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# MICROWAVE AS CONTROL METHOD FOR THE RED PALM WEEVIL, *RHYNCHOPHORUS FERRUGINEUS* OLIVIER (COLEOPTERA, CURCULIONIDAE)

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**ABSTRACT:** The Red Palm Weevil (RPW), *Rhynchophorus ferrugineus* Olivier is considered one of the most dangerous pests that destroy palm trees. The extensive use of chemical agents to control it has led to environmental pollution. Consequently, this study aimed to shed insight into the practice of alternate approaches to eliminate this pest. The experiments were conducted using a home microwave, as well as a modified microwave device consisting of 2 or 4 magnetron units. The microwave was used to study the effectiveness against eggs, larvae, pupae, and adults in the laboratory and semi-field to calculate mortality percentages and to determine the efficiency of the lowest energy level, and the suitable exposure time that highly reduced all weevil stages. The results showed that there was no hatching process of eggs exposed for 15, 20, and 30 seconds at different power levels, but hatching occurred in eggs exposed for 10 seconds. It was also noted that the higher the energy level, the lower the egg-hatching rate. In the case of larvae, it was observed that there was a direct relationship between the size of larvae, energy levels, & exposure time, and mortality percentages. Also, concerning pupae and adult stages, the same relationship was found between the reduction percentages, energy levels, and exposure durations. Respectable control results for insect stages were recorded with modified microwaves in semi-field experiments. The longer the exposure time, the greater the reduction percentages of weevil stages without differences between devices having 2 or 4 magnetron units.

**Key words**: Physical control, red palm weevil, electromagnetic radiation, safe control

## INTRODUCTION

The invasive red palm weevil (RPW), Rhynchophorus ferrugineus Olivier (Coleoptera, Curculionidae), has become a catastrophic pest of palm palms around the world. This major pest has caused substantial economic harm to date palm trees. The RPW was first discovered in the Middle East in the 1980s, and it quickly expanded to many nations, including Asia, Africa, the Mediterranean area, the Caribbean, Europe, and North America (Rmili *et al.*, 2020). In Egypt, *R. ferrugineus* is widespread, infesting over 261,000 palm trees between 1992 and 2000, with approximately 23% of these trees requiring removal (El-Sebay, 2007 and Sauvard *et al.*, 2010). Larval stage is particularly destructive, causing frond deformities that ultimately lead to palm death (Idris *et al.*, 2015). The larvae create cavities and tunnels within the palm tree trunk, disrupting nutrient and water transfer between the root system and the crown, compromising the tree’s mechanical integrity (Rach *et al.*, 2013, Rmili *et al.*, 2020). Various control methods have been developed to combat *R. ferrugineus*, including biological, chemical, mechanical, and physical techniques. Among the physical techniques, gamma radiation and X-ray have been employed to eliminate the insect (Ramachandran, 1991). Additionally, electromagnetic energy at microwave frequencies has shown promise (Massa *et al.*, 2011). The physical techniques are combined

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with other control methods within an integrated pest management strategy (Giblin-Davis *et al*., 2013), including insect traps, plant extracts, synthetic insecticides, and biological control (Faleiro, 2006, EPPO, 2008, El-Shafie *et al*., 2011, Di Ilio *et al*., 2018, El Namaky *et al*., 2020, El Sadawy *et al*., 2020). The idea behind using microwaves against RPW is twofold: either inducing a lethal thermal increase in the pest without harming plant tissues or affecting the reproduction of survivors (Hamid, 1968). Microwaves are electromagnetic fields oscillating in the 300 MHz to 300 GHz frequency range. Their thermal effect is widely used for food processing and industrial applications. The US Federal Communications Commission (FCC) has allocated the industrial, scientific, and medical (ISM) bands (915 MHz ± 25, 2450 MHz ± 50, 5800 MHz ± 75, and 24125 MHz ± 125) for microwave industrial use (Metaxas, 1996, and Ehlers & Metaxas, 2003). When a dielectric material is exposed to rapid time-varying electromagnetic fields at microwave frequencies, water molecules within it can move, oscillate, or rotate due to the applied electric field, generating friction and heat. Microwaves (MWs) have found applications in remote sensing, imaging, quality assessment, and dielectric heating in pre- or post-harvest environments (Mahabadi *et al*., 2013). Notably, using microwave radiation for red palm weevil eradication offers advantages such as speed, efficiency, and absence of toxic or pollution residues. Unlike chemical insecticides, weevils are unlikely to develop resistance to radiation.

This research aims to test the effectiveness of microwave against eggs, larvae, pupae, and adults in the laboratory and semi-field to measure the mortality % and decide the lowest energy level and exposure time that affects all weevil stages.

## MATERIALS AND METHODS

Laboratory experiments were conducted using microwaves to investigate the impact of different energy levels and exposure durations on the life stages of the red palm weevil. The study was carried out at Dr. Yousry El-Sebay Laboratory Research of Red Palm Weevil at El-Kassasin, Ismailia governorate.

### 1. Home microwave experiments

The microwave used is Daewoo 220 v, 50HZ, Output power: 1000 W, capacity 55 liters, and cavity dimensions 480 mm (W) x 339 mm (H) x 589 mm (D). The operating frequency of the oven was 2450 MHz.

#### 1.1 Effect of energy levels and exposure time on the mortality of some weevil stages

In this research, eggs were placed in Petri dishes on filter paper moistened with distilled water inside the home microwave (Fig. 1). Each treatment had four replicates (each replicate containing five eggs). Three energy levels (100, 90, and 70 %) were applied for exposure times of 10, 15, 20, and 30 sec. After that, the treated and untreated eggs were incubated at 27°C where hatching was daily assessed. Three energy levels (100, 60, and 30%) were also used for different larval instars (first - second - fourth - sixth - eighth and last larvae) as well as pupae and adults. Exposure duration was 10, 20, and 30 sec. Each treatment had four replicates, and each replicate had five stages. Post-treatment and the control were placed in the incubator at a temperature of 27°C and the mortality was evaluated daily for two weeks after treatment.

#### 1.2 Time needed for mortality of weevil stages inside palm trunks in a home microwave

Insects and larvae were put at depths of 10, 15, and 20 cm within palm trunk pieces (20-25 cm length) that were exposed to a power level of 100 % for different periods which was recorded until insect stages mortality occurred. Temperature records were taken at each depth after treatment. Each treatment had three replicates, and each replicate had four individuals of each stage.

**Fig. 1: Home microwave**

## 2. Experiments with developed two and four magnetrons microwave

The number of magnetron units has been increased to two and four units in addition to the remote-control unit Figures (2 and 3). Larvae and adults were put inside palm trunks in the middle with different diameters of 40, 50, and 60 cm and length 50 cm. It takes up to 30 and 45 min and the temperature was measured at each distance. Each treatment was replicated four times, and each replicate had five individuals.

## Statistical analysis

Data obtained from several experiments were analyzed using standard statistical methods. Analysis of variance (ANOVA) was used to check the significance of differences between means at $P \leq 0.05$. The percent mortality of *R. ferrugineus* was calculated by the following formula:

Mortality % = (No. of dead insects ÷ Total no. of initial insects) × 100

Mortality percentages were calculated by using the Abbott Formula (Abbott, 1925). Simple correlation and partial regression for obtained data were determined by the SAS program (2001).

**Fig. 2: Microwave dual magnetron**

**Fig. 3: Microwave quad magnetron**

## RESULTS AND DISCUSSION

### 1. Home microwave experiments

#### 1.1 Effect of energy levels and exposure durations on the mortality of some insect egg stage

Results compiled in Table (1) show that hatching eggs exposed for periods of 15, 20, and 30 sec. at different energy levels were nil, but hatching occurred for eggs exposed for 10 sec. The analysis of variance showed highly significant differences between the average numbers of unhatched eggs. The average number of unhatched eggs was the highest (17 eggs) at the energy level of 100%, but the lowest one of 3.6 was recorded in the case of untreated eggs. The increment of energy levels, the decrement of hatched eggs.

**Table (1): Effect of energy levels and exposure durations on egg hatching % of *R. ferrugineus* in home microwave**

| Power | Average no. of unhatched eggs 10 sec. | Mortality % | P. value | LSD 5% |
|---|---|---|---|---|
| **100** | 17.0 a | 85 | 0.0000*** | 1.656 |
| **90** | 16.0 ab | 80 | | |
| **70** | 14.4 b | 65 | | |
| **Control** | 03.6 c | 18 | | |

The same letter in the column means no significant difference

#### 1.2 Effect of energy levels and exposure durations on the mortality of larval stages

The results indicated that exposing larvae from the first, second, fourth, sixth, eighth, and final instars to three energy levels of 100%, 60%, and 30% for exposure durations of 10, 20, and 30 seconds resulted in the mortality of all larvae in the sixth, eighth, and final instars across all energy levels and exposure durations (Figure 4). While the average numbers of dead larvae for the first, second, and fourth instars significantly differed at the same energy levels and exposure durations (Table 2). There was a highly significant difference between the averages at the three energy levels, except for 100 and 60 % energy levels at 30 sec., where the difference between the averages of larval death was not significant. It was also noted that there was no effect on the first and second instar larvae at the 10 sec. exposure time, but larvae appeared to die. Respecting the fourth instar, at 20 and 30 sec., death occurred at the second and first ages, respectively. Thus, the effect increased due to the increase of larval size. Also, as the energy level or time increases, it leads to an increase in the death of the larvae.

The obtained results were agreed with Mady *et al*., 2021 who found that microwave heating (2.45 GHz, 500 W) caused larvae required MW heating for only 40 sec. to achieve 100% mortality. Larval mortality ranged from 50 to 60% at 10 sec., 60 to 70% at 20 sec., and 80 to 90% at 30 sec therefore, there was a positive relation between MW exposure time and mortality rate, with increasing MW exposure time causing a significant increase in *R. ferrugineus* mortality. The results are in harmony with the findings of other authors, where Darwish, *et al.* (2014) and El-Shafei (2015) reported that the mortality of tested *Ephestia cautella* stages increased by increasing the exposure time in each microwave power. El-Shafei, *et al.* (2018) mentioned that the effectiveness of 100, 200, and 300-watt microwave powers against egg and the 4th instar larvae of *plodia interpunctella* at the different exposure times the efficacy of the higher microwave power level was more effective than the lower one.

**Table (2): Effect of energy levels and exposure durations on mortality of larval stages in home microwave**

| Time | Power level | Mean numbers of larval stages & Mortality % | | | | | | | | P. value | LSD 5% |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1st | M. % | 2nd | M. % | 4th | M. % | 6th | M. % | | |
| 10 sec. | 100% | 0.0 c | 0.0 | 0.0 c | 0.0 | 3.0 b | 60 | 5.0 a | 100 | 0.000*** | 0.629 |
| | 60% | 0.0 c | 0.0 | 0.0 c | 0.0 | 1.0 b | 20 | 5.0 a | 100 | 0.000*** | 0.629 |
| | 30% | 0.0 c | 0.0 | 0.0 c | 0.0 | 1.0 b | 20 | 5.0 a | 100 | 0.000*** | 0.629 |
| 20 sec. | 100% | 0.0 c | 0.0 | 4.5 b | 90 | 5.0 a | 100 | 5.0 a | 100 | 0.000*** | 0.445 |
| | 60% | 0.0 c | 0.0 | 0.0 c | 0.0 | 4.0 b | 80 | 5.0 a | 100 | 0.000*** | 0.445 |
| | 30% | 0.0 d | 0.0 | 1.0 c | 20 | 2.5 b | 50 | 5.0 a | 100 | 0.000*** | 0.445 |
| 30 sec. | 100% | 4.75 a | 95 | 4.75a | 95 | 5.0 a | 100 | 5.0 a | 100 | 0.589 ns | 0.545 |
| | 60% | 5.0 a | 100 | 5.0 a | 100 | 4.75a | 95 | 5.0 a | 100 | 0.426 ns | 0.385 |
| | 30% | 0.0 c | 0.0 | 2.0 b | 40 | 4.0 a | 80 | 5.0 a | 100 | 0.000*** | 1.089 |

The same letter in each column means no significant difference


**Fig. 4: Larvae after exposure inside the home microwave.**

### 1.3 Effect of energy levels and exposure durations on the mortality of pupae and adult insects

The same action in the case of pupae and adults occurred likely as shown in the case of larvae Figure (5).

The statistical analysis of exposing pupae and adult insects to the previous three energy levels and exposure periods of 10, 20, and 30 sec (Table 3) shows highly significant differences between the averages at the three energy levels. As the energy level or time increased, an increase in mortality in the case of the pupae or adult insects occurred.

The obtained results agree with Mady *et al*. (2021) who found that microwave heating (2.45 GHz, 500 W) caused 100% mortality of adults in 4 min and most stopped moving in a few seconds. The mortality rate ranged from 70-90% after 3 min. of exposure, 50-70% after 2 min., and 40-60% after 1 min. Also, El-Shafei, *et al.* (2018) found that reduction percentages in emerging adults of *Plodia interpunctella* at the different exposure times increased gradually by increasing the exposure period to microwave power.

**Fig. 5: Larvae and adults after exposure inside the home microwave.**

**Table (3): Effect of energy levels and exposure durations on mortality of pupae and adults in home microwave**

| **Power** | **Mortality % of Pupae** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Mortality %** | **10 Sec.** | **Mortality %** | **20 Sec.** | **Mortality %** | **30 sec.** | **LSD 5%** | **P. value** |
| **100%** | 50 | 2.5 b | 100 | 5.0 a | 100 | 5.0 a | 0.000*** | 0.533 |
| **60%** | 20 | 1.0 b | 80 | 4.0 a | 100 | 5.0 a | 0.000*** | 1.066 |
| **30%** | 10 | 0.5 c | 50 | 2.5 b | 100 | 5.0 a | 0.000*** | 1.306 |
| **Power** | **Mortality % of Adults** | | | | | | | |
| | **Mortality %** | **10 Sec.** | **Mortality %** | **20 Sec.** | **Mortality %** | **30 sec.** | **LSD 5%** | **P. value** |
| **100%** | 50 | 2.5 b | 100 | 5.0 a | 100 | 5.0 a | 0.001** | 1.192 |
| **60%** | 0.0 | 0.0 b | 100 | 5.0 a | 100 | 5.0 a | 0.000*** | 8.989 |
| **30%** | 0.0 | 0.0 c | 60 | 3.0 b | 100 | 5.0 a | 0.000*** | 0.754 |

The same letter in each column means no significant difference

### 1.4 Time needed for insect and larval mortality inside palm trunks

In this experiment, larvae and adults were placed inside pieces of palm trunk at different depths of 10, 15, and 20 cm. These parts were exposed to the highest power level of 100 %, for different periods. Figure (6) depicts the estimated mortality rates and temperatures for each depth and exposure period. At a depth of 10 cm, there was a highly significant difference in the averages of dead individuals, where there were no dead insects or larvae up to two minutes after exposure, when the temperature reached 68.00 °C and death began after that, and the averages of dead were 1.333, 1.667, 4.0, and 4.0 at 3, 4, 4.5, and 5 min., where the temperature reached 80.33 °C after 3 min and increased until it reached 90.0 °C after 5 min, while at a depth of 20 cm, the lowest average mortality% for individuals was 2.0, with 50% of individuals dying after 20 minutes when the temperature reached 80.3 °C, and the highest average mortality% for individuals after half an hour, with an average of 4.0 individuals, at a temperature of 90.0 °C.

These results are confirmed by Massa *et al*. (2024) who reported that the lethal temperature of 55 °C at 3.5 cm under the surface, is reached after about 170 sec. Moreover, Batt and El-Rehewy (2019) in Egypt found that the mortality percentages of dry wood termite, *Cryptotermes brevis* in both pine and beech wood, the shortest exposure time which gave 100% mortality recorded 20 sec with power level 100 wattages within pine wood while, required 80 wattages with beech wood, the longest exposure time which appeared100% mortality was 50 sec for pine wood at 50 wattages, while it was 60 sec at the power level of 10 wattages for beech wood.

**Table (4): Time needed for insect and larval mortality inside palm trunks at a power level of 100% in home microwave**

| Depths | Time | Mean | Mortality % | Temp. | P. value | LSD5% |
|---|---|---|---|---|---|---|
| **10 cm** | 20 sec. | 0.0 c | 0 | 43.67 | 0.000*** | 0.4997 |
| | 30 sec. | 0.0 c | 0 | 54.67 | | |
| | 60 sec. | 0.0c | 0 | 60.33 | | |
| | 2 min. | 0.0 c | 0 | 68.00 | | |
| | 3 min. | 1.333 b | 33 | 80.33 | | |
| | 4 min. | 1.667 b | 42 | 81.00 | | |
| | 4.5 min. | 4.0 a | 100 | 81.67 | | |
| | 5 min. | 4.0 a | 100 | 90.00 | | |
| **15 cm** | 6 min. | 2.333 b | 58 | 78.33 | 0.020* | 1.087 |
| | 8 min. | 3.0 ab | 70 | 84.67 | | |
| | 10 min. | 4.0 a | 100 | 90.00 | | |
| | 15 min. | 4.0 a | 100 | 90.67 | | |
| **20 cm** | 20 min. | 2.0 b | 50 | 80.33 | 0.027 * | 1.332 |
| | 25 min. | 3.333 a | 83 | 81.33 | | |
| | 30 min. | 4.0 a | 100 | 90.00 | | |

The same letter in the column means no significant difference

**Fig.6: Dead larvae and adults inside palm trunks**

## 2. Experiments developed using a dual magnetron microwave

In these experiments, a modified microwave containing two magnetrons plus a remote control was used. The larvae and insects were placed inside palm trunks at 40, 50, and 60 cm depth.

As shown in Table (5) it was found that the differences between the average mortality of insects and larvae placed inside the trunks at 40 and 50 cm was not significant, while it was significant when the depth inside the trunk was 60 cm. The longer the exposure time, the increment in the percentage of mortality for both larvae and adults.

**Table (5): Time needed for insect and larval mortality inside palm trunk of date palm at 100% power level of developed dual magnetron microwave.**

| Diameter cm | Time minutes | Mean | Mortality% | Temp. | P. value | LSD 5% |
|---|---|---|---|---|---|---|
| 40 | 30 | 3.25 a | 65 | 76.25 | 0.537 ns | 0.934 |
| | 45 | 3.50 a | 70 | 87.50 | | |
| 50 | 30 | 3.50 a | 70 | 74.00 | 0.537 ns | 1.869 |
| | 45 | 4.00 a | 75 | 84.75 | | |
| 60 | 30 | 3.25 b | 65 | 70.50 | 0.011 * | 1.171 |
| | 45 | 5.00 a | 100 | 80.50 | | |

The same letter in the column means no significant difference

## 3- Experiments developed using a quad magnetron microwave

Data in Table (6) shows mortality of insects and larvae within trunks of date palm in case of 4 magnetron microwave.

Statistical analysis of variance proved that for 30 and 45 minutes the differences between the averages were insignificant when the depth was 40 cm, while it was significant with the others. The longer the exposure time, the greater the number of dead individuals.

**Table (6): Time needed for insect and larval mortality inside palm trunk of date palm at 100%power level of developed quad magnetron microwave**

| Diameter cm | Time minutes | Mean | Mortality% | Temp. | P. value | LSD 5% |
|---|---|---|---|---|---|---|
| **40** | 30 | 3.25 a | 60 | 72.25 | 0.134 ns | 1.427 |
| | 45 | 3.50 a | 80 | 81.75 | | |
| **50** | 30 | 3.50 a | 70 | 69.50 | 0.002 * | 0.706 |
| | 45 | 4.00 a | 100 | 76.50 | | |
| **60** | 30 | 3.25 b | 85 | 61.00 | 0.024* | 0.612 |
| | 45 | 5.00 a | 100 | 76.25 | | |

The same letter in the column means no significant difference

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# الميكروويف كطريقة لمكافحة سوسة النخيل الحمراء
# *Rhynchophorus ferrugineus*

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[٢] المعمل المركزي للنظم الخبيرة الزراعية – مركز البحوث الزراعية – الدقي – جيزة – مصر

**الملخص العربى**

تعتبر سوسة النخيل الحمراء واحدة من أخطر الآفات المدمرة لأشجار نخيل البلح. وقد أدى الاستخدام المكثف لطرق المكافحة الكيميائية إلى إحداث تلوث بيئي. ولذلك كان الهدف من هذا البحث هو تسليط الضوء على استخدام طرق بديلة للقضاء على هذه الآفة. أجريت التجارب باستخدام الميكروويف المنزلي بالإضافة إلى جهاز ميكروويف معدل يتكون من ٢ أو ٤ وحدات ماجنترون. تم استخدام الميكروويف لدراسة فعاليته ضد البيض واليرقات والعذارى والحشرات الكاملة في المختبر وشبه الحقل لقياس نسبة الموت وتحديد أقل مستوى طاقة وفترة تعريض تؤثر على جميع المراحل.

أظهرت النتائج أنه لم يحدث فقس للبيض الذي تم تعريضه لمدة ١٥ ، ٢٠ ، ٣٠ ثانية عند مستويات الطاقة المختلفة (١٠٠،٩٠،٧٠٪) ولكن حدث الفقس في حالة البيض المعرض لمدة ١٠ ثوانٍ. ولوحظ أيضًا أنه كلما ارتفع مستوى الطاقة إنخفض نسبة فقس البيض. وفي حالة اليرقات لوحظ أنه هناك علاقة طردية بين حجم اليرقات ومستويات الطاقة ووقت التعرض مع النسبة المئوية للموت. أيضاً في حالة العذارى والحشرات الكاملة، وجدت نفس العلاقة بين النسبة المئوية للموت في هذه المراحل ومستويات الطاقة وفترات التعريض. من النتائج المتحصل عليها فى مكافحة الحشرة باستخدام الميكروويف المعدل في التجارب شبه الحقلية وجد انه كلما زادت فترة التعريض زادت نسبة الموت ولم يوجد فروق واضحة فى درجات الحرارة داخل الأنسجة بين الجهاز الذي يحتوي على ٢ أو ٤ وحدات ماجنترون ولكن الفرق كان فى مساحة التعريض.

**الكلمات المفتاحية:** المكافحة الفيزيائية، سوسة النخيل الحمراء، الإشعاع الكهرومغناطيسي، المكافحة الآمنة.