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EFFECT OF NON-CATALYTIC INFRARED RAY ON THE GRAIN MOTH *Sitotroga cerealella* (LEPIDOPTERA: GELECHIIDAE)

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Grain moth

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Wheat

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ABSTRACT

This study was conducted under laboratory conditions to find out the effect of the non-catalytic infrared on the mortality rates and development of various stages of the grain moth *Sitotroga cerealella*. Result of the study revealed that treated eggs, first and fourth instars, pupae and adults mortality increased by increasing non-catalytic infrared waves exposure time from 40 and 60 seconds at 40 and 50° C. Highest egg mortality (56.7%) and hatching period (6.1 days) was reported on the exposure of 60 seconds at 50° C while the lowest values 3.3% and 4.5 days respectively was reported for the control treatments. Similar conditions were reported for the first and fourth instars, pupae and adults mortality. Infrared waves exposure for 60 seconds at 50° C significantly influenced the development of *S. cerealella* and showed 53.31% first stage larval mortality, 50% fourth stage larval mortality, 46.7% pupal mortality and 66.7% adult mortality. Furthermore, it was reported that infrared wave did not have any negative effect on the seed germination and 60 second exposure at 50° C showed 96 percent seeds germination.

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1 Introduction

The economic loss due to stored grain pest is a serious problem worldwide. About 200 insect species were reported from stored grains and among these, angoumois grain moth, *Sitotroga cerealella* (Olivier) (Lepidoptera Gelechiidae), is considered as common, top of the list and most destructive pest of stored grain especially for store grains. Mostly, infestations of *S. cerealella* reported at postharvest stage, but sometime this insect also attacked preharvest or at the fruiting stage. The damage caused by *S. cerealella* is crucial under both temperate and tropical conditions (Germanov, 1982). The larvae of *S. cerealella* attack a variety of kernels, such as corn, barley, sorghum, wheat, soybean, rice, paddy and other stored cereal grain. Further, *S. cerealella* can also attack on the stored spices such as piper, Coriander, ginger, turmeric and many other non crop wild plants (Dakshinamurthi & Regupathy, 1988; Ukeh et al., 2008; Pan et al., 2008; Ashamo, 2010; Trematerra et al., 2011; Trematerra, 2015). In case of store wheat grain, Khan et al. (2010) reported that about 12 wheat genotypes were damaged by *S. cerealella* and it causes annually 19.2-58.2% damage and 12.19 – 40.93% losses. Newly hatched *S. cerealella* caterpillar bores into the grain and usually complete larval and pupal stage here without showing any visible symptom (Weston & Rattlingourd, 2000). *S. cerealella* larvae mostly feed on the seed endosperm. Under favourable conditions (30°C and 80 % relative humidity) *S. cerealella* complete its larval development in 19 days only (Hill, 1990). Further it was reported that temperature and humidity are the two factors which influence the rate of larval development and Grewal & Atwal, (1967) suggested that 25 – 30°C temperature and 80% RH are most favourable for development, survival and reproduction of *S. cerealella*. Later on Hansen et al. (2004) suggested that high relative humidity and temperatures higher than 30°C negatively influenced the development of this insect.

Although there are many control strategies such as use of edible oils, synthetic chemicals, plant derivatives, bacterial protoxins, biopesticides, biocontrol enhancers and semiochemicals are available for the management of *S. cerealella* but the most commonly used method is fumigation with the help of hazards chemicals. These chemicals are not only hazards for human being but also caused serious environmental pollution also. By keeping these facts in consideration, there is a dire need to explore the alternate and environment friendly method of pest management which should be cheap and readily available (Rajendran & Chayakumari, 2003; Ashamu & Khanna, 2006; Butron et al., 2008).

Heat can be used for the management of store grain pest by using phenomena thermal lethality. Heat can be generate by many ways, among this use of electromagnetic energies is the most common one. Infrared radiation is harmless electromagnetic radiation with 700 nm to 1mm wavelengths. These waves have higher wavelengths than those of visible light (Penner, 1998). Infrared radiation is strongly emitted from hot objects, and can be easily absorbed by living tissues so it can be used in insect pest management (Tilton & Schroeder, 1963). Infrared radiation is quickly absorbed by water particles and causing sudden increases

in the body temperature (Wehling, 1998). The moisture content of insects is reported up to 60% while in seed grains water content is limited and it is up to 11-13%. Under this situation, insects will receive a lethal dose of IR energy; as a result, this technology can substitute the use of traditional chemical like the phosphine and it can be used as an alternative in store grain insect pest management (Khamis et al., 2010). Khamis et al. (2011) reported high level *Rhyzoperth dominica* mortality when they used flameless catalytic infrared emitter. Athanassiou et al. (2016) artificially infested *Corinthian currants* by *Ephestia elutella* larvae and adults of the *Oryzaephilus surinamensis* and *Tribolium confusum* and treated these with IR in agitating flow process at different temperature (45,50,55,60,65 and 70 °C) and exposure time (1,2,3,4,5,8,10 and 20s). Results of study revealed that all IR treatment provided maximum insect control. Similarly, Duangkhamchan et al. (2017) tested efficacy of infrared heating method (50-60°C) against rice weevils *Sitophilus oryzae* eggs and reported 100% insect mortality at 2 minutes exposures. Present study was conducted to find out the lethal effect of the non-catalytic infrared radiation on grain moth *Sitotroga cerealella*.

2 Materials and Methods

2.1 Materials

For this study, insect population of *S. cerealella* (Lepidoptera: Gelechiidae) was provided by the Ministry of Science and Technology, IPM Centre, Entomology Lab, Baghdad, Iraq. Twenty pairs of collected insects were reared on 250 gm wheat seeds in plastic containers (14X7.5 cm) incubated at 28 ±2° C temperature and 20% relative humidity.

Infrared radiation was generated by IR device with Halogen bulb of tungsten heat radiator in quartz tubes (Commercially known as Halo Theram, made by Osram – America). This device can generate IR energy (up to 1100 nm.). The device was provided with a cooler and thermometer to monitor the temperature as mentioned in Technical Data (2016).

2.2 Experimental procedures

2.2.1 Effect of infrared ray on 24 hours old eggs of *S. cerealella*

Three exposure times (15, 30 and 60 seconds) and two temperatures (40 & 50 °C.) with three replicates were used in this study. Twenty four hours old ten eggs were collected in 9 cm. diameter Petri dishes for each exposure time and temperatures. All treatments, (except the control dishes), were exposed to the IR for selected range of temperatures and time periods. Petri dishes which subjected to the treatments were kept under the I.R. device. All experimental dishes were supplied with 5 gm of nutrient powder to feed hatching larvae. After treatment, all the treated and control Petri dishes were covered with mousseline cloth and incubated in an incubator at 30±2 °C temperature and 70±5% R.H. Mortality and hatching percentage were recorded at regular interval till the completion of study.

2.2.2 Effect of the infra-red ray on 1st and 4th Instar larvae of *S. cerealella*

Twenty four hours old ten newly hatched first instars larvae were collected from infected wheat grains. These 1st instars were kept in a 7 cm long and 1 cm diameter test tube and exposed to IR for selected time periods (15, 30 and 60 seconds) and temperatures (40 & 50 °C.) with three replicates for each treatment. Control 1st instars were not exposed to any IR exposure. Each tube was supplied with 5 gm of nutrition powder to feed larvae. Tubes were blocked with sterilised gauze and covered with mousseline cloth for proper aeration and incubated in an incubator at 30±2°C temperature and 70±5% RH. Mortality, first larval and pupal stage period, pupae and emerging adults numbers were recorded. Mortality percentage was calculated after 14 hours of exposures to the 7 days for each stage larval, pupal and adults. Similar conditions were also applied for the 4th instar larvae and data has been recorded on its mortality, larval and pupal stage period, pupae and emerging adults' numbers.

2.2.3 Effect of IR ray on 24 hours old pupae of *S. cerealella*

To estimate the effect of IR on 24 hours old pupae, ten freshly hatched pupae were collected in 9 cm. diameter Petri dish and exposed to IR for three different exposure times (15, 30 and 60 seconds) and two selected temperatures (40 & 50 °C.) with three replicates for each treatment. Dishes (except the control dishes) were subjected to the treatments and put in the IR device 10 cm. away from the source. Dishes were covered with mousseline cloth and incubated at 30±2 °C and 70±5% RH. Data related to mortality was recorded from 12 hours of exposures to the seven days. Pupal time and deformation percentage (if found) were also recorded.

2.2.4 Effect of IR ray on *S. cerealella* adults

Twenty four hours old adults (5 pairs per experimental unit), were collected in 8.5 cm long and 2.5 diameter test tube and exposed to IR for three different exposure times (15, 30 and 60 seconds) at two selected temperatures (40 & 50 °C.) with three replicates for each treatment. Rest of the experimental conditions were similar to the previous section and data related to mortality were recorded.

2.2.5 Effect of IR ray on Wheat (*Triticum aestivum*) grains germination

To evaluate the effect of IR on wheat grain germination, twenty healthy wheat grains were selected. Seeds were taken into 9 cm diameter Petri dishes with waterlogged filter papers and were exposed to IR for the pre-decided exposure time and temperatures. Each dish was supplied with 5 ml of water and incubated at 30±2 °C temperature and 70±5% RH. Germination percentage recorded daily for five days as mentioned below:

Percentage of germination

$$= \left(\frac{\text{Germinating Seeds counts}}{\text{Total Seeds}} \right) \times 100$$

3 Results and Discussion

3.1 Effect of IR ray on 24 hours old eggs of *S. cerealella*

Effect of the IR rays on egg mortality was represented in table 1. Results of the study revealed a significant effect of IR on the egg mortality, and it increased with the increase of temperature and exposure time. Among various exposure time and temperature intervals, the highest mortality (56.7%) was reported at 60 seconds exposure and 50°C temperature which was followed by the same exposure time on 40° C temperature (43.3%). In IR treatments, lowest egg mortality (6.7%) was reported from the 15 second exposure time and 40°C temperature while overall lowest egg mortality was reported from the control (3.3%) without IR treatment.

In the case of hatching period, no significant differences were reported and all the exposure time and temperature showed almost similar hatching periods. High exposure time and temperature caused delays in hatching and highest hatching period was 6.1 days which was reported at 60-second exposure and 50°C. While in control without IR exposure this hatching period was only 4.5 days. Results of this study are in agreement with the findings of Khamis et al. (2011) who reported significant reduction in the *S. oryzae* eggs hatching in wheat grains and it was affected by temperature and distance from IR. IR treatment increases cell temperature which increase egg mortality and inhibit egg hatching. Mahroof et al. (2003) determined time–mortality relationships for eggs, neonate larvae, old larvae, pupae, and adults of the red flour beetle. Kirkpatrick (1975b) reported 493% egg mortality when wheat grain infested with rice weevils and lesser grain borers were exposure to infrared radiation at 43.38°C. Further, Kirkpatrick (1975a) suggested that eggs and early instars of the lesser grain borer and Angoumois grain moth were more resistant to infrared treatments than eggs and early instars of rice weevils.

3.2 Effect of IR ray on 24 hours old 1st Instar larvae

Effect of IR on 1st. instar larvae has been given in Table 2. A significant effect of infrared radiation was reported on 1st Instar larvae, when these were exposed to IR for 15, 30 and 60 seconds at 40 and 50°C. Among various tested combinations, the highest 1st instar mortality (36.7 and 53.3 %) was reported on the 60 second exposure at both temperatures 40 and 50°C respectively while the lowest value was reported from 15 second exposure at 40 and 50° C. This value was 3.3 and 6.7 % respectively for this exposure.

No significant difference was reported in larval period and longest 1st. larval stage was reported at 60 seconds exposure (6.0 and 6.5 days on 40 and 50° C respectively) while it was reported 4.3 and 4.5 days on the 15 seconds exposure on the same temperatures. Similarly, exposure of IR also affected the development of pupae; minimum pupa development (63.3%) was reported at 60 seconds exposure at 40°C.

Table 1 Effect of the IR rays exposure on the egg's hatching and mortality

Temperature	Exposure (In Seconds)	Egg mortality %	Hatching period (days)
Control	0	3.30	4.5
40	15	6.70	4.5
	30	23.3	5.0
	60	43.3	5.8
	L.S.D. 0.05	5.84	0.32
50	15	10.0	4.6
	30	36.7	5.3
	60	56.7	6.1
	L.S.D. 0.05	15.70	0.56

Table 2 Effect of the Infra-red Ray on the development of 24 hours old, 1st instar of *S. Cerealella*

Temperature (C.)	Exposure (Seconds)	1 st larval stage mortality %	1st larval stage period (Days)	Pupae %	Average pupal period (Days)	Emerging adults %
Control	0	1.30	4.1	98.7	5.1	98.7
40	15	3.30	4.3	96.7	5.3	96.7
	13	20.0	5.0	80.0	5.6	80.0
	60	36.7	6.0	63.3	6.3	56.7
	L.S.D. 0.05	5.53	0.31	6.64	0.22	7.03
50	15	6.70	4.5	93.3	5.5	93.3
	30	30.0	5.5	70.0	6.3	66.7
	60	53.3	6.5	46.7	7.0	36.7
	L.S.D. 0.05	13.56	0.46	14.28	0.44	19.38

It was followed (46.7%) by the same exposure time at 50°C. On the other hand, highest pupa development (96.7 and 93.3 %) was reported at 15 seconds exposure at 40 and 50°C respectively. The longest accumulated pupation period was 6.3 and 7.0 days for 60 seconds of exposure at 40 and 50° C, but it was not significantly different from the 15second exposure at 40 and 50° C which showed 5.3 and 5.5 days. Minimum adults' emerging percentage was 56.7 and 36.7% which was reported with 60 seconds exposure and at 40 and 50°C temperatures respectively while this value was 96.7 and 93.3 % for the 15 seconds treatment at the same temperature range respectively. Similar types of results were reported by Khamis et al. (2011) in their study on *S. oryzae* that showed the IR effect on larvae increases by exposure time and distance from the ray source. Tilton & Schroeder (1963) also reported similar effect of IR on the rate of adult emergence of rice weevils, lesser grain borers, and Angoumois grain moths from rice. Recently, Subramanyam (2004 & 2005) reported sawtoothed grain beetle, rice weevil, red flour beetle, lesser grain borer and merchant grain beetle, *Oryzaephilus Mercator* (Fauvel) (Coleoptera: Silvanidae) adult mortality by exposing infrared radiation.

3.3 Effect of Infrared Ray on the development of *S. cerealella* 4th instar larvae

Table 3 showed significant differences between 40 and 50° C temperature factor with 30 and 60 seconds exposure to IR. The highest 4th instar larvae mortality was 30 and 50% consequently at 60 seconds on 40 and 50° C while it was 16.7 and 26.7% for 30

seconds exposure at the same temperatures. In case of control, no 4th instar larvae mortality was reported in this study.

In case of larval stage duration, longest larval duration were 6.3 and 7 days at 60 seconds on 40 and 50°C temperature while in the case of control and 30 seconds exposure this value was reported 4.7 and 5.3 days respectively. In the case of pupation percentage, the minimum population was reported from 60 seconds exposure and this value was 70 and 50% at 40 and 50°C., but it was 83.3 and 73.3% when exposure was 30 seconds on 40 and 50°C. Pupae took 6.5 and 7.1 days in converting adults when these were exposed to IR for 60 seconds at 40 and 50° C temperature while this period was 6.1 days when these pupae exposed to IR for 30 seconds.

Emerging adults' percentage was minimum when the exposure was 60 seconds on 40 and 50° C respectively. At same temperature range, 30 second exposure gave 83.3 and 73.3% adult percentage. There were also significant differences in 15 seconds exposure for both 4th larval instar and the pupation periods. It was (5, 5.1) and (5.5, 5.8) days on 40 and 50°C respectively as compared to the control which was 4.7 and 5.1 days for each. There was no significant difference at 15 seconds exposure in the 4th larval instars, pupas and emerging adults on 40 and 50° C. The results agree with the study of Khamis et al. (2010) those who studied the effect of IR on various stages of *Rhyzopertha dominica*, *S. oryzae* and *Tribolium castaneum*. Their results showed that mortality at all stages was affected by temperature and it was 99-100% when the temperature was 108-114°F.

Table 3 Effect of Infrared ray on the various developmental stages of 4th instar larvae of *S. cerealella*

Temperature (C.)	Exposure (Seconds)	4 th larval stage mortality %	4 th larval stage period (Days)	Pupae %	Average pupal period (Days)	Emerging adults %
Control	0	0	4.7	100	5.1	100
40	15	0	5.0	100	5.5	100
	30	16.7	5.3	83.3	6.1	83.3
	60	30.0	6.3	70.0	6.5	63.3
L.S.D. 0.05		9.77	0.34	7.54	0.34	13.16
50	15	0	5.1	100	5.8	100
	30	26.7	6.0	73.3	6.5	73.3
	60	50	7.0	50.0	7.1	43.3
L.S.D. 0.05		18.61	0.46	17.37	0.33	16.93

Table 4 Effect of Infrared ray on 24 hours old pupae development

Temperature (°C)	Exposure (Seconds)	Pupae mortality (%)	Pupae stage period (Days)	Emerging Adults (%)	Deformations (%)
Control	0	0.0	5.1	100	0.0
40	15	0.0	5.3	100	0.0
	30	16.7	5.5	83.3	0.0
	60	26.7	6.1	73.3	3.3
L.S.D. 0.05		9.88	0.33	6.57	1.69
50	15	0.0	5.6	100.0	0.0
	30	20.0	6.3	80.0	0.0
	60	43.3	7.0	56.7	10.0
L.S.D. 0.05		19.09	0.42	18.75	6.33

Table 5 Effect of Infrared ray exposure on adult of *S. cerealella*

Temperature (C.)	Exposure (Seconds)	Adult mortality %
Control	0	0
40	15	6.7
	30	20
	60	46.7
L.S.D. 0.05		4.34
50	15	13.3
	30	36.7
	60	66.7
L.S.D. 0.05		10.37

3.4 Effect of the Infrared ray on 24-hours old pupae of *S. cerealella*

When twenty-four hours old pupae were exposed to IR, significant differences was reported between 40 and 50°C temperature at 30 and 60 seconds exposure as compared to the control. Highest pupae mortality was 26.7 and 43.3% at 60 seconds exposure at 40 and 50° C temperature, while it was 16.7 and 20% with 30 seconds

on the both temperatures (40 and 50° C) respectively. The Longest pupation period was 6.1 and 7 days with 60 seconds exposure at 40 and 50° C and it was 5.5, 6.3 days for 30 seconds exposure on the same temperatures respectively but for the control this value was 5.1 days.

Adults emerging percentage with 60 seconds exposure at 40 and 50°C was 73.3 and 56.7% respectively while it was reported 83.3 and 80% on the exposure of 30 seconds at the same temperatures respectively while for the control, 100% larval emergence was reported (Table 4). Pupation period study results showed significance differences at 15 seconds at 40 and 50° C. It was 5.3 and 5.6 days compared to the control which have 5.1 days. Results presented in table 4 did not show any significance difference in pupae mortality and adults emerging percentage with 15 seconds exposure on the same temperatures. On the exposure of 60 seconds at 40 and 50° C, table 4 shows 3.3 and 10% deformation of emerging adults, but it was 0% with the control treatment. Results agreed with Kirkpatrick et al. (1973) when they evaluated the I.R., Gamma Ray and their combination effect on various life stages of *R. dominica* on wheat. The researchers reported that pupae were affected by increasing IR exposure time.

Table 6 Effect of the Infrared ray on wheat seeds *T. aestivum* germination

Temperature (C.)	Exposure (Seconds)	Seeds germination %
Control	0	90.0
40	15	91.6
	30	93.3
	60	95.0
	L.S.D. 0.05	3.05
50	15	91.7
	30	95.0
	60	96.0
	L.S.D. 0.05	2.36

3.5 Effect of Infrared ray on *S. cerealella* adults

When *S. cerealella* adults were exposed to IR rays, significant differences were reported in various temperature range and time of exposure (Table 5). Highest adult mortality was reported on the exposure of 60 seconds for 40 and 50°C, and it was 46.7 and 66.7% respectively. On the exposure of 30 seconds, 20 and 36.7% adult mortality was reported at the same temperatures (40 and 50°C) consequently. Reduction in exposure time caused a decline in mortality rate, and lowest mortality was reported in the control treatments. These results show similarity with the findings of Mohammad & Amerah (2013), these researchers identify lethal effect of IR. on some stored wheat and wheat flour insects. They reported that exposure of 180 seconds to IR, raised the flour temperature and killed 58.67% of *Tribolium castaneum*. They also reported that 240 seconds exposure of IR raised the temperature of the grain and causing the death of 60% of *Sitophilus granaries* and 56.67% of *Rhizopertha dominica*. They concluded that increase in the exposure time and decrease in the distance from the ray source caused increasing in temperature and mortality.

3.6 Effect of Infrared Ray effect on wheat (*Triticum aestivum*) grains germination

Result of this study indicated a significant effect of infrared radiation on all the stages of *S. cerealella*. Effect of these radiation on the wheat grain was also evaluated in present study. To assess the effect of these IR rays on wheat seed germination, wheat seed were also exposed to selected time durations (15, 30 and 60 seconds) and temperature ranges (40 and 50°C). Results presented in Table 6 showed no significance effect of infrared rays on wheat seed germination. All the treatments showed almost similar germination, which indicates that IR does not affect the seed germination but have the capability to kill the seed insects. Because of this phenomenon, IR can be used as an effective pest control measure. In this study some difference in the seed germination was reported, this may be because of genetic or environmental factors. Here highest and lowest seed difference was reported at 60 second exposure and control treatments. A similar type of results was obtained by Kirkpatrick (1975b). They

indicated that wheat and rice grains could resist IR temperature up to 80° C without any effect on the flour or bread quality.

Conflict of interest

Authors would hereby like to declare that there is no conflict of interests that could possibly arise.

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