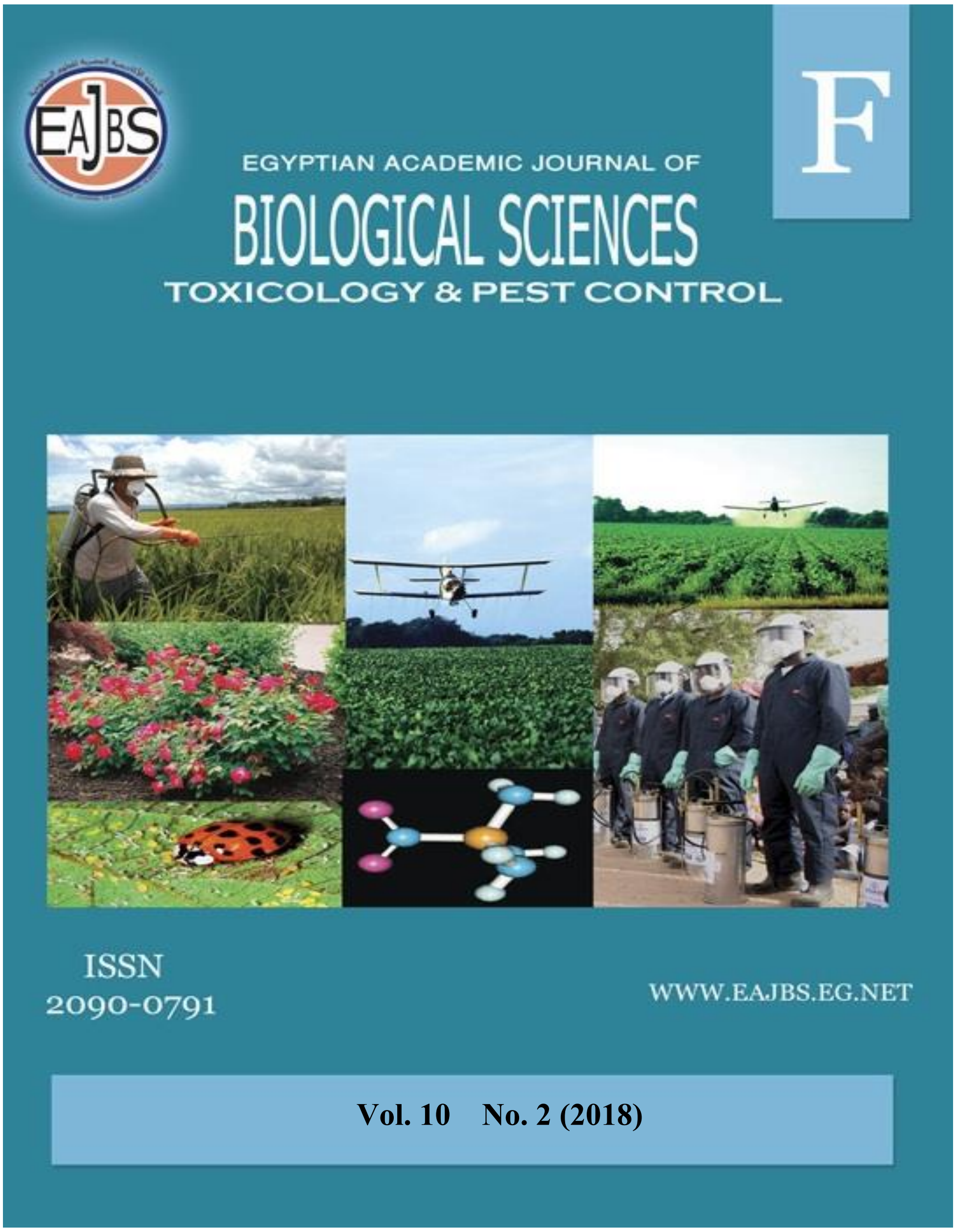

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Disinfestation of Stored-Grains with *Tribolium castaneum* by Using Joint Action of Gamma Radiation and some Essential Oils

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ABSTRACT

Management of stored-grain insects using gamma radiation could be enhanced by other feasible control methods such as essential oils as potential alternatives to chemical insecticides. This work was carried out to find the effect of two essential oils rosemary (*Rosmarinus officinalis* L.)and cinnamon(*Cinnamomum aromaticum*) and /or gamma radiation doses separately on *Tribolium castaneum* adult's mortality and the combined effect of gamma radiation doses and at $LC_{50}$of each essential oil (based on Probit analysis) on adult's mortality. The insects were subjected to five radiation doses (150, 200, 250, 300 and 350 GY), then exposed to the LC_{50}'s from each essential oil and its effect on certain biological aspects of *T. castaneum*. The mortality rate was increased in the combined treatments of ($LD_{50}$of gamma radiation and $LC_{50}$of the two essential oils) more than any of the separate treatments. The additive effect was more detectable when higher doses of gamma radiation were combined with LC_{50} of either of the two essential oils. From the mentioned results, the mortality effect of the essential oils against stored grain pests can be enhanced by its combining with gamma radiation. As well, the results showed that the combination experiments caused significant reduction in the number of eggs deposited per female, hatchability percentage of eggs, total larval duration, the pupal period and total developmental period, while the pre-oviposition period and incubation period of eggs were obviously increased. From the mentioned results, the insecticidal effectiveness of the essential oils against stored grain pests can be enhanced by combining the oil treatments with gamma radiation.

INTRODUCTION

The storage pest *Tribolium castaneum*(Herbst) (Coleoptera: Tenebrionidae), can be a major pest in stored grains. This species has been found associated with a wide range of commodities including grain, flour, peas, beans, cacao, nuts, dried fruits, and spices, but milled grain products such as flour appear to be their preferred food Campbell and Runnion(2003)**.** Members of genus *Tribolium* are known to produce toxic quinones, which contaminate flour and flour products (Gorham 1987)**.**

Both larvae and adults with a reduction in quality and quantity of stored products (BagheriZenouz, 1997) inflict damage. Gamma radiations are used to produce mortality or sterility in the insects. This technique can be used by irradiating the insects at doses sufficiently high to produce the desired effects (Shishir *et al.*,2009).Gamma radiation has greater penetrating power for killing insects infesting commodities Brower and Tilton (1970).Gamma radiation has been combined with other means in attempts to reduce the effective radiation dose required to achieve control.In order to control of red flour beetle *Tribolium castaneum* (Herbst), fumigants are mostly used against stored-grain insect pests, not only because of their broad activity spectrum, but also because of their penetrating power resulting in minimal or no residues on the treated products. Although effective fumigants (e.g. methyl bromide and phosphine) are available, there is global concern about their negative effects, such as ozone depletion, environmental pollution, toxicity to non-target organisms, pest resistance, and pesticide residues (Benhalimaet *et al.,* 2004). The wide use of these fumigants has raised residue levels and has led to the development of resistance in certain species (Rossi *et al.*, 2010)**.** Due to environmental unfavorable effects of the fumigants, their use has recently been banned in many countries (Carpenter *et al.,* 2000). Thus, there is an urgent need to develop a safe alternative fumigants for stored-grain pest management.Essential oils Fumigation as natural pesticides and gamma irradiation are two ecologically safe methods that could be used in the management of stored-grain insects Ahmadi and Moharramipour (2016)**.**The red flour beetle *Tribolium castaneum* (Herbst) is one of the main stored-product pests that were reported to be sensitive to essential oils. According to (Clemente *et al*.2003), the toxic effect of the extracts of *R .officinalis* L. can be used to control *T. castaneum*. As well as (Ashwin, *et al.*, 2017**)**using essential oils likes Cinnamon oil (*Cinnamom umverum*), Clove oil (*Syzygium aromaticum*), Rosemary oil (*Rosmarinus officinalis*), Bergamot oil (*Citrus Bergamia*) and Japanese Mint oil (*Mentha arvensis*).These oils showed potential which can be developed as possible natural fumigants or repellents for control of the pulse beetle. There are several reports on the sensitivity of *T. castaneum* to radiation (Tuncbileket *et al.*, 2003).(Ayvazet *et al.*, 2002) found that a dose of 200 Gy gamma radiations was sufficient for acceptable mortality of *T. castaneum* adult in 30 days. On the other hand, the use of gamma radiation and essential oils alone at high doses is very expensive and time-consuming; therefore to reduce costs, it is important to look for a strategy that uses low doses without reducing the efficacy.Also used of low irradiation doses combined with other treatments is a way to minimize the negative effects of irradiation on food quality (Dionisio *et al.,*2009)**.** The use of gamma radiation and plant essential oils are the most promising new approaches for controlling this insect. In this study, we explored the combined effect of low doses of gamma radiation and lower concentrations of two essential oils, rosemary and cinnamon, aiming to reduce the cost of effective management of *T. castaneum*.

MATERIALS AND METHODS

Insect Rearing:

The red flour beetle *T. castaneum* was reared in the glass container (250ml) containing wheat flour covered with a fine mesh cloth for ventilation. Adults were obtained from laboratory stock cultures maintained at the Plant Protection Dept. Faculty of Agric., Benha University, Egypt. Adult insects (1-3 days old) were used. The cultures were maintained in the dark in an incubator at 28 ± 1 ºC and 65±5% RH. All experiments were carried out under the same environmental conditions.

Irradiation:

The source of gamma radiation used during the present study was from a Cobalt 60 (Co^{60}) irradiator installed in the cyclotron project, Nuclear Research Center, Abu Zaabal, Egypt; the dose rate of irradiation source was 1 Gray/ second. To study the effect of gamma irradiation, healthy and active adult insects (1-3 day old) were irradiated with five doses (150; 200; 250; 300 and 350 Gy), five replicates were prepared, after irradiations, the insects were kept in the dark in the growth room, and the mortality was measured for 7 days post-treatment.

Essential Oils Used:

Two essential oils Rosemary oil(*Rosmarinus officinalis* L.) and Cinnamon oil (*Cinnamomum aromaticum Nees*)belonging to families; Lamiaceae and Lauraceae were used during these investigations. Both essential oils were bought from Al-Gomhuria Company of drugs, chemicals and medical supplies in Egypt. The fumigant toxicity of these oils was tested to the adults of *T. castaneum*.

Fumigation Test*:*

In this experiment, 200 ml glass jars with tight covers were used as fumigation chambers for the plant oil. A series of essential oil concentrations in the air was used 62.5, 125, 250, 500 and 1000 µl/l.air for both essential oils to evaluate the mortality of insects after the initial concentration setting experiment. Five replicate were made for treated and untreated (control) adults. Inside every jar, one filter paper was inserted at the bottom. Then one ml from each oil concentration was taken and added to every glass jar on a filter paper for achieving the mentioned oil dosages inside the well-closed jars. Thirty adults were put inside each jar in cotton bags (2×1 cm) with a few amounts of crushed wheat. The jars well-closed and incubated at 28±1 °C and 65±5% R.H. The same steps were followed in the control treatment. Mortality for each dose was investigated independently, the numbers of dead (immobile) and live insects in each bottle were determined until 7 days post-treatment. The 25%, 50% and 90% lethal concentrations (LC_{25}, LC_{50} and LC_{90}) values were assessed by Probit analysis (Finney, 1971). The effects of sub lethal concentrations (LC_{50}) for the two oils on some biological aspects of an adult's stage of *T. castaneum* were calculated.

The Combined Effect of Gamma Radiation and Two Essential Oils on Certain Biological Aspects of *T. castaneum*:

In this experiment, we combined the various doses of gamma irradiation with the LC_{50} from each essential oil to investigate the toxicity effects on adults of *T. castaneum*, after 24h from irradiation, the irradiated adults were exposed to the LC_{50} of both essential oils *R. officinalis* and *C. aromaticum* oils; mortality was measured during 7 days post-treatment. Insects were considered dead if no leg or antennal movements were observed. Each experiment was conducted in five replicates with thirty insects in each replicate.

For evaluating the joint action of Gamma radiation and essential oils in various mixtures the following equation adopted by(Mansour et al., 1966)was used:

$$\text{Co-toxicity factor} = \frac{\text{\% Observed mortality - \% Expected mortality}}{\text{\% Expected mortality}} \times 100$$

This factor was used to classify the results into three categories: A positive factor of 20 or more meant potentiation (synergistic effect), a negative factor of 20 or more meant antagonism, and any intermediate value i.e. between +20 and -20 was considered only an additive effect.The$LD_{50}$of gamma irradiation was calculated from the results of different gamma ray doses and combined with LC_{50} of Rosemary oil & Cinnamon oils and its effect on certain biological aspects of *T. castaneum* adults.

Statistical analysis:

The dosage mortality response was determined by probit analysis (Finney 1971) using a computer program of Noack and Reichmuth(1978).

RESULTS

Gamma radiation, two essential oils and their combination were investigated against the adults' stage of *T .castaneum*. The mortality of *T. castaneum* increased markedly with an increase of the radiation dose and oil concentration, that's shown in Table 1 and Fig 1. As irradiation doses of 150; 200; 250; 300 and 350 GY caused 6.6, 13.3, 19.9, 23.3 and 38.8% mortality after one day post-irradiation, respectively. These mortality percentages were increased with the increasing irradiation doses and exposure period to reach 35.5, 53.3, 63.3 76.6 and 81.1% mortality after one-week post-irradiation. The results showed that the doses need to kill 50% of the population(LD_{50}) value at 7 days post-treatment was 191.95 GY Table2, Also the time required to obtain 50% mortality for the adult of *T. castaneum* was 1.54 days, as will show in Table 2 and3.In the case of the fumigation toxicity of essential oils, the results showed that the mortality was increased by increasing the plant oils concentrations and exposed period. At 1000 µl/lair adult mortalities were 23.3 and 16.6% after 1-day exposure and increased after 7 days post-treatment to 88.8 and 71.1 % for rosemary and cinnamon essential oils, respectively, while at 62.5 µl/l. air adult mortalities values were 2.2 and 0.0 % after 1-day exposure and increased at 7 days post-treatment to 31.1 and 24.4% for rosemary and cinnamon essential oils respectively.

Table (1): The effect of gamma radiation and two essential oils on the mortality percentage of *T. castaneum* adult after exposure periods.

Treatment	Accumulative adult mortality % after indicated days				
	1	2	3	5	7
Gamma radiation alone					
350 Gy	38.8	55.5	68.8	74.54	81.1
300 GY	23.3	44.5	56.6	61.1	76.6
250 GY	19.9	37.7	48.8	55.5	63.3
200 GY	13.3	23.3	32.2	44.4	53.3
150 GY	6.6	11.1	22.2	28.8	35.5
Control	0.0	0.0	0.0	0.0	0.0
Rosemary oil alone					
1000 µl/l.air	23.3	42.2	67.7	74.4	88.8
500 µl/l.air	17.7	28.8	44.4	64.4	73.3
250 µl/l.air	13.3	22.2	28.8	37.7	52.2
125 µl/l.air	6.6	15.5	24.4	32.2	45.5
62.5µll.air	2.2	8.8	14.4	22.2	31.1
Control	0.0	0.0	0.0	0.0	0.0
Cinnamon oil alone					
1000 µl/l.air	16.6	25.5	38.8	53.3	71.1
500 µl /l.air	11.1	20.0	31.1	46.6	62.2
250 µl /l.air	5.5	12.2	26.6	35.5	47.7
125 µl /l.air	3.3	10.0	17.7	22.2	30
62.5 µl /l.air	0.0	4.4	15.5	20	24.4
Control	0.0	0.0	0.0	0.0	0.0

The lethal concentrations (LC_{50}) of rosemary and cinnamon essential oils to adult stage of *T. castaneum* are shown in Table (2).The results showed that at 7 days post-treatment the LC_{50} value was 162.56and 296.30 µl/l. air. For rosemary and cinnamon essential oils, respectively, the results showed that Rosemary was more toxic to *T. castaneum* than cinnamon essential oils. As well, the LT_{50} for the adults of *T. castaneum* were 2.18 and 4.05 days, for rosemary and Cinnamon essential oils, respectively Table(3).Results showed that mortality increased in insects with the increase in the concentration and exposure time of essential oils. A significant difference was observed in mortality among the essential oils. In all experiments, the mortality rate of insects treated with either gamma radiation or any essential oils separately was much lower than the mortality of the combined treatment. When we combined various doses of Gamma radiation 150; 200; 250; 300 and 350 Gy with $LC_{50}$of rosemary oils (162.56 µl/l.air) mortality percentages of53.3, 46.6, 30, 25.5 and 18.8% after one day post-treatment have occurred, these percentages were increased with increasing doses and exposed period to reach 100, 100, 86.6, 73.3 and 24.4% after one week post-treatment. Furthermore, a combination of these radiation doses with the LC_{50} of *C. aromaticum*(296.30 µl/L.air) increased the mortality from 36.6, 31.1, 25.5, 17.7 and 12.2% after one day**.**

Table 2.Lethal concentrations values and parameters of probit regression line estimates of gamma radiation and the two essential oils against *T. castaneum* adults after 7 days post-treatment.

Lethal concentrations and their confidence limits			Slope ± SD	R
LD_{25}	LD_{50}	LD_{90}		
Gamma radiation				
122.42 90.43-165.43	191.95 165.05-223.25	451.39 331.70-614.27	3.45±0.007	0.996
LC_{25}	LC_{50}	LC_{90}		
Rosemary oil				
52.77 29.27-95.13	162.56 116.23-227.61	1382.29 676.78-2823.22	1.37±0.068	0.980
Cinnamon oil				
72.90 38.48-138.09	296.30 200.34-438.23	4261.04 1284.36-14136.51	1.10±0.019	0.991

Table 3.Lethal time values and parameters of probit regression line estimate for the adult of *T. castaneum* exposed to gamma radiation and the two essential oils after 7 days post-treatment.

Lethal time and their confidence limits			Slope ± SD	R
LT_{25}	LT_{50}	LT_{90}		
Gamma radiation				
0.49 0.20-1.17	1.54 1.02-2.34	13.39 5.97-30.02	1.36±0.012	0.992
Rosemary oil				
1.09 0.27-1.54	2.18 1.76-2.70	8.13 5.49-12.03	2.24±0.065	0.985
Cinnamon oil				
1.69 1.20-2.36	4.05 3.10-5.29	21.37 9.91-46.07	1.27±0.051	0.981
Gamma radiation + Rosemary oil				
0.77 0.52-1.12	1.12 0.87-1.44	2.29 1.79-2.92	4.13±0.50	0.948
Gamma radiation + Cinnamon oil				
0.99 0.78-1.26	1.54 1.31-1.81	3.52 2.92=4.24	3.56±1.18	0.909

Post treatment to 100, 93.3, 78.8, 74.4 and 52.2 % after 7 days post-treatment, as it shows in Table (4) and Fig (1). Also, the times needed to obtain 50% mortalities for the adult of *T. castaneum* were 1.12 and 1.54 days, with the combination of gamma and rosemary and cinnamon oils, respectively. This result clearly indicates that the combination of gamma radiation and rosemary oils was the most toxic effect to the adult stage of *T. castaneum*, while the least effective one was using cinnamon oil alone. Although it was shown that the combination of gamma radiation and two essential oils could be provided a significant increase in mortality of *T. castaneum*, according to the Co-toxicity formula, the additive effect was observed when combined most gamma radiation doses andLC_{50} of two essential oils. Those are shown in Table 5 and Fig 2. that, combinations of gamma radiation and essential oils could be used as an effective alternative to chemical insecticides in grain against stored product insects. This method has the advantages of enhancing the efficacy of each treatment alone and reducing tile exposure period required for complete kill especially for the most tolerant insect stages. As well as, when we studied the effect of sublethal dose or concentration of gamma radiation, rosemary oil, cinnamon oil and their combination on certain biological aspects of *T. castaneum* in the laboratory at 28±1° C, the results indicated that the treatment of *T. castaneum* adults with all treatment caused significantly decreased. In the number of eggs laid per female, hatchability rate of eggs, total larval duration, the duration of pupal stage and total developmental period of immature stages while the pre-oviposition period of eggs and incubation period were obviously increased. Meanwhile, the larval mortality in the treatment was higher than control. On the other hand, no significant differences were found between the treatments and the control for the incubation period and pupal stage duration. These results are given in Tables (6)**.**

Table4.The effect of the combined action of gamma radiation and two essential oils on the percentage mortality of adult *T. castaneum* .after exposed period.

Conc.	Accumulative adult mortality % after indicated days				
	1	2	3	5	7
Gamma radiation +LC_{50} of Rosemary oil					
350 Gy	53.3	77.7	91.1	100	100
300 GY	46.6	64.4	85.5	94.4	100
250 GY	30	53.3	62.2	76.6	86.6
200 GY	25.5	44.4	51.1	68.8	73.3
150 GY	18.8	37.7	42.2	56.6	65.5
Control	0.0	0.0	0.0	0.0	0.0
Gamma radiation +LC_{50} of Cinnamon oil					
350 Gy	36.6	62.2	74.4	88.8	100
300 GY	31.1	56.6	66.6	73.3	93.3
250 GY	25.5	37.7	48.8	56.6	78.8
200 GY	17.7	33.3	37.7	53.3	74.4
150 GY	12.2	23.3	31.1	47.7	52.2
Control	0.0	0.0	0.0	0.0	0.0

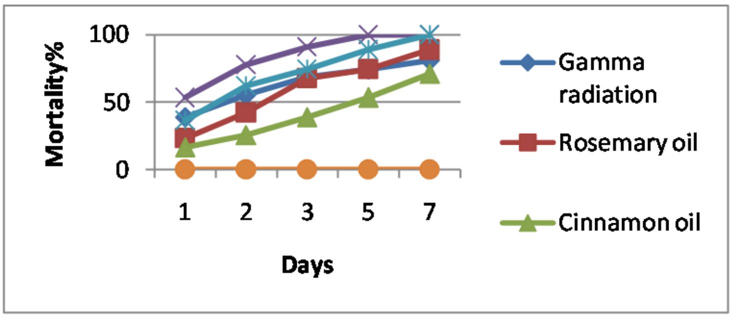

Fig. (1): The toxicity effect of gamma radiation, two essential oils and their combination on the percentage mortality of adult *T. castaneum*, after the exposed period *at* **the highest** dose

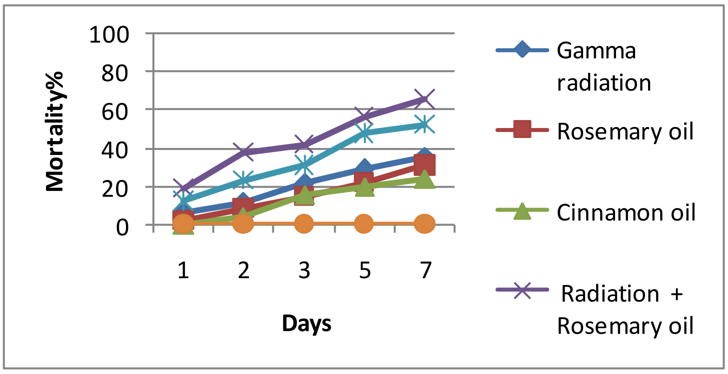

Fig. (2): The toxicity effect of gamma radiation and two essential oils and their combination on the percentage mortality of adult *T. castaneum.* after the exposed period *at* **the least** dose.

Table 5. The combined effect of radiation and two essential oils on mortality of *T. castaneum*adult after 7 days post-treatments.

% mortality for different treatment					Co-toxicity factor		Type of joint action	
Gamma radiation Doses[1]	Rosemary oil con.[2]	Cinnamon oil con[3]	Gamma doses + $LC_{50}$of rosemary oil	Gamma doses + LC_{50} of Cinnamon oil	G+R	G+C	G+R	G+C
35.5	31.1	24.4	65.5	52.2	-1.65	-10.68	A	A
53.3	45.5	30	73.3	74.4	-25.81	-10.68	D	A
63.3	52.2	47.7	86.6	78.8	-25.02	-29.01	D	D
76.6	73.3	62.2	100	93.3	-33.29	-32.78	D	D
81.1	88.8	71.1	100	100	-41.14	-34.30	D	D

A= antagonistic effect D= additive effect S= synergistic effect

1=doses(150-350) 2=con.[2](26.5-1000)µl/l.air 3=con[3].(26.5-1000)µl /l.air.

Table (6): Effect of sublethal dose (LD_{50}) of gamma radiation, Rosemary oil, Cinnamon oil and their combination on certain biological aspects of *T. castaneum*

Biological aspects	Treatments					
	Gamma LD_{50} 191.95 Gy	Rosemary LC_{50} 162.56 mg/l.air	Cinnamon LC_{50}296.30 mg/l.air	LD_{50} Gamma+ Lc_{50} Rosemary	LD_{50} Gamma+ Lc_{50} Cinnamon	control
Total eggs laid daily per female during two weeks	730^{b}±2.10	534^{e}±1.25	622^{c}±1.15	504^{f}±0.25	600^{d}±1.00	995^{a}±1.15
Percent decrease in egg numbers	26.63^{e}±0.45	46.33 b±0.25	37.48^{d}±1.02	49.34 ^{a}±0.75	39.69^{c}±0.75	-
Hatchability rate of eggs	62.84^{d}±1.75	74.42^{c}±2.25	85.23^{b}±1.00	53.54^{f}±1.25	58.30^{e}±0.75	94.82^{a}±0.50
Pre-oviposition period (day)	8.12^{c}±0.25	7.54^{d}±0.75	6.58^{e}±1.00	10.66^{a}±1.15	9.25^{b}±0.25	5.56^{f}±1.15
Incubation period of eggs (day)	4.58^{d}1.10	5.21^{a}±1.75	5.05^{b}±0.45	4.50^{e}±0.25	4.74^{c}±0.14	4.25^{f}±0.85
Larval stage duration (day)	25.08^{a}±0.57	23.97^{d}±0.50	24.14^{c}±0.75	21.87^{f}±1.00	22.54^{e}±1.10	24.62^{b}±0.25
pupal stage duration (day)	6.04^{b}±1.25	5.27^{c}±2.52	6.24^{a}±1.12	4.87^{e}±0.85	3.65^{f}±1.12	5.24^{d}±1.25
Total development period immature stages (day)	35.70^{a}±1.15	34.45^{c}±0.85	35.43^{b}±1.25	30.61^{f}±1.75	30.93^{e}±1.00	34.11^{d}±0.85
Mortality of larvae stage %	26.41^{e}±0.25	32.87^{d}±1.52	36.81^{c}±1.45	48.54^{a}±1.00	41.36^{b}±2.52	2.32^{f}±1.65
Pr	0000***	0000***	0000***	0000***	0000***	0000***

Means followed by the same letter in each column for each generation are not significantly different at P>0.0.

DISCUSSION

Irradiation and fumigation by essential oil are two main methods that could be used in IPM.Gamma radiations are used to produce mortality or sterility in the insects. This technique can be used by irradiating the insects at doses sufficiently high to produce the desired effects. The mortality of *T.castaneum* increased markedly by increasing the radiation dose and oil concentration**.**These data were agreed with Rejesus and Lapis (1973)who irradiated the insects to 200 Gy of gamma radiation killed all *T. castaneum* within 28 days after the irradiation, which suggests that the mortality observed in our shorter-term experiments could be higher at longer observations. After radiation treatments, the larval feeding activity was sharply reduced. Bothaina *et al.,(*2004)reported that feeding and damage caused by navel orange worm larvae could be reduced by as much as 78% after 300 Gy treatments . Irradiation can also extend the shelf life of various products and maintain the quality of the product over a longer period. The study also agreed with (Abbas 2010)as stated that the effect of gamma radiation on *Oryzae philuss urinamensis* by doses between (60,200,350 and 700 Gy) the required dose of radiation to prevent adult emergence from irradiated 5-days-old pupa was 700 Gy. The dose of 200 Gy caused 100% mortality of irradiated adults 28 days after treatment.Hassan *et al.*, (2013)reported that the lethal effect of gamma radiation doses 0.75 and 1.0 KGy on the adults *Callosobruchus maculates* reared on cowpeas and chickpeas were slow during the first and third days post treatments. By increasing the dose to 1.5 KGy, the percentage of adult's mortality in both seeds was 53.0 and 40.0, respectively after 24h of treatment. On the other hand the dose 2KGy caused acute mortality for adults post treatment for cowpeas. Saad, and Kabbashi(2014),who irradiated the insects to doses between (0, 3.5, 4, 5, 6 and 8 KGY) of Gamma rays. The obtained results show that all the used doses of Gamma rays effect a mortality of 80 – 100% and 93 – 100% adults of the red flour beetle *Triboluim castaneum* Herbest, respectively. The fumigant treatment of essential oils has a great effect on adult mortality percentage of *T. castaneum*. These results are confirmed with (Choi *et al.,* 2004), these oils are safe to humans and other mammals, and they are environmentally non-persistent. This study has shown that fumigation with the essential oils from *R. officinalis* and *P. atriplicifolia* has a toxic effect on *T. castaneum*. The essential oil from *R. officinalis* is an effective antioxidant in foodstuffs. The mode of action of oils may involve elements of acetylcholinesterase inhibition and octopaminergic effects toward insects. Isman (2006) stated that the rapid effect of essential oils is because of their neurotoxic mode of action. According to the results obtained from the present study insects mortality increased with increasing concentration levels and exposure time. Also,Papachristos andStampoulos (2004) reported an insecticidal effect of *R. officinalis* on *Acanthosce- lides*obtectus (Say) adults when the concentration of the oil in the air was in the range from 0.8 mg/L to 47.1 mg/L. Shakarami(2013)stated that the effects of four plant essential oils, *Menthaaquatica, Thymus daenensis, Myrtuscommunis* and *Artemisia hausskenechtii* against two adult flour weevils, *T. castaneum* and *T. confusum*. Similar results were observed by(Azab *et al*. 2017)**.**The data indicated clearly that the mortality of tested insects increased with increase in concentration, exposure period and temperature. The complete mortality of *S. oryzae* adults was obtained at conc. 1.5 % (v/w) for the three tested oils, after 14 days exposure period at 30°C. In addition to toxicity action against adult insects. .The combination of several independent techniques for the control of pest as integrated pest management (IPM) is one of the main strategies. Combined treatments with gamma radiation and essential oils from *R. officinalis* and *C. aromaticum* caused a higher mortality of *T. castaneum* than did each of the two treatments alone. The data in agreement with Ahmadi and Moharramipour (2011) indicated that the combination of gamma radiation and *R. officinalis* essential oil could reduce the feeding of *T. castaneum* larvae. They showed that the relative growth rate had significantly decreased ($P < 0.05$) by combining the gamma radiation and *R. officinalis* and that the severity of the reduction rate increased by increasing doses. Also, relative food consumption rate decreased when gamma radiation and *R. officinalis* were combined and its reduction severity had a relative convert relative with increasing of doses. Ahmadi and Moharramipour (2016) found that .The mortality rate was assessed 72 h after the last treatment. Integration of gamma radiation and *R. officinalis* oil enhanced the mortality of *C. maculates* compared with control treatments of either irradiation or fumigation alone. Synergistic effects on mortality of 1-2 days old adults of *C. maculates* were observed when exposed to the combination of gamma radiation and essential oil. In addition to toxicity action against adult insects, plant oils generally have an ovicidal action; most of the tested oils caused a high reduction in eggs deposition and larval penetration. Egg mortality is caused by the physical properties of the oil coating, blocking respiration, rather than by a specific chemical effect. **Hassan (2013)** obtained that the latent effects of different plant oils on adult stage when beetles of *C. maculates* were fed on seeds treated with the lowest two concentrations (0.0312, 0.0625%) of different oils, the number of eggs laid per female was decreased in all different oils especially in case of cowpea treated with sweet basil and lemongrass. Most of the different oils caused a high reduction in larval penetration in both types of seeds. The use of different plant oils caused the reduction in the progeny comparing to the control. Mbata and Payton (2013) on *C. maculate.* The data have shown that the rate of development beetle was slower in F1 progeny resulting from treated both seeds with the tested oils than those resulting with the control (33.33 and 38.33 days, respectively). On the other hand the concentration 0.0625% of sweet basil or geranium was found to be highly effective in decreasing the percentage of emergence (30.0and 40.0) in cowpeas, respectively. The highest percentage of emerged adults (76.5 and 64.0) was obtained when treated cowpeas and chickpeas with concentration 0.0312 % of petitgrain oil as compared to 91.0 and 85.0% in control, respectively.

CONCLUSION

In this work, we attempted to control *T. castaneum* with certain essential plant oils which seem to be safer and less contaminant to the environment. Also, these materials are cheap, available, and could be used to control other stored-product pests. Also, we conclude that the combined treatment of gamma radiation and two essential oils were established results which have a more significant effect than both gamma radiation and plant essential oil each of them alone.

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ARABIC SUMMARY

منع اصابة الحبوب المخزونة بحشرة خنفساء الدقيق الصدئية بأستخدام التأثيرالمشترك لكل من أشعة جاما وبعض الزيوت العطرية

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يمكن تحسين مكافحة حشرات الحبوب المخزنة باستخدام أشعة جاما وبواسطة طرق أخرى مجدية مثل الزيوت الأساسية النباتية كبدائل محتملة للمبيدات الحشرية الكيميائية. في هذة التجربة ، أجريت دراسات للتعرف على تأثير اثنان من الزيوت النباتية الأساسية هما: الروزمارى والقرفة بالإضافة إلى استخدام إشعاع جاما كل على حدة، وكذلك خليط من جرعات مختلفة من إشعاع جاما مع LC_{50} (استنادا إلى تحليل بروبيت) من كل زيت نباتى ضد الحشرات الكاملة لخنفساء الدقيق الصدئية. وتم تعريض الحشرات لخمسة جرعات إشعاعية هى (١٥٠، ٢٠٠، ٢٥٠، ٣٠٠، ٣٥٠ جراى)، ثم تعرضت ل LC_{50} من كل زيت أساسي في الهواء. وكذلك تم دراسة تاثيرLD_{50} لكل من اشعة جاما LC_{50}, زيت الروزمارى وزيت القرفة وكذلك مخاليطهم على بعض الجوانب البيولوجية لحشرة خنفساء الدقيق الصدئية.

ادت معاملات الخلط الى زيادة معدل وفيات الحشرات أكثر من استخدام اى معاملة بمفردها. وكان التأثير الإضافي أكثر وضوحا عندما تم الخلط بين الجرعات العالية اشعة جاما مع قيمة LC_{50} من الزيوت النباتية الأساسية المستخدمة. واظهرت النتائج كذلك ان تجارب الخلط أدت الى حدوث انخفاض معنوي في عدد البيض التى تضعة الأنثى ونسبة الفقس للبيض ومدة طور اليرقات وفترة طور العذراء ومدة دورة حياة الحشرة، في حين ان فترة ما قبل وضع البيض وفترة حضانة البيض قد زادت بشكل واضح بالمقارنة بالكنترول. ومن النتائج المذكورة، ويمكن تحسين فعالية المبيدات الحشرية من الزيوت النباتية ضد افات الحبوب المخزونة عن طريق استخدام أشعة جاما و الزيوت النباتية.