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Combination effects between gamma radiation and spraying equipment for three cotton boll pests controlling

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Abstract
Pneumatic knapsack motor sprayer (Cifarilli) and Hand-held Hydraulic sprayer (Matabi) were used as two sprayer equipment for assessment the spraying efficacy. Nine compounds related to bio-agent groups were used; one of them (orange oil) was exposed to gamma radiation doses of 160, 320 & 640 Gy for potentiating purpose with *B. thuringiensis* mixture. The treatments were *Bacillus thuringiensis* (Kurstaki), Orange oil, *B. thuringiensis* + orange oil, *B. thuringiensis* + orange oil 160 Gy, *B. thuringiensis* + orange oil 320 Gy, *B. thuringiensis* + orange oil 640 Gy, azadirachtin, azadirachtin + orange oil and emamectin benzoate. The treatments aforementioned were evaluated with the two spraying equipment used against three pests of cotton bolls that were pink bollworm, *Pectinophora gossypiella* (Saund); spiny bollworm, *Earias insulana* (Boisd.) and Cotton seed bug, *Oxycarenus hyalinipennis* (Costa) population and infestation reduction percentages. Pneumatic knapsack motor sprayer (Cifarilli) was higher than Hand-held Hydraulic sprayer (Matabi) in success the control of the three pests in population and infestation reductions of three pests used. Moreover, *B. thuringiensis* + orange oil 640 Gy was considered the best gamma radiation treatment that caused reduction percentages in population and infestations against three pests used but lower than emamectin benzoate efficacy. Meanwhile, *B. thuringiensis* or orange oil had the least value when used singly for three pests controlling. In addition, the compounds used especially *B. thuringiensis* + orange oil 640 Gy enhanced the most cotton crop parameters acts in seed numbers, lint and seed weights during the two cotton seasons 2018 & 2019.
So, gamma radiation can potentiate the orange oil when mixed with *B. thuringiensis* to become the most effective compounds as companion with Pneumatic knapsack motor sprayer (Cifarilli) uses against the three pests mentioned and cotton crop parameters compared with the same compounds without exposing to gamma radiation. It could be recommended to use the treatments with Low Volume spraying equipment to cause a satisfactory coverage on cotton plants. Its spectrum droplets were ranging between 124-178 µm with sufficient number ranging from 35-200 N/cm². Also, performance rate of Pneumatic Knapsack motor sprayer (Cifarilli) (20 L./Fed.) was 12 Fed./day; while, It was 3.46 Fed./day for Hand-held Hydraulic sprayer (Matabi) (56 L./fed.). Moreover, Low Volume spraying reducing the time lost in the process filling of machines with the spray solution to get homogenous spray coverage and saving the spray lost on the ground.

Keywords: Gamma radiation, cotton bolls, cotton crop, pneumatic knapsack motor sprayer (Cifarilli), hand-held hydraulic sprayer (matabi)

Introduction
Cotton (*Gossypium barbadense*, L.) infested by many economic pests; from these the pink bollworm, *Pectinophora gossypiella* (Saund); spiny bollworm, *Earias insulana* (Boisd.) and cotton seed bug, *Oxycarenus hyalinipennis* (Costa) that are the most destructive insect pests causing the economic damage to cotton bolls. *P. gossypiella* is the serious pest for cotton bolls; the newly hatched penetrates squares, flower buds, flowers and bolls shortly after hatching and then penetrates the lint and seeds of fully mature bolls, thus decreasing the quantity and quality of lint and seeds [1]. Also, *E. insulana* is a threat insect pest for cotton bolls, the larvae feed on top boring for the soft and growing tissues especially the terminal buds and later it attack the flower buds and bolls [2]. Sucking behavior of *O. hyalinipennis* (adult and nymphs) disturb the cotton crop at early (squares and flowers) as well as the late stages (open bolls) but most economic losses are caused in the late stage. It extracts the sap by damaging the seeds and the reproductive parts [3].

A large number of chemical pesticides are used annually for pest control causing the negative impact on human health and environment; in addition, the resistance problem in these pests [4]. Also, many searches were trend to use bio-agent compounds for controlling the cotton bollworms to try being successful step in removing chemical pesticides from the environment. Gamma irradiation as a genetic control method is unique among biological methods; it involves the release of genetically modified insects to control the same species [5]. Inherited effects of gamma irradiation doses were studied by many authors as [6-8]. [9,10] evaluated *Azadirachta indica* against *P. gossypilla and H. armigera* and stated that the compound have insecticidal potential showed significant mortality response.

Efficiency of different ground sprayers was carried out by [11,12] that detected a significant variation in the spray deposit due to arrangement of the nozzles, spray volume, spraying type and rate of application. The world global attention was directed to minimize of spraying volume and control costs that may be happened by using a cheap and effective insecticides or using developmental ground spraying technique with low application costs [13, 14].

Aim of current field trial is use the Pneumatic Knapsack motor sprayer (Cifarilli) and Hand-held Hydraulic sprayer (Matabi) for cotton plant coverage. Also, use of gamma radiation to potentiate *B. thuringiensis* efficacy by using orange oil exposed to three gamma radiation doses (160, 320 & 640 Gy) comparing with the same compounds without exposing to gamma doses; in addition, the additive compound (Azadirachtin + orange oil) and emamectin benzoate. Nine treatments used to control the three insect pests of *P. gossypiella*, *E. insulana* and *O. hyalinipennis* on cotton bolls at 2018 & 2019 cotton seasons and crop parameters enhancement.

Materials and Methods

Trial place: A field trial of cotton (Giza 86 varieties, 2017 strain) was done to evaluate the potency of nine treatments for controlling the three insect pests of *P. gossypiella*, *E. insulana* and *O. hyalinipennis* those infesting cotton bolls at 2018 & 2019 growing cotton seasons at Plant Protection Research Institute Station, Qaha district, Qaluobeiah province. The experimental area was divided according to the complete randomized block design including four replicates for each treatment; each replicate was 6x7 m (1/100 feddan). Three rows of cotton plants among treatments left without spraying as barrier zone to avoid drift spray. The trial was done under local meteorological conditions of 35ºC average temperature, 60% average RH and 2m/sec. average wind velocity.

The tested compounds were applied three times at 15 days intervals. The first spray was applied when the per cent infestation of green bolls reached about 3% at 21th and 27th July in 2018 and 2019 cotton seasons, respectively. Boll samples were collected at random before applying the compounds and then weekly after application. One hundred bolls (25 bolls x 4 replicates) were collected from each treatment and examined.

Insects: Three pests were investigated on green cotton bolls were tabulated in Table (1).

Table 1: Insects infested the cotton bolls.

English name	Bionomial name	Family	Order
Pink Bollworm	*Pectinophora gossypiella* (Saunders)	Gelechiidae	Lepidoptera
Spiny Bollworm	*Earias insulana* (Boisduval)	Noctuidae	Lepidoptera
Cotton Seed Bug	*Oxycarenus hyalinipennis* (Costa)	Lygaeidae	Hemiptera

Compounds: Nine treatments belong to four compounds as in Table (2).

Table 2: Compounds used, common name and application rate.

Trade name	Common name	Application rate	Product Co.	Imported Co.
Biotect 9.4% W.P	*Bacillus thuringiensis* (Kurstaki)	300g/ feddan	Organic for biotechnology co. Beheira Governorate, Egypt.	
PREV-AM 6% SL	Orange oil	400 ml/ 100 liter water	ORO-AGRI, USA	Bridge Trade for import & export
Achook 0.15% EC.	Azadirachtin, *Azadirachta indica*	750 cm3/ feddan	Bahar agrochem & feeds, India	Al- Masrya for agriculture development, Beheira Governorate, Egypt.
Triumph 1.92% EC.	Emamectin Benzoate	150 ml/ feddan	AKKO B.V, Holand	Bridge Trade for import & export

Gamma radiation

Orange oil compound was exposing to gamma radiation doses of 160, 320 and 640 Gy at dose rate of 1.084 KGy/h by a Cesium137 Hendy Gamma Cell Research at National Center for Radiation Researches & Technology.

Nine treatments were used as follows: 1. *B. thuringiensis*, 2. Orange oil, 3. *B. thuringiensis* + orange oil, 4. *B. thuringiensis* + orange oil 160 Gy 5. *B. thuringiensis* + orange oil 320 Gy 6. *B. thuringiensis* + orange oil 640 Gy, 7. Azadirachtin, 8. Azadirachtin + orange oil 9. Emamectin benzoate.

The per cent reduction in population and infestation were calculated according to [15]:

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

Where Ta = number of infested bolls from the treatment after application.

Tb = number of infested bolls from the treatment before application.

Ca = number of infested bolls from the control after application.

Cb = number of infested bolls from the control before application.

Spraying equipment

Two ground equipments were selected to perform the scope of current work:

1. Pneumatic knapsack motor sprayer (Cifarilli), Spraying volume (20 L/fed.), Italy made.
2. Hand-held Hydraulic sprayer (Matabi) Spraying volume (56 L/fed.), Spain made.

Calibration and performance rate parameters of the two equipments were mentioned in Table (3).

Table 3: Techno-Operational data, calibration and performance rate of certain sprayer equipment applied on Cotton field.

Equipments	Pneumatic Knapsack sprayer (Cifarilli)	Hydraulic sprayer (Matabi)
Type of atomization	Mechanical Pneumatic	Manual Hydraulic
Nozzle type	Air shear nozzle	Hollow cone nozzle 80º
Pump type	Centrifugal fan	Hydraulicair pump
Number of nozzles	1	1
Pressure (bar)	-	5
Spray tank (L.)	20	20
Rate of application (L/fed.)	20	56
Working speed (Km/h.)	2.4	2.4
Swath width (m.)	5	1.5
Flow rate (L/min.)	1	0.8
Spray height (m.)	0.5	0.5
Type of Spraying	Target in all sprayers	
Productivity * (fed./h.)	2.85	0.86
Rate of performance (fed./day)	12	3.4

*Number of spraying hours = 8 hours daily, number of workers =2

Equipment calibration and adjustment

a. Spray deposit Collection

Before spraying each treatment, a sampling line constructed of five wire holder fixed in diagonal line inside each treatment to collect the lost spray among plants; each wire holder top had a fixed water sensitive paper (Novartis Cards®) on it; also, the water sensitive paper cards put on five plants ; to collect the droplets deposit on cotton leaves at both upper and lower levels of plant according to [16]. Cards were collected and transferred carefully to the laboratory for measuring and calculating the number of droplets/cm² and its volume mean diameter (VMD) µm in all treatments was done.

b. Spray deposit determination

Number and size of blue spots (deposited droplets) on the water sensitive papers (Novartis cards®) measured with scaled monocular lens (Strüben) ® (15X) Japanese lens. Volume mean diameter (VMD) µm and number of droplets in one square centimeter (N/cm²) were estimated according to [11].

c. Spraying phytotoxic effect

It was determined by recording any color change, leaf curling or flaming up to 15 days after each spraying according to [17].

Cotton crop parameters

The cotton crop numbers of seeds and weights of lint and seeds (g) were assessed as compared to the control. The samples were collected per 100 open cotton bolls.

Statistical analysis

All investigated data were analyzed by using Costat statistical program software, 1990 and Duncan multiple range test [18] at 5% probability level to compare the differences among time means.

Results and Discussion

A field trial was done at Plant Protection Research Institute Station, Qaha district, Qalubeiah province during two cotton seasons (2018 & 2019). The aim of trial is potentiating *B. thuringiensis* by exposing orange oil to three gamma doses (160, 320 & 640 Gy) for mixing with *B. thuringiensis* comparing with the mixture of *B. thuringiensis* + orange oil without exposing to gamma doses and azadirachtin + orange oil; in addition uses all of them singly. Two spraying machine of Pneumatic Knapsack motor sprayer (Cifarilli) (20 L\Fed.) and Hydraulic Matabi sprayer (56 L\Fed.) were used for enhancing the spraying efficacy against three cotton pests. The controlling target pests were pink bollworm, *P. gossypiella*; spiny bollworm, *E. insulana* and cotton seed bug, *O. hyalinipennis*. The reduction percentages of larval population and infestation for three pests were done. Moreover, determined the cotton crop acts in seed number, lint & seed weight/100 opened cotton boll during two cotton seasons trials (2018 & 2019).

Pink and spiny bollworms

a. Larval population reductions

Nine compounds were applied on cotton green bolls when larval population and infestation was about 3% of *P. gossypiella* or *E. insulana* or both of them.

The pink and spiny larval population reductions had slightly increased at 2019 than 2018 cotton seasons; moreover, Pneumatic knapsack motor sprayer (cifarilli) was more efficacy than Hydraulic Matabi sprayer in larval population reduction percentages as shown in Table (4 & 5). Emamectin benzoate was the best treatment caused bollworms larval population reduction during two cotton seasons (77.8 & 81.1% and 61.5 & 70.1% for Pneumatic knapsack motor sprayer and Hand-held Hydraulic sprayer during 2018 & 2019 cotton seasons, respectively). The second efficacy compound was *B. thuringiensis* + orange oil 640 Gy (73.9 & 71.3% and 59.4 & 62.8% reductions in bollworms population when using knapsack motor sprayer and Hand-held Hydraulic sprayer, respectively during 2018 & 2019 cotton seasons. Table (4 & 5) cleared that gamma radiation dose of 640 Gy was the best dose can potentiate the orange oil when mixing with *B. thuringiensis*, followed by doses of 320 and 160 Gy. The mixture compound of azadirachtin + orange oil had moderate efficacy ranged from 52.3-65% larval population reductions by two spraying machine uses during two cotton seasons. Moreover, *B. thuringiensis* + orange oil mixture had the lower efficacy on the pink and spiny bollworms population reductions, but the values were the best when it was comparing with *B. thuringiensis* or orange oil singly uses.

b. Infestation reduction

The same trend in larval population reduction was also obvious in the pink and spiny bollworms infestation reductions (Table 6 & 7); but the infestation reduction was the highly than population.

By using the two spraying machine aforementioned, emamectin benzoate was considered the best treatment caused the highly reduction in bollworms infestation, followed by *B.*

thuringiensis + orange oil 640 Gy, *B. thuringiensis* + orange oil 320 Gy, *B. thuringiensis* + orange oil 160 Gy, orange oil + azadirachtin, azadirachtin, *B. thuringiensis* + orange oil without exposing to gamma doses, *B. thuringiensis* and then orange oil singly.

Table 4: Per cent reduction in larval populations of the pink and spiny bollworms during application by using two spraying equipment with some compounds at 2018 cotton season.

Compounds	% Larval population reductions during application									Seasonal Average
	1st spray			2nd spray			3rd spray			
	7	14	Aver.	7	14	Aver.	7	14	Aver.	
Pneumatic knapsack motor sprayer (Cifarilli)										
B. thuringiensis	9.33^{c}	10.7^{d}	10.02^{c}	12.6^{d}	11.1^{c}	11.9^{d}	14.3^{c}	15.2^{d}	14.8^{d}	12.2^{d}
Orange oil	8.88^{c}	9.9^{d}	9.39^{c}	10^{d}	10^{c}	10^{d}	12.6^{c}	13.4^{d}	13^{d}	10.8^{d}
B. thuringiensis +Orange oil	11.1^{c}	12.6^{d}	11.9^{c}	13.2^{d}	14.3^{c}	13.8^{d}	17.3^{c}	18.8^{d}	18.1^{d}	14.6^{d}
B. thuringiensis +Orange oil 160 Gy	48.8^{b}	60^{bc}	54.4^{b}	64.4^{bc}	69^{b}	66.7^{bc}	70.2^{b}	76^{b}	73.1^{b}	64.7^{c}
B. thuringiensis +Orange oil 320 Gy	52.2^{ab}	60.1^{bc}	56.2^{ab}	63.3^{bc}	68.8^{b}	66.1^{bc}	75.5^{b}	77^{b}	76.3^{b}	66.2^{bc}
B. thuringiensis +Orange oil 640 Gy	55^{ab}	65^{ab}	60^{ab}	68^{ab}	78^{a}	73^{ab}	88.8^{a}	88.8^{a}	88.8^{a}	73.9^{ab}
Azadirachtin	48.8^{b}	54.7^{c}	51.8^{b}	57^{c}	59.9^{b}	58.5^{c}	67.1^{b}	62.2^{c}	64.7^{c}	58.3^{c}
Azadirachtin +Orange oil	50^{b}	55^{c}	52.5^{b}	62.2^{bc}	66.6^{b}	64.4^{c}	75^{b}	74.4^{b}	74.7^{b}	63.9^{c}
Emamectin benzoate	59^{a}	70^{a}	64.5^{a}	74^{a}	86^{a}	80^{a}	88.8^{a}	89^{a}	88.9^{a}	77.8^{a}
L.S.D$_{0.05}$	7.04	7.84	8.05	7.86	8.48	7.87	11.5	7.59	7.65	7.74
Hydraulic matabi sprayer										
B. thuringiensis	8.88^{b}	9.9^{b}	9.39^{b}	10.8^{c}	9.5^{c}	10.2^{d}	11.1^{e}	12.6^{d}	11.9^{d}	10.5^{d}
Orange oil	7.7^{b}	8.88^{b}	8.29^{b}	8.88^{c}	8.3^{c}	8.59^{d}	10.8^{e}	11.1^{d}	10.95^{d}	9.28^{d}
B. thuringiensis +Orange oil	9.9^{b}	10.8^{b}	10.4^{b}	11.1^{c}	12.6^{c}	11.9^{d}	15.2^{e}	16.4^{d}	15.8^{d}	12.7^{d}
B. thuringiensis +Orange oil 160 Gy	40^{a}	47.7^{a}	43.9^{a}	49.5^{ab}	57^{a}	53.3^{abc}	62.2^{c}	64.4^{b}	63.3^{b}	53.5^{bc}
B. thuringiensis +Orange oil 320 Gy	42.2^{a}	49^{a}	45.6^{a}	51^{ab}	59^{a}	55^{ab}	63^{bc}	65.5^{b}	64.3^{b}	54.9^{ab}
B. thuringiensis +Orange oil 640 Gy	44.4^{a}	50^{a}	47.2^{a}	54^{ab}	62.2^{a}	58.1^{ab}	70^{ab}	76^{a}	73^{a}	59.4^{ab}
Azadirachtin	38^{a}	44.4^{a}	41.2^{a}	45.5^{b}	47^{b}	46.3^{c}	55^{d}	50^{c}	52.5^{c}	46.7^{c}
Azadirachtin +Orange oil	40^{a}	45^{a}	42.5^{a}	47^{b}	53^{b}	50^{bc}	63.3^{bc}	65.5^{b}	64.4^{b}	52.3^{bc}
Emamectin benzoate	45^{a}	49^{a}	47^{a}	58^{a}	62.2^{a}	60.1^{a}	75^{a}	80^{a}	77.5^{a}	61.5^{a}
L.S.D$_{0.05}$	8.67	8.03	7.93	8.64	8.88	7.98	7.04	7.84	7.88	6.91

Table 5: Per cent reduction in larval populations of the pink and spiny bollworms during application by using two spraying equipment with some compounds at 2019 cotton season.

Compounds	% Larval population reductions during application									Seasonal Average
	1st spray			2nd spray			3rd spray			
	7	14	Aver.	7	14	Aver.	7	14	Aver.	
Pneumatic knapsack motor sprayer (Cifarilli)										
B. thuringiensis	12.6^{e}	12^{g}	12.3^{f}	14.2^{f}	16.9^{f}	15.6^{g}	20.7^{e}	20.7^{e}	20.7^{e}	16.2^{f}
Orange oil	10.8^{e}	11^{g}	10.9^{f}	12^{f}	13^{g}	12.5^{g}	15.2^{f}	16.2^{f}	15.7^{f}	13^{g}
B. thuringiensis +Orange oil	18.8^{d}	20.2^{f}	19.5^{e}	23.5^{e}	24.5^{e}	24^{f}	27.1^{d}	28^{d}	27.6^{d}	23.7^{e}
B. thuringiensis +Orange oil 160 Gy	55^{c}	59^{c}	57^{c}	66.6^{c}	72.2^{c}	69.4^{cd}	72.2^{c}	75^{b}	73.6^{c}	66.7^{c}
B. thuringiensis +Orange oil 320 Gy	55^{c}	61^{bc}	58^{c}	66^{c}	75^{b}	70.5^{bc}	77^{b}	70^{c}	73.5^{c}	67.3^{c}
B. thuringiensis +Orange oil 640 Gy	60^{b}	64^{b}	62^{b}	70^{b}	76^{b}	73^{b}	78^{b}	80^{a}	79^{b}	71.3^{b}
Azadirachtin	52.2^{c}	54.4^{d}	53.3^{d}	62.2^{d}	68.9^{d}	65.6^{e}	72.2^{c}	68.9^{c}	70.6^{c}	63.2^{d}
Azadirachtin +Orange oil	55.5^{c}	59^{e}	57.3^{c}	64.4^{cd}	69^{d}	66.7^{de}	72.2^{c}	70^{c}	71.1^{c}	65^{cd}
Emamectin benzoate	71.3^{a}	78^{a}	74.7^{a}	80^{a}	85^{a}	82.5^{a}	89^{a}	83^{a}	86^{a}	81.1^{a}
L.S.D$_{0.05}$	3.46	3.62	1.94	2.87	2.59	3.17	1.94	4.10	3.72	2.74
Hydraulic Matabi sprayer										
B. thuringiensis	12^{d}	11^{e}	11.5^{f}	13^{f}	15^{f}	14^{f}	17^{f}	15^{f}	16^{g}	13.8^{f}
Orange oil	7.7^{e}	8^{f}	7.85^{g}	10^{g}	10^{g}	10^{g}	13^{g}	13.3^{f}	13.2^{h}	10.3^{g}
B. thuringiensis +Orange oil	16.2^{c}	17^{d}	16.6^{e}	20.2^{e}	22.5^{e}	21.4^{e}	24.4^{e}	25^{e}	24.7^{f}	20.9^{e}
B. thuringiensis +Orange oil 160 Gy	50^{b}	52^{c}	51^{cd}	64^{b}	65^{c}	64.5^{b}	66.6^{c}	66.6^{b}	66.6^{c}	60.7^{bc}
B. thuringiensis +Orange oil 320 Gy	52^{b}	55^{b}	53.5^{b}	63.3^{b}	66.6^{bc}	64.95^{b}	69.9^{b}	61^{c}	65.5^{cd}	61.3^{bc}
B. thuringiensis +Orange oil 640 Gy	51^{b}	55^{b}	53^{bc}	63^{b}	68.8^{b}	65.9^{b}	70^{b}	69^{b}	69.5^{b}	62.8^{b}
Azadirachtin	50^{b}	52.2^{bc}	51.1^{cd}	59^{c}	64.4^{c}	61.7^{c}	68.8^{bc}	59^{cd}	63.9^{d}	58.9^{c}
Azadirachtin +Orange oil	50^{b}	50^{c}	50^{d}	52^{d}	55^{d}	53.5^{d}	59^{d}	57^{d}	58^{e}	53.8^{d}
Emamectin benzoate	62.5^{a}	62.5^{a}	62.5^{a}	68.4^{a}	78^{a}	73.29^{a}	75^{a}	74^{a}	74.5^{a}	70.1^{a}
L.S.D$_{0.05}$	2.99	2.75	2.02	2.99	2.04	2.72	2.11	2.88	2.19	3.13

Table 6: Infestation per cent reductions of the pink and spiny bollworms during application by using two spraying equipment with some compounds at 2018 cotton season.

Compounds	% Infestation reductions during application									Seasonal Average
	1st spray			2nd spray			3rd spray			
	7	14	Aver.	7	14	Aver.	7	14	Aver.	
Pneumatic knapsack motor sprayer (Cifarilli)										
B. thuringiensis	7.32^{c}	8.08^{e}	7.7^{e}	13.6^{e}	17.1^{e}	15.4^{e}	20.2^{f}	20.2^{e}	20.2^{e}	14.4^{e}
Orange oil	6.16^{c}	7.7^{e}	6.93^{e}	10.8^{e}	15.5^{e}	13.2^{e}	18.8^{f}	20.2^{e}	19.5^{e}	13.2^{e}
B. thuringiensis +Orange oil	10^{c}	11.1^{e}	10.6^{e}	15.6^{e}	20.2^{e}	17.9^{e}	21^{f}	24.4^{e}	22.7^{e}	17.1^{e}
B. thuringiensis +Orange oil 160 Gy	52^{b}	69.9^{b}	60.9^{bc}	69.9^{bc}	72.2^{bc}	71.1^{bc}	76.6^{cd}	80^{bc}	78.3^{bc}	70.1^{bc}
B. thuringiensis +Orange oil 320 Gy	54^{ab}	72.2^{b}	63.1^{abc}	74^{abc}	78^{ab}	76^{ab}	80^{bc}	85^{ab}	82.5^{ab}	73.9^{ab}
B. thuringiensis +Orange oil 640 Gy	55^{ab}	75^{ab}	65^{abc}	77^{ab}	82^{a}	79.5^{a}	85^{ab}	88.8^{a}	86.9^{a}	77.1^{ab}
Azadirachtin	50^{b}	52.2^{d}	51.1^{d}	54^{d}	56^{d}	55^{d}	60^{e}	58.8^{d}	59.4^{d}	55.2^{d}
Azadirachtin +Orange oil	52^{b}	62.2^{c}	57.1^{cd}	67^{c}	66.6^{c}	66.8^{c}	70^{d}	76^{c}	73^{c}	65.6^{c}
Emamectin benzoate	60^{a}	80^{a}	70^{a}	80^{a}	86^{a}	83^{a}	88.8^{a}	90^{a}	89.4^{a}	80.8^{a}
L.S.D$_{0.05}$	6.89	5.93	6.98	7.58	7.69	7.78	7.88	7.52	7.69	7.74
Hydraulic Matabi sprayer										
B. thuringiensis	7^{b}	7.2^{b}	7.1^{b}	11.1^{c}	15.5^{e}	13.3^{c}	17.7^{e}	17^{e}	17.4^{e}	12.6^{d}
Orange oil	5.5^{b}	6.16^{b}	5.83^{b}	9.9^{c}	13.8^{e}	11.9^{c}	15.5^{e}	17^{e}	16.3^{e}	11.3^{d}
B. thuringiensis +Orange oil	8.08^{b}	8.08^{b}	8.08^{b}	12.2^{c}	16.4^{e}	14.3^{c}	17.7^{e}	20.2^{e}	18.9^{e}	13.8^{d}
B. thuringiensis +Orange oil 160 Gy	47^{a}	53^{a}	50^{a}	60^{a}	58.8^{c}	59.4^{a}	63^{bc}	69^{bc}	66^{bc}	58.5^{ab}
B. thuringiensis +Orange oil 320 Gy	48^{a}	54^{a}	51^{a}	60^{a}	62.2^{bc}	61.1^{a}	65^{abc}	72^{abc}	68.5^{bc}	60.2^{ab}
B. thuringiensis +Orange oil 640 Gy	50^{a}	55^{a}	52.5^{a}	62.2^{a}	65^{ab}	63.6^{a}	69^{ab}	75^{ab}	72^{ab}	62.7^{ab}
Azadirachtin	46^{a}	50^{a}	48^{a}	50^{b}	48^{d}	49^{b}	53.3^{d}	50^{d}	51.7^{d}	49.6^{c}
Azadirachtin +Orange oil	47^{a}	50^{a}	48.5^{a}	60^{a}	58.8^{c}	59.4^{a}	61^{c}	65.5^{c}	63.3^{c}	57.1^{b}
Emamectin benzoate	52^{a}	55^{a}	53.5^{a}	65^{a}	69^{a}	67^{a}	72.2^{a}	80^{a}	76.1^{a}	65.5^{a}
L.S.D$_{0.05}$	6.93	7.28	7.14	7.02	5.68	6.93	6.92	7.84	6.87	7.001

Table 7: Infestation per cent reduction of the pink and spiny bollworms during application by using two spraying equipment with some compounds at 2019 cotton season

Compounds	% Infestation reductions during application									Seasonal Average
	1st spray			2nd spray			3rd spray			
	7	14	Aver.	7	14	Aver.	7	14	Aver.	
Pneumatic knapsack motor sprayer (Cifarilli)										
B. thuringiensis	10^{f}	12^{g}	11^{g}	20.2^{g}	23.9^{g}	22.1^{h}	33.3^{g}	24.4^{g}	28.9^{g}	20.7^{h}
Orange oil	8^{g}	10^{h}	9^{h}	15.5^{h}	20.2^{h}	17.9^{i}	30.3^{h}	22.2^{h}	26.3^{h}	17.7^{i}
B. thuringiensis +Orange oil	15.5^{e}	17.8^{f}	16.7^{f}	24.2^{f}	28.8^{f}	26.5^{g}	37.5^{f}	30.3^{f}	33.9^{f}	25.7^{g}
B. thuringiensis +Orange oil 160 Gy	55^{c}	59^{d}	57^{d}	66.6^{c}	72.2^{cd}	69.4^{d}	72.2^{d}	75^{c}	73.6^{d}	66.7^{d}
B. thuringiensis +Orange oil 320 Gy	56^{c}	62^{c}	59^{c}	67^{c}	75^{c}	71^{c}	76^{c}	78^{b}	77^{c}	69^{c}
B. thuringiensis +Orange oil 640 Gy	60^{b}	65^{b}	62.5^{b}	72.2^{b}	78^{b}	75.1^{b}	79^{b}	82^{a}	80.5^{b}	72.2^{b}
Azadirachtin	52.2^{d}	56^{e}	54.1^{e}	60^{e}	60^{e}	60^{f}	64^{e}	62.8^{e}	63.4^{e}	59.2^{f}
Azadirachtin +Orange oil	53^{d}	55^{e}	54^{e}	64.4^{d}	69.9^{d}	67.2^{d}	72.2^{d}	72.2^{d}	72.2^{d}	64.5^{e}
Emamectin benzoate	78.8^{a}	80.5^{a}	79.7^{a}	85.5^{a}	85.5^{a}	85.5^{a}	87.2^{a}	82.2^{a}	84.7^{a}	83.3^{a}
L.S.D$_{0.05}$	1.49	1.23	1.57	1.88	2.89	2.22	1.49	2.11	1.89	1.49
Hydraulic Matabi sprayer										
B. thuringiensis	9^{e}	10^{f}	9.5^{f}	16^{g}	17^{g}	16.5^{g}	28^{g}	18^{f}	23^{g}	16.3^{h}
Orange oil	7.7^{e}	8^{g}	7.85^{g}	10^{h}	14.4^{h}	12.2^{h}	25^{h}	14^{g}	19.5^{h}	13.2^{i}
B. thuringiensis +Orange oil	13^{d}	15.1^{e}	14.1^{e}	20^{f}	20^{f}	20^{f}	32^{f}	22^{e}	27^{f}	20.4^{g}
B. thuringiensis +Orange oil 160 Gy	50^{c}	52^{c}	51^{cd}	64^{c}	65^{c}	64.5^{c}	66.6^{c}	66.6^{b}	66.6^{c}	60.7^{d}
B. thuringiensis +Orange oil 320 Gy	52^{b}	53^{c}	52.5^{c}	63.3^{c}	66.6^{b}	64.9^{c}	68.8^{b}	69.9^{a}	69.4^{b}	62.3^{c}
B. thuringiensis +Orange oil 640 Gy	52^{b}	56^{b}	54^{b}	65.5^{b}	69.9^{a}	67.7^{b}	70^{b}	70^{a}	70^{b}	63.9^{b}
Azadirachtin	50^{c}	50^{b}	50^{d}	50^{e}	55^{e}	52.5^{e}	60^{e}	59^{d}	59.5^{e}	54^{f}
Azadirachtin +Orange oil	50^{c}	52^{c}	51^{cd}	61^{d}	62.2^{d}	61.6^{d}	64^{d}	65^{c}	64.5^{d}	59^{e}
Emamectin benzoate	62.5^{a}	68.8^{a}	65.7^{a}	72.2^{a}	70^{a}	71.1	77.2^{a}	70^{a}	73.6^{a}	70.1^{a}
L.S.D$_{0.05}$	1.81	1.52	1.49	1.21	1.89	1.49	1.46	2.21	2.56	1.49

Cotton seed bug

a. Population

Table (8 & 9) showed by using two spraying equipment of Pneumatic knapsack motor sprayer and Hydraulic Matabi sprayer; the first sprayer showed the higher efficacy on the application than the second one. Treatments of emamectin benzoate as well as *B. thuringiensis* + orange oil 640 Gy nearly were considered the best treatments caused reduction in seed bug population, followed by *B. thuringiensis* + 320 Gy and *B. thuringiensis* + 160 Gy that had potentiating efficacy on cotton seed bug population than its reduction on cotton seed bug without exposing orange oil to gamma doses.

Table 8: Per cent reduction in cottonseed bug populations during application by using two spraying equipment with some compounds at 2018 cotton season

Compounds	% Reduction of cotton seed bug populations during application									Seasonal Average
	1st spray			2nd spray			3rd spray			
	7	14	Aver.	7	14	Aver.	7	14	Aver.	
Pneumatic knapsack motor sprayer (Cifarilli)										
B. thuringiensis	20^{d}	25^{d}	22.5^{d}	25^{d}	35^{d}	30^{d}	11.8^{f}	10^{e}	10.9^{e}	21.1^{d}
Orange oil	22^{cd}	30^{cd}	26^{d}	28^{d}	38^{d}	33^{d}	15.5^{ef}	11^{e}	13.3^{e}	24.1^{d}
B. thuringiensis +Orange oil	22^{cd}	35^{c}	28.5^{cd}	30^{d}	40^{d}	35^{d}	22.2^{e}	13^{e}	17.6^{e}	27.03^{d}
B. thuringiensis +Orange oil 160 Gy	32^{b}	45^{b}	38.5^{b}	55^{c}	68.8^{abc}	61.9^{bc}	59.9^{c}	60^{c}	59.95^{c}	53.5^{bc}
B. thuringiensis +Orange oil 320 Gy	32^{b}	51^{ab}	41.5^{b}	57^{bc}	72.2^{ab}	64.6^{abc}	69^{b}	68.8^{b}	68.9^{b}	58.3^{b}
B. thuringiensis +Orange oil 640 Gy	48^{a}	58.8^{a}	53.4^{a}	63.3^{ab}	75.5^{a}	69.4^{ab}	80^{a}	78^{a}	79^{a}	67.3^{a}
Azadirachtin	25^{bcd}	45^{b}	35^{bc}	52.5^{c}	62.5^{c}	57.5^{c}	47.1^{d}	47.5^{d}	47.3^{d}	46.6^{c}
Azadirachtin +Orange oil	30^{bc}	44.4^{b}	37.2^{b}	52.5^{c}	65.5^{bc}	59^{c}	51.1^{d}	50^{d}	50.6^{d}	48.9^{c}
Emamectin benzoate	48^{a}	56.6^{a}	52.3^{a}	65.3^{a}	76.6^{a}	70.95^{a}	80^{a}	79^{a}	79.5^{a}	67.6^{a}
L.S.D$_{0.05}$	7.84	7.49	7.88	7.58	8.29	8.16	8.29	8.54	8.39	8.32
Hydraulic Matabi sprayer										
B. thuringiensis	18^{d}	22^{c}	20^{d}	21^{b}	29^{b}	25^{b}	7.7^{c}	7.7^{d}	7.7^{d}	17.6^{d}
Orange oil	20^{cd}	23^{c}	21.5^{d}	23^{b}	30^{b}	26.5^{b}	13^{c}	8.88^{d}	10.94^{d}	19.6^{d}
B. thuringiensis +Orange oil	20^{cd}	25^{c}	22.5^{cd}	25^{b}	33^{b}	29^{b}	16.6^{c}	10^{d}	13.3^{d}	21.6^{d}
B. thuringiensis +Orange oil 160 Gy	30^{b}	43^{ab}	36.5^{ab}	50^{a}	62.2^{a}	56.1^{a}	50^{b}	50^{b}	50^{b}	47.5^{abc}
B. thuringiensis +Orange oil 320 Gy	30^{b}	44^{ab}	37^{ab}	50^{a}	60^{a}	55^{a}	62.2^{a}	63.3^{a}	62.8^{a}	51.6^{ab}
B. thuringiensis +Orange oil 640 Gy	40^{a}	50^{a}	45^{a}	52.2^{a}	58.8^{a}	55.5^{a}	65^{a}	64.4^{a}	64.7^{a}	55.1^{a}
Azadirachtin	24^{bcd}	38^{b}	31^{bc}	49^{a}	59^{a}	54^{a}	42^{b}	40^{c}	41^{c}	42^{c}
Azadirachtin +Orange oil	28^{bc}	40^{b}	34^{b}	49^{a}	60^{a}	54.5^{a}	47^{b}	48^{bc}	47.5^{bc}	45.3^{bc}
Emamectin benzoate	40^{a}	50^{a}	45^{a}	50^{a}	60^{a}	55^{a}	65^{a}	65^{a}	65^{a}	55^{a}
L.S.D$_{0.05}$	7.49	7.59	8.64	8.73	8.39	7.69	8.54	8.39	8.88	8.48

The mixture of azadirachtin + orange oil had potentiating effect on cotton seed efficacy compared to the same compound when used singly. Also, *B. thuringiensis* + orange oil had the best efficacy compared to use each of them singly.

Table 9: Per cent reduction in cotton seed bug populations during application by using two spraying equipment with some compounds at 2019 cotton season

Compounds	% Reduction of cotton seed bug populations during application									Seasonal Average
	1st spray			2nd spray			3rd spray			
	7	14	Aver.	7	14	Aver.	7	14	Aver.	
Pneumatic knapsack motor sprayer (Cifarilli)										
B. thuringiensis	25^{d}	30^{f}	27.5^{e}	35^{d}	40^{e}	37.5^{e}	14^{d}	12^{e}	13^{e}	26^{e}
Orange oil	28^{cd}	35^{ef}	31.5^{e}	38^{d}	40^{e}	39^{e}	17^{d}	15^{e}	16^{e}	28.8^{e}
B. thuringiensis +Orange oil	28^{cd}	39de	33.5^{de}	38^{d}	45^{e}	41.5^{e}	18^{d}	18.8^{e}	18.4^{e}	31.1^{e}
B. thuringiensis +Orange oil 160 Gy	35^{bc}	49.9^{c}	42.5^{bc}	62.2^{bc}	64.4^{cd}	63.3^{c}	72.2^{b}	53^{c}	62.6^{bc}	56.1^{bc}
B. thuringiensis +Orange oil 320 Gy	35^{bc}	52.2^{bc}	43.6^{bc}	69.9^{ab}	70^{bc}	69.95^{b}	76^{ab}	63^{b}	69.5^{b}	61.02^{b}
B. thuringiensis +Orange oil 640 Gy	38^{bc}	59.9^{ab}	48.95^{ab}	68.8^{ab}	75.5^{ab}	72.2^{ab}	80^{a}	76.6^{a}	78.3^{a}	66.5^{a}
Azadirachtin	35^{bc}	45^{cd}	40^{cd}	55^{c}	58^{d}	56.5^{d}	62.2^{c}	45^{d}	53.6^{d}	50.03^{d}
Azadirachtin +Orange oil	35^{bc}	47^{cd}	41^{c}	58^{c}	62.2^{cd}	60.1^{cd}	69.9^{b}	48^{cd}	58.95^{cd}	53.4^{cd}
Emamectin benzoate	48^{a}	62.2^{a}	55.1^{a}	74.4^{a}	79^{a}	76.7^{a}	82^{a}	82^{a}	82^{a}	71.3^{a}
L.S.D$_{0.05}$	6.802	8.41	7.001	8.64	7.69	5.77	6.93	6.82	7.78	5.47
Hydraulic Matabi sprayer										
B. thuringiensis	24^{c}	27^{f}	25.5^{e}	29^{d}	33^{f}	31^{e}	10^{e}	7.7^{d}	8.85^{d}	21.8^{d}
Orange oil	25^{c}	31^{ef}	28de	32^{d}	33^{f}	32.5^{e}	13^{e}	10.2^{d}	11.6^{d}	24.03^{d}
B. thuringiensis +Orange oil	25^{c}	35de	30^{cde}	34^{d}	39^{e}	36.5^{e}	15^{e}	12.2^{d}	13.6^{d}	26.7^{d}
B. thuringiensis +Orange oil 160 Gy	32^{ab}	45^{b}	38.5^{ab}	47^{bc}	54.4^{cd}	50.7^{cd}	62.2^{bc}	47.7^{b}	54.95^{b}	48.1^{c}
B. thuringiensis +Orange oil 320 Gy	30^{b}	45^{b}	37.5^{abc}	49^{bc}	60^{bc}	54.5^{bc}	64.4^{bc}	50^{b}	57.2^{b}	49.7^{bc}
B. thuringiensis +Orange oil 640 Gy	34^{ab}	51.1^{a}	42.6^{ab}	52.2^{b}	65^{ab}	58.6^{b}	68.8^{ab}	62.2^{a}	65.5^{a}	55.6^{ab}
Azadirachtin	30^{b}	39^{cd}	34.5^{bcd}	44^{c}	49^{d}	46.5^{d}	53^{d}	40^{c}	46.5^{c}	42.5^{c}
Azadirachtin +Orange oil	32^{ab}	40^{c}	36^{bcd}	45^{bc}	52.2^{d}	48.6^{cd}	58.8^{cd}	45^{bc}	51.9^{bc}	45.5^{c}
Emamectin benzoate	35^{a}	54.4^{a}	44.7^{a}	63.3^{a}	68.8^{a}	66.1^{a}	72.2^{a}	65.5^{a}	68.9^{a}	59.9^{a}
L.S.D$_{0.05}$	3.68	4.16	7.69	6.92	6.92	7.04	6.92	5.55	5.88	7.02

a. Infestation

The previous trend was also appeared in cotton seed bug infestation reduction as in Table (10 & 11), but *O. hyalinipennis* infestation reductions had values higher than population.

Table 10: Per cent reduction in cotton seed bug infestations during application by using two spraying equipment with some compounds at 2018 cotton season

Compounds	% Reduction of cotton seed bug infestations during application									Seasonal Average
	1st spray			2nd spray			3rd spray			
	7	14	Aver.	7	14	Aver.	7	14	Aver.	
Pneumatic knapsack motor sprayer (Cifarilli)										
B. thuringiensis	25 c	40 d	32.5 f	50 e	25 e	37.5 f	20 h	7.7 f	13.9 f	27.9 f
Orange oil	25 c	40 d	32.5 f	52.2de	28 de	40.1 f	25 g	12.2ef	18.6ef	30.4ef
B. thuringiensis +Orange oil	28 c	44.4cd	36.2 e	62.2abc	33 d	47.6 e	30 f	15 e	22.5 e	35.4 e
B. thuringiensis +Orange oil 160 Gy	25 c	55.5ab	40.3cd	55cde	70 b	62.5 c	75cd	70 b	72.5bc	58.4 c
B. thuringiensis +Orange oil 320 Gy	35 b	55.5ab	45.3 b	58.8bcd	72.2 b	65.5bc	78bc	72.2 b	75.1 b	61.9bc
B. thuringiensis +Orange oil 640 Gy	40 a	58.8 a	49.4 a	63.3 ab	75.5 ab	69.4 ab	80 b	75.5ab	77.8ab	65.5ab
Azadirachtin	25 c	50bc	37.5de	50 e	61.3 c	55.7 d	65.4e	50 d	57.7 d	50.3 d
Azadirachtin +Orange oil	32.2b	52.2 b	42.2cd	55cde	69.9 b	62.5 c	72.2d	60 c	66.1 c	56.9 c
Emamectin benzoate	40 a	60.6 a	50.3 a	68.8 a	78.8 a	73.8 a	85 a	80 a	82.5 a	68.9 a
L.S.D$_{0.05}$	4.04	5.75	3.401	6.93	5.61	5.704	4.04	5.79	6.93	5.86
Hydraulic matabi sprayer										
B. thuringiensis	22bc	38 c	30 b	40bc	19 f	29.5 f	15 d	7.7 e	11.4 d	23.6 f
Orange oil	22bc	38 c	30 b	42bc	22 f	32ef	16 d	8.88 e	12.4 d	24.8ef
B. thuringiensis +Orange oil	24bc	37 c	30.5 b	42bc	29 e	35.5 e	20 d	10 e	15 d	27 e
B. thuringiensis +Orange oil 160 Gy	20 c	42 b	31 b	40bc	56.6 c	48.3 cd	62.2bc	44 c	53.1bc	44.1 cd
B. thuringiensis +Orange oil 320 Gy	25 b	42 b	33.5ab	43abc	60.6bc	51.8bc	65abc	45 c	55bc	46.8 c
B. thuringiensis +Orange oil 640 Gy	30 a	42 b	36 b	45.5ab	65.5ab	55.5ab	68ab	50 b	59ab	50.2 b
Azadirachtin	23bc	40bc	31.5 b	37 c	50 d	43.5 d	59 c	40 d	49.5 c	41.5 d
Azadirachtin +Orange oil	25 b	40bc	32.5 b	40bc	57 c	48.5 cd	63bc	43 cd	53bc	44.7 cd
Emamectin benzoate	30 a	48.8 a	39.4 a	50 a	70 a	60 a	70 a	55 a	62.5 a	53.9 a
L.S.D$_{0.05}$	3.87	3.401	5.68	6.93	5.81	5.61	5.64	3.58	5.64	3.09

Table 11: Per cent reduction in cotton seed bug infestations during application by using two spraying equipment with some compounds at 2019 cotton season

Compounds	% Reduction of cotton seed bug infestations during application									Seasonal Average
	1st spray			2nd spray			3rd spray			
	7	14	Aver.	7	14	Aver.	7	14	Aver.	
Pneumatic knapsack motor sprayer (Cifarilli)										
B. thuringiensis	25 e	30 e	27.5 e	40 d	45 f	42.5 e	40 f	30 f	35 g	35 g
Orange oil	28de	34 e	31 de	42.2d	49ef	45.6 e	45ef	36.6e	40.8 f	39.1fg
B. thuringiensis +Orange oil	33.3d	42.2d	37.8 d	46.6d	53 e	49.8 e	49.9de	38.8e	44.4 f	43.9 f
B. thuringiensis +Orange oil 160 Gy	50 c	58bc	54 c	72.2bc	69bc	70.6bcd	69 b	55 cd	62 d	62.2 cd
B. thuringiensis +Orange oil 320 Gy	60 b	65ab	62.5 b	72.2bc	72.2 b	72.2bc	79.9 a	58 c	68.95c	67.9bc
B. thuringiensis +Orange oil 640 Gy	69 a	69 a	69ab	78.2ab	79 a	78.6ab	82.2 a	70 b	76.1 b	74.6ab
Azadirachtin	45 c	55 c	50 c	65 c	60 d	62.5 d	55 cd	35ef	45 f	52.5 e
Azadirachtin +Orange oil	45 c	58bc	51.5 c	69.9bc	65 cd	67.5 cd	60 c	50 d	55 e	58de
Emamectin benzoate	72.2a	72.2a	72.2 a	82.2 a	85 a	83.6 a	87 a	80 a	83.5 a	79.8 a
L.S.D$_{0.05}$	5.68	7.69	7.14	7.84	6.78	8.29	6.89	5.94	5.75	6.87
Hydraulic Matabi sprayer										
B. thuringiensis	22 e	28 e	25 c	35 d	39 f	37 e	30 f	19 g	24.5 f	28.8 f
Orange oil	22 e	31 de	26.5 c	37 d	42.2 f	39.6 e	35ef	22fg	28.5 f	31.5ef
B. thuringiensis +Orange oil	28 d	36.6d	32.3 c	38 d	44.4ef	41.2 e	38 e	25 f	31.5ef	35 e
B. thuringiensis +Orange oil 160 Gy	45 c	54.4bc	49.7 b	65bc	58bc	61.5bcd	53.3cd	43 cd	48.2 c	53.1 c
B. thuringiensis +Orange oil 320 Gy	50bc	55bc	52.5 b	65bc	62.2ab	63.6abc	59bc	45 c	52bc	56.03bc
B. thuringiensis +Orange oil 640 Gy	54ab	59 ab	56.5ab	68.8ab	66.6 a	67.7ab	63.3ab	55 b	59.2ab	61.1ab
Azadirachtin	44 c	50 c	47 b	61 c	50 de	55.5 d	46.6 d	30 e	38.3 de	46.9 d
Azadirachtin +Orange oil	44 c	54.4bc	49.2 b	64.4bc	53 cd	58.7 cd	50 d	40 d	45 cd	50.9 cd
Emamectin benzoate	58.8a	65.5 a	62.2 a	73 a	69 a	71 a	66.6 a	60 a	63.3 a	65.5 a
L.S.D$_{0.05}$	5.59	6.97	8.64	7.04	6.86	7.14	6.81	4.04	8.46	5.86

Cotton crop parameters

Cotton crop assessment (seed numbers, lint and seed weights) for each 100 opened cotton bolls is an important step to obvious the effective of nine treatments used on the quality of cotton crop as demonstrated in Table (12 & 13) that mentioned the role of gamma radiation treatments and two spraying equipment for potentiating compounds used to purpose of crop quality enhancement.

By using two spraying equipment, the Pneumatic knapsack motor sprayer (cifarilli) had the role for enhancing the cotton crop assessment than Hydraulic Matabi sprayer during the two cotton seasons (2018 &2019).

a. Seed numbers

Treatment of *B. thuringiensis* + orange oil 640 Gy caused increasing in cotton seed numbers to 1340 & 1290 seeds and 1240 & 1188 seeds/ opened 100 bolls as affected by Pneumatic knapsack motor sprayer (cifarilli) and Hydraulic Matabi sprayer, respectively during 2018 & 2019 cotton seasons compared to untreated 989 & 954.5 seeds/ 100

opened boll at 2018 & 2019 cotton seasons, respectively. Also, *B. thuringiensis* + orange oil 320 Gy and *B. thuringiensis* + orange oil 160 Gy had increased the cotton seed compared to untreated, followed by compounds of azadirachtin + orange oil, azadirachtin, *B. thuringiensis* + orange oil, *B. thuringiensis* and then orange oil singly (Table 12 &13).

b. Lint weight (g)

B. thuringiensis + orange oil 640 Gy had the highest lint weight/100 opened boll, it was 90 & 82 g/100 opened bolls as a result of application by using Pneumatic knapsack motor sprayer (cifarilli) and 84 & 78 g for Hydraulic Matabi sprayer during 2018 & 2019 cotton seasons compared with untreated (50.2 & 46.4 g for 2018 & 2019 cotton seasons), followed by *B. thuringiensis* + orange oil 320 Gy, *B. thuringiensis* + orange oil 160 Gy, azadirachtin + orange oil, azadirachtin, *B. thuringiensis* + orange oil, *B. thuringiensis* and then orange oil (Table 12 & 13).

c. Seed weight (g)

B. thuringiensis + orange oil 640 Gy was the best treatments increased the seed weight that had 120 & 99 g cotton seed weights for Pneumatic knapsack motor sprayer (cifarilli) and 100 & 97 gm for Hydraulic Matabi sprayer during 2018 & 2019 cotton seasons comparing with 86.6 &75.5 g for untreated cotton seed at 2018 and 2019 cotton seasons (Table 12 &13). In addition, *B. thuringiensis* + orange oil 320 Gy increased the seed weight at two seasons, followed by *B. thuringiensis* + orange oil 160 Gy, azadirachtin + orange oil, azadirachtin, *B. thuringiensis* + orange oil, *B. thuringiensis* and orange oil.

Table 12: Cotton crop parameters as affected by some compounds applications with using two spraying equipment at 2018 cotton season

Compounds	Average weights (gm/100boll)					
	Seed numbers	Comparison With untreated	Lint weights	Comparison With untreated	Seed weights	Comparison With untreated
Pneumatic knapsack motor sprayer (Cifarilli)						
Untreated	989 ^{d}	- ^{d}	50.2 ^{f}	- ^{f}	86.6 ^{f}	- ^{h}
B. thuringiensis	1100 ^{c}	+111 ^{c}	65 ^{e}	+14.8 ^{e}	95 ^{def}	+8.4 ^{f}
Orange oil	1000 ^{d}	+11 ^{d}	55 ^{f}	+4.8 ^{f}	90 ^{ef}	+3.4 ^{g}
B. thuringiensis + Orange oil	1210 ^{b}	+221 ^{b}	68 ^{e}	+17.8 ^{e}	96 ^{def}	+9.4 ^{f}
B. thuringiensis + Orange oil 160 Gy	1285 ^{ab}	+269 ^{ab}	80 ^{b}	+29.8 ^{b}	108 ^{bc}	+21.4 ^{c}
B. thuringiensis + Orange oil 320 Gy	1335 ^{a}	+346 ^{a}	86 ^{a}	+35.8 ^{a}	115 ^{ab}	+28.4 ^{b}
B. thuringiensis + Orange oil 640 Gy	1340 ^{a}	+351 ^{a}	90 ^{a}	+39.8 ^{a}	120 ^{a}	+33.4 ^{a}
Azadirachtin	1220 ^{b}	+231 ^{b}	70 ^{de}	+19.8 ^{de}	97 ^{de}	+10.4 ^{f}
Azadirachtin +Orange oil	1280 ^{ab}	+291 ^{ab}	78 ^{bc}	+27.8 ^{bc}	104 ^{cd}	+17.4 ^{d}
Emamectin benzoate	1230 ^{b}	+241 ^{b}	74 ^{cd}	+23.8 ^{cd}	100 ^{cde}	+13.4 ^{e}
L.S.D$_{0.05}$	68.6	81.6	5.60	5.49	9.19	2.49
Hydraulic Matabi sprayer						
Untreated	989 ^{e}	- ^{c}	50.2 ^{f}	- ^{j}	86.6 ^{e}	- ^{g}
B. thuringiensis	1000 ^{de}	+1 1 ^{c}	54 ^{ef}	+3.8 ^{h}	87 ^{e}	+0.4 ^{fg}
Orange oil	990 ^{e}	+1 ^{c}	52 ^{f}	+1.8 ^{i}	86.8 ^{e}	+0.2 ^{fg}
B. thuringiensis + Orange oil	1065 ^{cde}	+76 ^{b}	56 ^{def}	+5.8 ^{g}	88 ^{de}	+1.4 ^{ef}
B. thuringiensis + Orange oil 160 Gy	1198 ^{ab}	+209 ^{a}	74 ^{bc}	+23.8 ^{c}	94 ^{bc}	+7.4 ^{c}
B. thuringiensis + Orange oil 320 Gy	1220 ^{a}	+231 ^{a}	80 ^{ab}	+29.8 ^{b}	98 ^{ab}	+11.4 ^{b}
B. thuringiensis + Orange oil 640 Gy	1240 ^{a}	+251 ^{a}	84 ^{a}	+33.8 ^{a}	100 ^{a}	+13.4 ^{a}
Azadirachtin	1080 ^{cd}	+91 ^{b}	60 ^{de}	+9.8 ^{f}	89 ^{cde}	+2.4 ^{de}
Azadirachtin +Orange oil	1120 ^{bc}	+131 ^{b}	70 ^{c}	+19.8 ^{d}	93 ^{bcd}	+6.4 ^{c}
Emamectin benzoate	1100 ^{c}	+111 ^{b}	63 ^{d}	+12.8 ^{e}	90 ^{cde}	+3.4 ^{d}
L.S.D$_{0.05}$	78.2	53.3	6.69	1.58	5.32	1.19

Table 13: Cotton crop parameters as affected by some compounds applications with using two sprayer equipment at 2019 cotton season

Compounds	Average weights (gm/100boll)					
	Seed numbers	Comparison With untreated	Lint weights	Comparison With untreated	Seed weights	Comparison With untreated
Pneumatic knapsack motor sprayer (Cifarilli)						
Untreated	954.5 ^{f}	- ^{j}	46.4 ^{i}	- ^{i}	75.5 ^{d}	- ^{d}
B. thuringiensis	990 ^{def}	+35.5 ^{h}	51 ^{gh}	+4.6 ^{h}	82 ^{c}	+6.5 ^{c}
Orange oil	975 ^{ef}	+20.5 ^{i}	48 ^{hi}	+1.6 ^{i}	77.5 ^{d}	+2 ^{d}
B. thuringiensis + Orange oil	1010 ^{cdef}	+55.5 ^{g}	53 ^{fg}	+6.6 ^{g}	83 ^{c}	+7.5 ^{c}
B. thuringiensis + Orange oil 160 Gy	1100 ^{b}	+145.5 ^{c}	69 ^{c}	+22.6 ^{c}	91 ^{b}	+15.5 ^{b}
B. thuringiensis + Orange oil 320 Gy	1240 ^{a}	+285.5 ^{b}	78 ^{b}	+31.6 ^{b}	96 ^{a}	+20.5 ^{a}
B. thuringiensis + Orange oil 640 Gy	1290 ^{a}	+335.5 ^{a}	82 ^{a}	+35.6 ^{a}	99 ^{a}	+23.5 ^{a}
Azadirachtin	1030 ^{cde}	+75.5 ^{f}	55 ^{f}	+8.6 ^{f}	84 ^{c}	+8.5 ^{c}
Azadirachtin +Orange oil	1065 ^{bc}	+110.5 ^{d}	65 ^{d}	+18.6 ^{d}	90 ^{b}	+14.5 ^{b}
Emamectin benzoate	1045 ^{bcd}	+90.5 ^{e}	59 ^{e}	+12.6 ^{e}	88 ^{b}	+12.5 ^{b}
L.S.D$_{0.05}$	54.7	6.46	3.36	1.67	3.44	3.14
Hydraulic Matabi sprayer						
Untreated	954.5 ^{d}	- ^{i}	46.4 ^{e}	- ^{g}	75.5 ^{f}	- ^{f}
B. thuringiensis	985 ^{cd}	+30.5 ^{g}	49 ^{de}	+2.6 ^{efg}	78 ^{ef}	+2.5 ^{e}
Orange oil	965 ^{cd}	+10.5 ^{h}	47 ^{e}	+0.6 ^{fg}	75.5 ^{f}	0 ^{f}

B. thuringiensis + Orange oil	999 cd	+44.5 f	50 de	+3.6 def	79 ef	+3.5 e
B. thuringiensis + Orange oil 160 Gy	1040 c	+85.5 c	61 c	+14.6 c	89 bc	+13.5 c
B. thuringiensis + Orange oil 320 Gy	1120 b	+165.5 b	72 b	+25.6 b	94 ab	+18.5 b
B. thuringiensis + Orange oil 640 Gy	1188 a	+233.5 a	78 a	+31.6 a	97 a	+21.5 a
Azadirachtin	1000 cd	+45.5 f	52 de	+5.6 de	80 ef	+4.5 e
Azadirachtin +Orange oil	1025 cd	+70.5 d	59 c	+12.6 c	87 cd	+11.5 c
Emamectin benzoate	1015 cd	+60.5 e	53 d	+6.6 d	83 de	+7.5 d
L.S.D$_{0.05}$	66.6	7.33	5.13	3.13	5.41	2.26

It can be classified the nine treatments used efficacy against three cotton boll pests (*P. gossypiella, E. insulana* and *O. hyalinipennis*) on the field application to four categories as follows:

1. First category that had the highly efficacy on three tested pests than other treatments. It's were emamectin benzoate and *B. thuringiensis* + orange oil 640 Gy.
2. Second category that had a high efficacy on tested pests but slightly decreased comparing with first category. It's were *B. thuringiensis* + orange oil 320 Gy and *B. thuringiensis* + orange oil 160 Gy.
3. Third category had intermediate efficacy on the tested pests. It's were azadirachtin + orange oil and azadirachtin.
4. Fourth category that had lower efficacy on tested pests. It's were *B. thuringiensis* or orange oil when used singly.

Table 14: Spraying coverage on cotton plants by certain sprayer equipment

Treatments	Droplets number (N/Cm^2)			Volume mean droplets (VMD) µm		
	Upper level	Middle level	Lower level	Upper level	Middle level	Lower level
	Pneumatic Knapsack motor sprayer (Cifarilli)					
B. thuringiensis	125 g	120 h	110 g	152 b	150 b	148 b
Orange oil	115 h	110 i	105 h	157 a	155 a	155 a
B. thuringiensis + Orange oil	135 f	128 g	125 f	150b c	150 b	148 b
B. thuringiensis + Orange oil 160 Gy	159 d	150 d	140 d	140 d	140.3 d	140 de
B. thuringiensis + Orange oil 320 Gy	164 c	155 c	149 c	140 d	144 c	144 c
B. thuringiensis + Orange oil 640 Gy	180 b	170.3 b	160 b	131 e	135 e	135 f
Azadirachtin	147 e	135 f	127 f	140 d	139 d	138 ef
Azadirachtin +Orange oil	150 e	140 e	130 e	148 c	145 c	142 cd
Emamectin benzoate	200 a	190 a	180 a	124 f	125 f	127 g
L.S.D$_{0.05}$	3.462	1.932	2.612	2.970	2.057	3.134
	Hydraulic Matabi sprayer					
B. thuringiensis	120 g	125 g	115 g	160 b	160 a	155 b
Orange oil	110 h	118 h	109 h	178 a	157 b	170 a
B. thuringiensis + Orange oil	130 f	139 f	125 f	157 bc	155 bc	155 b
B. thuringiensis + Orange oil 160 Gy	159 d	165 d	155 c	150 e	150 d	150 d
B. thuringiensis + Orange oil 320 Gy	170.7 c	175 c	160 b	150 e	145 e	144 e
B. thuringiensis + Orange oil 640 Gy	176 b	180 b	160 b	139 f	135 f	133 f
Azadirachtin	150 e	155 e	145 e	155 cd	154 c	153 bc
Azadirachtin +Orange oil	158 d	163 d	150 d	153 de	153 c	151 cd
Emamectin benzoate	180 a	190 a	170 a	132 g	130 g	130 g
L.S.D$_{0.05}$	3.368	2.564	2.998	3.462	2.849	2.289

Spraying compounds coverage on cotton leaves

Data in Table (14) showed that droplets size and numbers were ranged from 125 to 150 µm and 110 to 190 N/cm^2 for Pneumatic Knapsack motor sprayer (Cifarilli) uses; while, it ranged between 130-168 µm and 112-180 N/cm^2 for size and droplet numbers when Hydraulic Matabi sprayer used.

Data in Table (15) indicated that, in general all the tested spraying equipment gave satisfactory coverage on cotton crop; i.e. more than 50 droplets/ cm^2, and droplet sizes ranged from 124 to 178 µm (VMD). Meanwhile, the difference in the mortality percentage among treatments was due to the differences mode of action belonging to bio-agent compounds and spraying equipment kind. The same table obvious the spraying coverage homogeneity that was the best in case of Pneumatic Knapsack motor sprayer (Cifarilli) followed by Hydraulic Matabi sprayer. Also, there was no phytotoxic effect on cotton leaves after application treatments; also, there was no change in the leaves color, leaf curling or flaming up phenomena. The Pneumatic Knapsack motor sprayer performance rate was 12 fed. /day; it was the best equipment, but the lower performance rate was Rotary Matabi sprayer since it could spray only 3.46 fed. /day.

Data in Table (16) showed that lost spray percentages among compounds recommended doses were ranged between 8-10.5 % from the total spray volume by using Pneumatic Knapsack motor sprayer (Cifarilli). While, ranged between 14.2-16.6% for Hydraulic Matabi sprayer.

Table 15: Treatments spray quality by certain sprayer equipment

Treatments	Spray quality= VMD/N/cm^2= degree of homogeneity					
	Pneumatic Knapsack motor sprayer (Cifarilli)			Hydraulic Matabi sprayer		
	Upper level	Middle level	Lower level	Upper level	Middle level	Lower level
B. thuringiensis	1.2^{ab}	1.25^{a}	1.29^{a}	1.3^{ab}	1.28^{a}	1.35^{a}
Orange oil	1.37^{a}	1.4^{a}	1.48^{a}	1.6^{a}	1.3^{a}	1.56^{a}
B. thuringiensis + Orange oil	1.1^{ab}	1.17^{a}	0.83^{a}	1.2^{ab}	1.1^{a}	1.2^{a}
B. thuringiensis + Orange oil 160 Gy	0.88^{ab}	0.93^{a}	1^{a}	0.96^{ab}	0.9^{a}	0.97^{a}
B. thuringiensis + Orange oil 320 Gy	0.83^{ab}	0.93^{a}	0.97^{a}	0.88^{ab}	0.83^{a}	0.9^{a}
B. thuringiensis + Orange oil 640 Gy	0.73^{ab}	0.79^{a}	0.9^{a}	0.79^{ab}	0.75^{a}	0.83^{a}
Azadirachtin	0.95^{ab}	1.03^{a}	1.09^{a}	1.04^{ab}	0.99^{a}	1.06^{a}
Azadirachtin +Orange oil	0.99^{ab}	1.04^{a}	1.09^{a}	0.97^{ab}	0.94^{a}	1^{a}
Emamectin benzoate	0.62^{b}	0.66^{a}	0.71^{a}	0.73^{b}	0.68^{a}	0.76^{a}
L.S.D$_{0.05}$	0.571	0.898	0.859	0.758	0.744	0.849

The spray height is constant ~ 0.5 meter in all treatments
VMD= Volume mean diameter, N/cm^2= Number of droplets/cm^2

Table 16: Treatments lost spray by certain sprayer equipment

Treatments	Lost spray				
	On plants		On ground		% (N/Cm^2) on ground
	(N/Cm^2)	(VMD)	(N/Cm^2)	(VMD)	(N/Cm^2)
	Pneumatic Knapsack motor sprayer (Cifarilli)				
B. thuringiensis	120^{g}	150^{b}	36^{f}	170^{b}	10.2^{a}
Orange oil	110^{h}	155^{a}	35^{g}	175^{a}	10.5^{a}
B. thuringiensis + Orange oil	129^{f}	149^{b}	38^{e}	166^{d}	10^{a}
B. thuringiensis + Orange oil 160 Gy	150^{d}	140^{e}	42^{c}	168^{c}	9.1^{b}
B. thuringiensis + Orange oil 320 Gy	156^{c}	142^{d}	42^{c}	176^{a}	8.9^{c}
B. thuringiensis + Orange oil 640 Gy	170^{b}	133^{f}	43^{b}	171^{b}	8.4^{c}
Azadirachtin	136^{e}	139^{e}	40^{d}	168^{c}	9.7^{b}
Azadirachtin +Orange oil	140^{e}	145^{c}	39^{d}	165^{d}	9.5^{b}
Emamectin benzoate	190^{a}	125^{g}	46^{a}	160^{e}	8^{c}
L.S.D$_{0.05}$	3.33	2.963	2.163	3.462	1.221
	Hydraulic Matabi sprayer				
B. thuringiensis	120^{h}	158^{b}	59^{f}	163^{b}	16.3^{a}
Orange oil	112^{i}	168^{a}	56^{g}	167^{a}	16.6^{a}
B. thuringiensis + Orange oil	131^{g}	156^{c}	63^{e}	160^{c}	16^{a}
B. thuringiensis + Orange oil 160 Gy	160^{d}	151^{e}	73^{c}	161^{c}	15.2^{b}
B. thuringiensis + Orange oil 320 Gy	169^{c}	146^{f}	76^{b}	151^{f}	15^{b}
B. thuringiensis + Orange oil 640 Gy	172^{b}	135^{g}	76^{b}	157^{d}	14.7
Azadirachtin	150^{f}	154^{d}	71^{d}	154	15.8^{b}
Azadirachtin +Orange oil	157^{e}	152^{e}	73^{c}	157^{d}	16^{a}
Emamectin benzoate	180^{a}	130^{h}	77^{a}	155^{e}	14.2^{c}
L.S.D$_{0.05}$	3.368	2.998	2.289	3.462	1.212

(N/Cm^2)= Droplets number (VMD) =Volume mean droplets (μm)

Gamma doses contribute for improving the efficacies of the orange oil when it's exposed to gamma radiation doses of 160, 320 & 640 Gy and mixed with *B. thuringiensis* for each dose. Previous studies agree with our current work as [19] conducted the field trial to assess the bio-efficacy of emamectin benzoate, spinosad and endoxacarb against bollworms larval population during 2002-2003 cotton season. It was mentioned that damage due to bollworms was least in emamectin benzoate which resulted into more number of good opened bolls with highest seed cotton yield. While, [6] carried out the field experiment during the two cotton seasons (2004 and 2005) and stated that Dipel-2x efficacy was increased gradually with gamma irradiation from 5 to 80 Gy. Also, the treatments increased lint and seed weights (gm/100bolls). In addition, [7] concluded that emamectin benzoate gave deleterious effect on the most biological and prediction aspects of *P. gossypiella*. [20] assessed the resistance of *H. armigera* field population to spinetoram, chlorantraniliprole, flubendiamide and emamectin benzoate; it was showed that resistance to spinosad and emamectin benzoate was non or very low resistance during 2003-2013. Furthermore, [8] reported that a heavily % DNA of *S. littoralis* had destruction rang: 40-92% caused by Chitosan + 60 Gy that had the highly % DNA destruction (8.399%), followed by chitosan + 30Gy (7.829%), *M. anisopliae* + 15 Gy (5.681%), chitosan (3.991%), *B. thuringiensis* + 30 Gy (3.902%), *M. anisopliae* + 60 Gy (2.604 %) and chitosan + 15 Gy (1.868%) [21]. Stated that azadirachtin exposed to gamma doses (400 & 700 Gy) gave potentiating effect to control three cotton boll pests and cotton crop parameters when carried out the cotton field trial at 2018 & 2019. In addition, [22] stated that gamma ray doses (50 & 500Gy) treatments were the most efficacies against *E. insulana* egg stage than magnetic flux treatments (20& 180 mlt).

At current work, the additive compound of azadirachtin +orange oil had potentiating effect than azadirachtin or orange oil singly as well as *B. thuringiensis* + orange oil treatments. Meanwhile, [9] conducted that neem extracts in different parts of plants showed significant mortality response against 3rd instar larvae of cotton; *P. gossypiella*, *S. litura* and *H. armigera*. The surviving insects showed the behavior with decreasing in insect weight and slower feeding activity as

compared to the control. Also, [23] suggested that azadrachtin targets had more than one protein in *H. armigera*, for thus it could be a potent bio-pesticide.

A satisfactory coverage was obtained on cotton plants, the droplet spectrum in the field experiment was agreed with the optimum droplet sizes that mentioned by [14] in case of low volume equipment. Also, the best equipment in this respect was Pneumatic Knapsack motor sprayer (Cifarilli) followed Hand-held Hydraulic sprayer (Matabi). Performance rate of Pneumatic Knapsack motor sprayer (Cifarilli) was 12 Fed/day. But the lowest rate of performance was Hand-held Hydraulic sprayer (Matabi) since it could spray only 3.46 Fed /day. The results agreed with [24, 25] that recommended KZ oil and Pyriproxyfen followed by Agerin using low volume spraying because of reducing the time lost in process filling the machines, improve the homogeneity of the spray solution on the plant leaves and saving the lost spray on the ground; the results also in agreement with [26] they recommended by using Profenofos followed by Pyriproxyfen and Spinosad with Agromondo sprayer [27]. Showed that Motorized Knapsack sprayer (Agromondo) was the best equipment to control seedling pests at early season of cotton. The performance rate of Knapsack motor sprayer (Arimitsu) was 15.25 Fed./day; but the lowest rate of performance was Hand-held Hydraulic sprayer (Matabi) since it could spraying only 3.4 Fed./day [28]. Stated that spray quality were near to 1 in case of Pneumatic Knapsack motor sprayer (Cifarilli) and Hand-held Hydraulic sprayer (Matabi) that indicated a high spray coverage homogeneity and best control.

Conclusion

Generally, it could be concluded that Pneumatic Knapsack motor sprayer (Cifarilli) contribute to success the pest control than Hand-held Hydraulic sprayer (Matabi). Moreover, gamma radiation doses (160, 320 &640 Gy) improve the orange oil action when mixed with *B. thuringiensis* to become the efficacy action was the highest if it compared with *B. thuringiensis* + orange oil without exposing to gamma radiation doses or both of them when used singly.

It could be mentioned that there was a negative correlation between (VMD) and the reduction percentages of the pests. At vice versa, there was a positive correlation between droplets number and the three cotton boll pest reduction percentages in all treatments. The performance rate of Pneumatic Knapsack motor sprayer (Cifarilli) (20 L./Fed.) was 12 Fed./day. It was the best equipment, but the lowest rate was Hand-held Hydraulic sprayer (Matabi) (56 L./fed.) since it could spray only 3.46 Fed./day.

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