Evaluating the Effectiveness of Treating Wheat Flour with ECO_2-Fume® Fumigant, Gamma Irradiation and Microwave Heating in Controlling Adults and Larvae of the Saw-Toothed Grain Beetle, *Oryzaephilus surinamensis* and the Effect of These Treatments on Some Flour Components

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Abstract

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The aim of this study was to evaluate the effectiveness of treating wheat flour with ECO_2-Fume® fumigant (mixture of phosphine and carbon dioxide), gamma irradiation, and microwave heating in controlling adults and larvae of the Suriname sawfly beetle. Wheat flour was exposed to ECO_2-Fume in Shona Qalyoub (Qalyubia Governorate, Egypt), and flour samples were exposed to gamma irradiation at the National Center for Radiation Research and Technology, and microwave oven under laboratory conditions. ECO_2-Fume fumigant at a concentration of 25, 30, 40 and 50 g/m^3, with exposure for three days was used. The mortality rate was 100% for adults and larvae, when applied at a rate of 50 g/m^3. The decline rate in the number of adults in the first generation was 100%, and there was no emergence of adults when treatment was made at the larval stage. Gamma irradiation was used at doses of 200, 400, 600, and 800 Gray. The highest mortality rate was 100% when adult insects were exposed to 800 Gray, ten days after treatment, and the larval mortality rate was 100%, five days after treatment at the concentrations of 800 and 600 Gray. In addition, population decrease rate (%) of adults of the first generation and larvae was 100% with all concentrations used. Microwave energy was used against adults and larvae of the Suriname saw beetle by exposing it to three different microwave powers, namely 180, 300, and 450 watts, for different exposure durations (20, 40, 60, 80, 100 and 120 seconds). The death rate reached 100% within 120 seconds with 450 watts. Regarding the effect of previous treatments on the main chemical components of wheat flour, the results generally showed slight differences in the protein, carbohydrates and fats content in wheat flour treated with gas at 50 g/m^3 and gamma rays at 800 Gray. Whereas, in the case of microwave treatment at 450 W, significant differences in protein, carbohydrate and fat content were recorded when compared with the control treatment.

Keywords: Stored products, insects, fumigant, radiation, microwave.

Introduction

The Saw-toothed grain beetle, *Oryzaephilus surinamensis* (L.), is a serious pest of stored grains, particularly milled and processed products. Additionally, it appears on a very broad range of other products, such as dried fruits, nuts, and oilseeds **(**Rees, 2008). The most common tools for managing these insects are fumigants (Akinkurolere *et al.*, 2006). Phosphine (PH3) is still the most used fumigant and the least expensive to control insect pests in stored products. Despite the fact that phosphine-resistant stored-grain insects are on the rise (Konemann *et al.*, 2017), these pests continue to pose a threat (Norwood, 2017). To increase the toxicity of PH_3, another approach is to combine it with another fumigant.

Carbon dioxide (CO_2) can become toxic to insects in large quantities, and it takes a long time for all stages of insects to die from it (Hasan *et al.*, 2016). CO_2 is a prime option for co-fumigation with PH_3 because of its characteristics. It makes it possible for PH_3 to be distributed equally throughout the grain mass, ensuring that insects are exposed to both gases at once. CO_2 prevents phosphine flammability, which is crucial for workplace safety (Constantin *et al.*, 2020). Additionally, exposure to both gases at once might enhance toxicity, reduce the survival of insect species and their various life phases, consequently lowering tolerance and resistance levels to PH_3 (Cato *et al.*, 2019).

Irradiation is a physical, environmentally friendly treatment which does not leave any residue in the product. It is increasingly used as an alternative to methyl bromide and other chemical fumigants for disinfestation of insect pest in stored grains (Hammad, 2020). Irradiation destroys insect cellular molecules such as DNA and RNA at levels used for phytosanitary treatment, and as a result, it is effective in relation to all stages of insect development. In several nations, phytosanitary irradiation (PI) is permitted for stored products (Hallman, 2013). An adequate test for the effectiveness of irradiation is the prevention of reproduction, which includes the prevention of oviposition, egg hatching, larval development, pupation, adult emergency, and development of eggs in F1 generation (Hallman, 2013).

The frequency range of microwaves, a kind of electromagnetic radiation, is 300 MHz to 3000 GHz. A distinctive feature of microwaves is that they raise the temperature of a medium as they pass through it. Thus, there are a variety of practical uses for microwaves in the food and agriculture industries (Seyedabadi, 2015). Microwave heat kills pests at different stages of growth quickly and without

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leaving behind harmful chemical residues in food products or the environment, making it an efficient method of pest control (Halverson *et al.*, 1998). But the effect of microwave heating on product quality has remained a problem (Sadeghi *et al.*, 2018). But given that changes in product quality can ultimately affect product marketing, this heat may have a negative impact on the colour of dried goods like figs, which could pose a significant obstacle to the application of microwave heating technology.

Therefore, the main objective of this study was to evaluate the efficacy of ECO_2-Fume gas, gamma radiation and microwave heating against *O. surinamensis* larvae and adults under laboratory conditions to replace the use of chemical control.

Materials and Methods

Insect culture

The initial cultures of saw-toothed grain, *Oryzaephilus surinamensis*, adults and larvae were maintained in the Stored Grain Pests Department of the Plant Protection Research Institute. The artificial diet used to raise adult *O. surinamensis* beetles consisted of 99% crushed wheat and 1% yeast (Finkelman *et al.*, 2006). These jars were incubated for two weeks at 27±1°C and 65±5% RH.

ECO_2-Fume formulation

The ECO2-Fume formulation included carbon dioxide (CO_2) 98%, phosphine (PH_3) 2% (by weight, 2.6% by volume). ECO_2-Fume gas was applied in a Shona (grain store) Qalyoub, Qalyubia governorate, Egypt. There were three piles of 240-jute sacks, each containing 100 kg of wheat grains. 50 gm of wheat flour was packed in each jute bag (14×20cm). Twenty adult beetles (7-14 days old) and ten larvae (5 days old) of *O. surinamensis* were added to each jute bag then closed well and secured with rubber bands. There were 24 bags altogether for each concentration of ECO_2-Fume gas, with 6 bags per direction (North, South, Middle, West). The packed bags were added to the group and distributed in the previously indicated four directions. A plastic sheet measuring 14 by 20 meters was used to cover the heaps precisely and tightly. The necessary concentration was calculated after sealing the fumigation area and placing the gas cylinder on the platform balance. Four ECO_2-Fume concentrations were used: 25, 30, 40 and 50 g/m^3. Three days after exposure to ECO_2-Fume gas, the piles were aerated, and the jute bags containing adults were checked immediately for adult mortality and corrected based on Abbott's formula (Abbott, 1925), and the adults were removed 14 days later to obtain the F1 progeny. Larvae bags were kept at 27±2°C and 75±5% RH (F1 progeny). Insects' reduction rate (%) was estimated. Identical processes but without the use of ECO_2-Fume gas were performed as a control treatment.

Irradiation technique

Indian gamma cell radiation unit 0.744 is a (KGray/h) to get these concentrations 200, 400 and 600 Gray. The Canadian gamma cell uses 0.425 KGray/h for 800 Gray facility that is part of the Atomic Energy Authority's National Center for Radiation Research and Technology in Nasr City, Cairo, Egypt.

Each glass jar contained 10 g Wheat Flour. Twenty adult beetles (7-14 days old), ten larvae (5 days old) of *O. surinamensis* were added to each glass jar. Adults and larvae were irradiated in the same cell with radiation range of 200, 400, 600 and 800 Gray.

Every treatment was conducted in three replicates. Three replicates of untreated Wheat flour were also used as a control treatment. All jars were stored under laboratory conditions after being covered with muslin cloth and secured with a rubber band. After treatment, 1, 2, 3, 4, 7 and 14 days later, mortality rates were noted and corrected in accordance with Abbott's formula (Abbott, 1925) and 14 days later, the adults were removed to obtain F1 Progeny in samples including adults. Before the beetle emerged, the larvae were maintained at 27.2°C and 75.5% RH.

Microwave treatment

The experiment makes use of a microwave frequency of 2450 MHz. It utilized a microwave oven made by Electra in Japan, model EM-280 M, with a 28L capacity and a cavity measuring 21.9×35×35 mm. Three energy settings (low, medium-low, and medium) with corresponding power of 17, 44, and 66% were available from the oven (output: 800W).
In a glass jar, samples of 10g of wheat flour with 20 adults and 10 larvae of *O. surinamensis* were placed. Samples containing *O. surinamensis* adults and larvae were exposed to 180, 300 and 450W for 20, 40, 60, 80, 100 and 120 seconds. Both the insect and control groups were tested in three replications. The treated samples were placed in the incubator under constant conditions (30°C, 60% RH). At 24 hours after exposure, observations on the mortality of adults and larvae were made. The Abbott formula for calculating natural mortality in untreated controls was used to compute the corrected mortality rate (Abbott, 1925). Adults were removed after 14 days to obtain F1 progeny in samples which contained adults, whereas larvae were kept at 27±2°C and 75±5% RH until the beetle emerged.

Determination of chemical components of wheat flour following different treatments

The effect of ECO_2-Fume gas at 50 g/m^3, gamma radiation at 800 Gray and microwave at 450W on the major nutritional components (protein, carbohydrate and lipids) of treated and non-treated wheat flour was investigated Three replicates of 10 g of wheat flour were exposed to the high concentration of treatments, and analysis was then conducted on the treated and non-treated wheat flour. Tested samples were selected randomly. Total proteins were determined by using Bradford's technique (1976). Total carbohydrates were estimated in acid extracts of a sample by the phenol-sulphuric acid reaction (Dubois *et al.*, 1956). Total lipids were extracted and quantified by the method of Bligh & Dyer (1959).

Statistical analysis

The average mortality rate (%) of the studied insects was calculated and corrected using Abbott's technique for statistical analysis (Abbott, 1925). Simple correlations and partial regression were used for the effect of ECO_2-Fume and radiation, which can be attributed to variance explanation ratios (EV %) of the effect of concentration and time. In the case of microwave treatment, the combined effect of time and energy was used. Collection, Regression, and ANOVA in SAS were used to evaluate the collected data (Anonymous, 2003). The analysis of data was performed on each dependent variable, and means significance was determined by using LSD test (P=0.05).

Results and Discussion

Effect of ECO_2-Fume® fumigant against adult and larvae of *Oryzaephilus surinamensis*

The effects of different ECO_2-Fume gas concentrations on the mortality and reduction rate in adults F1-progeny, in addition to the mortality and number of adult emergence of *O. surinamensis* larvae are summarized in Table 1. Adult and larval mortality rates increased with increasing ECO2-Fume gas concentration. There was a significant difference in the mortality rate of adults and larvae of *O. surinamensis* at different concentrations of ECO_2-Fume gas. Results obtained showed that adults and larval stages of *O. surinamensis*, treated with 50 g/m^3 for three days reached 100% mortality. Mortality rate following the use of different concentrations (40, 30 and 25 g/m^3) were 100, 78.33, 60% and 100, 83.33, 63.33% for adults and larvae, respectively, and higher concentrations (40 and 50 g/m^3) induced higher mortality of 100%. ECO_2-Fume gas was also more effective on larvae than on adults. Insects in non-fumigated control jute bags remained alive. On other hand, the reduction in F1-progeny was high compared to adult and larval mortality, and reached 100% at different concentrations of ECO_2-Fume gas for adults after 45 days, and no adults emerged from the larval stage.

Highly significant positive correlation values were observed between mortality rate of *O. surinamensis* adults and larvae and fumigant concentration were 0.94 and 0.91, with P-values between 0.0514 and 0.0890. The explained variance (EV %) was 89.99 and 82.99 %, respectively, on the adults and larvae of *O. surinamensis*.

Lethal concentrations of Eco2-Fume gas on the adult and larvae of *O. surinamensis* under practical conditions, under plastic sheet. The LC_{50} for adults and larvae were 23.82 and 23.12 g/m^3, respectively. In addition, the LC_{90} were 32.63 and 31.91 g/m^3 for adults and larvae, respectively. The obtained results showed that the larvae of *O. surinamensis* were more sensitive to Eco2-Fume gas than adults.

The results obtained in this study are in line with those of Amin *et al.* (2020) who showed that effectiveness of ECO_2-Fume gas was improved with increased concentration, and that three days after treatment, a dose of 50 g/m^3 caused 100% mortality of all insect stages. Low phosphine levels are more efficient at causing 100% mortality of all life stages in shorter time periods because the stress caused by elevated CO_2 levels on insects makes them more susceptible. Mohamed & Sayed (2017) reported that the fumigation with ECO2-Fume gas, three days after exposure, cau8sed 100% mortality of adults and juvenile stages of *Ephesia cautella*, *Ephesia calidella*, and *O. surinamensis***.** These findings are also in agreement with previous findings **(**Constantin *et al.*, 2020; Kengkanpanich *et al.*, 2018) which indicated that adding CO_2 + PH_3 increased its toxicity and lowers the amount needed to kill insects.

Effect of gamma irradiation against adult and larvae of *O. surinamensis*

Results concerning the toxic effect of gamma radiation on adult mortality and reduction% in F1-progeny of *O. surinamensis* also, mortality of larvae and number of adult emergence at 30±1°C and 65±5% RH, are presented in Table 2. Data showed that the adults and larvae of *O. surinamensis* mortality increased with increasing gamma radiation dose. The lowest mortality rate for adults and larvae stages were 6.66 and 26.66% at 200 Gray 5 days after treatment. The highest mortality for adults was 100% at 800 Gray 10 days after treatment. Whereas the larval mortality of *O. surinamensis* was 100% at 800 Gray 5 days after treatment. Ten 10 days post-irradiation, the mortality rates reached 98.33& 100% for adults and larvae at 600 Gray, respectively. On other hand, the reduction in F1 progeny was highly impactful compared to adult and larval mortality. These values reached 100% at different doses of gamma radiation for adults 45 days after treatment, and there was no adult emergence in the case of larvae. A significant difference in the mortality rate of the irradiated and non-irradiated adults and larvae at different concentrations of gamma radiation for different time intervals was observed.

Significant positive correlation between mortality rate and exposure time of adults and larvae of *O. surinamensis* and reached 0.88 and 0.67 with P-values of 0.0001 and 0.0010, respectively, whereas non-significant positive correlation between mortality rate and radiation dose were obtained for adults and larvae of *O. surinamensis* and reached 0.38 and 0.63, respectively. The explained variance (EV %) for the adults and larvae of *O. surinamensis*, was 93.12 and 86.58%, respectively. These results indicate that exposure time are more effective on *O. surinamensis* than dose of gamma radiation.

Lethal dose of gamma radiation on the adult and larvae of *O. surinamensis* under field conditions were determined. The LD_{50} for adults and larvae were 313.07 & 252.45, respectively. Also, the LD_{90} were 932.12 & 547.07 for adults and larvae, respectively. The results obtained showed that the larvae of *O. surinamensis* were more sensitive to gamma radiation than adults.

The above mentioned results are in agreement with earlier findings (Abd-El-Aziz *et al*., 2023), who indicated that the mortality of *O. surinamensis* increased with increasing doses and exposure time. Abbas *et al*., (2010) showed that gamma radiation was more effective against the adults and larvae of *O. surinamensis*. Adults exposed to the 200 Gray dose died completely 28 days after the radiation treatment. The developmental durations increased in a dose-dependent manner. In addition, Mansour (2016) observed that the irradiation sensitivity of 1-2 days old *Trigoderma granarium* adults increased with increasing dose. Females were more prone to irradiation than males.

Effect of microwave heating against adult and larvae of *O. surinamensis*

Results obtained (Table 3) showed that the corrected mortality rate in *O. surinamensis* adults and the percentage decrease in F1 offspring, and in the case of larvae the larval mortality rate and the number of adult emergences were corrected at 30±1°C and 65±5%. Rs. Compared to no mortality detection in untreated conditions, mortality increases in adult and larval stages when exposure time or power settings are increased. Using microwave energy at a power level of 180 W for 20 sec, the lowest mortality percentages for the adult and larva stage was 8 and 16%, respectively. At 300 W and 120 s the adult and larval mortality rates were 90 and 100%, respectively. By increasing exposure times and microwave power levels, adult and larval mortality of *O. surinamensis* increased, reaching 100% at 120 s exposure time and 450 W power. For each power, an increase in the exposure time led to increased mortality.

Table 1. Mortality rate of adults and larvae of *Oryzaephilus surinamensis* infesting wheat flour exposed to ECO_2-Fume® fumigant at various concentrations.

Fumigant concentration (g/m^3)	Adults		Larvae	
	Corrected mortality rate	Reduction (%) in F1 progeny	Corrected mortality rate	Adult emergence
25	60.00±1 c	100.00	63.33±1.57 c	0
30	78.33±1.15 b	100.00	83.33±0.57 b	0
40	100.00±0.00 a	100.00	100.00±0.00 a	0
50	100.00±0.00 a	100.00	100.00±0.00 a	0

Means followed by the same letters in the same column are not significantly different at P=0.05.

Table 2. Mortality rate of adults and larvae of *Oryzaephilus surinamensis* treated with gamma irradiation.

Stage	Dose (Gray)	Corrected mortality rate (%) after different periods (days)					Reduction (%) in F1 progeny
		1	3	5	7	10	
Adult	200	0.00 b	0.0 c	6.66 c	33.33 c	73.33 b	100.00 a
	400	0.00 b	15.0 b	43.33b	53.33 b	80.00 b	100.00 a
	600	0.00 b	20.0 ab	58.33 a	80.00 a	98.33 a	100.00 a
	800	6.66 a	28.33 a	68.33 a	88.33 a	100.00 a	100.00 a
Larva	200	0.00 c	0.00 c	26.66 d	40.00 c	86.67 b	100.00 a
	400	0.00 c	0.00 c	45.00 c	66.66 b	96.67 a	100.00 a
	600	26.66 b	60.00 b	80.00 b	100.00 a	100.00 a	100.00 a
	800	70.0 a	83.33 a	100.00 a	100.00 a	100.00 a	100.00 a

Means followed by the same letters in the same column are not significantly different at P=0.05.

Table 3. Mortality rate of *O. surinamensis* adults exposed to microwave heating at various exposure times and power levels.

Power (W)	Exposure time (sec)	Corrected mortality rate (%) after 1 day		Reduction (%) in F1 progeny of adult	Adult emergence (%)
		Larvae	Adult		
180	20	16.00 e	8.00 f	7.96	6.33
	40	30.00 d	20.00 e	23.43	4.66
	60	46.60 c	38.30 d	36.81	4.00
	80	63.30 b	58.30 c	61.34	3.00
	100	90.00 a	75.00 b	82.33	1.00
	120	100.00 a	86.66 a	90.79	0.00
300	20	26.60 e	16.50 f	20.24	4.66
	40	43.30 d	35.00 e	35.57	4.00
	60	66.60 c	55.00 d	57.66	2.66
	80	83.30 b	70.00 c	74.23	2.00
	100	100.00 a	83.00 b	85.27	0.00
	120	100.00 a	90.00 a	94.47	0.00
450	20	63.30 c	30.00 e	27.00	2.33
	40	86.60 b	48.30 d	44.78	2.00
	60	96.60 a	70.00 c	75.46	0.00
	80	100.00 a	88.33 b	92.03	0.00
	100	100.00 a	96.66 a	97.55	0.00
	120	100.00 a	100.00 a	100.00	0.00

Means followed by the same letters in the same column are not significantly different at P=0.05.

The adult's reduction in F1-progeny of *O. surinamensis* reached 100% at 120 s exposure time and 450 W power, on the other hand there was no adults emergence following 120 s exposure of larvae at different powers.

Non-significant positive correlation values between mortality rate and microwave heating exposure time and power the adults of *O. surinamensis* were 0.12 to 0.55, and 0.25 and 0.41 for larvae. The combined effect of exposure time and microwave energy of the adult and larvae of *O. surinamensis*, was 30.87 and 20.48%, respectively. Lethal time (50%) (LT_{50}) of microwave heating on the adults and larvae of *O. surinamensis* under field conditions were 254.09 and 201.22, respectively. Likewise, the LT_{90} were 1067.52 and 416.06 for adults and larvae, respectively. The results obtained showed that the larvae of *O. surinamensis* were more sensitive to microwave heating than adults.

These results are in agreement with earlier findings (Reza *et al*., 2019), and Purohit *et al.* (2013) obtained similar findings with *Callosobruchus maculatus* (F.). Likewise, Manickavasagan *et al.* (2013) working on date pests reported microwave power and exposure time significantly affected the death rates of adults and larvae of *Tribolium castaneum* (Hrbest) and *O. surinamensis*, with the effect being more pronounced in the larvae of *T. castaneum* than in the adults. Furthermore, Abotaleb *et al.* (2021) discovered that *T. granarium* adults and larvae suffered high mortality rate in response to increased microwave exposure time and energy.

Effect of different treatments on the total proteins, lipids and carbohydrates

The effect of ECO_2-Fume gas at 50 g/m^3, gamma radiation at 800Gy and microwave at 450 powers on the major chemical constituents of treated wheat flour and non-treated are summarized in Table 4. In general, the results showed that protein, carbohydrates and lipid contents varied slightly, in treated wheat flour with ECO_2-Fume gas at 50g/m^3 and gamma radiation at 800 Gray. Whereas in case of microwave heating at 450 W great differences in contents of protein, carbohydrates and lipids were observed, as compared to the control treatment**.**

Table 4. Determination of proportion of main nutritional components in wheat flour after different treatments.

Treatments	Total protein (%)	Total carbohydrates (%)	Total lipids (%)
ECO_2 Fume	8.64±0.01	60.95±0.48	2.48±0.01
Gamma radiation	8.79±0.06	60.55±0.04	2.66±0.01
Microwave heating	4.66±0.24	70.20±0.82	1.44±0.09
Control (untreated)	8.60±0.56	60.80±1.88	2.61±0.22

Similar results were obtained by Ertürk *et al.* (2018), who showed that the green pepper fruit treated with phosphine (ECO_2-Fume) for 24 h at 500, 1000 and 2000 ppm no adverse impacts on fruit quality (physical, chemical, and sensory analysis) following treatment, storage, and shelf life was observed**.** Amin *et al.* (2022) indicated that the 50 g/m^3 fumigation concentration had no statistically significant impact on the quality of cowpea germination or any of the chemical components of cowpea seeds. Hammad (2020) reported that irradiation is a physical, environmentally friendly treatment which does not leave any residues in the treated product. It is increasingly used as an alternative to methyl bromide and other chemical fumigants for disinfestation of insect pest in stored grains. In case of microwave heating, Sadeghi *et al.* (2018) reported that the effect of microwave heating on product quality has remained a problem. Que (2013) found that the microwave radiation also affects the baking quality of flour and wheat grains. In line with our findings, Qu *et al.* (2017) found that during an exposure of 20 seconds at 700 W, the gluten, farinograph characteristics, and viscosity of the flour made from wheat that had been microwave-treated were somewhat affected.

It can be concluded that this study provides information about the efficacy of ECO_2-Fume gas, gamma radiation and microwave heating in the management of *O. surinamensis* infested wheat flour. Results obtained showed that exposure to 50 g/m^3 of ECO_2-Fume gas or exposure to 800 Gray gamma radiation was effective in eliminating adults and larvae of *O. surinamensis*, and is preferable than microwave heating because of its negative effect on the product quality.

الملخص

عياد، إيمان لطفي وهند طه عبد الحليم. 2025. تقييم فعالية معالجة دقيق القمح بمادة التبخير ®ECO2-Fume وأشعة جاما والتسخين بالموجات الدقيقة (ميكروويف) في مكافحة بالغات ويرقات خنفساء السورينام المنشارية (*Oryzaephilus surinamensis*) وتأثير هذه المعاملات في بعض مكونات الدقيق. مجلة وقاية النبات العربية، 43(1):80-86. https://doi.org/10.22268/AJPP-001285

هدفت هذه الدراسة إلى تقييم فعالية معالجة دقيق القمح بغاز الإيكوفيوم (مخلوط الفوستوكسين وثاني أوكسيد الكربون) وأشعة جاما والموجات الدقيقة (الميكرويف) في مكافحة بالغات ويرقات خنفساء السورينام المنشارية. تمّ تعريض دقيق القمح لغاز الإيكوفيوم في شونة القليوبية (محافظة القليوبية، مصر)، بينما تم تعريض عينات الدقيق لأشعة جاما في المركز القومي للبحوث والتكنولوجيا، وللموجات الدقيقة – تحت ظروف المختبر. استخدم غاز الإيكوفيوم بتركيز 25، 30، 40 و 50 غ/م^3 مع التعريض لمدة ثلاثة أيام، حيث بلغت نسبة الموت 100% للحشرات الكاملة واليرقات، عند التطبيق بمعدل 50 غ/م^3. كذلك كانت نسب الانخفاض 100% في تعداد الجيل الأول للحشرات الكاملة، كما لم يحدث خروج للحشرات الكاملة عند معاملة اليرقات. استخدمت أشعة جاما بجرعات 200، 400، 600 و 800 جراي، وكانت أعلى نسبة موت (100%) عند تعريض الحشرات الكاملة للجرعة 800 جراي بعد عشرة أيام من المعاملة، وأما عند اليرقات كانت نسبة الموت 100% بعد خمسة أيام من المعاملة مع الجرعات 600–800 جراي، وكانت نسبة الانخفاض في تعداد الجيل الأول للحشرات الكاملة واليرقات 100% مع جميع التراكيز المستخدمة. عند

تعريض الحشرات الكاملة ويرقات خنفساء السورينام المنشارية لثلاثة مستويات مختلفة من الموجات الدقيقة ، وهي 180، 300 و 450 واط، لمدد تعريض مختلفة (20، 40، 60، 80، 100 و 120 ثانية)، وصلت نسبة الموت إلى 100% خلال 120 ثانية عند 450 واط. كما أظهرت النتائج بشكل عام وجود اختلافات طفيفة في محتوى البروتين والكربوهيدرات والدهون لدقيق القمح المعالج بالغاز عند 50 غ/م^3، وأشعة جاما عند 800 جراي، بينما تمّ تسجيل وجود اختلافات كبيرة في محتوى البروتين والكربوهيدرات والدهون عند استخدام التسخين بالموجات الدقيقة(الميكروويف) عند مستوى 450 واط مقارنةً بالشاهد غير المعامل.

كلمات مفتاحية: مواد مخزونة، حشرات، مدخنات، إشعاع، ميكروويف.

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