of maize. The green chilli water extract recorded the lowest grain yield (2051kg/ha) and it was at par with *L. camara* leaf water extract (2089 kg/ha) and tobacco decoction (2198 kg/ha).

Fodder yield (Kg/ha)

The highest fodder yield recorded in *N. rileyi* 1% WP (4069 kg/ha) and it was at par with *B. thuringiensis* (4033 kg/ha). Azadirachtin 1500 ppm (3513.3 kg/ha), *B. bassiana* 5% WP (3506 kg/ha) and neem seed kernel extract (3259 kg/ha) were found at par to each other in production of fodder. The green chilli water extract recorded the lowest (2779 kg/ha) fodder yield and it was at par with *L. camara* leaf water extract (2827 kg/ha) and tobacco decoction (2884 kg/ha).

These findings are in accordance with the findings of Mallapur *et al.*, (2018) who reported the high potentiality of *N. rileyi* in combating the notorious invasive pest, *S. frugiperda in* maize, whereas in Andhra Pradesh 36.9 per cent infection of *N. rileyi* on *S. litura* in ground nut field was observed (Vimala, 1994 and Sridher, 1996). Unlike chemical approaches, the entomopathogenic fungi can self-perpetuate where in, the farmers will be provided with an added advantage of avoiding repeated spraying which would save time, labour and money as well it can safeguard the environment as it is an eco-friendly approach. According to Capalbo *et al.*, (2001) mortality of neonate larvae was 100 per cent within two days of

spraying of *B. thuringiensis* (*Bt*) and all larvae were found dead on leaves. Among the pathogens, *B. thuringiensis, M. anisopliae* and *B. bassiana* can cause significant mortality in FAW populations and help to reduce leaf defoliation in crops (Molina-Ochoa *et al.*, 2003).

It can be concluded that *N. rileyi* 1% WP (2 x10^8cfu/g) @ 40 g/10 litre water or *B. thuringiensis* var. *kurstaki* 1% WG @ 20 g/10 litre water first at initiation of pest and subsequent two sprays at 10 days interval found effective and economical for the management of fall armyworm, *S. frugiperda* infesting maize.

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