

Controlling of *Spodoptera frugiperda* (JE. Smith) using biological compounds exposed to gamma rays and economic evaluation of maize crop

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Abstract

Several biotic compounds, including *Bacillus thuringiensis* (Kurs.), Emamectin benzoate, and Spinosad exposed or not exposed to gamma ray at doses (120 & 480 Gy), were used in a field experiment conducted in the El-Ayat region of Giza province to increase their toxicity to the Fall armyworm, *Spodoptera frugiperda* (Smith). In the field trial, concentrations of 1/2 (T1), 1/4 (T2), 1/8 (T3), and 1/16 (T4) of the biotic recommended dosages were utilized. For the purpose of assessing *S. frugiperda* management, larval population reduction was employed. The maize crop's economic assessment as a result of various treatments was also estimated. The *S. frugiperda* larval population was significantly reduced by half of the recommended dose of the compounds utilized, and this was followed by treatments of 1/4, 1/8, and 1/16 of the indicated doses. The results showed that the highest reduction in the number of *S. frugiperda* larvae on corn plants occurred in the Emamectin benzoate +480 Gy treatment; Meanwhile, *B. thuringiensis* not exposed to gamma rays gave the least reduction in larval numbers. Economic evaluation parameters of maize crop acts in productivity (kg), total costs (pounds), total revenue (pounds), net return (pounds), cost benefit ratio, margin over variable costs, pounds on return, added value and reduction in yield. The best yield result was obtained from corn treated with composites exposed to a gamma dose of 120 Gy in Spinosad +120 Gy, followed by Emamectin Benzoate +120 Gy and *B. Thuringiensis* +120 Gray with half the recommended dose. Thus, gamma ray doses can enhance the compounds to give a sufficient *S. frugiperda* larval population reduction percentages with 1/2 recommended dose than other treatments. Also, gamma doses, especially 120 Gy potentiates the compounds used (*B. thuringiensis*, Emamectin benzoate & Spinosad) to give the highly economic evaluation parameters of maize crop.

Keywords: *Spodoptera frugiperda*, gamma ray, *Bacillus thuringiensis*, emamectin benzoate, spinosad, field experiment, economic evaluation

Introduction

Maize (*Zea mays*, Lederer) is considered one of the strategic crops grown across the world with the largest productivity than other cereal crops. Whether for human consumption or animal and poultry as fodder that affects the industry and production of red or white meat. An insect pest such Fall armyworm (FAW), *Spodoptera frugiperda* (Smith) attacks various crops around the world; also, causing large crop yield reductions, especially, in maize this insect pest was recorded for the first time in Egypt during 2019 on maize plants in Aswan Governorate, spreading from Upper Egypt to the governorates of Lower Egypt and the Nile Delta (Rashed *et al.*, 2022) [27]. Due to their acute toxicity and economical rates, chemical pesticides are one of the safest options for managing on *Spodoptera frugiperda* in an emergency (Paredes-Sanchez *et al.*, 2021) [26]. Researching the effectiveness of pesticides is insufficient; it's also critical to weigh the costs against the benefits (Leach and Mumford, 2008) [23]. Nonetheless, the most difficult part of pest management is economic analysis, which calculates crop loss from pests and crop loss from control (Oerke, 2006) [25]. The FAO definition of crop loss is the reduction in yield attributed to the pest, or the difference between attainable yields and actual yields (Walker, 1983) [33]. There are two methods for estimating yield loss: directly, using field surveys or experiments (Walker, 1983) [33]; or indirectly, by determining the relationship between pest incidence and yield loss

(Walker, 1991) [34]. Chemical control has hazards and is more expensive. Radiation technology offers a safer and more reliable option. Radiation also shortens the life spans of insects (Baxter and Blair, 1969) [12]. Additionally, other studies have shown that gamma radiation caused insect sterility and altered the progeny's life span in relation to radiation doses and the irradiated stage. This means that when insects are exposed to ionizing radiation, their genetic makeup is altered to the point where dominant fatal mutations occur, which effectively suppresses and eradicates a variety of lepidopteran insect pests (Sayed and Zahran, 2017) [30]. Currently, radiation is thought to be one of the most effective ways that chemical control may convert on the insect resistance after several treatments. The gamma irradiation dosages administered to the *S. frugiperda* larvae were 50, 100, 200, and 300 Gy. According to Arthur *et al.* (2013) [10], the fatal dosage of radiation for larvae was 300 Gy, but the sterilizing dose for adults was 200 Gy. The impact of gamma radiation on the spore activity, toxicity, and crystal structures of two modified strains of *Bacillus thuringiensis* (Bt), TnX and TnY, as well as the reference strain HD-1, was assessed by Shifeng *et al.* (2013) [1]. We tried to find cobalt-60 gamma radiation doses that would inactivate *B.t.* spores without compromising their toxicity. There was no discernible spore production or appreciable decrease in the effectiveness of *B.t.* against lepidopteran larvae during the radiation dosage range of 10–15 kilo grays. Further sodium dodecyl sulfate

Polyacrylamide gel electrophoresis (SDS-PAGE) results, however, reveal that the protoxin's components are impacted by gamma radiation and that, in contrast to the controls, some bands are absent following treatment; the variation in the protoxin band pattern is dependent on the type of Bt variety. Furthermore, transmission electron microscopy and scanning electron microscopy were used to examine the spore crystal structure of three Bt strains. When compared to the controls, the size and morphology of the treated Bt spores and crystals remain unchanged, according to the data. Used gamma radiation is a useful tool for inactivating modified Bt strain spores while maintaining stable Bt toxicity against the intended insect larvae. Furthermore, Ibrahim and Sayed (2023)^[19] noted that gamma radiation (100, 200, 300, and 400 Gy) is a safe, effective physical method of eradicating *S. frugiperda* that may also lower the number of pests. Additionally, it works incredibly well against the target pests' enzymatic activities. In order to manage some pests in both laboratory and field settings, scientists have also employed gamma rays as a potentiating impact on certain bio-insecticides, such as *B. thuringiensis*, *B. bassiana*, azadiractin, Spinosad, and chitosan (Amer (2006)^[2]; Amer, *et al.* (2015)^[6]; Amer, *et al.* (2020)^[4], and Amer, *et al.* (2023)^[7].

This work aimed to, study reduction of *S. frugiperda* larval population and economic evaluation for maize crop as a result of different treatments was estimated".

Materials and methods

Bio-insecticide compounds used

1. Protecto 9.4% WP (*Bacillus thuringiensis* (Kurstaki)) application rate 300 g /faddan, (product company Bio-insecticide production unit, plant protection research Institute, Agriculture Research Center, Egypt).
2. Andraws L. 1.9% EC. (Emamectin benzoate) application rate 150cm³/ faddan, product company Nanjing redsun Co., Ltd, China (Cam for Agriculture chemicals)
3. Master Top 48% SC (Spinosad) application rate 15 cm³/100 L water, product company (Qilu pharmaceutical (Inner Mangolia) Co, Ltd, China. Starchem Industrial chemicals, Egypt).

Usage rate have been suggested to study the best rates and concentrations which used to recommend *Bacillus thuringiensis* (Kurs.), (Protecto): (1(T₁), 0.5(T₂), 0.25(T₃) & 0.13(T₄) g/L).

Emamectin benzoate, (Andraws L): (0.375(T₁), 0.1875(T₂), 0.0938 (T₃) & 0.0469(T₄) ml/L). Spinosad, (Master Top): (0.075(T₁), 0.0375(T₂), 0.01875 (T₃) & 0.009375(T₄) ml/L).

Gamma radiation

The biotic compounds: *B. thuringiensis*, Emamectin benzoate & Spinosad were exposing to gamma ray (120 & 480 Gy) at a dosage rate (0.682 KGy/h) in Cesium Hendy Gamma Cell Research used at National Center for Radiation Researches & Technology apparatus. The following nine treatments were administered: *B. thuringiensis*, *B. thuringiensis* + 120 Gy, *B. thuringiensis* +480 Gy, Emamectin benzoate, Emamectin benzoate + 120 Gy, Emamectin benzoate +480 Gy, Spinosad, Spinosad + 120 Gy and Spinosad + 480 Gy.

In El-Ayat district, Giza governorate, Egypt, a field experiment using maize, *Zea mays* (Hi-tech 2031 variety), was conducted to evaluate the reduction in the larval population of *Spodoptera frugiperda* (Smith) treated by the nine aforementioned treatments in 2023. Used area was half faddan to carried the experiment (15 plants, 15 lines, and 3 replicates for each treatment); each treatment took up 82.5 m². The spraying occurs after 11 days from planting, Spraying using the phagocytic method. Twice sprays were applied using bio-insecticides between each treatments period 12-day intervals. The first and second sprays of the 2023 maize season, carried out on May 28 and June 11, respectively. Before spray by using bio-insecticides, samples of maize were randomly collected to examination. Thenceforth, the samples were taken after 1, 3, 5, 7, and 10 days from spray. For every fifteen lines, one plant was gathered and studied for every treatment. *B. thuringiensis* and Spinosad were used at (1/2, 1/4, 1/8 & 1/16) recommended doses were applied. Also, untreated plot was done.

Henderson and Telton formula was used (1955)^[18].

% Reduction = 100 (1 - (Ta x Cb / Tb x Ca)).

Where Ta = number of larval populations from the treatment after application.

Tb = number of larval populations from the treatment before application.

Ca = number of larval populations from the control after application.

Cb = number of larval populations from the control before application.



Fig 1: showing plants when spraying begins, 11 days after planting



Fig 2: Fall armyworm *Spodoptera frugiperda* (JE. Smith) infestation

Economic evaluation parameters.

The follow parameters were calculated as economic evaluations:

1. **Productivity (Kg):** productivity = total output/total input.
2. **Price (pound)/kg.**
3. **Total revenue (pound):** Total Revenue (TR)= Quantity (Q) x Price (P).
4. **Net return (pound):** subtract the purchase price of the investment from its selling price.
5. **Cost benefit ratio (CBR):** Calculated by dividing the proposed total cash benefit of a project/ the proposed total cash cost of the project.
6. **Margin over variable costs:** refers to the margin results calculated by subtracting variable production costs from revenue.
7. **Pound on return:** comparing the difference between its current value and its initial value, and then dividing the result by its initial value.
8. **Added value:** Added value = The selling price of a product - the cost of bought in materials and component.
9. **Reduction yield percentage:** Reduction yield % = $b / \bar{y} * 100$

b= unit effect (regression value)

\bar{y} = the average mean yield / sample.

Statistical Analysis.

Larval population reduction of *Spodoptera frugiperda* (Smith) data were analyzed by using SAS statistical program software, 1999^[29] with Duncan multiple range tests (Duncan, 1955)^[16] at 5% probability level for comparing the differences means.

Results and discussion

Spodoptera frugiperda Control

This work used ten treatments of *B. thuringiensis*, *B. thuringiensis* +120 Gy, *B. thuringiensis* +480 Gy, Emamectin benzoate, Emamectin benzoate +120 Gy, Emamectin benzoate +480 Gy, Spinosad, Spinosad+120 Gy, Spinosad +480 Gy and untreated were applied with 1/2, 1/4, 1/8 & 1/16 recommended doses for *S. frugiperda* controlling in 2023 at El-Ayat district, Giza Governorate. Larval population reductions of *S. frugiperda* as a result of two sprays at 12 days intervals; with aforementioned compounds by recommended doses were used to evaluate the best treatments and level dose for *S. frugiperda* controlling. The spraying occurs after 11 days from planting, Spraying using the phagocytic method. Because the infestation appears in the early stages of the plant's life. Therefore, it was necessary to take the age of the plant into account and also in order to control the pest from the beginning of the infestation and obtain a crop completely free of infection.

B. thuringiensis treatments

Table (1) show that treatments *B. thuringiensis* +480 Gy was record the highly mortality in reductions of *S. frugiperda* larval populations than other treatments used. Also, *B. thuringiensis* with 1/2 recommended dose (T₁) was the best tested dose used than other doses. *B. thuringiensis* +480 Gy treatments with 1/2, 1/4, 1/8 & 1/16 recommended doses for *S. frugiperda* reduction in larval populations were 89.7, 86.6, 80.9 & 79.02%, respectively. Meanwhile, *B. thuringiensis* +120 Gy treatments ranging from 88.8 to 74.9% for four recommended doses. While, *B. thuringiensis* treatments without exposing to gamma doses had the lowest reductions in *S. frugiperda* larval populations which ranged between 87.1 to 65.3% with tested four doses used.

Table 1: Efficiency of *B. thuringiensis* treatments conjugated with gamma ray with the different concentration and percentage of reduction of fall armyworm *Spodoptera frugiperda*

Date			<i>Bacillus thuringiensis</i> (Kurs.)											
			<i>B. thuringiensis</i>				<i>B. thuringiensis</i> +120 Gy				<i>B. thuringiensis</i> +480 Gy			
			T ₁	T ₂	T ₃	T ₄	T ₁	T ₂	T ₃	T ₄	T ₁	T ₂	T ₃	T ₄
1 st spray	28 May	1-day	55.6	77.8	33.3	57.1	84.6	100	75	75	100	72.7	83.3	63.6
	30 May	3-day	64.4	91.1	73.3	31.4	93.8	100	70	50	84	85.5	66.7	70.9
	1 June	5-day	82.2	73.3	82.2	42.9	100	76	80	70	76	85.5	73.3	78.2
	3 June	7-day	73.3	82.2	73.3	77.1	87.7	84	80	80	100	85.5	86.7	78.2
	6 June	10-day	100	91.1	73.3	31.4	87.7	76	80	80	92	90	80	70.9
	8 June	12-day	100	82.2	91.1	42.9	81.5	60	70	50	92	78.2	86.7	78.2
	Means		79.3 ABCD	83.0 ABC	71.1 CD	47.1 E	89.2 AB	82.7 ABC	75.8 BCD	67.5 D	90.7 A	82.9 ABC	79.5 ABCD	73.3 CD
	F value		5.32***											
L.S.D		7.26												
2 nd spray	9 June	1-day	82.2	100	82.2	77.1	87.7	68	100	80	100	85.5	93.3	100
	11 June	3-day	100	88.9	100	85.7	76.9	90	100	62.5	100	87.5	83.3	90.9
	13 June	5-day	100	77.8	88.9	100	84.6	80	87.5	87.5	90	100	66.7	81.8
	15 June	7-day	100	77.8	100	85.7	92.3	90	75	100	70	90.9	91.7	72.7
	18 June	10-day	100	80.3	80.3	87.3	100	100	66.7	88.9	82.2	91.1	77.8	83.8
	Mean		96.4 A	85.0 AB	90.3 AB	87.2 AB	88.3 AB	85.6 AB	85.8 AB	83.8 B	88.4 AB	91.0 AB	82.6 B	85.8 AB
	F value		2.85*											
	L.S.D		2.65											

T₁= 1/2 dose T₂= 1/4 dose T₃= 1/8 dose T₄= 1/16 dose

Values in the same column followed by the same letter do not significantly differ from each other according to Duncan's multiple range tests at 5% level
L.S.D= Least Significant Difference

Emamectin benzoate treatments

Emamectin benzoate cause highly reductions in *S. frugiperda* larval population with treatments, especially in Emamectin benzoate + 480 Gy with four (1/2, 1/4, 1/8 & 1/16) recommended doses used (95.9, 90.5, 88.5 & 82.9%

larval population reductions, respectively), followed by Emamectin benzoate + 120 Gy treatments that had values of 92.5, 87.5, 81.7 & 77.2% larval population reduction for 1/2, 1/4, 1/8 & 1/16 recommended doses. While, Emamectin benzoate without exposing to gamma doses caused the least *S. frugiperda* larval population reductions (ranging between 89.7- 75.4%) compared with the same compound when exposed to gamma doses of 480 or 120 Gy as illustrated in Table (2).

Table 2: Efficiency of Emamectin benzoate treatments conjugated with gamma ray with different concentration and percentage of reduction of fall armyworm *Spodoptera frugiperda*.0.0.0.0.0.0.0

Date			Emamectin benzoate											
			Emamectin Benzoate				Emamectin benzoate +120 Gy				Emamectin benzoate +480 Gy			
			T ₁	T ₂	T ₃	T ₄	T ₁	T ₂	T ₃	T ₄	T ₁	T ₂	T ₃	T ₄
1 st spray	28 May	1-day	76.9	75	72.7	87.5	100	100	60	77.8	100	100	100	80
	30 May	3-day	87.7	70	56.4	90	78.2	100	76	91.1	85.5	91.1	93.3	76
	1 June	5-day	75.4	80	70.4	60	92.7	60	84	82.2	85.5	100	93.3	68
	3 June	7-day	87.7	80	85.5	80	92.7	90	84	82.2	100	82.2	86.7	76
	6 June	10-day	81.5	90	78.2	70	85.5	80	84	70.9	100	82.2	80	84
	8 June	12-day	100	80	70.9	20	85.5	80	68	70.9	92.7	82.2	73.3	76
	Means		84.9 ABCD	79.2 BCDE	72.3 DE	67.9 E	89.1 AB	85.0 ABCD	76.0 CDE	79.2 BCDE	93.9 A	89.6 AB	87.8 ABC	76.6 BCDE
	F value		2.90**											
L.S.D		4.02												
2 nd spray	9 June	1-day	87.7	90	100	70	100	90	92	91.1	100	91.1	80	100
	11 June	3-day	100	87.5	100	87.5	100	87.5	80	77.8	90.9	77.8	83.3	90
	13 June	5-day	71.9	100	81.8	87.5	90.9	87.5	90	66.7	100	88.9	91.7	90
	15 June	7-day	92.3	100	81.8	87.5	100	87.5	90	77.8	100	100	91.7	90
	18 June	10-day	86.3	100	91.9	88.9	91.9	100	91.1	60.5	100	100	100	82.5
	Mean		87.64 BCD	95.5 AB	91.1 ABC	84.28 CD	96.56 AB	90.5 ABC	88.62 BCD	74.78 D	98.18 A	91.56 ABC	89.34 ABC	90.5 ABC
	F value		2.59*											
	L.S.D		5.66											

T₁= 1/2 dose T₂= 1/4 dose T₃= 1/8 dose T₄= 1/16 dose

Values in the same column followed by the same letter do not significantly differ from each other according to Duncan's multiple range tests at 5% level

L.S.D= Least Significant Difference

Spinosad treatments

Spinosad + 480 Gy treatments when used with 1/2 recommended dose caused reductions in *S. frugiperda* larval population as follow 93.03, 88.3, 82.8 & 77.6% with 1/2, 1/4, 1/8 & 1/16 recommended doses, followed by Spinosad + 120 Gy treatments that ranging between 92.1-76.2% and Spinosad singly without gamma doses treatments (89.1-71.4) as in Table (3).

The results obtained showed that the reduction percentages of *S. frugiperda* larval population was the highest when using Emamectin benzoate +480 Gy treatment when used at 1/2 recommended dose only that reached to 95.9%. Also, Spinosad +480 Gy treatment can also rise from larval population reduction (93.03%) but it was the lower than the previous treatment 3% nearly. Followed by treatments of Emamectin benzoate +120 Gy (92.5%) as well as Spinosad +120 Gy nearly (92.1%), Emamectin benzoate without exposing to gamma ray (89.7%) as well as *B. thuringiensis* +480 Gy (89.7%), Spinosad singly (89.1%), *B. thuringiensis* +120 Gy (88.8%), then *B. thuringiensis* singly (87.1%) as described in Tables (1-3).

Table 3: Efficiency of Spinosad treatments conjugated with gamma ray with the different concentration and percentage of reduction of fall armyworm *Spodoptera frugiperda*

Date			Spinosad											
			Spinosad				Spinosad +120 Gy				Spinosad +480 Gy			
			T ₁	T ₂	T ₃	T ₄	T ₁	T ₂	T ₃	T ₄	T ₁	T ₂	T ₃	T ₄
1 st spray	28 May	1-day	100	100	71.4	75	90.9	91.7	60	81.8	83.3	90.9	60	100
	30 May	3-day	100	91.1	88.6	70	90.9	100	84	85.5	93.3	100	76	60
	1 June	5-day	100	91.1	100	70	100	93.3	100	78.2	93.3	85.5	92	100
	3 June	7-day	85.5	73.3	77.1	70	100	80	84	78.2	86.7	90	84	86.7
	6 June	10-day	85.5	73.3	65.7	60	85.5	86.7	68	70.9	86.7	80	68	60
	8 June	12-day	78.2	73.3	65.7	43.8	85.5	86.7	68	49.1	86.7	80	76	60
	Means		91.5 A	83.7 ABCD	78.1 BCD	64.8 E	92.1 A	89.7 A	77.3 CD	74.0 DE	88.3 AB	87.7 ABC	76.0 D	77.8 CD
	F value		5.17***											
L.S.D		3.49												
2 nd spray	9 June	1-day	85.5	73.3	77.1	70	78.2	80	84	78.2	93.3	90	84	86.7
	11 June	3-day	72.7	88.9	71.4	75	81.8	58.3	73.3	63.6	100	81.8	100	50
	13 June	5-day	90.9	77.8	85.7	87.5	100	91.7	86.9	81.8	100	81.8	90	66.7
	15 June	7-day	90.9	100	85.7	75	100	91.7	93.3	81.8	100	90.9	90	83.3
	18 June	10-day	90.9	100	100	88.9	100	92.6	94.1	88.9	100	100	91.1	100
	Mean		86.2 BCD	88.0 BC	84.0 BCD	79.3 CD	92.0 AB	82.9 BCD	86.3 BCD	78.9 CD	98.7 A	88.9 ABC	91.0 AB	77.3 D
	F value		2.94*											
	L.S.D		7.65											

T₁= 1/2 dose T₂= 1/4 dose T₃= 1/8 dose T₄= 1/16 dose

Values in the same column followed by the same letter do not significantly differ from each other according to Duncan's multiple range tests at 5% level

L.S.D= Least Significant Difference

Additionally, Tables (1-3) demonstrated that other recommended doses of biotic compounds (1/4, 1/8, and 1/16) produced the same sequence in the compound's efficiency; however, the compounds applied at 1/4 recommended doses gradually reduced the larval population of *S. frugiperda*, followed by those applied at 1/8 recommended dose. The compounds applied at 1/16 recommended doses showed the least reduction percentage in larval population of *S. frugiperda* when compared to those used at 1/2 recommended dose. Furthermore, compared to the same compounds without exposure to gamma doses, the results showed that biotic compounds administered after being subjected to a 480 Gy gamma treatment had a highly efficiency on *S. frugiperda* larval population decreases. Additionally, treatments with Emamectin benzoate provided the extremely *S. frugiperda* larval population reductions, followed by exposing to 120 Gy comparing with the same compounds without exposing to gamma doses. Moreover, Emamectin benzoate treatments gave the highly *S. frugiperda* larval population reduction, followed by Spinosad and then *B. thuringiensis* that considered the lowest in its efficiency comparing with other treatment applications.

Gamma rays were employed by earlier writers to intensify used bio-insecticides, such as Amer (2006)^[2], who conducted field tests during the cotton seasons of 2004 and 2005. *B. thuringiensis* that progressively became more efficient between 5 and 80 Gy of gamma radiation. The lint and seed weights (gm/100bolls) were also raised by the treatments that were used. Furthermore, treated *B. thuringiensis* to insect pests of *P. gossypiella*, *S. littoralis*, and *A. craccivora* which was exposed to gamma doses of 150, 250, and 350 Gy showed lower fatal doses than *B. thuringiensis* not exposed to gamma doses, according to Amer *et al.* (2012)^[3]. Furthermore, *B. thuringiensis*, *M. anisopliae*, and chitosan, a biopolymer molecule, were subjected to gamma doses of 15, 30, and 60 Gy by Amer *et al.* (2015)^[6] in order to maximize their effects. When applied to *S. littoralis* larvae in their fourth instar, a dose of 60 Gy proved to be more effective than alternative dosages. At the same time, magnetic flux treatments of 20 and 180 mT were shown to be less damage than gamma doses of 50 and 500 Gy against the egg stage of *E. insulana*, according to Amer *et al.* (2019)^[5], additionally, *Bacillus thuringiensis* (Kur.), *B. thuringiensis* +160 Gy, *B. thuringiensis* +320 Gy, *B. thuringiensis* +640 Gy, azadirachtin, *B. thuringiensis* +azadirachtin, and diflubenzuron were used in cotton field experiments carried out in the 2018 and 2019 seasons to reduce the population

and infestation percentages of three pests of cotton bolls (*P. gossypiella*, *E. insulana*, and *O. hyalinipennis*). The best treatments for reduction percentage of population of three pests were found to be *B. thuringiensis* + 640 Gy and diflubenzuron. These results were followed by *B. thuringiensis* + 320 Gy, *B. thuringiensis* + 160 Gy, and *B. thuringiensis* + azadirachtin, azadirachtin, and finally *B. thuringiensis* alone Amer *et al.* (2020) [4], Addition, the treatments used enhance the most cotton crop parameters acts in the lint and seed weights during both cotton seasons. In the meanwhile, Kushwaha (2022) [22], studied the effectiveness of grease and Emamectin benzoate in controlling *Spodoptera frugiperda* on a maize field during the winter months of 2020 and 2021 in Sarlahi, Nepal, using five replicates. When the maize crop reached knee height, treatments were given, and between 5 and 8% of the total plants were harmed by larvae. After seven days of treatment, there was a decrease in infestation. When Emamectin benzoate was applied to the plots, fall armyworm larvae were discovered dead, but they were not present when grease was applied. The lack of crop damage among the grease-treated plants may be the result of the larvae's restricted mobility on the maize crop. Grease, an environmentally benign substance, may be utilized as an agro-ecological technique to manage fall armyworm larvae in small-scale land-holding maize farms. However, Mian *et al.* (2022) [24], found that, when applied deltamethrin on *S. frugiperda*, was the most harmful pesticide, followed by Chlorantraniliprole and Emamectin benzoate. After one day following the initial spray, there were 1.11 larvae per plant, 1.13 larvae per plant, and 1.17 larvae per plant of Emamectin benzoate. A minimum number of larvae noticed with deltamethrin (0.07 larvae/plant), Chlorantraniliprole (0.11 larvae/plant), and Emamectin benzoate (0.13 larvae/plant) at three days after the first spray was applied. The fewest larvae were seen (0.07, 0.10, and 0.10 larvae/plant) with deltamethrin, Chlorantraniliprole, and Emamectin benzoate at 14 days following the second spray, respectively. Furthermore, Amein (2023) [8], reported that the *B. thuringiensis* LC50 value for the second larvae of *S. frugiperda* was 0.125 mg/ml. The therapy resulted in a considerable decrease in the larval instar as the second instar and an extension of the larval and pupal lengths. Additionally, in a lab trial, Amein and Abdelal (2023) [9], assessed the effectiveness of Teflubenzuron, Emamectin benzoate, and Alfa-cypermethrin on *S. frugiperda* larvae in their fourth instar. For *S. frugiperda* larvae treated with Teflubenzuron, Emamectin benzoate, and α -cypermethrin, the corresponding LC50 values were 0.18 ppm, 0.019 mg/ml, and 0.6046 mg/ml. lengthening of the larval life cycle, lowering the percentage of pupation and pupal duration impacted by the applied therapies. Additionally, Han *et al.* (2023) [17], studied on three pesticides (Emamectin benzoate, spinetoram, and Chlorantraniliprole) and their toxicity was assessed in *S. frugiperda* larvae feeding on sweet corn in the third leaf stage after spraying the pesticides five and twenty-five times using conventional field application. They also used Poly-organosilicon as a synergist. When applied to maize leaves, Chlorantraniliprole was more effective than spinetoram and Emamectin benzoate. The field treatments clearly showed that spraying Chlorantraniliprole or spinetoram at a 25-fold concentration had a control effect on *S. frugiperda* after 17 days. Additionally, this technique might involve cutting the active component to 4/5 or 3/4 for a seed coating treatment or a single field spray, respectively.

Furthermore, In several areas of the Bani-Suef governorate in Egypt, Khamis *et al.* (2023) [22], assessed the regular inspections of sorghum and maize crops throughout the 2021 and 2022 seasons and found extraordinary infestations of *Spodoptera frugiperda*. The Food and Agriculture Organization's inclination to use bio-rational pesticides against *S. frugiperda* in Egypt was supported by *Beauveria bassiana* and spinetoram. The LC25 values of *B. bassiana* after 48 hours were 2.7×10^6 and 5.2×10^6 conidia mL⁻¹, and the spinetoram values were 0.019 and 0.048 mg/L-1 when applied in laboratory against *S. frugiperda* larvae on their second and fourth instars, respectively. On the biological parameters, sub-lethal effects (LC25) were achieved against both instar larvae. Compared to spinetoram (75.99 and 79.49%), LC25 of *B. bassiana* decreased adult emergency by 89.91 and 91.05% more than the second and fourth instar larvae, respectively. More than spinetoram (19.74 eggs), the second instar larvae exposed to *B. bassiana* LC25 decreased female fecundity (0.00 eggs). In the end, *B. bassiana* and spinetoram might provide effective control, particularly on *S. frugiperda* larvae in their early instars. Meanwhile, In order to increase the lethality of some biocide compounds (*Bacillus thuringiensis* (Kurs.), Emamectin benzoate, and Spinosad) for the goal of eradicating fall armyworms, or *Spodoptera frugiperda* (Smith), Amer *et al.* (2023) [7], examined these compounds either exposed or not to gamma ray doses (120 and 480 Gy). Current maize field studies are using concentrations (1/2, 1/4, 1/8, and 1/16) of the permissible dosages of biocides. Lethal dosage effectiveness and time-response were employed as assessment metrics for controlling *S. frugiperda*. Treatments using Spinosad were shown to have the best dosage lethality for controlling *S. frugiperda*, with treatments including Emamectin benzoate and *B. thuringiensis* coming in third and fourth. In contrast to the previously described treatments, Emamectin benzoate treatments had the lowest time-response lethality. Gamma-ray doses of 480 Gy and 120 Gy have the ability to enhance the effects of *B. thuringiensis* biocide chemicals, such as Emamectin benzoate. and Spinosad to become more deadly than the same substances without being exposed to gamma radiation, conserving both the dose and the reaction time for the management of *S. frugiperda* in maize plants. However, Aly *et al.* (2024) [11], assessed the efficacy of three insecticides against *S. frugiperda* larvae in their fourth instar in a laboratory setting: Lufenuron, Emamectin benzoate, and *Bacillus thuringiensis* (kurs.). The larvae were gathered from the corn fields in the Qena Governorate, Upper Egypt, and then raised in a laboratory. The concentration-dependent mortality rates for the three insecticides were determined using toxicity tests; Emamectin benzoate showed the maximum toxicity, followed by B.t. and Lufenuron. The differences in chemical compositions and mechanisms of action are responsible for the variation in efficacy. Additionally, research was done on how these pesticides affected the growth of larvae. While Lufenuron and B.t induced extended larval development and delayed pupation, Emamectin benzoate caused protracted larval development.

Economic evaluation parameters

B. thuringiensis treatments

All *B. thuringiensis* treatments with 1/2 (T₁), 1/4 (T₂), 1/8 (T₃) & 1/16 (T₄) at recommended doses which used for *S. frugiperda* controlling increased the economic evaluation

parameters for maize crop acts in productivity (Kg), price (pounds), total costs (pounds), total revenue in pounds and net return in pounds (Table 8). *B. thuringiensis* +120 Gy when applied with half recommended dose (T₁) was the best *B. thuringiensis* treatment that gave 72.27 Kg productivity, 797 pounds. Opposite was happened in *B. thuringiensis*+ 480 Gy with 1/16 (T₄) recommended dose compared with the data of untreated maize crop area as shown in the same table. Also, the same treatment of *B. thuringiensis* +120 Gy with 1/2 recommended dose (T₁) was record the best result of cost benefit ratio (CBR) (1.71), margin over variable costs (531), pound in return (0.71) and added value (693). Contrary, in *B. thuringiensis* +480 Gy treatment with 1/16 recommended dose (T₄) had values of 0.97, 202, -0.03 & 314, respectively comparing with untreated area that were 1.19, 367, 0.19 & 416, respectively as in Table (4).

Emamectin benzoate treatments

Table (5) showed that the best economic evaluation parameters as a result of Emamectin benzoate applications for maize average productivity for *S. frugiperda* controlling increased the maize crop investment that reach to 94.65 Kg caused 1041 pounds in total revenue and net return of 575 pounds in Emamectin benzoate treatment when exposed to gamma ray of 120 Gy with 1/2 recommended dose (T₁). Opposite, with happened in Emamectin benzoate +480 Gy treatment with 1/16 recommended dose (T₄) that depressed the productivity to 33.62 Kg with loss in pounds reach to -95

pounds for plot area 82.2 m² comparing with untreated maize crop area (Table 11).

The same trend appeared in Table (11) that showed the treatment of Emamectin benzoate +120 Gy increased the cost benefit ratio (CBR) to 2.24 with margin over variable costs of 855, pound in return (1.24 pound) and added value (903); on the other hand, the pound in return loss in -0.20 pound in the treatments of Emamectin benzoate + 480 Gy with 1/16 recommended dose (T₄) when applied for *S. frugiperda* controlling compared with untreated area.

Spinosad treatments

Economic evaluation parameters of Spinosad treatments had the highly results when Spinosad +120 Gy with (T₁) 1/2 recommended dose treatment was applied for *S. frugiperda* controlling. The maize crop productivity was 120.3 Kg with 1323 pounds total revenue and 858 pounds net return (Table 13). Also, the cost benefit ratio (CBR) was 2.85 with margin over variable costs (531), 1.85 pounds on return and 1221 added value, followed by Spinosad + 120 Gy (T₂), (T₃) & (T₄). Treatments of Spinosad singly with the four concentrations used, followed the previous treatments in the economic evaluation parameters investment and then the treatments of Spinosad +480 Gy with the four concentrations used (from T₁ to T₄) had the lowest productivity of maize crop comparing with untreated maize crop productivity and the investment earning (Table,6).

Table 4: Economic evaluation parameters of maize crop affected by *B. thuringiensis* application for *S. frugiperda* controlling at field conditions

Treatments	Economic evaluation parameters								
	Productivity (kg)	Price in pounds/kg	Total costs in pounds	Total revenue in pounds	Net return in pounds	Cost Benefit Ratio (CBR)	Margin over variable costs	Pound on return	Added Value
Untreated	20.34	11	464	554	90	1.19	367	0.19	416
<i>B. thuringiensis</i> (T ₁)	61.24	11	467	674	206	1.44	418	0.44	532
<i>B. thuringiensis</i> (T ₂)	60.71	11	465	668	202	1.44	482	0.44	565
<i>B. thuringiensis</i> (T ₃)	55.5	11	466	610	145	1.19	367	0.19	416
<i>B. thuringiensis</i> (T ₄)	52.73	11	466	580	114	1.25	326	0.25	440
<i>B. thuringiensis</i> +120 Gy (T ₁)	72.27	11	465	797	330	1.71	531	0.71	693
<i>B. thuringiensis</i> +120 Gy (T ₂)	64.62	11	465	711	246	1.53	448	0.53	566
<i>B. thuringiensis</i> +120 Gy (T ₃)	62.16	11	470	684	213	1.45	430	0.45	541
<i>B. thuringiensis</i> +120 Gy (T ₄)	61.95	11	469	681	213	1.45	442	0.45	548
<i>B. thuringiensis</i> +480 Gy (T ₁)	61.36	11	465	675	210	1.45	389	0.45	517
<i>B. thuringiensis</i> +480 Gy (T ₂)	51.52	11	465	567	102	1.22	280	0.22	409
<i>B. thuringiensis</i> +480 Gy (T ₃)	49.79	11	466	548	82	1.18	328	0.18	426
<i>B. thuringiensis</i> +480 Gy (T ₄)	41.18	11	467	453	-14	0.97	202	-0.03	314

T₁= 1/2 dose T₂= 1/4 dose T₃= 1/8 dose T₄= 1/16 dose

Table 5: Economic evaluation parameters of maize crop affected by Emamectin benzoate application for *S. frugiperda* controlling at field conditions

Treatments	Economic evaluation parameters								
	Productivity (kg)	Price in pounds/kg	Total costs in pounds	Total revenue in pounds	Net return in pounds	Cost Benefit Ratio (CBR)	Margin over variable costs	Pound on return	Added Value
Untreated	20.34	11	464	554	90	1.19	367	0.19	416
Emamectin benzoate(T ₁)	60.64	11	469	667	198	1.42	428	0.42	534
Emamectin benzoate(T ₂)	56.21	11	470	618	148	1.31	364	0.31	476
Emamectin benzoate(T ₃)	54.05	11	465	595	129	1.28	482	0.28	492
Emamectin benzoate(T ₄)	53.35	11	466	587	121	1.26	333	0.26	446
Emamectin benzoate +120 Gy (T ₁)	94.65	11	466	1041	575	2.24	855	1.24	903
Emamectin benzoate+120 Gy (T ₂)	91.94	11	467	1011	544	2.16	756	1.16	869
Emamectin benzoate+120 Gy (T ₃)	64.58	11	465	710	246	1.53	448	0.53	565

Emamectin benzoate+120 Gy (T ₄)	62.52	11	465	688	223	1.48	531	0.48	585
Emamectin benzoate+480 Gy (T ₁)	55.26	11	467	608	141	1.30	357	0.30	469
Emamectin benzoate+480 Gy (T ₂)	54.41	11	465	598	134	1.29	313	0.29	441
Emamectin benzoate+480 Gy (T ₃)	45.23	11	466	498	32	1.07	278	0.07	376
Emamectin benzoate+480 Gy (T ₄)	33.62	11	465	370	-95	0.80	83	-0.20	212

T₁= 1/2 dose T₂= 1/4 dose T₃= 1/8 dose T₄= 1/16 dose

Table 6: Economic evaluation parameters of maize crop affected by Spinosad application for *S. frugiperda* controlling at field conditions

Treatments	Economic evaluation parameters								
	Productivity (kg)	Price in pounds/kg	Total costs in pounds	Total revenue in pounds	Net return in pounds	Cost Benefit Ratio (CBR)	Margin over variable costs	Pound on return	Added Value
Untreated	20.34	11	464	554	90	1.19	367	0.19	416
Spinosad (T ₁)	81.10	11	467	892	425	1.91	636	0.91	750
Spinosad (T ₂)	71.14	11	466	783	317	1.68	528	0.68	642
Spinosad (T ₃)	68.92	11	470	758	288	1.61	504	0.61	616
Spinosad (T ₄)	64.40	11	466	708	243	1.19	367	0.19	416
Spinosad +120 Gy (T ₁)	120.3	11	465	1323	858	2.85	531	1.85	1221
Spinosad +120 Gy (T ₂)	95.15	11	469	1047	578	2.23	807	1.23	913
Spinosad +120 Gy (T ₃)	86.72	11	465	954	489	2.05	448	1.05	809
Spinosad +120 Gy (T ₄)	83.06	11	465	914	448	1.96	482	0.96	811
Spinosad +480 Gy (T ₁)	80.07	11	466	881	415	1.89	661	0.89	759
Spinosad +480 Gy (T ₂)	71.34	11	465	785	320	1.69	499	0.69	627
Spinosad +480 Gy (T ₃)	59.57	11	467	655	188	1.40	404	0.40	516
Spinosad +480 Gy (T ₄)	54.77	11	465	202	137	1.30	316	0.30	444

T₁= 1/2 dose T₂= 1/4 dose T₃= 1/8 dose T₄= 1/16 dose

The infestation-yield relationship

Addition, Table (7) take attention to *S. frugiperda* control with Spinosad + 120 Gy (T₁) treatment was the highest productivity (Kg) value (120 Kg) and the least reduction in yield (-4.94%) with 1.8 *S. frugiperda* larval population;

opposite was happened with Emamectin benzoate +480 Gy (T₄) that had 33.62 Kg productivity and -17.67% reduction in yield comparing with untreated that had reduction in yield 20.34 Kg productivity and (-29.21%) with 9.1 *S. frugiperda* larval population.

Table 7: *S. frugiperda* larval population in maize and yield crop on different treatments

Treatments	<i>S. frugiperda</i> larval population	Productivity (kg)	Reduction yield %
Untreated	9.1	20.34	-29.21
<i>B. thuringiensis</i> (T ₁)	2	61.24	-9.70
<i>B. thuringiensis</i> (T ₂)	2.3	60.71	-9.79
<i>B. thuringiensis</i> (T ₃)	2.7	55.5	-10.70
<i>B. thuringiensis</i> (T ₄)	3.3	52.73	-11.27
<i>B. thuringiensis</i> +120 Gy (T ₁)	2.6	72.27	-8.22
<i>B. thuringiensis</i> +120 Gy (T ₂)	2.6	64.62	-9.19
<i>B. thuringiensis</i> +120 Gy (T ₃)	2.3	62.16	-9.56
<i>B. thuringiensis</i> +120 Gy (T ₄)	2.8	61.95	-9.59
<i>B. thuringiensis</i> +480 Gy (T ₁)	2.9	61.36	-9.68
<i>B. thuringiensis</i> +480 Gy (T ₂)	2.4	51.52	-11.53
<i>B. thuringiensis</i> +480 Gy (T ₃)	3.4	49.79	-11.93
<i>B. thuringiensis</i> +480 Gy (T ₄)	3.3	41.18	-14.43
Emamectin benzoate(T ₁)	2.9	60.64	-9.80
Emamectin benzoate(T ₂)	1.8	56.21	-10.57
Emamectin benzoate(T ₃)	3.2	54.05	-10.99
Emamectin benzoate(T ₄)	2.8	53.35	-11.14
Emamectin benzoate +120 Gy (T ₁)	2	94.65	-6.28
Emamectin benzoate+120 Gy (T ₂)	1.75	91.94	-6.46
Emamectin benzoate+120 Gy (T ₃)	2.8	64.58	-9.20
Emamectin benzoate+120 Gy (T ₄)	3	62.52	-9.50
Emamectin benzoate+480 Gy (T ₁)	1.4	55.26	-10.75
Emamectin benzoate+480 Gy (T ₂)	1.7	54.41	-10.92
Emamectin benzoate+480 Gy (T ₃)	1.7	45.23	-13.14
Emamectin benzoate+480 Gy (T ₄)	2.7	33.62	-17.67
Spinosad (T ₁)	2.2	81.10	-7.33
Spinosad (T ₂)	2.2	71.14	-8.35
Spinosad (T ₃)	2	68.92	-8.62
Spinosad (T ₄)	3.1	64.40	-9.23
Spinosad +120 Gy (T ₁)	1.8	120.3	-4.94

Spinosad +120 Gy (T ₂)	2.7	95.15	-6.24
Spinosad +120 Gy (T ₃)	4.2	86.72	-6.85
Spinosad +120 Gy (T ₄)	3.7	83.06	-7.15
Spinosad +480 Gy (T ₁)	1.9	80.07	-7.42
Spinosad +480 Gy (T ₂)	2.4	71.34	-8.33
Spinosad +480 Gy (T ₃)	2.7	59.57	-9.97
Spinosad +480 Gy (T ₄)	1.9	54.77	-10.85
Correlation (r)	-0.40*		---
Coefficient of determination	0.16		---
F value	6.68*		---
(E.V%)	16%		---
B	-5.94		---

Treatments of Spinosad was considered the best maize crop productivity and earning, followed by Emamectin benzoate treatments and *B. thuringiensis* treatments.

In general, gamma doses of 120 and 480 Gy can enhance the applications of biotic compounds (*B. thuringiensis*, Emamectin benzoate, and Spinosad) with four recommended doses of the compounds (1/2, 1/4, 1/8, and 1/16) to become more effective than when used alone without being exposed to gamma doses in terms of *S. frugiperda* larval population reduction and crop economic evaluations. The most effective treatment for reducing *S. frugiperda* larval populations was Emamectin benzoate + 480 Gy at half the recommended dose (T₁). However, Spinosad + 120 Gy at half the recommended dose (T₁) also resulted in highly increased productivity and investment while reducing *S. frugiperda* larval populations sufficiently. So, it was recommended that Spinosad + 120 Gy treatment was the best treatment for *S. frugiperda* controlling and income increase by maize crop productivity increasing.

The economic evaluation was the focus of attention many authors as Deshmukh, *et al.* (2021) [15], which founded that conducted during 2017–2020, a total of 150 smallholder maize farms were randomly selected and surveyed from three major maize-growing districts in Karnataka for the pesticide usage patterns, pesticide cost and yield. During 2020, FAW infestation level was recorded at 2.15 larvae/ 100 plants with 3.80 Davis damage score. Maize farmers used an average of 2.12 pesticide sprays per season for FAW control in the surveyed districts during 2020. Maize yield was 4.46, 3.76, 4.06 and 4.18 tons/ hectare during 2017, 2018, 2019 and 2020, respectively, and the average cost on pesticides spent by farmers/ 100 kg maize grain during the same years was 0.124, 2.04, 1.68 and 1.39 US\$, respectively. On the other hand, Van den Berg *et al.* (2021) [32], indicated that *S. frugiperda* causes 11-100% of yield losses in Africa and 30-70% in the Americas. Four outdoor tests showed varying yield benefits, with the first study showing a 32.6% yield advantage after four treatments. The other three experiments used two spray sequences. In the Egyptian region of Luxor, Bakry and Abdel-Baky (2023) [11], reported that *S. frugiperda* effects on the yield and constituents of maize. An infestation of *S. frugiperda* larvae was found in maize plants during the third week of June and continued until harvest in the seasons 2021 and 2022. The characteristics of maize growth, such as plant height, stem diameter, and percentage of green leaves on the plant, indicated that the treated plants had greater rates of *S. frugiperda* infestations. In contrast, untreated maize plants showed lower yield (kg/ha), grain, straw, and opposite characteristics compared to insecticide-treated plants (chlorpyrifos, chlorfenapyr, methomyl, and Emamectin benzoate). In compared with untreated plants, treated plants

were expected to have higher stem (cm), stem diameter (cm), cob weight (g), number of rows/cob, number of grains/cob, grain weight (g), and weight of 1000 grains (g). Furthermore, during the dry and wet seasons of 2021–2022, Briones-Ochoa, *et al.* (2023) [13], planted around 1200 m², utilizing three commercial hybrids—ADV-9139, Trueno NB-7443, and INIAP-551—in which the effects of the treatments were assessed: T₁: Insecticide sequence (CLE) predicated on Emamectin benzoate, Lufenuron, and Chlorantraniliprole. T₂: *Bacillus thuringiensis*-based biological pesticide (BT). T₃: Treatment based on methomyl (MET). Plot T₄: Untreated (UP). An economic study was carried out, and plant or cob damage, plant height, cob insertion, and grain output were assessed. For the ADV-9139 hybrid, the least amount of damage to plants and cobs was observed. When it came to insecticides, CLE demonstrated the best damage control in plants; however, when CLE (T₁) and BT (T₂) were sprayed, the cobs suffered less damage. The height of the plant and cob insertions was lower in the hybrid ADV9139, whose greatest predicted grain yields were found. The plots that received BT treatment had the largest increase in grain yield. The findings demonstrate that managing this ravenous insect may be accomplished at the lowest possible social, economic, and ecological costs by combining pesticide sprays with a genotype of maize that is partially resistant. In addition, Charitha and Kumar (2023) [14], used the insecticidal application of Indoxacarb (425 ml/ha), Spinetoram (250 ml/ha), Azadirachtin (5 ml/ha), Nisco Sixer Plus (500 ml/ha), lambda cyhalothrin (320 ml/ha), cypermethrin (1 Lit/ha), fipronil (60 g/ha), and untreated against *Spodoptera frugiperda* on maize plants with three replicates. The experiment was carried out in Kharif 2022. The results indicated that Lambda cyhalothrin (T₅) (58.34 q/ha), Indoxacarb (T₁) (60.49 q/ha), and Spinetoram (T₂) (64.58 q/ha) had the maximum grain yields. With a cost-benefit ratio of 1:2.31, Spinetoram (T₂) treatment yielded the highest ratio, ahead of Indoxacarb (T₁) at 1:2.11 and Lambda cyhalothrin (T₅) at 1:2.10. Furthermore, Kandil and Dabour (2023) [20], examined the link between the population of *S. frugiperda* larvae and the yield of maize grains; they also evaluated the yield loss percentage, voltinism (the number of generations in a year), and the economics of producing maize under various insecticidal treatments. Methomyl and Emamectin benzoate treatments employed in binary or trinary sequences to control *S. frugiperda*. The population of *S. frugiperda* larvae and maize yield were negatively correlated. The largest yields of maize were obtained with a trinary application of methomyl and Emamectin benzoate, which yielded 4.249 and 3.416 t/fed in the first and second seasons, respectively. The untreated region had the most yield losses in the first and second seasons, at 77.76 and

78.89%, respectively. The largest net benefit over untreated and net benefit/total expenses were achieved by methomyl, emamectin benzoate, and methomyl sequence. In Egypt, farmers are advised to use a series of pesticides, including methomyl 15 days post-planting, Emamectin benzoate, and methomyl at appropriate dosages, with a 10-day gap between each treatment, to prevent the spread of armyworms.

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