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Potency of microbial insecticides, as a biocontrol fall armyworm (*Spodoptera frugiperda* J.E. Smith) in maize fields at Kafrel-Sheikh Governorate, Egypt

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Abstract
An experiment was carried out during two successive summer seasons in 2022 and 2023 to determine the potency of two microbial insecticides combined with a chemical insecticide against fall armyworms (*Spodoptera frugiperda* Smith) on maize plants in field conditions in El-Sabein village, Sidi Salem District, Kafr El-Sheikh governorate, Egypt. Results indicated that the highest monthly average of *S. frugiperda* was recorded in August with an average of 19.25±0.88 and 17.90 ±1.19 larvae in the first and second seasons, respectively. The greatest average population decrease percentage was Spinetoram, which showed reductions of 89.33 and 91.30% during the first and second seasons, respectively, and represented by all average 90.31%. Followed by Emamectin Benzoate (SG 5%) with average values of 85.38 and 87.33% reduction during the both seasons, respectively with overall average 86.35%. Protecto (*Bacillus thuringiensis*) with average values of 44.09 and 43.65%, in the first and second seasons, respectively and represented by overall average of 43.87%. On the other hand, Biossiana 2,5%WP (*Beauveria bassiana*) had the lowest compounds, with average values of 39.42 and 41.68% at the first and second seasons, respectively, and an overall average of 40.55%. Furthermore, the overall average of the mean population reduction of all compounds against *S. frugiperda* was 65.27%, with reported values of 64.55 and 65.99 in the both seasons, respectively.

Keywords: Microbial insecticides, Fall Armyworm, *Spodoptera frugiperda*.

Introduction
Maize (*Zea mays* L.: family: Poaceae) is an essential crop for global farmers as a source of income where humans and animals feed on it, especially in poor countries. (Sangle *et al*., 2020) [19]. Corn comes in third place after wheat and rice, and it is considered the most major economic grain crops for farmers in Egypt. In 2020, the total area planted with corn in Egypt reached 871,076.12 hectares, with an average productivity of one ton. A total production of about 8154.48 tons of grain/ha. (El-Rasoul *et al*., 2020) [8]. Several insect pests attack corn plants during different growth stages at Egypt such as fall armyworm (FAW) *Spodopter afrugiperda* (Smith) it is among the most dominating, dangerous and detrimental insect species that has lately spread to Egypt and other countries of the world maize fields. *S. frugiperda* larvae feed on more than eighty plant hosts (such as sorghum, sugarcane, maize, as well as other crops and vegetables), causing significant damage to the crop in terms of quality and quantity (Youssef, 2018 and Dahi *et al*., 2020) [21, 5]. According to a recent estimate, without the use of control measures, fall armyworm has a possibility of causing estimated losses at 8.3 to 20.6 million tons of maize per year (in insect value2481-6187 million US dollars) in twelve nations that produce maize in sub-Saharan Africa, which represents about 20% of the total maize production of those countries during the 2019 season (Karki *et al*., 2023) [14]. Maize is one of its preferred plant hosts and it has been observed that average global maize yield losses range between 17 and 36% due to fall armyworm larvae. Infestations of fall armyworm have led to food insecurity and caused economic losses of US$9.4 billion yearly within Africa, particularly in nations with low or middle incomes where maize is a staple crop for citizens. (Overton, 2021; Eschen, *et al*., 2021and FAO 2019) [16, 9, 10]. In older plants, larger larvae, especially 5th and 6th instar larvae, can feed on the flower and the cob or kernels of corn, reducing yield and quality.

(Sagar *et al*.,2020 and Capinera *et al*., 2017) [18, 4]. The immature larvae feed the leaves in vast quantities, leaving holes and harm on the leaf surface which damage the flowers and adversely affect photosynthesis and other vital plant functions. (Lamsal *et al*., 2020; Suby *et al*., 2020 and Harrison *et al*., 2019) [15, 20, 12]. Biological control of insect pests using insect pathogenic microorganisms is considered one of the most important modern trends in combating many agricultural pests around the world, especially in the field of producing food free of chemical pesticide residues due to the specificity of its goal, ease of application, self-perpetuity, and clear safety for the environment. Microbial formulations, which are manufactured from pathogens and natural enemies arthropods, are widely found in many pesticide markets around the world (Pilkington *et al*., 2010 and Abbas *et al*.,2022) [17, 1]. The effectiveness of pest control mainly on the entomopathogenic fungi, *Beauveria bassiana*, has been proven beyond doubt over time (Ismael *et al*.,2023) [13]. In Egypt, Also, using *Bacillus thuringiensis*as a bio-control succeeded in reducing the population number of *S. frugiperda* on maize plants under field conditions (El-Hadary *et al*., 2023) [7]. The purpose of this study was for studying the populations density of *S. frugiperda* and determine the effectiveness of two microbial and chemical insecticides against *S. frugiperda* on maize plants under field conditions

Materials And Methods

Experimental Design

An experiment was conducted during two successive maize summer seasons; 2022 and 2023 for the purpose to determine the population density of *Spodoptera frugiperda* (Smith) and evaluate the potency of tow Microbial insecticides and two chemical insecticide against its insect on the previously mentioned of maize plants at El-Sabein village, Sidi Salem District, Kafr El-Sheikh governorate, Egypt. An area of about 400 m^2 was assigned for each insecticide treatment, laid out in a randomized complete block design with four replicates. The plot cultivated with 321hybrid maize variety on 20th of May in both seasons. The variety was provided by Sakha Agricultural Research Station, Kafr El-Sheikh governorate. Throughout the growing season, traditional agricultural methods were followed as recommended.

Treatments: Each season of maize grown, the four materials two microbial insecticides and two chemical insecticide were treated twice. The knapsack sprayer (20L volume) was used for each application, and the rates stated in table (1) were followed.

Table 1: Tests compound with formulations, rates, and trade names used in insect control

Treated name	Common name	Manufacturer	Concentration
Radiant 12% SC	Spinetoram	Dow AgroSciences Company	65 CM^3/Fadden
Highlex 5%SG	Emamectin benzoate	Asia Chmical Company Ltd. Japan for El manar Company	60gm/Fadden
Protecto (9.4% W.P)	*Bacillus thuringiensis* var. *kurstaki*-3200 International toxicity Unit (IU)	Bio- Insecticides Production Unit Plant Protection Research Institute	400gm/Fadden
Biossiana 2,5%WP	*Beauveria bassiana* (Balasamo) (1 X 10^8 colony-forming unit (CFU) mg^{-1})	Bio- Insecticides Production Unit Plant Protection Research Institute	200 gm/100 litter/feddan

T: Treatment; SC: Suspension concentrate; EC: Emulsifiable concentrate; Soluble granules

Data collection and observation

Every week, the population number of *S. frugiperda* larvae was recorded with data randomly obtained from ten plants. The tested compounds, were applied two times, July 18th and August 18th in 2022 and 2023 season under field condition. Numbers of *S. frugiperda* larvae were recorded pre to the spray, and again once, twice, four, and six days after.

Statistical analysis

Henderson and Tilton's formula (1955) was used for estimating the population decreases of *S. frugiperda*. ANOVA was utilized for analyzing the data, and Duncan's multiple range test was used to compare the means (Duncan, 1955) [6].

Results And Discussion

Population density of *Spodoptera frugiperda* Smith on 10 maize plants during 2022 and 2023 season

Data arranged in Table (2) mentioned that the population density of fall armyworm larvae, *S. frugiperda* on 10 maize plants under field conditions. In the first season 2022 the number of *S. frugiperda* on maize plants began with 5 insects / 10 plants on the 18th of Jun and the highest peak of larvae of the, *S. frugiperda* were recorded on 9th July and represented by 23.75 larvae on maize plants when Max. Tem (°C) 33.50 °C and 70.12.% R.H. The highest monthly average of *S. frugiperda* was recorded in August with average of 19.25±0.88 larvae during the first season. The obtained results showed that in 2023 season, *S. frugiperda* on maize plants started firstly in low numbers (1.00 larvae/ 10 plants) on 11th of Jun. The population number increased to 14.00 larvae/ 10 plants on 26th of Jun 2023 as a Table (3)**.** The highest number of larvae *S. frugiperda* were recorded on 28th of August and represented by 20.37 larvae/10 plants on maize plants when Max. Tem (°C) 34.50 °C and 75.70% R.H. The highest monthly average of *S. frugiperda* was recorded in August with average of 17.90 ±1.19 larvae.

As a conclusion, data in Tables (2 and 3) determined that, the population density of fall armyworm larvae, *S. frugiperda* on 10 maize plants under field conditions represented by total average number of 13.08±2.25 and 12.23±2.31 larvae in 2022 and 2023, respectively.

Table 2: Population density of fall armyworm larvae, *Spodoptera frugiperda* in maize field during 2022 season.

Date	Mean No/10 plants	Mean weather factors		
		Max. Tem (°C)	Min. Temp. (°C)	R.H.%
Jun 11th	0.00	37.40	26.80	61.00
18th	5.00	31.60	25.60	67.50
25th	11.00	32.80	26.20	64.00
Average ± SE	5.33±3.18	33.93±1.77	26.20±0.35	64.17±1.88
Jul 2nd	15.10	32.40	26.60	69.00
9th	23.75	33.50	26.30	70.12
16th	20.00	31.60	24.50	70.50
23th	17.34	33.30	25.70	71.50
30th	20.00	35.00	24.90	74.00
Average ± SE	19.24±1.45	33.16±0.57	25.60±0.40	71.02±0.84
Aug, 6th	21.26	33.00	24.80	72.50
13th	19.00	33.90	24.60	71.60
20th	17.00	33.50	25.30	74.00
27th	19.72	36.90	26.50	73.20
average±SE	19.25±0.88	34.33±0.88	25.30±0.43	72.83±0.51
Sep. 3rd	12.00	34.60	27.10	65.30
10th	5.00	32.50	27.20	68.80
Average ± SE	8. 50±3.50	34.33± 1.05	25.30±0.05	72.83±1.75
Total average ± SE	13.08±2.25	33.71±0.47	25.86±0.25	69.50±1.04

Values in row followed by similar letter were not significant at 5% level of probability

Table 3: Population density of fall armyworm larvae, *Spodoptera frugiperda* in maize field during 2023 season

Date	Mean No./ 10 plants	Mean weather factors		
		Max. Tem (°C)	Min. Temp. (°C)	R.H.%
Jun,12th	1.00	32.10	23.80	69.00
19th	3.00	32.50	23.80	73.00
26th	14.00	33.00	24.30	64.80
Average ± SE	6±4.04	32.53±0.26	23.96±0.16	68.93±2.36
Jul 3nd	11.65	32.90	24.10	78.50
10th	14.00	34.60	24.70	76.10
17th	18.25	33.50	26.00	75.00
24th	15.00	32.70	24.70	77.10
31th	16.00	34.40	25.00	77.70
Average ± SE	14.98±1.09	33.62±0.38	24.90±0.31	76.88±0.61
Aug, 7th	19.25	35.00	25.40	72.00
14th	17.00	32.00	25.60	79.70
21th	15.00	32.80	26.10	74.00
28th	20.37	34.50	25.60	75.70
Average ± SE	17.90 ±1.19	33.57±0.70	25.67±0.14	75.35±1.63
Sep 4th.	13.00	33.60	25.10	76.20
11th	7.10	36.50	26.30	71.30
Average ± SE	10.05±2.95	35.05±1.45	25.70±0.60	73.75±2.45
Total average ± SE	12.23±2.31 abc	33.69±0.69	25.05±0.30	73.72±1.76

Values in row followed by similar letter were not significant at 5% level of probability.

Correlation among weather factors and populations of fall armyworm larvae, *Spodoptera frugiperda*

According to the results (Table 4) the population of *S. frugiperda* larvae correlated negatively with each of temperature (max., min). this means that in the2022season, populations of of *S. frugiperda* larvae increased with low temperature and decreased with high temperatures. in the2023 season, however, population of larvae of *S. frugiperda* correlated positively with each temperature (max., min) and relative humidity in two seasons.

Table 4: Correlation coefficient values among populations of larvae of fall armyworm, *Spodoptera frugiperda* and (maximum, minimum) temperature and relative humidity in two maize field growing seasons.

Item	"R" Value	
	2022	2023
Max. Temp × Larvae	-0.106	0.2161
Min. Temp × Larvae	-0.5506	0.555
Av. RH% X larvae	0.7742	0.3879

Efficiency of tested compounds in reducing fall armyworm larvae, *Spodoptera frugiperda*

Data in the Table 5 stated that efficiency of tested compounds in reducing fall armyworm larvae, *S. frugiperda* on maize plants in 2022 season. It was determined that all of the treatments were significantly more effective in decreasing the *S. frugiperda* larvae population than the untreated control at 24 h, 2 days, 4 days, and 6 days after

spraying. Data obtained 24 hours after spraying showed significant variations between the treatments. The percentage of reduction in the larval population varied among the treatments, ranging from 9.03 to 97.19%. It can be noticed that the highest of population reduction percentage were recorded with (Spinetoram) and represented by 90.79, 93.78 and 94.81% reduction after 2,4 and 6days, respectively during the first spray on 18-Jul with values average 89.74%. while the highest population reduction percentage in second spray in 20 Aug was 97.19% after 6days from treatment and represented by overall average 89.33%. Followed by Emamectin Benzoate (SG 5%) with 94.44 and 93.12% reduction during the first and second spray, respectively with overall average of 85.39%. While, Protecto (*Bacillus thuringiensis*) with average values 43.16 and 45.02 reduction in the first and second spray, respectively and represented by overall average 44.09%. On the other hand, the lowest compounds were Biossiana 2,5%WP (*Beaveria bassiana*) with average values 37.15 and 41.70%, during the first and second spray, respectively and represented by overall average 39.42%

Table 5: Potency of tested compounds in reducing of fall armyworm, *S. frugiperda* larva in maize fields at Kafer El- sheikh Governorate during 2022season

Treatment		Date	Population reduction%					Overall average
Trade name	Common name		1 Days	2 days	4 days	6 Days	Average	
Radiant (12% SC)	Spinetoram	18-Jul	79.58	90.79	93.78	94.81	89.74	89.33
		20 Aug.	76.85	89.57	92.12	97.19	88.93	
Emamectin Benzoate (SG 5%)	Emamectin Benzoate	18-Jul	69.23	86.67	93.33	94.44	85.91	85.39
		20 Aug.	63.89	87.25	95.19	93.12	84.	
Biossiana 2,5%WP	*Beauveria bassiana*	18-Jul	9.03	35.78	52.95	50.86	37.15	39.42
		20 Aug.	13.87	42.65	56.74	53.57	41.70	
Protecto 9.4% WP	*Bacillus thuringiensis*	18-Jul	17.94	40.76	55.85	58.12	43.16	44.09
		20 Aug.	19.56	43.27	57.41	59.85	45.02	

Data in the table (6) indicated that potency of tested compounds in reducing fall armyworm, *S. frugiperda* larvae in maize field conditions during 2023season. It can be noticed that the highest of population reduction percentage were recorded with (Spinetoram) and represented by 97% reduction after,4 days during the first spray on 18-Jul with values average 90.27%. while the highest population reduction percentage in second spray in 20 Aug was 96.57% after 6days from treatment and represented by overall average 92.33%. followed by Emamectin Benzoate (SG 5%) with 87.70 and 86.97% reduction in the first and second spray, respectively with overall average 87.34%. Protecto (*B. thuringiensis*) with average values 42.51 and 44.79% reduction at the both spray, respectively and represented by overall average 43.65%. On the other hand, the lowest compounds was Biossiana 2,5%WP (*Beaveria bassiana*) with average values of 41.27and 42.09%during the first and second spray, respectively and represented by overall average 41.68%

Table 6: Potency of tested compounds in reducing fall armyworm, *S. frugiperda* larva in maize fields at Kafer El- sheikh Governorate during 2023 season

Treatment		Date	Population reduction%					Overall average
Trade name	Common nam		1 Days	2 days	4 days	6 Days	Average	
Radiant (12% SC)	Spinetoram	18-Jul	78.90	89.33	97.64	95.24	90.27	91.30
		20 Aug.	83.25	94.45	95.07	96.57	92.33	
Emamectin Benzoate (SG 5%)	Emamectin Benzoate	18-Jul	80.65	82.01	95.86	92.29	87.70	87.34
		20 Aug.	76.56	87.25	90.62	93.48	86.97	
Biossiana 2,5%WP	*Beauveria bassiana*	18-Jul	14.54	37.78	55.15	57.62	41.27	41.68
		20 Aug.	17.89	39.09	51.96	59.42	42.09	
Protecto 9.4% WP	*Bacillus thuringiensis*	18-Jul	20.67	39.56	53.98	55.84	42.51	43.65
		20 Aug.	23.99	43.52	51.92	59.76	44.79	

Data in the Table 7 and Fig 1 showed that average and all average of tested compounds in Population reduction of *S. frugiperda* larvae in maize field conditions during 2022 and 2023season. It can be noticed that the highest of average population reduction percentage were recorded with (Spinetoram) and represented by and 89.33and 91.30% reduction during first and second season, respectively, and represented by all average 90.31%. followed by Emamectin Benzoate (SG 5%) with 85.38and 87.33% reduction at the first and second seasons, respectively with overall average 86.35%. Followed by Protecto (*Bacillus thuringiensis*) with average values 44.09 and 43.65% during the first and second seasons, respectively and represented by overall average 40.57%. on the other hand, the lowest compounds was *Beauveria bassiana* with average values 39.42 and 41.68% during the first and second seasons, respectively and represented by overall average 41.96%. Additionally mean average of population reduction of all compounds against of *S. frugiperda* was recorded values 64.55and 65.99 at the first and second seasons, respectively and represented by overall average 65.27%. This results concurrence with (El-Hadary *et al*., 2023) [7] who tested *Bacillus thuringiensis* as a bio-control succeeded in reducing the larval density of this pest to 64.8% and 75.3% in corn field during two successive seasons respectively.

Table 7: Average and all average of tested compounds in Population reduction *S. frugiperda* larvae in maize field conditions during 2022 and 2023season

Treatment	Rate	Average Population reduction%		All average
		2022 season	2023 season	
Radiant 12% SC	Spinetoram (500ml)	89.33	91.30	90.31
Highlex 5%SG	Emamectin Benzoate 60gm	85.38	87.33	86.35
Biossiana 2,5%WP	*Beauveria bassiana* 300gm	39.42	41.68	40.55
Protecto (Local) 9.4% WP	*Bacillus thuringiensis* 300gm	44.09	43.65	43.87
Total	Total	258.22	263.96	261.08
Mean	Mean	64.55	65.99	65.27

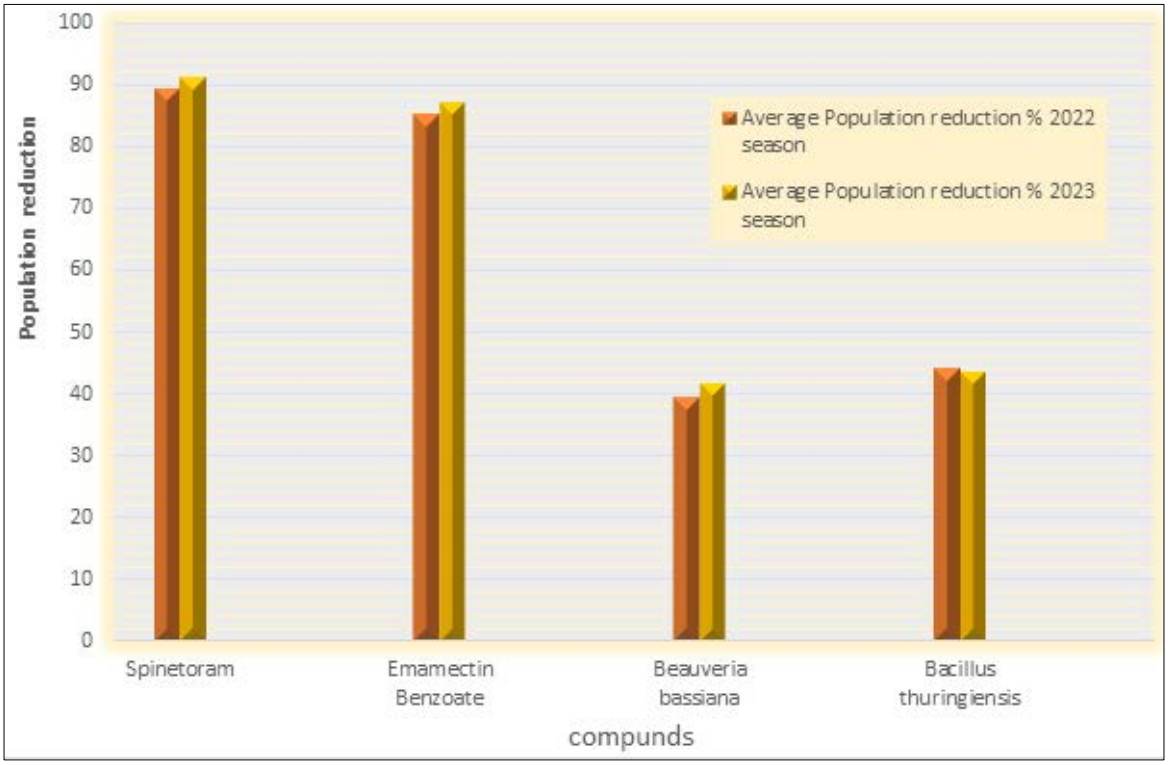

Fig 1: Average and all average of tested compounds in Population reduction *Spodoptera frugiperda* larvae in maize field conditions during 2022 and 2023season

Discussion

The recorded data revealed that the population density of fall armyworm larvae, *S. frugiperda* on 10 maize plants under field conditions represented by total average number of 13.08±2.25 and 12.23±2.31 larvae in 2022 and 2023, respectively. Additionally mean average of population reduction of all compounds against of *S. frugiperda* was recorded values 64.55and 65.99 in the first and second seasons, respectively and represented by overall average 65.27%**.** The results are in conformity with the findings of Karki *et al*., (2023) [14] Among the treatments, the percentage of the larval population that was reduced ranged from 37.14 to 93.49%. With a reduction rate of 93.49%, chlorantraniliprole showed the largest reduction in FA larvae population when compared to the control. Spinetoram and emamectin benzoate also shown significant reductions in larval numbers. with corresponding percentages of 72.62 and 63.50%, respectively. Also, our results are agreement with finding of (Birhanu *et al*., 2019) [3] in Ethiopia, Larval mortality was highest at 33.30% for radiant 120 sc, the least effective treatments were malathion and carbaryl, which caused 6.7% larval mortality. However, not all of the insects could be recovered from the infected plants, therefore the overall percentage of mortality was not 100%. In Egypt utilizing *B. thuringiensis*, a biopesticide, which reduced *S. frugiperda* populations number in maize fields in the two governorates Beni soyf and qalubia were 64.8% and 75.3%, respectively. (El-Hadary *et al*., 2023) [7]. Additionally, our results concur with the findings of (Abou-Elkassem *et al*., 2024) [2] when revelated that after 10 days from treatments, Biossiana 2,5% WP *(B. bassiana*) treatment induced overall average larval reductions, demonstrating that Biossiana induced value (59.47%) while Protecto 9.4% WP (*B. thuringiensis)* resulted in the lowest reduction with overall average (32.56%). However, 4thinstar larvae in maize fields had total mortalities of 53.33, while Protecto had the lowest reduction (43.53% reduction) after five and seven days post treatments.

Conclusion

The study on the efficacy of microbial and chemical insecticides against Spodoptera frugiperda on maize plants in Egypt reveals important insights for managing this pest. The data demonstrates that both Spinetoram and Emamectin Benzoate significantly reduced larval populations, with reductions reaching up to 97% and 94% respectively, proving their high effectiveness. In contrast, Bacillus thuringiensis and Beauveria bassiana showed lower efficacy, though still beneficial, with average reductions of around 44% and 42% respectively. These findings

underscore the potential for integrating both chemical and biological control methods to manage fall armyworm infestations effectively and sustain maize production.

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