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Lethal dose and time-response of some biocides affected by gamma ray for *Spodoptera frugiperda* (Lepidoptera: Noctuidae) controlling in maize fields

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Abstract

Maize (*Zea* mays) field trial was done at El-Ayat district, Giza governorate to evaluate some biocide compounds (*Bacillus thuringiensis* (Kurs.), Emamectin benzoate and Spinosad) exposed or non-exposed to gamma ray doses (120 and 480 Gy) to potentiate its lethality for fall armyworm, *Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae) controlling purposes. Concentrations (1/2, 1/4, 1/8 and 1/16) of the recommended doses of biocides used in current maize field trials. The evaluation parameters of lethal doses efficacy and time-response for *S. frugiperda* controlling were used. Spinosad treatments were considered the best dose lethality for *S. frugiperda* controlling, followed by Emamectin benzoate and finally *B. thuringiensis* treatments. Meanwhile, Emamectin benzoate treatments gave the least time-response lethality than other treatments aforementioned. Gamma ray dose of 480 Gy, followed by 120 Gy can potentiate the biocide compounds of *B. thuringiensis*, Emamectin benzoate and Spinosad to become lethality more than the same compounds without exposing to gamma doses and saving the dose and the time-response for controlling *S. frugiperda* in maize plants.

Introduction

The fall armyworm (FAW) *Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae) is a polyphagous pest feeds on 353 host plants nearly (Montezano *et al.*, 2018 and Huang *et al.*, 2020), tropical and sub-tropical areas of the West and South of America were its original (Otim *et al.*, 2021). FAW does not have diapause (Du Plessis *et al.*, 2020), thus, it prevails over its plant hosts away from the severe cold (Huang *et al.*, 2020). Recently, because of world trade, *S. frugiperda* has spread to other countries (Huang *et al.*, 2020). The first recorded of *S. frugiperda* in Africa was in 2016 (Goergen *et al.*, 2016), and through three years, it prevails in 47 African countries (Wan *et al.*, 2021). *S. frugiperda* prevails Egypt from Sudan and recorded the first time on corn plants in 2019 at Kom-Ombo City, Aswan Governorate (Dahi *et al.*, 2020), then it entered Luxor, Qena, Sohag and Assiut Governorate in 2021 (Mohamed *et al.*, 2022). Maize is the favorite host for *S. frugiperda*. It can minimize the annual crop maize ranging between 21-53% without control methods (Huang *et al.*, 2020).

Chemical pesticide control was considered one of the successive ways to control *S. frugiperda* as an emergency state because of the acute toxicity. However, the insecticide resistance for this insect has prevented its success (Paredes-Sanchez *et al.*, 2021).

Radiation processing may cause a direct or indirect effect on chemical changes in substances. In direct action, radiation directly hits the DNA molecules, disrupting the molecular structure that damages cells (Ibrahim *et al.,* 2017). Direct effects are typical for cells with low water content, such as dried substances. Indirect effects are caused by water radiolysis. Ionizing radiation can disturb the structure that binds the water molecule and produces free radicals, as hydroxyl (OH), hydrated electron (e^- aq), hydrogenated atom (H), and others (Liyana *et al.,* 2018). These radicals create reactions with other substance components (Ashraf *et al.*, 2019). When microbes are irradiated, the energy from the radiation breaks the bonds in the DNA, the largest molecules in the nucleus and RNA, causing defects in the genetic instructions (Hossein *et al.,* 2010). The effectiveness of the process depends also on the organism's sensitivity to irradiation, and the amount of DNA in the target organism (Ashraf *et al.*, 2019). Furthermore, radiation does not leave any chemical residues after the treatment, ensuring the quality and safety of the food (Balakrishnan *et al.*, 2022). Meanwhile, gamma radiation is a biocontrol way as a safe method for pest control in cereal and crop maintenance; also, food processing. Recently, gamma doses used for bioinsecticide potentiation to enhance the compound efficacy than its original toxicity for successive applications against many crop pests as described by Amer *et al.* (2012) mentioned that LC_{50} on target insects (*P. gossypiella, S. littoralis,* and *A. craccivora*) treated with *B. thuringiensis* and exposed to gamma doses (150, 250 and 350 Gy) were lower than un-exposing *B. thuringiensis* to gamma doses. Also, Amer *et al.* (2015) exposed *B. thuringiensis*, *M. anisopliae* and biopolymer compound (Chitosan) to gamma ray doses of 15, 30 and 60 Gy, respectively for potentiating effect. It showed a potentiated effect, especially with a dose of 60 Gy was more effective than other doses used against *S. littoralis* treated as 4th instar larvae. In addition, Amer *et al.* (2019) stated that gamma-ray doses (50 and 500 Gy) treatments were the most efficacy against *E. insulana* egg stage than magnetic flux treatments (20 and 180 mlt).

So, efficacy assessments act in a dose and time-response lethality of some biocide compounds (Protecto; *B. thuringiensis*, Kurs., Andraws L.; Emamectin benzoate and Master Top and Spinosad) exposed to gamma ray doses (120 and 480 Gy) to potentiate purposes for fall armyworm, *S. frugiperda* controlling was suggested.

Materials and methods

1. Insect:

S. frugiperda.

2. Compounds:

Nine treatments belong to three biocide compounds as in Table (1).

Table (1): Compounds used.

Trade Name	Common name	Application Rate	Product company	Imported Company
Protecto 9.4% WP	*Bacillus thuringiensis* (Kurstaki)	300 g/feddan	Pesticide production unit, plant protection research Institute, Agriculture Research Center, Egypt.	
Andraws L. 1.9% EC.	Emamectin benzoate	150cm^3/feddan	Nanjing redsun Co., Ltd, China	Cam for Agriculture chemicals
Master Top 48% SC	Spinosad	15 cm^3/100 L water	Qilu pharmaceutical (Inner Mangolia) Co, Ltd, China.	Starchem Industrial chemicals, Egypt.

The treatments preparing doses according to (1/2, 1/4, 1/8 and 1/16) recommended doses as follows:

Protecto (*Bacillus thuringiensis*): (1, 0.5, 0.25 and 0.13 g/L).

Andraws L (Emamectin benzoate): (0.375, 0.1875, 0.0938 and 0.0469 ml/L).

Master Top (Spinosad): (0.075, 0.0375, 0.01875 and 0.009375 ml/L).

3. Gamma radiation:

B. thuringiensis, Emamectin benzoate & Spinosad compounds were exposed to gamma radiation doses of 120 & 480 Gy at a dose rate of 0.682 KGy/h by a Cesium Hendy Gamma Cell Research at National Center for Radiation Research and Technology. Nine treatments were used as follows: 1. *B. thuringiensis*, 2. *B. thuringiensis* + 120 Gy 3. *B. thuringiensis* +480 Gy 4. Emamectin benzoate 5. Emamectin benzoate + 120 Gy 6. Emamectin benzoate +480 Gy 7. Spinosad 8. Spinosad + 120 Gy 9. Spinosad + 480 Gy.

A field trial of maize (*Z. mays*) (Hi-tech 2031 variety) was done to evaluate the efficacy of nine treatments against *S. frugiperda* that infested maize crops in 2023 at El-Ayat district, Giza governorate. The trial area was nearly 1/2 feddan (10 plant lines/ treatment) and each treatment was 7.3 x 13 m^2. The tested compounds were applied two times at 12 days intervals. The 1st and 2nd sprays were applied on 28th May and 11th June 2023 maize season, respectively. Maize plant age was 20 days at 1st spray used; samples were collected at random before applying the compounds and then at 1,3,5,7 and 10 days after the application. One plant/each line/10 lines was collected for each treatment and examined. The biocide compounds of *B. thuringiensis*, Emamectin benzoate and Spinosad (1/2, 1/4, 1/8 and 1/16) recommended doses were used in the trial application.

4. Lethal dose and time-response:

LC_{50}, LC_{90}, LT_{50}, LT_{90} and Slope values were calculated by using Ldp-line software (www.Ehabbakr software/Ldp line). Mortality percentage was calculated according to Abbott (1925) and Finney (1971). The comparson among treatment efficacy was according to Sun (1950).

Toxicity index = LC_{50} or LT_{50} (LC_{90} or LT_{90}) of the compound A/ LC_{50} or LT_{50} (LC_{90} or LT_{90}) of the compound B X 100 Where A: The most effective compound and B: The other tested compound.

Results and discussion

1. Lethal dose:

B. thuringiensis (Protecto) was used with four doses of 1,0.5,0.25 and 0.13 g/L that act 1/2, 1/4, 1/8 and 1/16 recommended doses. Table (2) shows that LC_{50} was 0.686 g/L and LC_{90} was 8.256 g/L at 1-day after treatments for *S. frugiperda* controlling in maize plants at field conditions; this value decreased with time increased until reached 0.058g/L and 0.901 g/L for LC_{50} and LC_{90}, respectively at 22-day after treatments. Table (3) describes the effect of gamma ray (120 Gy) exposed to *B. thuringiensis* can potentiate the compound to reach the LC_{50} and LC_{90} to 0.495 and 7.552 g/L at 1-day after treatment only and the values decreased gradually to reach 0.043 & 0.858 g/L for LC_{50} and LC_{90}, respectively compared with the LC_{50} and LC_{90} values of *B. thuringiensis* original without radiation exposure. *B. thuringiensis* was exposed to gamma ray dose of 480 Gy have potentiation efficacy on *S. frugiperda* at the field conditions, the LC_{50} and LC_{90} were 0.249 and 2.321 g/L, respectively at 1-day after treatments only and the values gradually decreased after days passed until 22-day from treatments that reached to 0.0006 and 1.007 g/L, respectively. Previous data in Tables (2-4) demonstrated that *B. thuringiensis* +480 Gy was the best treatment efficacy, followed by *B. thuringiensis* + 120 Gy compared with *B. thuringiensis* without exposure to gamma ray doses.

Emamectin benzoate with four doses (0.375, 0.1875, 0.0938 and 0.0469 ml/L) that act 1/2, 1/4, 1/8 and 1/16 of recommended doses were used. Emamectin benzoate without exposure to gamma ray caused sufficient efficacy on *S. frugiperda* larvae at field conditions. LC_{50} and LC_{90} were 0.409 and 4.065 ml/L at 1-day after treatment. The values decreased gradually and caused (LC_{50} and LC_{90} were 0.015 and 0.376 ml/L, respectively) mortality at 17-day after treatment as shown in Table (5). Also, Table (6) showed that Emamectin benzoate when exposed to 120 Gy had potentiation efficacy appeared in LC_{50} and LC_{90} values that were 0.201 and 1.841 ml/L, respectively at 1-day after treatment and decreased gradually in values to reach LC_{50} and LC_{90} of 0.002 and 0.301 ml/L, respectively at 15-day after treatment and reached to hundred percent at 17-day after treatments. Emamectin benzoate + 480 Gy had the best efficacy on *S. frugiperda* larvae at field application condition acts in LC_{50} and LC_{90} values that reached to 0.115 and 1.180 ml/L, respectively at 1-day after treatment and had decreased in values until to reached 0.003 and 0.324 ml/L at 13-day after treatments and the larval mortality was 100% at 15-day after treatment as shown in Table (7) compared with the previous treatments of Emamectin benzoate + 120 Gy and E mamectin without exposing to gamma ray.

Table (2): *Bacillus thuringiensis* lethal doses on *Spodoptera frugiperda* larvae in maize plants.

Bacillus thuringiensis	**LC_{50} (g/L)**	**LC_{90} (g/L)**	**Slope± SE**	**Toxicity index**	
				LC_{50}	**LC_{90}**
1-day after treatment	0.686	8.256	1.036± 0.794	8.455	10.91
3-day after treatment	0.553	6.579	1.112± 0.702	10.49	13.69
5-day after treatment	0.453	5.321	1.199± 0.842	12.80	16.93
7-day after treatment	0.368	4.365	1.270± 0.749	15.76	20.64
10-day after treatment	0.311	3.339	1.299± 0.854	18.65	26.98
12-day after treatment	0.297	2.986	1.464± 0.7196	19.53	30.17
13-day after treatment	0.252	2.215	1.537± 0.7353	23.02	40.68
15-day after treatment	0.211	1.897	1.617± 0.7592	27.49	47.49
17-day after treatment	0.136	1.134	1.752± 0.854	42.65	79.45
19-day after treatment	0.088	0.994	1.885± 0.752	65.91	90.64
22-day after treatment	0.058	0.901	1.998± 0.8997	100	100

Table (3): *Bacillus thuringiensis* +120 Gy lethal doses on *Spodoptera frugiperda* larvae in maize plants.

***Bacillus thuringiensis* +120 Gy**	**LC_{50} (g/L)**	**LC_{90} (g/L)**	**Slope± SE**	**Toxicity index**	
				LC_{50}	**LC_{90}**
1-day after treatment	0.495	7.552	0.583± 0.8056	8.687	11.36
3-day after treatment	0.460	5.594	0.376± 0.7688	9.348	15.34
5-day after treatment	0.444	3.674	0.644± 0.6922	9.685	23.35
7-day after treatment	0.388	3.346	0.418± 0.7216	11.08	25.64
10-day after treatment	0.357	3.048	0.966± 0.6509	12.04	28.15
12-day after treatment	0.311	2.659	1.293± 0.6677	13.83	32.27
13-day after treatment	0.283	2.112	1.669± 0.6962	15.19	40.63
15-day after treatment	0.187	1.516	1.408± 0.6966	22.99	56.59
17-day after treatment	0.181	1.247	1.012± 0.6649	23.76	68.81
19-day after treatment	0.104	1.002	2.189± 0.7178	41.35	85.63
22-day after treatment	0.043	0.858	2.986± 0.7672	100	100

Table (4): ***Bacillus thuringiensis*** **+480 Gy lethal doses on** ***Spodoptera frugiperda*** **larvae in maize plants.**

Bacillus thuringiensis + 480 Gy	LC_{50} (g/L)	LC_{90} (g/L)	Slope± SE	Toxicity index	
				LC_{50}	LC_{90}
1-day after treatment	0.249	2.321	0.423± 0.8556	0.241	43.39
3-day after treatment	0.211	2.001	0.666± 0.7608	0.284	50.32
5-day after treatment	0.189	1.895	0.644± 0.6922	0.317	53.14
7-day after treatment	0.099	1.802	0.828± 0.7220	0.601	55.88
10-day after treatment	0.087	1.725	0.966± 0.6509	0.684	58.38
12-day after treatment	0.042	1.666	1.296± 0.6877	1.422	60.44
13-day after treatment	0.022	1.621	1.779± 0.6982	2.691	62.12
15-day after treatment	0.009	1.521	1.408± 0.6988	6.122	66.21
17-day after treatment	0.005	1.445	1.712± 0.6649	11.32	69.69
19-day after treatment	0.0009	1.321	1.989± 0.7178	66.67	76.23
22-day after treatment	0.0006	1.007	2.026± 0.7672	100	100

Table (5): Emamectin benzoate lethal doses on ***Spodoptera frugiperda*** **larvae in maize plants.**

Emamectin benzoate	LC_{50} (ml/L)	LC_{90} (ml/L)	Slope± SE	Toxicity index	
				LC_{50}	LC_{90}
1-day after treatment	0.409	4.065	0.267± 0.6819	3.667	9.249
3-day after treatment	0.355	3.794	0.645± 0.7339	4.225	9.910
5-day after treatment	0.189	2.811	0.931± 0.6894	7.937	13.38
7-day after treatment	0.133	2.077	0.632± 0.6674	11.28	18.10
10-day after treatment	0.093	1.585	0.993± 0.6894	16.13	23.72
12-day after treatment	0.049	1.395	1.045± 0.7339	30.61	26.95
13-day after treatment	0.040	0.529	1.201± 0.6953	37.5	71.08
15-day after treatment	0.021	0.521	1.618± 0.7776	71.4	72.17
17-day after treatment	0.015	0.376	1.831± 0.7798	100	100
19-day after treatment	-	-	-	-	-

Table (6): Emamectin benzoate+120 Gy lethal doses on ***Spodoptera frugiperda*** **larvae in maize plants.**

Emamectin benzoate + 120 Gy	LC_{50} (ml/L)	LC_{90} (ml/L)	Slope± SE	Toxicity index	
				LC_{50}	LC_{90}
1-day after treatment	0.201	1.841	0.267± 0.6009	0.995	16.35
3-day after treatment	0.157	1.531	0.445± 0.7259	1.282	19.66
5-day after treatment	0.045	1.425	0.491± 0.6344	4.44	21.12
7-day after treatment	0.032	1.325	0.632± 0.6004	6.25	22.72
10-day after treatment	0.024	0.499	0.793± 0.4216	8.33	60.32
12-day after treatment	0.019	0.403	0.845± 0.5339	10.53	74.69
13-day after treatment	0.008	0.322	0.985± 0.6123	25	93.48
15-day after treatment	0.002	0.301	1.197± 0.6923	100	100
17-day after treatment	-	-	-	-	-

Table (7): Emamectin benzoate+480 Gy lethal doses on *Spodoptera frugiperda* larvae in maize plants.

Emamectin benzoate + 480 Gy	LC_{50} (ml/L)	LC_{90} (ml/L)	Slope± SE	Toxicity index	
				LC_{50}	LC_{90}
1-day after treatment	0.115	1.180	0.603± 0.7559	2.609	22.41
3-day after treatment	0.088	1.379	0.745± 0.6661	3.409	23.23
5-day after treatment	0.052	1.330	0.851± 0.6991	9.375	26.19
7-day after treatment	0.026	0.864	0.909± 0.6554	11.54	35.76
10-day after treatment	0.019	0.636	0.969± 0.7518	15.79	91.96
12-day after treatment	0.015	0.409	1.268± 0.6563	20	95.37
13-day after treatment	0.003	0.324	1.292± 0.6563	100	100
15-day after treatment	-	-	-	-	-

Biocide compound, Spinosad treatments were used in 1/2, 1/4, 1/8 and 1/16 recommended doses that were 0.075, 0.0375, 0.01875 and 0.009375 ml/L. Spinosad treatments had the best efficacy on *S. frugiperda* larvae than other tested compounds aforementioned (*B. thuringiensis* and Emamectin benzoate) at field conditions, especially Spinosad exposed to 120 Gy and 480 Gy had the high efficacy compared with the efficacy of the same compound without exposing to gamma ray doses (Tables 8-10). Spinosad +480 Gy had a hundred percent of *S. frugiperda* larval mortality at 13-day after treatment. The dose application needed for *S. frugiperda* controlling was lower in Spinosad + 120 Gy treatment (Table 9) than Spinosad without exposure to gamma ray treatment (Table 8).

Table (8): Spinosad lethal doses on *Spodoptera frugiperda* larvae in maize plants.

Spinosad	**LC_{50} (ml/L)**	**LC_{90} (ml/L)**	**Slope± SE**	**Toxicity index**	
				LC_{50}	**LC_{90}**
1-day after treatment	0.052	1.107	0.741± 0.6717	7.69	7.05
3-day after treatment	0.038	0.562	0.801± 0.6953	10.53	13.88
5-day after treatment	0.030	0.329	1.019± 0.7777	13.33	23.71
7-day after treatment	0.021	0.319	1.070± 0.7094	19.05	24.45
10-day after treatment	0.019	0.277	1.093± 0.6894	21.05	28.16
12-day after treatment	0.018	0.235	1.099± 0.8654	22.22	33.19
13-day after treatment	0.011	0.166	1.245± 0.7339	36.36	46.99
15-day after treatment	0.008	0.124	1.444± 0.7078	50	62.90
17-day after treatment	0.005	0.106	1.506± 0.7217	80	73.58
19-day after treatment	0.004	0.078	1.593± 0.7493	100	100
22-day after treatment	-	-	-	-	-

Table (9): Spinosad+120 Gy lethal doses on *Spodoptera frugiperda* larvae in maize plants.

Spinosad + 120 Gy	LC_{50} (ml/L)	LC_{90} (ml/L)	Slope± SE	Toxicity index	
				LC_{50}	LC_{90}
1-day after treatment	0.030	0.417	0.782± 0.6356	6.67	13.43
3-day after treatment	0.023	0.388	0.874± 0.6124	8.69	14.43
5-day after treatment	0.017	0.318	0.924± 0.6254	11.76	17.61
7-day after treatment	0.014	0.236	0.933± 0.7310	14.29	23.73
10-day after treatment	0.013	0.234	1.013± 0.6473	15.38	23.93
12-day after treatment	0.009	0.163	1.106± 0.6796	22.22	36.81
13-day after treatment	0.008	0.138	1.126± 0.6153	25	43.48
15-day after treatment	0.006	0.128	1.146± 0.7065	33.33	43.75
17-day after treatment	0.005	0.085	1.189± 0.6322	40	65.88
19-day after treatment	0.002	0.056	1.464± 0.6435	100	100
22-day after treatment	-	-	-	-	-

Table (10): Spinosad+480 Gy lethal doses on *Spodoptera frugiperda* larvae in maize plants.

Spinosad + 480 Gy	LC_{50} (ml/L)	LC_{90} (ml/L)	Slope± SE	Toxicity index	
				LC_{50}	LC_{90}
1-day after treatment	0.030	0.319	0.631± 0.7798	3.333	23.51
3-day after treatment	0.019	0.277	0.801± 0.6953	5.263	27.08
5-day after treatment	0.009	0.235	1.019± 0.7777	11.11	31.91
7-day after treatment	0.008	0.106	1.093± 0.6894	12.5	70.75
10-day after treatment	0.004	0.104	1.245± 0.7339	25	72.12
12-day after treatment	0.001	0.075	1.444± 0.7078	100	100
13-day after treatment	-	-	-	-	-

2. Time-response lethality:

B. thuringiensis exposed to 480 Gy contributed to the time-response for *S. frugiperda* controlling at field condition that cleared in Table (11) that showed *B. thuringiensis* +480 Gy with 1g/L that acts the half-recommended dose needs to 3-days nearly to control the larval population into the half, followed by *B. thuringiensis* +120 Gy (4 days nearly) and *B. thuringiensis* singly without exposing to gamma ray (5 days nearly). The same sequence appeared in other concentrations using 1/4 recommended dose (0.5 g/L), 1/8 recommended dose (0.25 g/L) and 1/16 recommended dose (0.13 g/L). The same trend that was found in previous Table (11) was found in current Table (12); still, Emamectin benzoate with a gamma dose of 480 Gy, followed by Emamectin benzoate + 120 Gy and Emamectin benzoate without exposure to gamma dose had a lower time-response efficacy on *S. frugiperda* larval mortality than *B. thuringiensis* treatments used. Also, Table (13) showed the shortest time-response on *S. frugiperda* larvae efficacy at field conditions with four concentrations used of Spinosad exposed to gamma ray of 480 Gy, followed by Spinosad+120 Gy and finally Spinosad without exposure to gamma ray.

Table (11): *Bacillus thuringiensis* time-response lethality on *Spodoptera frugiperda* larvae in maize plants.

Bacillus thuringiensis	**LT_{50} (days)**	**LT_{90} (days)**	**Slope± SE**	**Toxicity index**	
				LT_{50}	**LT_{90}**
T_1 (1 g/L)	5.12	25.02	1.543±0.4243	100	100
T_2 (0.5 g/L)	7.31	30.31	0.978±0.3900	70.04	82.55
T_3 (0.25 g/L)	14.03	36.12	0.957±0.4163	36.49	69.27
T_4 (0.13 g/L)	17.12	42.03	0.901±0.3776	29.91	59.53
***Bacillus thuringiensis* + 120 Gy**					
T_1 (1 g/L)	4.008	17.22	1.358±0.4525	100	100
T_2 (0.5 g/L)	6.137	22.23	0.966±0.3888	65.31	77.46
T_3 (0.25 g/L)	10.58	31.09	0.880±0.3966	37.88	55.39
T_4 (0.13 g/L)	15.25	35.07	0.343±0.7885	26.28	49.10
***Bacillus thuringiensis* + 480 Gy**					
T_1 (1 g/L)	3.116	7.076	1.067±0.5659	100	100
T_2 (0.5 g/L)	5.08	10.37	1.037±0.7458	61.34	68.24
T_3 (0.25 g/L)	7.075	13.05	0.654±0.5656	44.04	54.22
T_4 (0.13 g/L)	9.07	15.77	0.560±0.4976	34.36	44.87

Table (12): Emamectin benzoate time-response lethality on *Spodoptera frugiperda* larvae in maize plants.

Emamectin benzoate	LT_{50} (days)	LT_{90} (days)	Slope± SE	Toxicity index	
				LT_{50}	LT_{90}
T_1 (0.375 ml/L)	3.622	13.68	1.246±0.3584	100	100
T_2 (0.1875 ml/L)	6.160	15.15	0.972±0.4501	58.79	90.29
T_3 (0.0938 ml/L)	9.522	17.47	0.867±0.4610	38.04	78.31
T_4 (0.0469 ml/L)	11.21	20.30	0.699±0.4340	32.31	67.39
Emamectin benzoate +120 Gy					
T_1 (0.375 ml/L)	2.041	10.53	1.195±0.4859	100	100
T_2 (0.1875 ml/L)	4.908	12.73	0.883±0.4575	41.59	82.72
T_3 (0.0938 ml/L)	7.573	14.72	0.737±0.3792	26.95	71.54
T_4 (0.0469 ml/L)	10.18	17.52	0.449±0.4516	20.05	60.10
Emamectin benzoate + 480 Gy					
T_1 (0.375 ml/L)	1.842	8.329	1.552±0.4693	100	100
T_2 (0.1875 ml/L)	3.631	9.459	1.220±0.4086	50.73	88.05
T_3 (0.0938 ml/L)	4.735	10.41	1.188±0.4225	38.90	80.01
T_4 (0.0469 ml/L)	6.484	13.47	1.019±0.3926	28.41	61.83

Table (13): Spinosad time-response lethality on *Spodoptera frugiperda* larvae in maize plants.

Spinosad	LT_{50} (days)	LT_{90} (days)	Slope± SE	Toxicity index	
				LT_{50}	LT_{90}
T_1 (0.075 ml/L)	4.069	15.06	1.186±0.4179	100	100
T_2 (0.0375 ml/L)	8.086	17.64	1.068±0.3791	50.32	85.37
T_3 (0.01875 ml/L)	11.67	19.85	1.018±0.3935	34.87	75.87
T_4 (0.009375 ml/L)	13.43	22.64	0.754±0.3788	30.29	66.52
Spinosad + 120 Gy					
T_1 (0.075 ml/L)	3.262	12.52	1.142±0.3425	100	100
T_2 (0.0375 ml/L)	5.324	15.80	0.940±0.3455	61.27	79.24
T_3 (0.01875 ml/L)	8.692	17.08	0.833±0.3469	37.53	73.30
T_4 (0.009375 ml/L)	11.43	19.29	0.585±0.3593	28.54	64.9
Spinosad + 480 Gy					
T_1 (0.075 ml/L)	2.075	10.05	1.502±0.4208	100	100
T_2 (0.0375 ml/L)	4.183	13.77	1.185±0.4567	49.61	72.98
T_3 (0.01875 ml/L)	6.449	16.58	1.068±0.5359	32.18	60.62
T_4 (0.009375 ml/L)	7.316	18.79	0.560±0.4976	28.36	53.49

Current work adopted the results of the previous authors such as Mendez *et al.* (2002) who reported that Spinosad is a neurotoxin mixture produced during the fermentation of a soil actinomycete that has high activity towards Lepidoptera, especially *S. frugiperda*. Spraying of 3 ppm Spinosad had very little effect on the insect natural enemies on maize plants. Also, the same authors added the time-response curves of *S. frugiperda* to Spinosad until 100 hrs. In addition, Williams *et al.* (2004) performed field trials in 2002 and 2003 to determine the efficacy of maize four-based granular formulations with ultralow rates of the naturally derived Spinosad (0.1, 0.3, and 1.0 g [AI]/ha), for *S. frugiperda* controlling in maize, (*Z. mays*) in southern Mexico. Also, Spinosad applications were compared with chlorpyrifos (150 g [AI]/ha). In both years, the application of Spinosad caused excellent levels of control, acting by the number of living *S. frugiperda* larvae recovered from experimental plots. The efficacy of Spinosad applied at 0.3 and 1.0 g (AI)/ha was very similar to that of chlorpyrifos. Natural reinfestation of *S. frugiperda* in treated plots returns similar to the control by 10-15 d post-application. Many Spinosad-intoxicated larvae collected in the field died later in the laboratory in 2002, but not in 2003. Meanwhile, Amer (2006) showed that the combination of gamma irradiation with *B. thuringiensis* activated the spores of the biocide compound and caused a potentiation effect. Also, the same authors carried out field experiments during the two cotton seasons 2004 and 2005. The results illustrated that the efficacy of Dipel-2x (*B. thuringiensis*) increased gradually with gamma radiation exposure from 5 to 80 Gy. Moreover, Amer *et al.* (2020) carried out cotton field experiments in 2018 and 2019 cotton seasons at Qaha Research Station, Plant Protection Research Institute, Qalyoubia Governorate. Seven compounds were *B. thuringiensis* (Kurstaki), *B. thuringiensis* +160 Gy, *B. thuringiensis* +320 Gy, *B. thuringiensis* +640 Gy, Azadirachtin, *B. thuringiensis* +Azadirachtin and Diflubenzuron. The treatments were evaluated for three pests of cotton bolls (*Pectinophora gossypiella* Saund; *Earias insulana*, Boisd. and *Oxycarenus hyalinipennis*, Costa) population and infestation reduction percentages. *B. thuringiensis* +640 Gy and diflubenzuron were considered the best treatments that caused reduction percentages in population and infestations against the pests used, followed by *B. thuringiensis* +320 Gy, *B. thuringiensis* +160 Gy and *B. thuringiensis* + azadirachtin, azadirachtin and then *B. thuringiensis*. Recently, Han *et al.* (2023) focused on the application of three pesticides of Chlorantraniliprole 35%, Spinetoram 6% and Emamectin Benzoate 3%, combined with Polyorganosilicon (HTY-A8) or special flight additives (MF) as synergists used pesticides to control *S. frugiperda* before transplanting in a fresh corn nursery. Their toxicity was determined in *S. frugiperda* larvae feeding on sweet corn leaf treated with 5 and 25 times of conventional field application concentration. *S. frugiperda* period of pest control validity of the three tested compounds in the larvae was about 20 days, while Emamectin benzoate was much shorter. The active component content of Chlorantraniliprole in the corn leaves was significantly higher than that of Emamectin benzoate and Spinetoram. The field experiment showed that the control effect on *S. frugiperda* could last for 17 days by spraying Chlorantraniliprole or Spinetoram at 25 times the conventional concentration before transplanting.

Current data could be concluded that gamma rays (120 and 480 Gy) can contribute to potentiating the biocide compounds (*B. thuringiensis*, Emamectin benzoate and Spinosad) to become its efficacy acts in dose and time-response lethality on *S. frugiperda* larval mortality was the higher than the same compounds without exposing to gamma ray. The biocides compounds used can be divided into three categories according to their efficacy on *S. frugiperda*.

The first category is considered the best lethal dose act in Spinosad + 480 Gy, for *S. frugiperda* controlling, followed by Spinosad + 120 Gy and Spinosad without exposing to gamma ray. Meanwhile, Emamectin benzoate + 480 Gy, had the shortest time-response lethality for *S. frugiperda* controlling, followed by Emamectin benzoate + 120 Gy and Emamectin benzoate singly.

-The second category had a moderate lethal dose action acts in Emamectin benzoate + 480 Gy, for *S. frugiperda* controlling, followed by Emamectin benzoate + 120 Gy and Emamectin benzoate without exposure to gamma ray. While Spinosad treatments (Spinosad + 480 Gy, followed by Spinosad + 120 Gy and Spinosad singly) had a moderate time-responses lethality.

-The third category was *B. thuringiensis* +480 Gy, followed by *B. thuringiensis*+ 120 Gy and then *B. thuringiensis* singly without exposure to gamma rays had the least action in both dose and time-response lethality.

Also, the compounds that are exposed to gamma ray 480 Gy, followed by 120 Gy can save on the dose and the time-response to become the dose needed for controlling lower than the dose used in original compounds without exposing to gamma doses.

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