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Original Article

Use of some eco-friendly insecticide alternatives to control the red flour beetle, *Tribolium castaneum*

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Abstract:
Tribolium castaneum (Herbst) (Coleoptera: Tenebrionidae) causes extensive damage to a variety of stored products, reducing their nutritional and monetary value. However, using insecticides to control these insects may have an impact on both human health and the environment. Therefore, identifying more environmentally friendly alternatives is critical that can be utilized as substitutes for pest or insect management, such as ozone gas, gamma radiation and plant oils. In this study, the toxicity of ozone gas, gamma radiation and four plant oils (clove, colonyth, garlic and camphor) was investigated. The efficacy of ozone gas at 1000, 1500, 2000 and 2500 ppm on adult of *T. castaneum* was assessed. Mortality increased steadily as concentrations increased, except 2500 ppm give to 100% mortality after one-day post treatment. Also, the impact of gamma radiation was studied on irradiated adults of *T. castaneum*. No mortality was recorded at 10, 20, 40 and 60 GY after 5 days post treatment. While, after 10 days give 28% mortality at 60 GY. On the other hand, the reduction in F1-progeny give 67.16, 83.58, 100 and 100% at the same doses, respectively. In case of the four botanical oils, the insecticidal energetic expanded as exposure time and concentration increased. The highest toxic botanical oils was clove and camphor oils at 6 ml/kg (w/v) after at the same concentration.

Keywords: *Tribolium castaneum*, ozone gas, gamma radiation, plant oils, insecticidal activity.

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1- INTRODUCTION

Human nutrition worldwide is generated primarily from cereal crops (**Tilman, 1999**). Among these cereal crops, wheat is one of the most significant; in 2009, more than two thirds of a billion tons were produced worldwide (**FAO, 2011**). The most significant grain crop is wheat (*Triticum aestivum*), which supplies 20% of the world's protein and 40% of its energy calories. (**Kumar *et al.*, 2015**).

It is always necessary to guard against product deterioration when it is being stored, particularly when it comes to weight loss and quality loss, which is mostly caused by fungus and insects that typically cooperate. Cereal grains constitute a significant portion of the global food supply and comprise the majority of commodities kept in storage. Following harvest, the grain is typically kept on the farm or in sizable commercial elevators, where a variety of beetles can infest it. Among them the red flour beetle, *Tribolium castaneum* Herbst (Coleoptera Tenebrionidae) is one of the most pervasive and harmful pests of products that have been stored; it feeds on various grain and stored grain products (**Weston and Rattlingourd, 2000; Mishra *et al.*, 2012a; 2012b**). It is a unique worldwide pest of stored products and is an important secondary pest of stored products, including maize, rice and wheat, especially in tropical areas (**Sabbour, 2014 and Wagan *et al.*, 2016**).

This pest can cause serious damage to stored grain and destroy the whole grain. In addition, the quality of the product is affected by the presence of eggs and disease insects and holes on the seeds. (**Lu and He, 2010**).

In the grain storage industry, the increase in resistance levels is due to the limited access to insecticides, the ineffective use of these insecticides in the long term and the lack of proper structure for the use of weapons. (**Collins *et al.*, 2005** and **Sousa *et al.*, 2009**).

Although the toxic impacts of O_3 on stored products insect pests are well documented, further research is needed to determine the evolutionary risk to populations exposed to selective pressure with O_3. Based on evolutionary theory, it is predicted that resistance to insecticides will evolve in populations that remain under chemical selection pressure as different traits are selected to increase survival in different environments bad. (**Foster *et al.*, 2000; Coustau *et al.*, 2000; Arnaud and Haubruge, 2002** and **Guedes *et al.*, 2010**).

Much work has been done to use radiation to control pests in stored crops (**Brower and Tilton, 1983; Hassan, 1999; Azelmat *et al.*, 2005** and **Boshra and Mikhaiel, 2006**). Irradiation is an accepted method of effective control of insect pests in grain and flour in many countries and is considered for all cereals, grain products and other dry food products. (**Brower and Tilton, 1983**).

Essential oils from aromatic plants are infused with natural products as insecticides and as a defense against stored food pests (**Conti *et al.*, 2011; Athanassiou *et al.*, 2013** and **Bougherra *et al.*, 2015**). This study aims to assess the efficacy of ozone gas against all developmental stages of *T. castaneum;* eggs, larvae, and adults, as well as evaluate the effectiveness of irradiation on these life stages. Additionally, the study aims to investigate the insecticidal properties of camphor, colocynth, garlic, and clove oils against adult *T. castaneum*.

2- MATERIALS AND METHODS

2.1-Model insect:

Laboratory strain of the red flour beetle, *T. castaneum* from Dept. of Stored Product Pests, Plant Protection Research Institute, Agriculture Research Center were used during this work.

Red flour beetle, *T. castaneum* (Herbs) was reared under laboratory conditions on wheat flour (28±2°C and 65± 5% RH) in the laboratory of Plant Protection Department, Faculty of Agriculture and Natural Resources, Aswan University, Also in laboratory of stored product Dept., Plant protection Research institute, Agriculture Research Center, Doky, Giza, Egypt. Wheat flour and crushed wheat were well cured by snowing at -18°C for 2 weeks before use to eliminate contamination from other insects.

2.2- Rearing of insect culture:

The Egyptian wheat (*Triticum aestivum*) variety, Sakha 95 was used in present work. The grain were cleaned of foreign matter, washed thoroughly with water and dried properly in sunlight, kept in freezer at -20°C two weeks before used and then showed to ambient conditions for 7 days till grain wetness content is sto4abilized at approximately 12% the disinfested grains were then put in clean jars and covered tightly.

The red flour beetle *T. castaneum* was stored in glass jars (2kg capacity) each container has its own style 250g of wheat flour and introduced 500 insects of *T. castaneum* and it is covered with burlap and secured with a rubber band. Insect culture was stored at controlled of 28±2°C and 65± 5% RH in incubator.

The adults were introduced to wheat flour in glass jars for 2 weeks, the mature insects are removed and placed in containers of wheat flour with the usual methods until they mature.

2.3- Gases used:

2.3.1- Ozone gas:

Ozone was obtained from air using an ozone generator model OZO 6 VTTL OZO Max Ltd, Shefford, Quebec, Canada (OZO Max Ltd, Shefford, Child, Canada) from dry air with an excess of air feed gas in the laboratory. The amount of ozone output is controlled by a monitor with an integrated sensor that switches for different ozone concentration ranges, and a limiter on the monitor allows concentration control within a selectable rang. **(Darwish, *et al*., 2019)**

2.3.2- Bioassay test of Ozone gas:

Twenty-five pairs of T. *castaneum* (adult, larvae and 100 eggs) and 20 grams of crushed wheat were placed in cloth bags and closed well with rubber band. These bags were kept in glass jars covered with a rubber stopper. The ozone gas is connected with the Ozone unit and the jar by a thin tube. The concentrations used in this experiment were 1000, 1500, 2000 and 2500 ppm for 3 hours. Death of adults, larvae and eggs was assessed after 1, 3, 5, 7, 10 days from treatment and after 45 days the number of individuals produced is calculated. **(Abd-El-Aziz, *et al.*, 2017).**

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2.4- Irradiation of *T. castaneum*:

Irradiation application:

This work was carried out at the Radiation Unit of the Egyptian Atomic Energy Reference, Nasr City, Cairo.

The adult, larvae and 100 eggs of red flour beetle was exposed to four concentration of radiation (10, 20, 40 and 60 GY). In a cloth bag, 20 grams from crushed wheat were placed, in addition to 25 pairs of *T. castaneum* and they were tied tightly, four replications were made for each concentrations. Death of adults was appreciated after 1, 3, 5, 7, 10 days from treatment and after 45 days calculated the number of individuals produced. **(Abd-El-Aziz, *et al.*, 2017)**

2.5- Botanical oils used:

The tested plant oils were Camphor, Clove, Garlic and Colocynth; these oils were obtained from El-Gomhoria Company, Egypt.

Table (1): English name, species and their Family used in the experiment.

English name	Plant species	Family
Camphor	*Cinnamomum camphor*	Lauraceae
Clove	*Syzygium aromaticum*	Myrtaceae
Garlic	*Allium sativum*	Amarylidaceae
Colocynth	*Citrullus colocynthis*	Cucubitaceae

2.5.1- Bioassay tests:

2.5.1.1- Botanical oils treatment

Concentrations of 2, 4, 6 and 8 ml/kg (v/w) 20 grams at crushed wheat were treated with the botanical oils in glass jars (125g) by adding each concentration to the media. Each of the 30 adult insects is classified (1-2 weeks old) of *T. castaneum* included in prescription glasses. Three replicates to each concentration at variety Time slots were used. It contains medicinal insect's 28±2°C and 65± 5% RH. Insect mortalities were recorded after 1, 3, 5, 7 and 14 days of treatment. Alive adult insects were after wards discarded from the media. **(El-Zun, *et al.*, 2016)**

2.6- Calculation of mortality, reduction, and statistical analysis:

For mortality evaluation of Ozone gas, irradiation and botanical oils was corrected according to **Abbott (1925)** as following:

Corrected mortality = %Mortality in treatment - %mortality in control / 100 – % mortality in control

The reduction of F1 progeny at 45 days after treatment was calculated according to **Henderson and Tilton (1955)** the following equation:

Reduction (%) = {(No. of emerged adults in control - No. of emerged adults in treatment)/ No. of emerged adults in control} x 100

Mortality in this treatment was compared with mortality in control.

The relevant percentages were calculated according to the method **Finney (1971)**. The calculated mortality rate and concentrations of each component were plotted using Ldp line software to obtain toxic regression lines.

3- RESULTS AND DISCUSSION

3.1- The impact of Ozone gas on *T. castaneum* adults.

The impact of Ozone gas on *T. castaneum* (adults, larvae and eggs) at 28± 2°C and 65 ± 5 %RH. The efficacy results of Ozone gas at 1000, 1500, 2000 and 2500 ppm against the adult of *T. castaneum* are presented in **Table (1)** showed the corrected percent mortalities gradually by rising the concentrations, except the 2500 ppm. The results cleared that mortality at *T. castaneum* adult was 0.0, 0.0 and 1.5 % at 1000, 1500 and 2000 ppm after one day post treatment, these values reached 6.5, 11.0 and 21% after 10 days post treatment at the same concentrations. While, at 2500 ppm the death was 100% after one-day post treatment. The reduction in F1-progeny at the same concentrations (1000, 1500, 2000 and 2500 ppm) give high reduction compared than the mortality. These values of reduction were 17.8, 48.15, 94.77 and 100% for the same concentrations, respectively. The results appeared that the effect of Ozone gas on reduction of progeny higher than the death of *T. castaneum.*

Table (1): Mortality of adults of *T. castaneum* ascending periods (1, 3, 5, 7 and 10 day) when exposed to 1000, 1500, 2000 and 2500 ppm of Ozone.

	Conc./ ppm	Mortality % of *T. castaneum* adult after indicated days					F1	R
		1	3	5	7	10		
Ozone Gas	1000	0.00	0.50	3.50	4.50	6.50	78.50	17.78
	1500	0.00	3.00	7.50	9.00	11.00	49.50	48.15
	2000	1.50	6.50	11.00	14.50	21.00	5.00	94.77
	2500	100.00	100.00	100.00	100.00	100.00	0.00	100.00
L.S.D at 0.01		1.15**	2.42**	2.17**	1.53**	2.20**	2.03**	2.86**

The effect data of Ozone at 1000, 1500, 2000 and 2500 ppm against the eggs and larvae of *T. castaneum* at 28± 2°C and 65 ± 5 %RH. are cleared in **Table (2)** and **Table (3)** the reduction in number of emerged adults of *T. castaneum* were 73.37, 87.85, 92.06, 97.67% and 4.50, 65.00, 71.50 and 85.00 % to eggs and larvae for 1000, 1500, 2000 and 2500 ppm, respectively.

Table (2): The effect of the tested concentrations of Ozone gas against *T. castaneum* eggs after 45 days:

Ozone gas *T. castaneum* egg after 45 day		
Concentrations /ppm	**F1 -Progeny**	**Reduction**
1000	14.25	73.37
1500	6.50	87.85
2000	4.25	92.06
2500	1.25	97.67
L.S.D at 0.01	1.10**	2.06**

Table (3): The efficacy of the tested concentrations of Ozone gas against *T. castaneum* larvae after 45 days.

Ozone gas *T. castaneum* larvae after 45 day		
Concentrations/ ppm	**F1 -Progeny**	**Reduction**
1000	95.50	4.50
1500	35.00	65.00
2000	28.50	71.50
2500	15.00	85.00
L.S.D at 0.01	3.25**	3.25**

The obtained data showed that *T. castaneum* larvae were more tolerant to ozone than eggs. Mortality time values and parameters of the mortality curve for adults, eggs and larvae of *T. castaneum* exposed to Ozone gas are presented in **Table (4)** the LC_{50} for the adults, eggs and larvae were 3.04, 0.22 and 1.80 hrs, respectively. While, LC_{90} were 5.49, 3.51 and 3.89 hrs, respectively. The results appeared clearly that the adult were more tolerant to Ozone gas than eggs and larvae.

Table (4): Lethal time values for the adults, larvae and eggs at different concentrations of Ozone gas.

Concentrations/ ppm	**LC_{25}**	**LC_{50}**	**LC_{90}**	**Slope**	**R**
Adult	2.22	3.04	5.49	4.986±0.53	0.78
Larvae	1.20	1.80	3.89	3.840±0.35	0.95
Eggs	0.05	0.22	3.51	1.070±0.35	0.97

Results agree with those obtained by (**Darwish *et al.*, 2019**) who found that the mortality of *O. surinamensis* adults and larvae increases with increasing concentration and exposure time to ozone gas. Adults have a mortality rate of 5.2% within 1 hour. Increasing exposure 90.4% at 4hr. after 7 days. In addition, death of larvae was 6.4 at 0.5 hr and increase to 90.2% at 4hr after 7 days. **Abd El-Ghaffar *et al.* (2017**) investigated the effect of ozone on the red flour beetle *T .castaneum* (Herbst) adult and larvae at (1, 3 and 5 g/m3) for six different periods (0.5, 1, 2, 3, 4 and 5 hr). The results referred that increasing the concentrations and the exposure time increased the risk for the two phases examined, in addition to the hidden effect of ozone on the development of the insect and the age of this insect. **Ghazawy *et al.* (2021**) reported the effect of ozone gas against larvae of *T. granarium* and *T. castaneum*. The larval mortality of both species increased with increasing concentration and visibility period. Complete death was observed after 8h. The LT_{50-90} values decreased with increasing ozone exposure to larvae.

3.2- Effect of gamma irradiation against *T. castaneum* adults at 28± 2°C and 65 ± 5 %RH.

Data presented in Table (5) displays the impact of gamma radiation on *T. castaneum* adults that were subjected to exposure. No deaths were recorded in the control group 10 days after treatment. Also, doses of 10, 20, 40 and 60 GY, give mortality after 1-7 days ranged from 3.00 – 12.50 %. While, after 10 days give mortality 8.50, 13.50, 17.50 and 28.00 % to 10, 20, 40 and 60 GY, respectively. On the other hand, the reduction in F1-progeny was very high effect than the mortality. The reduction in F1-progeny at these doses were 67.16, 83.58, 100 and 100 % for 10, 20, 40 and 60 GY, respectively.

Table (5): Mortality of adults of *T. castaneum* exposed to different doses of gamma radiation after ascending periods (1, 3, 5, 7 and 10 day)

	Doses/ (Gy)	Mortality %of *T. castaneum* after indicated days					F1	R
		1	3	5	7	10		
Radiation	10	0.00	0.00	0.00	3.00	8.50	22.00	67.16
	20	0.00	0.00	0.50	4.50	13.50	11.00	83.58
	40	0.00	0.00	1.50	7.00	17.50	0.00	100.00
	60	0.00	0.00	3.00	12.50	28.00	0.00	100.00
L.S.D at 0.01		NS	NS	2.03**	2.76**	2.20**	5.25**	2.08**

Data is obtained from radiation tests of eggs and larvae are presented in **Table (6)** and **Table (7)**. A significant decrease in hatching results was observed, which depended on the radiation dose. Percentage adult emergence from irradiated eggs were 4.50, 2.75, 1.25 and 1.00 individual adult at 10, 20, 40 and 60 GY, respectively. While, the reduction in F1-progeny at these doses were 90.17, 93.99, 97.26 and 97.81 % at the same doses. On the other hand, the reduction in F1-progeny in larvae of *T. castaneum* exposed to radiation and survived to adulthood decreased with increasing radiation dose. The reduction were 18.50, 49.00, 94.50 and 97.00 % at 10, 20, 40 and 60 GY, respectively. These results showed the impact of gamma radiation on eggs of *T. castaneum* was higher than larvae at 10 and 20 GY. While, at 40 and 60 GY give the same effect in eggs and larvae.

Table (6): The efficiency of gamma radiation against *T. castaneum* eggs after 45 days.

Radiation *T. castaneum* egg after 45 day		
Doses/ (Gy)	**F1 -Progeny**	**Reduction**
10	4.50	90.17
20	2.75	93.99
40	1.25	97.26
60	1.00	97.81
L.S.D at 0.01	2.20**	2.18**

Table (7): The efficiency of gamma radiation against *T. castaneum* larvae after 45 days.

Radiation *T. castaneum* larvae after 45 day		
Doses/ (Gy)	**F1 -Progeny**	**Reduction**
10	81.50	18.50
20	51.00	49.00
40	5.50	94.50
60	3.00	97.00
L.S.D at 0.01	2.30**	2.30**

Lethal dose values and death regression line parameters for adults, larvae and eggs of *T. castaneum* exposed to gamma radiation are presented in **Table (8)**. the LD_{50} for the adults, larvae and eggs were 14.54, 0.82 and 0.05 GY, respectively. While, LD_{90} were 167.53, 2.52 and 1.03 GY, respectively. The findings indicated that adult *T. castaneum* exhibited greater resistance to gamma radiation compared to their larval and egg stages, in descending order of tolerance.

Table (8): Lethal doses values for the adults, larvae and eggs *T. castaneum* at different doses of gamma radiation.

Dose/ (GY)	LD_{25}	LD_{50}	LD_{90}	Slope	R
Adult	4.02	14.54	167.53	1.21±0.36	0.95
Larvae	0.46	0.82	2.52	2.63±0.33	0.95
Eggs	0.01	0.05	1.03	0.99±0.42	0.99

Results agree with results of (**Abbas and Nouraddin, 2011**) who found that exposure to 200 GY of radiation led to 100% mortality in infected adult specimens within 28 days after treatment. A dose-dependent increase in the growth periods of the vegetative parts of subjects exposed to gamma radiation. To manage the population, increase of *T. castaneum* in stored products, a radiation dose of 700 GY was recommended as an effective control measure. **Abd El-Aziz *et al.* (2017**) reported that the complete reduction in adult emergence (100%) required 1500 GY dose for all tested stages of *S. cevealella.* Our results appeared that dose of 1000 GY or less was inadequate to kill *S. cerealella* eggs and pupae.

3.3- The efficiency of four botanical oils against the adults of *T. castaneum* at 28± 2°C and 65 ± 5 %RH:

Toxicity of some botanical oils on *T. castaneum* adult infesting crushed wheat and reduction in F1-progeny at 28± 2°C and 65 ± 5 %RH were studied. The results of the impact of clove, colocynth, garlic and camphor oils on adults *T. castaneum* and reduction in F1-Progeny% are presented in **Table (9).**

3.3.1– Clove oil: The results of the impact of colve oil (*Syzygium roamaticum*) on adults of *T. castaneum* indicated that the death increased with increasing botanical oil concentration and exposure time. The adult's mortality of *T. castaneum*, at concentration 2% (v/w) after one-day exposure was 17.78% these mortality increased gradually to 74.71% after 14 days post treatment. While, the value of mortality was 100% at 6% (v/w) after one day post treatment. Also, data in **Table (9)** showed a pronounced adults impact of clove oil on F1-progeny of adults. Inhibition of F1-progeny recorded 88.57 for 2 ml/ kg while, 100% for other rested concentrations of clove oil.

3.3.2- Colonyth oil: Results concerning the bioactivity of colonyth oil (*Citrullus colocynthis*) against *T. castaneum* adults are given in **Table (9)**. It was apparent that low mortality percentages were recorded after 1, 3 and 5 days from treatment at all concentrations. Death increased with the increase in exposure time, after 7 and 14 days mortality for 2, 4, 6 and 8 ml/kg 3.33, 54.44, 84.44 and 100% and 8.89, 75.56, 97.78 and 100 %, respectively. But the reduction in F1-progeny was higher than the first death at all concentrations used. The reduction in F1-progeny were 60.71, 94.44, 100 and 100% at 2, 4, 6 and 8 ml/kg (v/w), respectively.

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3.3.3-Garlic oil: The results clearly appeared that garlic oil (*Allium sativum*) was low toxic at 2 and 4 % after 1, 3 and 5 days to the adults of red flour beetle. However, the toxic effect of garlic oil was concentration and time – dependent. At the highest concentration 8% (v/w) complete mortalities were watched after one day. On the other hand, the reduction at F1-progeny ranged from 47.78, 82.22, 100 and 100 % for 2, 4, 6 and 8 % (v/w) concentrations, respectively.

Table (9): Mortality of adults of *T. castaneum* after 14-day post exposure to different concentrations of four botanical oils.

Botanical oils	Conc. ml/kg	Mortality % of *T. castaneum* adult after indicated days					F1	R
		1	3	5	7	14		
Clove oil	2	17.78	44.44	55.56	64.37	74.71	2.22	88.57
	4	28.89	53.33	63.33	70.11	88.51	0.00	100.00
	6	100.00	100.00	100.00	100.00	100.00	0.00	100.00
	8	100.00	100.00	100.00	100.00	100.00	0.00	100.00
L.S.D at 0.01		3.76**	5.04**	6.51**	4.92**	4.60**	NS	NS
Colonyth oil	2	0.00	0.00	0.00	3.33	8.89	8.89	60.71
	4	13.33	26.67	37.78	54.44	75.56	1.11	94.44
	6	27.78	50.00	61.11	84.44	97.78	0.00	100.00
	8	100.00	100.00	100.00	100.00	100.00	0.00	100.00
L.S.D at 0.01		6.51**	6.51**	3.36**	3.36**	5.58**	3.76**	21.34**
Garlic oil	2	0.00	0.00	1.11	3.33	5.56	5.56	47.78
	4	15.56	25.56	37.78	53.33	72.22	2.22	82.22
	6	48.89	61.11	66.67	84.44	96.67	0.00	100.00
	8	100.00	100.00	100.00	100.00	100.00	0.00	100.00
L.S.D at 0.01		4.45**	3.76**	6.73**	7.71**	6.73**	3.36**	29.65**
Camphor oil	2	2.22	13.33	36.67	56.67	80.69	2.22	85.71
	4	42.22	56.67	71.11	83.33	97.70	0.00	100.00
	6	100.00	100.00	100.00	100.00	100.00	0.00	100.00
	8	100.00	100.00	100.00	100.00	100.00	0.00	100.00
L.S.D at 0.01		4.45**	7.71**	6.51**	7.71**	4.30**	NS	0.00**

3.3.4- Camphor oil: The results of the impact of camphor oil (*Cinnamomum camphor*) on adult of red flour beetle are presented in **Table (9).** The death increased by rising attention and duration of exposure. The adult's death of *T. castaneum* at 2, 4, 6 and 8 ml/kg (v/w) were 2.22, 42.22, 100 and 100 % after one day of treatment, respectively. These values gradually increased after three days (13.33, 56.67, 100 and 100) for the same concentrations, while, the mortalities of *T. castaneum* adult after 14 days increased to 80.69, 97.70, 100 and 100% for 2, 4, 6 and 8 ml/kg (v/w), respectively. On the other hand, the reduction of F1-progeny for camphor oil against *T. castaneum* at the same concentrations was high and the death recorded 85.71% mortality at 2 ml/kg while it was 100 % at 2, 4, 6 and 8 ml/kg (v/w), respectively. These results showed that the clove oil and camphor oil was more toxic against *T. castaneum* than garlic oil and colonyth oil.

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Data in **Table (10)** showed that, based on LC_{50} values the most toxic botanical oils was clove oil (LC_{50} 0.33 y.w.v) while, the Colocynth, garlic and camphor oils were moderate toxic on *T. castaneum* adults (LC_{50}, 1.63, 1.72 and 1.73 y.w.v) respectively. The results indicated that the toxicity of Clove, Colocynth and garlic oils against *T. castaneum* adults at LC_{90} (2.43, 2.73 and 2.85) were higher than camphor oil (LC_{90}, 5.25).

Table (10): The lethal concentrations and confidence limits of tested botanical oils after post treatment against the adults of *T. castaneum*.

Botanical oils	**LC_{25}**	**LC_{50}**	**LC_{90}**	**LC_{25}**		**LC_{50}**		**LC_{90}**		Slope ±SD	R
				Lower	Upper	Lower	Upper	Lower	Upper		
Clove	0.12	0.33	2.43	0.01	0.29	0.07	0.56	1.91	3.32	1.48±0.33	0.98
Colocynth	1.24	1.63	2.73	1.12	1.35	1.51	1.75	2.52	3.00	5.74±0.44	0.99
Garlic	1.32	1.72	2.85	1.19	1.44	1.60	1.84	2.63	3.15	5.85±0.46	0.99
Camphor	0.96	1.73	5.25	0.63	1.48	1.13	2.66	3.42	8.08	2.66±0.38	0.97

These results are in agreement with those obtained by (**Ghrasan Fathia *et al.*, 2018**) who examined the adult toxicity of botanical oils against *T. castaneum* and *Oryzaephilus surinamensis* (lavender, onion, flax, caraway and brown galingale). Results indicated that *O. surinamensise* was more susceptible to plant oils than *T. castaneum*, which increased resistance to these natural products. Also, the results showed that caraway and lavender oils were the most toxic among all treatments applied to *T. castaneum* with a lethal concentration of 50% (LC_{50}) values of 1, 2 and 2.4 µl percent ml. respectively. **Khanal *et al.* (2019**) assess the efficacy of clove oil against rice weevils at seven quantities of clove (4, 2, 1, 0.5, 0.25, 0.12 and 0.9) of clove bud/kg of wheat seed were tested on three kinds of wheat. The results suggested that clove buds, have considerable pesticidal impact on rice weevils and can be considered as choice tool to control rice weevils in wheat during post-harvest.

4- CONCLUSION

In light of the previous results, it could be concluded that ozone gas, gamma radiation, and essential oils are effective against adult red flour beetles. Mortality gradually increased by increasing the concentrations and period of exposure. The highest toxic plant oils was clove and camphor oils after one day post treatment and should be used as alternative candidate and considered in integrated pest management (IPM) programs to control red flour beetle.

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Availability of data and materials: *Not applicable.*

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