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Efficiency of Entomopathogenic Nematode and One Insect Growth Regulator, as a Biocontrol of Diamond Back Moth (*Plutella xylostella* L.), and Their Toxicity to Participate Predators at Cabbage Fields

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Abstract

Diamond back Moth (DBM), *Plutella xylostella* L. is one of the economically important insect pests that destroy cabbage crops in most countries of the world. The target of the present study was to examine the potency of gamma radiated nematodes, normal nematode *Steinernema carpocapsae* BA2, and insect growth regulator, Match 5%EC as alternative control methods for *P. xylostella* larvae compared with conventional insecticides (radiant and radiant mixture with match), as well as to examine their safety on *P. xylostella* predators inhibiting cabbage plants. This experiment was carried out at El-Riad District, Kafr El-Sheikh Province in 2020 and 2021 seasons. The results revealed that plants treated with irradiated nematode in rate of 120 IJ's +2 Gy / ml hosted the fewest number of *P. xylostella* larvae compared to the untreated plants with a significant reduction of 98.05% and 98.81% during 2020 and 2021, season. Further, 2 Gy irradiated *S. carpocapsae* BA2 was more potency in reducing numbers of insect larvae than normal nematodes and other treatments. Gamma irradiated nematodes at rate of 120 IJ's +2 Gy / ml seems to be the most auspiciously agents against *P. xylostella*. While insect growth regulator Match 5% gave overall average of 76.52 and 76.42% mortality in the two seasons, respectively. The 2 Gy irradiated *S. carpocapsae* BA_2 and normal nematode were safe on *P. xylostella* predators on cabbage plants, whereas chemical insecticides reduced numbers of predators.

Key words: Cabbage plants, Gamma Radiation, *Steinernema carpocapsae*.

Introduction

Cabbage (*Brassicae oleracea* L.) is one of the most important and widely cultivated vegetable crops owing to its nutritional, economic value to farmers and consumers and is a favorite food for many peoples of the world. This crop is native to Western Europe and countries located on the northern shore of the Mediterranean Sea **(Yawalkar and Hari, 1985)**. In Egypt, it is preferred by many farmers as a vegetable crop due to its high economic importance, like many farmers from other countries in the world. The cultivated area reached 42.942 feddan in 2005 **(Ezzo et al., 2008)**. *Plutella xylostella* L. is a main insect pest that occurred at more than one hundred countries around the world; it affects cruciferous crops, especially *B. oleracea* plants such as cauliflower, cabbage and brussel. Recently, a lot of economic damage has been caused by *P. xylostella* to cabbage plants which is difficult to control all over the world. It is primarily controlled with chemical insecticides. Reliance on this individual approach in the fight against this insect has led to a continuous increase ln the insecticide used rates, low effectiveness, the acquisition of resistance to many insecticides **(Gautam et al, 2018)**. In Egypt, most cruciferous species, especially field cabbages are attacked by several insect pests including cabbageworm, *Pieris rapae* (L.), and *P. xylostella*. However, the diamond back moth is more destructive and reduces yield in terms of quality and quantity every year **(Embaby and Lotfy, 2015)**. Farmers spray more than 25 times with insecticides to control this insect during one crop season **(Kumar et al., 2017)**. *Plutella xylostella* has shown resistance to 91 active ingredients of insecticides worldwide, including 12 strains of *Bacillus thuringiensis*, **(Sakomoto et al. 2004)**. If control measures are not taken into consideration, feeding injury caused by *P. xylostella* larva may reduce production to zero. The strength of the spread of this pest is due to the diversity and abundance of host plants, the lack of biological enemies, its high fertility (more than 20 generations per year in the tropics) and its rapid development of resistance to insecticides, **(Shelton, 2004 and Vickers et al., 2004**). The global economy loses about a billion dollars annually to control *P. xylostella* on crops of cruciferous family **(Talakar and Shelton,1993)**. The control programs currently available against *P. xylostella* are mainly based on the insecticides. **(Castelo and Gatehouse, 2001)**. However, synthetic pesticides, while valuable in terms of efficacy and suitability in the control of *P. xylostella*, cause many problems, including environmental hazardous, phytotoxicity, toxicity to non-target organisms, health risks to farmers and insect resistance. It is known to develop multiple and cross-resistance to newly all groups of pesticides applied in the field including new chemistries such as spinosyns, neonicotinoids, avermectins, oxadiazines and pyrazoles **(Sarfraz et al., 2005)**. The insect growth regulator chlorfluazuron was the most effective compound (LC50 of 0.0006 mg a.i. ml^{-1}) in reducing population of *P. xylostella* on the cabbage plants at Pakistan **(Abro et al., 2013)**. So far attempts for biological control of *P. xylostella* as an alternative to pesticides have mainly focused on the use of biological control agents as predators, parasites and pathogens. Entomopathogenic nematodes from the genus *Steinernema* and *Heterorhabditis* parasites have commercially successful as biocontrol agents for economic pests such as of *P. xylostella* **(Platt et al., 2020)**. The use of irradiation technique as a physical control method is cheaper, safe and can integrate with other best control methods. Many studies have done on the activation of entomopathogenic nematodes by gamma radiation **(Hedayat-allah et al., 2014; Sayed et al., 2015)**. *Steinernema carpocapsae* and *Steinernema carpocapsae* S_2 showed greater virulence efficiency and faster action on second and third instar larvae of *P. xylostella* compared to the non-irradiated strain **(Salem et al., 2007)**. The

Entomopathogenic nematodes (EPN), from the Heterorhabditis and Steinernema families is a biological control agent for the control of economically important insect pests. The infective juvenile (IJ) stage, which is the free-living, non-feeding survival stage of the EPN life cycle, can easily be mass- cultured, formulated, and applied as a biological control agent for use against thousands of insect species including several economically important pests that attack many crops **(Platt et al., 2020)**.The entomopathogenic nematode, *Steinernema asiaticum* showed significantly high larval mortality than untreated plants against *P. xylostella* in screen house and field conditions **(Kumar et al., 2022)**. The purpose of this work was to evaluate the potency of normal and gamma irradiated *S. carpocapsae*, one insect growth regulator and chemical insecticides against *P. xylostella* larvae and its predators in cabbage fields.

Materials and Methods

Plants and experimental design:

The experiments were carried out under open field conditions in cabbage growing two successive seasons: 2020 and 2021 at El-Raid District, Kafr El-Sheikh Province, Egypt. An area of about one feddan was divided into 48 plots of about 87.50 m^2 in a randomized complete block design with four replications. This area was cultivated with the cabbage (*Brassicae oleracea* L.) variety Oscrose on 2nd week of October in the two successive seasons. Agricultural practices were performed according to recommended but without use of pesticides and fungicides. The normal and gamma irradiated nematodes, *S. carpocapsae*, pesticides and untreated check plots were distributed randomly between plots.

Treatments:

Entomopathogenic nematodes:

1-Normal entomopathogenic nematodes:

The normal entomopathogenic nematodes (EPN) *S. carpocapsae* was brought from the National Research Center, Pests & Plant Protection Department, Giza, Egypt. The *S. carpocapsae* BA2 used in this study was isolated from Egyptian soil and identified by **Hussein and Abou El - Soud (2006).** All nematodes used in this study were reared in vivo according to **Glazer and Lewis (2000)**. Newly emerged infective juveniles (IJ's) were isolated and stored at 15 ºC for 15 days prior to treatment. Normal nematode concentrations were evaluated of 15 IJ's / ml, 30 IJ's / ml, 60 IJ's / ml and 120 IJ's / ml.

1- Radiated entomopathogenic nematodes:

Steinernema carpocapsae BH2 irradiation was performed using a gamma cell irradiation module (secium, Cs^{137} source) at the National Center for Radiation Research and Technology, Giza, Egypt. The dose rate was 0.83084 Rad/ sec. In this study, all data were calculated as a gray unit (Gy); where Gy = 100 rad. Concentrations used were 15 IJ's + 2 Gy / ml, 30 IJ's + 2 Gy / ml, 60 IJ's + 2 Gy / ml, and 120 IJ's + 2 Gy / ml from rediated nematodes.

2- Insect growth regulator:

Trade name: Match 5 % EC with rate of 100 ml / feddan.

Common name: Leufenuron.

4-Insecticides used:

4-1- Trade name: Radiant 12 % SC with rate of 80 ml / feddan.

Common name: Spinetoram

4-2- Mixed of Match+ Radiant: at rate of 80 and 40 ml/ fedd., respectively.

The Knapsack sprayer (20L volume) was used to spray the tested compounds.

Combined effect of entomopathogenic nematode, insect growth regulator and chemical insecticide on *P. xylostella*:

The normal and gamma irradiated nematodes, *S. carpocapsae*, insect growth regulator and chemical insecticide besides untreated check were distributed randomly between plots. Three applications with normal, gamma irradiated nematodes and insecticides were implemented at 15day intervals. The 1st, 2nd and 3rd applications were carried out on the 1st and 3rd weeks of December and 2nd week of January in both seasons, 2020 and 2021, respectively by motor sprayer. Counts of *P. xylostella* larvae and its associated predators were recorded before spraying on 10 cabbage plants/ replicate for each application, as well as 3, 5, 7, 10 and 14 days after application. Reduction in *P. xylostella* population were calculated using **Henderson and Tilton, s formula (1955)**.

Abundance of associated predators:

Coccinella spp. (eggs, larvae and adults), *Chrysoperla carnea* (Stephens). (Eggs and larvae), *Paederus alfierii* Koch (adults), *Scymnus* spp. (larvae and adults), and spiders (spiderlings and adults) were also recorded before treatment and 3, 5, 7, 10 and 14 days after application by the aid of lens on 10 cabbage plants /replicate and repeated four times. Reduction in predator populations was calculated by **Henderson and Tilton's formula (1955)**.

Statistical analysis

Data obtained were analyzed using one-way ANOVA and means separated using Duncan's Multiple Range Test. Correlation and regression coefficients were also determined, Statics were conducted using SPSS (2006).

Results

The efficiency of Entomopathogenic normal and gamma irradiated nematodes, *S. carpocapsae* BH_2 and insect growth regulator compared with chemical insecticides applications were evaluated against *p. xylostella* larvae infesting cabbage in October, November and March during the two successive seasons, 2020 and 2021.

1. Effect of Entomopathogenic, normal and gamma irradiated nematodes *S. carpocapsae* against the *P. xylostella* larvae:

Data presented in Tables 1and 2 showed the efficiency of tested Entomopathogenic normal and gamma irradiated nematodes, *S. carpocapsa*e against the *P. xylostella* larvae on cabbage plants during two seasons under field conditions. Three treatments by gamma irradiated nematodes, *S. carpocapsa*e concentrations of 15 IJ's + 2 Gy/ml, 30 IJ's + 2 Gy/ml, 60 IJ's + 2 Gy/ml, and 120 IJ's + 2 Gy/ml in each of the two seasons provided the most potency against *P. xylostella* larvae as the population density reduced in the first season with concentration 120 IJ's + 2 Gy / ml by 100% after 7 days from treatment. In the three applications average reduction ranging between 97.74 - 98.40% in the three applications. While, in the second season ranged between 98.76 and 99.08% in the same concentration. Also, represented by general average 98.05 and 98.81% during the first and second seasons, respectively. Followed by 60 IJ's + 2 Gy / ml where the reduction recorded 99.75, 91.22 and 98.25% after 7 days from treatment with average values 94.06, 94.50 and 94.35% in the three applications and represented by overall average 94.30 and 95.78% during the two seasons, respectively. On the other hand, the lowest reduction percentages in infestation were recorded by normal nematode at concentration 15 IJ's / ml. after 3 days from treatment where reduction percent ranged between 50.33 and 55.25% during the two successive seasons, respectively and represented by average values arranged between 62.77 and 64.53% in the first season, while in the second season arranged between 66.36 to 67.84, respectively. Also, represented by overall average values 63.65 and 66.95% in the two successive seasons, respectively in the same concentration**.**

2. Effect of insect growth regulator and insecticidal application on *P. xylostella* larvae:

During the first season, data illustrated in **Table (3),** showed that the highest reduction percent in population of *P. xylostella* larvae were noticed at 5 – days after applications with each of, match 5% EC, radiant 12%SC and their mixture.

Table (1): Efficiency of normal and gamma irradiated nematodes, *Steinernema carpocapsae* against the *Plutella xylostella* larvae on cabbage plants during 2020 season.

Days after application	Normal 15 IJ's	15 + 2 G Y	Normal 30 IJ's	30 + 2 G Y	Normal 60 IJ's	60 + 2 G Y	Normal 120 IJ's	120 + 2 G Y
				1st Application				
3	50.33	63.25	60.78	85.75	67.00	89.55	75.66	96.75
5	61.25	73.22	71.25	89.00	82.22	96.11	89.41	97.14
7	80.75	83.77	82.24	97.27	90.33	99.66	96.25	100.00
10	71.73	80.00	73.66	90.75	85.76	94 .00	92.25	99.25
15	54.25	72.75	61.25	83.66	70.00	91.00	79.00	98.77
Mean	**63.66**	**74.60**	**69.84**	**89.29**	**79.06**	**94.06**	**86.51**	**98.40**
				2nd Application				
3	53.32	65.33	61.00	78.22	69.88	88.73	76.62	95.88
5	63.75	77.00	70.00	89.64	85.00	95.22	90.00	99.22
7	82.33	85.75	85.33	97.75	92.00	99.25	96.00	100.00
10	66.00	81.22	72.25	89.11	87.25	96.55	93.50	99.00
15	57.24	74.33	64.00	86.25	72.33	92.75	76.22	95.55
Mean	**64.53**	**76.73**	**70.92**	**88.19**	**81.29**	**94.50**	**86.47**	**98.02**
				3rd Application				
3	51.22	64.75	62.25	79.55	68.00	86.22	77.25	94.25
5	62.25	75.55	71.75	88.55	83.25	96.75	91.33	98.15
7	82.25	84.88	86.33	98.22	93.75	100.00	97.75	100.00
10	63.00	83.25	71.00	90.00	89.00	95.66	95.33	99.88
15	55.11	72.33	62.66	88.33	74.22	93.00	80.15	95.66
Mean	**62.77**	**76.15**	**70.80**	**88.93**	**81.64**	**94.35**	**88.36**	**97.74**
General mean	**63.65**	**75.83**	**70.52**	**88.80**	**80.66**	**94.30**	**87.11**	**98.05**

IJ's = Infective Juveniles, GY = Gray Unit

Whereas it was observed at 7 – days after application of insect growth regulators, match. The mean reduction percent of the larval infestation on cabbage plants treated with match, radiant and their mixture were 77.39, 81.12 and 88.67 %, respectively for the 1st applications, 76.49, 81.68 and 90.76 %; respectively in case of 2nd applications 76.52, 80.95 and 89.38%, respectively for the 3rd application. The lowest reduction percentages in, *P. xylostella* larvae were observed after 15 days, application with all compounds, where the activity decreased with time. Based on the mean reduction percentages in the larval infestations, it was obvious that radiant is the most promising insecticide for controlling the pest, where the reduction rate was 88.67, 90.76 & 88.72% for the 1st, 2nd and 3rd applications; respectively. While, match proved to be the least efficient insecticide against the pest, where the noticed reduction values being 77.39, 76.49 & 75.67 % for the 1st, 2nd and 3rd the insecticidal applications; respectively. On the other hand, insect growth regulator, match 5% ranked the middle position among the two pesticides used for this insect pest control.

In 2021 season, almost the results showed similar trend of 2020 season **(Table 3).**

Table (2): Efficiency of normal and gamma irradiated nematodes, *S. carpocapsae* BH2 against the *Plutella xylostella* on cabbage plants **2021 season**.

Days after application	Normal 15 IJ's	15 + 2 G Y	Normal 30 IJ's	30 + 2 G Y	Normal 60 IJ's	60 + 2 G Y	Normal 120 IJ's	120 + 2 G Y
1st Application								
3	53.55	69.55	61.75	81.55	70.50	87.25	77.50	97.00
5	65.75	72.33	70.55	95.50	88.25	98.33	96.75	100.00
7	82.50	85.75	85.22	99.75	90.36	99.75	96.00	100.00
10	75.33	83.50	80.33	90.55	88.75	98.33	91.11	99.55
15	56.11	75.25	60.75	83.33	66.33	96.50	73.50	98.75
Mean	**66.65**	**77.28**	**71.72**	**90.14**	**80.84**	**96.03**	**86.97**	**99.08**
2nd Application								
3	54.75	68.33	58.50	83.25	71.88	89.75	75.22	96.18
5	65.77	73.50	71.33	93.00	81.50	97.25	90.50	100.00
7	85.55	86.55	86.13	99.55	91.22	99.75	97.33	100.00
10	68.50	82.25	75.55	91.75	84.75	97.75	92.75	99.50
15	57.24	77.55	61.22	81.55	65.55	94.66	70.66	97.25
Mean	**66.36**	**77.64**	**70.55**	**89.82**	**78.98**	**95.82**	**85.29**	**98.59**
3rd Application								
3	55.25	67.77	54.75	79.25	72.50	90.00	79.50	96.33
5	66.75	80.22	70.35	91.33	85.55	95.50	92.22	99.75
7	87.55	86.00	87.33	98.25	97.75	99.15	98.25	100.00
10	70.50	85.66	74.00	96.33	81.50	96.33	93.13	99.95
15	59.15	84.75	60.25	89.00	66.25	96.50	75.25	97.77
Mean	**67.84**	**80.88**	**69.34**	**90.83**	**80.71**	**95.10**	**87.67**	**98.76**
General mean	**66.95**	**78.65**	**70.55**	**90.26**	**80.18**	**95.78**	**86.64**	**98.81**

IJ's = Infective Juveniles, GY = Gray Unit

3. Effect of entomopathogenic nematode (*S. carpocapsae*), insect growth regulator (match) and radiant on overall average reduction percentages of *p. xylostella* larvae:

The overall average reduction percent of the *P. xylostella* larvae in 2020 and 2021 seasons are shown in Table (4). Results during two seasons indicated that gamma irradiated nematodes in concentration 120 IJ's +2 Gy / ml treatments followed with 60 + 2 G Y and radiant insecticide were the best treatments in reducing infestation with *P. xylostella* larvae according to statistical analysis. On the other hand, insect growth regulator Match 5% gave overall average 76.52 and 76.42% mortality in two seasons respectively. The statistical analysis indicated significant differences between all treatments. The lowest reduce number of *P. xylostella* larvae resulted from the lowest concentration of normal nematode during two seasons **(Table 4).**

4. Effect of normal and gamma irradiated nematodes (*S. carpocapsae*), insect growth regulator (Match 5% EC) and Rdiant 12%SC on the general mean reduction percentages predators:

During 2020, results in **Table (5)** reveled that normal and irradiated nematode were safe on associated predators in experiment. The lowest reduction percent of true spiders, coccinellids, *Aphidoletes aphiimyza* and *C. carnea* were in cases of cabbage treated with normal and gamma irradiated nematodes. However the highest reduction percent of *C. carnea,A. ophiimyzo*, coccineliids and true spider were found on cabbage treated with chemical insecticides. In the second season 2021, results were similar to season 2020 **Table (5).**

Table (3): Efficiency of one insect growth regulator (Match 5% EC) and Rdiant 12%SC applications against *P. xylostella* on cabbage plants during 2020 and 2021 season.

Days after application	2020 season			2021 season		
	Match	Match +Radiant	Radiant	Match	Match +Radiant	Radiant
1st Application						
3	72.25	78.00	85.25	70.00	79.33	82.00
5	80.22	85.25	97.75	81.25	85.00	95.22
7	86.75	91.33	93.11	85.33	90.13	90.75
10	77.50	80.75	87.00	74.00	81.15	83.55
15	67.22	70.22	80.22	70.33	71.00	77.35
Mean	77.39	81.12	88.67	76.16	81.32	85.77
2nd Application						
3	70.00	77.75	89.25	71.50	75.95	85.25
5	82.33	85.00	99.00	80.13	86.52	97.00
7	84.25	92.33	94.75	85.99	90.75	91.55
10	75.55	81.75	88.25	73.25	78.25	85.50
15	70.33	71.55	82.55	68.15	71.15	80.00
Mean	76.49	81.68	90.76	75.80	80.52	87.86
3rd Application						
3	75.00	75.11	87.33	73.50	76.51	84.00
5	81.75	83.75	96.00	83.25	85.00	97.50
7	85.00	88.50	93.25	88.15	89.25	92.65
10	79.33	80.66	86.00	76.66	81.73	84.11
15	75.25	72.25	81.00	70.75	70.50	79.50
Mean	75.67	80.05	88.72	76.75	80.60	87.55
General mean	76.52	80.95	89.38	76.24	80.81	87.06

Table (4): Effect of entomopathogenic nematode irradiated (*S. carpocapsae*), insect growth regulator (Match 5% EC) and Rdiant 12%SC on the general mean reduction percentages of *P. xylostella* larvae:

Treatments	**Concentration**	**General mean reduction percentage**	
		2020	**2021**
Pathogenic nematodes	**15**	63.65 f	66.65 f
	15 + 2 G Y	75.83 d	75.83 d
	30	70.52 e	70.52 e
	30 + 2 G Y	88.80 b	90.26 b
	60	80.66 c	80.18 b
	60 + 2 G Y	94.30 a	95.78 c
	120	87.11 b	86.64 b
	120 + 2 G Y	98.05 a	98.81 a
Match	**5%EC**	76.52 d	76.24 d
Match + Radiant	**(Match 5% EC) + (Rdiant 12%SC)**	80.95 c	80.81 c
Radiant	**12%SC**	89.38 b	87.06 b

Means followed by different letters are significantly different(P=0.05).

Table 5: Efficacy of normal and gamma irradiated nematodes (*S. carpocapsae*), one of insect growth regulator (Match 5%EC) and Rdiant 12%SC on the associated predators of *P. xylostella*

Treatments	Concentration	*Aphidoletes Aphidimyza*	*Chrysoperla Carnea*	Coccinellids	True spiders
		2020 season			
Pathogenic nematodes	**15**	0.00 a	0.00 a	0.00 a	0.00 a
	15 + 2 G Y	0.00 a	0.00 a	0.00 a	0.00 a
	30	0.00 a	0.00 a	0.00 a	0.00 a
	30 + 2 G Y	0.00 a	0.00 a	0.00 a	0.00 a
	60	0.00 a	0.00 a	0.00 a	0.00 a
	60 + 2 G Y	0.00 a	0.00 a	0.00 a	0.00 a
	120	0.00 a	0.00 a	0.00 a	0.00 a
	120 + 2 G Y	0.00 a	0.00 a	0.00 a	0.00 a
Match	**5%EC**	32.00	25.61	16.67	18.55
Match+Radiant	**(Match 5% EC) + (Rdiant 12%SC)**	71.35	51.00	41.66	64.15
Radiant	**12%SC**	88.27	80.55	72.27	83.50
		2021 season			
Pathogenic nematodes	**15**	0.00 a	0.00 a	0.00 a	0.00 a
	15 + 2 G Y	0.00 a	0.00 a	0.00 a	0.00 a
	30	0.00 a	0.00 a	0.00 a	0.00 a
	30 + 2 G Y	0.00 a	0.00 a	0.00 a	0.00 a
	60	0.00 a	0.00 a	0.00 a	0.00 a
	60 + 2 G Y	0.00 a	0.00 a	0.00 a	0.00 a
	120	0.00 a	0.00 a	0.00 a	0.00 a
	120 + 2 G Y	0.00 a	0.00 a	0.00 a	0.00 a
Match	**5%EC**	35.25	26.45	18.55	20.35
Match+Radiant	**(Match 5% EC) + (Rdiant12%SC)**	73.33	53.25	44.76	66.00
Radiant	**12%SC**	89.25	81.50	74.77	84.00

Means followed by different letters are significantly different(P=0.05).

5. Yield of cabbage head in response to different bio agent and insecticides treatments:

During the first season, data presented in **Table (6)** demonstrated that the highest head marketable cabbage was (5860.00 kg/fed.) on cabbage treated by irradiation nematode by rate 120 + 2 G Y, flowed by (5750.75 kg/fed.) on cabbage treated with radiant insecticide. However, the lowest cabbage yield was (1500.25 kg/fed.) on untreated cabbage plants**.** The results in the second season, 2021, were similar to that of the first season 2020 **(Table 6).** Also, the highest reduction percent of**,** *P. xylostella* was recorded in cabbage plants treated with irradiated nematodes in concentration of 120 IJ' + 2 Gy/ml**.** So, the highest cabbage crop production and price observed in treatment by irradiated nematodes at rate of 120 IJ' + 2 Gy/ml., the recorded healthy yield production. On the other hand, using the lowest concentration of pesticides, the two gave the lowest reduction percentage of healthy yield production.

DISCUSSION

The present findings were supported by **Abd EL-Razek and Gowen (2002)** who reported that the entomopathogenic nematode can successfully control *P. xylostella* on cabbage plants under field conditions. **Kumar et al., 2022** indicated that the entomopathogenic nematode *Steinernema asiaticum* showed a significantly higher larval population reduction percent of *P. xylostella* (48.33% mortality) compared to traditional chemical pesticides 18.0% mortality in malathion at 0.05% EC on cabbage plants field conditions.

Table (6): Yield of cabbage head in response to different bio agent and insecticide treatments during 2020 and 2021 season.

Treatment	Concentration	The total mean weight kg/ feddan of marketable head cabbage yield at each treatment	
		2020	2021
Pathogenic nematodes	15	3330.00 h	3300.25 h
	15 + 2 G Y	4400.75 f	4380.25 f
	30	3850.25 g	3825.25 g
	30 + 2 G Y	4850.75 e	4800.00 e
	60	5300.00 d	5250.75 d
	60 + 2 G Y	5600.25 c	5500.50 c
	120	5350.50 d	5330.00 d
	120 + 2 G Y	5860.00 a	5850.75 a
Match	Match 5%EC	5650.25 c	5664.25 c
Match + Radiant	Match 5%EC+ Radiant 12%SC	5700.00 c	5735.50 c
Radiant	Radiant 12%SC	5750.75 b	5800.00 b
Control	-	1500.25 i	1488.00 i

Also, these results are in line with the finding of **Omar *et al,* 2001 and El- Fakharany 2005** who observed that insecticide caused harm to insect predators; *Scymmus* spp., *C. undecimpunctata*, *Orius* sp. and *S. corolla*, While the entomopathogens were the safest compounds tested on all predators at vegetable plants. **Baur *et al*. (1995)** noticed that larval mortality of *P. xylostella* in a leaf disk ranged from <7% to >95% due to infection with *S. caposapsae*. It should also be noted that the entomopathogenic nematode is non-toxic to humans and farm animals. The infective juveniles kill the insect within 24-48 hours, it reproduces in large numbers, and again restarts its life cycle. The high concentrations from gamma irradiated nematodes *S. carpocapsae*. was more effective than normal nematodes treatment against of *P. xylostella* larvae on cabbage plants. The present results are incompatible with those of **Hedayat-allah *et al*., 2014and Sayed *et al*. 2015** when reported that gamma irradiated (2Gy) *S. carpocapsae* nematodes were more effective in reducing the number of both of *Galleria mellonella*. Further, they stated that 2 Gy irradiated *S. carpocapsae* disrupted the antioxidant contents of *S. littoralis* larvae and lead to larval death faster than normal *S. carpocapsae*. **Ali (2011)** reported that gamma radiation doses caused harmful effect and statistical analysis of the data from nematode isolates confirmed that diamondback moth larvae are highly susceptible to infection by *S. abbasi* than *S. carpocapsae*. These results are in line with the results of entomopathogenic nematodes compared to chemical insecticides, fungi, *B.thuringiensis* and with other types of entomopathogenic nematodes have been done **(Head et al.,2000).** As a conclusion our data indicated that gamma irradiated nematodes *S. carpocapsae*. can be used successfully in the control of *P. xylostella* larvae on cabbage plants under the field conditions and could be used in within integrated pest management programs.

Abbreviation

EPN=The Entomopathogenic nematodes
m^2 = meter*meter
BA2= Irradiated *Steinernema carpocapsae*
IJ's = Infective juvenile stage
C°= Degree Celsius
GY = Gray Unit
EC= Emulsifiable concentrate
EC= Suspension concentrate

Authors contributions

All authors contributed to the study conception were performed by Khafagy, I. F. M. M. Ismael and Mohsena, R. K. Mansour. the first draft of the manuscript was written by Khafagy, I. F and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no Competing interests.

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