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## Prediction of survival ratios of *Cadra cautella* (Lepidoptera: Pyralidae) different life stages after treated with ultraviolet radiation in dates



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## ABSTRACT

Date palm, is a tree of economic importance which is grown around the world, including Saudi Arabia. Its fruit is nutritious and possesses medicinal benefits. Almond moth, is a serious date fruits pest in the field as well as in the storage and causes severe economic losses. In the given research, ultraviolet radiation type B (UV-B, 315 nm) harmful effects were evaluated against all developmental stages of *C. cautella*. One and 3-d-old eggs, 12 and 18-d-old larvae, 1-d and 6-d-old pupae, and 1-d-old adults, were exposed to UV-B for different intervals. Eggs were exposed for 0–30 min and 0% hatchability was achieved both for 1-d and 3-d-old eggs after 30 min. The larvae were exposed for 6–24 h, and after 24 h, mortality was 100 and 97% for 12 and 18-d-old larvae, respectively. Similarly, the pupae were exposed for 0–30 h, and 100% mortality was achieved after 30 h for 1-d-old pupae. Furthermore, none of the 6-d-old pupae emerged as an adult after 12 h of exposure. When adults were exposed for 1–4 d, no mortality was observed; however, UV-B reduced fecundity and hatchability in the treated adults. The susceptibility order was as follows: eggs > larvae > pupae > adults. Several uncharacteristic behaviors of *C. cautella* were noted, such as females depositing eggs openly on food items and containers, mature larvae exiting from food, larvae starting to wander for pupation, and pupation occurring typically outside the food. The application of UV-B could be an effective management strategy because all developmental stages of *C. cautella* were susceptible to UV-B that might be helpful to protect the dates from *C. cautella* infestation.

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## 1. Introduction

The date palm, *Phoenix dactylifera* (Linnaeus, 1753), is a beneficial fruit producing tree grown worldwide (Chao and Krueger, 2007). Its fruit is of great economic value as it is nutritious and has medicinal importance, used as human food, rich in fiber; also, low-quality dates can be used for camels and horses feed (Ghnimi

et al., 2017; Alfaro-Viquez et al., 2018). The almond moth, *Cadra cautella* (Walker) (Lepidoptera: Pyralidae), is a serious pest of agricultural commodities, including date fruits in the field, as well as in the storage worldwide (Rees, 2007; Aldawood et al., 2013; Husain et al., 2017b). The primary infestation can be initiated in the field when the date fruits are still on the trees (Aldawood, 2013).

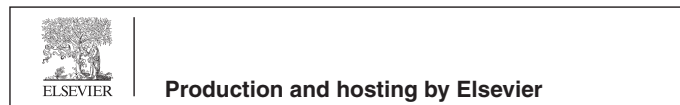
Similar to most insects, the larval stage of *C. cautella* is most damaging and cause considerable losses by feeding gregariously on date fruits. The life cycle of *C. cautella* is approximately 50–70 d, depending on the rearing medium and environmental conditions (Husain et al., 2017b). The larval period is almost 50% of their entire life span and during this period the larvae continuously feed. If control measures are not taken and ecological circumstances are suitable for growth and population proliferation of the pest then the loss level may reach 100% (personal observation).

Several strategies are used to manage *C. cautella* infestation, including the application of chemicals like methyl bromide, phosphine, and ozone (Isikber and Oztekin, 2009; Husain et al., 2015) as fumigants, modified atmosphere (Navarro, 2012; Hashem et al.,

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2012; Husain et al., 2015, 2017a), application of the plant extracts (Ayvaz and Karabörklü, 2008), and radiation with UV-C; nonetheless, the problem still exists. The above-mentioned chemicals can trigger environmental concerns and resistance problems. Let's say, the methyl bromide is almost banned worldwide and announced as an ozone layer damaging fumigant, while phosphine requires a longer exposure time to kill the insects thereby enhancing resistance (Bouma, 1993; Pimentel et al., 2008). Therefore, the exploration of new alternatives that are environmentally benign and economical must be studied (Singh and Sharma, 2015). Thus, the present research work focused on using ultraviolet (UV-B, 315 nm) radiation for the management of *C. cautella* in storage.

The lethal effects of UV radiation vary from species to species and UV type; thus, what might work for some species might not affect others. Furthermore, the visible light is toxic to several insect species (Hori et al., 2014). It damages the organisms physically, genetically by disrupting enzyme functions, as well as negatively affects, the epidermis, and organisms DNA. In living organisms, low doses of UV-B can enhance the synthesis of vitamin D (Ooninx et al., 2018), whereas higher doses are lethal and work as an oxidative stressor, which induces hydrogen peroxide hemolysis, that leads to free radicals formation and has lethal effects on living organisms (Jurkiewicz and Buettner, 1994; Afreen et al., 2006). Gamma irradiation tested against *Sitophilus granarius* (L.) (Coleoptera: Curculionidae), indicated the most of immature stages (Aldryhim and Adam, 1999).

The effects of UV radiation (either type B or C) have been examined against developmental stages of various stored grains insects pests, such as lesser mealworm, *Alphitobius diaperinus* (Panzer) (Coleoptera: Curculionidae) (Faruki et al., 2005); red flour beetles, *Tribolium castenium* and *T. confusium*, (Coleoptera: Curculionidae); almond moth, *C. cautella* (Faruki et al., 2007); Indian meal moth, *Plodia interpunctella*, (Lepidoptera, Pyralidae) (Bakr, 2013); and cowpea seed beetle, *Collasoburchus maculatus* (F.) (Coleoptera: Chrysomelodeae) (Heidari et al., 2016).

Several studies have been conducted; however, there is limited information regarding the effects of UV-B exposure to all developmental stages of *C. cautella*. Therefore, in the given research, lethal effects of UV-B against all developmental stages of *C. cautella* were studied in an effort to develop an effective, economical, and environmentally benign management strategy.

## 2. Materials and methods

### 2.1. *Cadra cautella* culture rearing

The *C. cautella* was reared at Economic Entomology Research Unit (EERU) laboratory under the conditions of  $25 \pm 2$  °C,  $65 \pm 5\%$  relative humidity (RH), and 15:9 (L:D) photoperiod on an artificial diet previously used by Aldawood et al. (2013). The rearing of *C. cautella* was retained in EERU laboratory since 2009. To avoid problems with colony genetics, wild individuals collected from a date palm orchard were mixed with the laboratory culture periodically.

### 2.2. Collection of the developmental stages for ultraviolet irradiation

All developmental stages of *C. cautella*, 1- d and 3-d-old eggs, 12- d and 18-d-old larvae, 1-d and 6-d-old pupae, and 1- d old moths, used in present study were obtained from the mother colony. To obtain 1- d and 3-d-old eggs, ten pairs of young adults were collected from colony and transferred into a 250 mL plastic container where they were free to mate and lay eggs. The container was cut on one side and a cotton piece soaked in 10% sugar solution was placed to provide additional sugar content for the adults. A fine mesh was placed on the mouth of the plastic container and the

container was inverted to harvest eggs in the lid. The next day, the eggs were collected from the lid of the plastic cup. To avoid infertility of eggs, the first day eggs were discarded, and eggs laid on the second day were used for the study. Similarly, 12 and 18- d-old larvae were also taken from the mother colony. However, to obtain one and 6-d-old pupae, the last larval instars were obtained from rearing culture and kept under observation till they become pupae. Upon larval molting into pupae, they were collected and used in the present study according to their relevant age group. For the adult stage, some of the pupae were allowed to emerge as adults. After eclosion, a pair of 1-d-old adults (male and female), were shifted in a 50 g plastic container and exposed to UV radiation.

### 2.3. Experimental design

There were different times of exposure for each stage to achieve 100% mortality. The final exposure times were determined after the preliminary studies. The exposure times were: 10, 20, 30, and 60 min for the egg stage; 6, 8, 12, and 18 h for the larval stage; and 6, 8, 12, 18, 24, and 30 h for the pupal stage. Additionally, the adults were irradiated for 1, 2, 3, and 4 d. A digital stop watch was used to count the relevant exposure times. The CRD (complete randomized design) was applied in the present study. We used 10 individuals for each stage in one replicate and there were four replicates for each exposure time. However, for adults, three pairs at each exposure and each pair was considered an individual replicate.

### 2.4. Ultraviolet radiation application

All the developmental stages were exposed to UV (ultra violet) radiation type B (UV-B, 280–315 nm) for different exposure times. The eggs, larvae, and pupae were kept in 50 g plastic container and labelled. These cups were placed 30 cm below a 40 W fluorescent UV lamp in a closed chamber at room temperature of  $25 \pm 2$  °C without any humidity control. For immovable stages, such as eggs and pupae, cups lids were removed. However, for moveable stages, such as larvae and adults, the cup cover was detached but to avoid larval escape and flying of the adults, the cup was covered with a metallic net (2 mm). The purpose was to expose all stages directly to UV. Moreover, the larval stage was also provided with 5 g of artificial diet (Aldawood et al., 2013). Similarly, controls for each treatment were conducted by placing the developmental stages under normal fluorescent light in the same manner. After the irradiation, the insects were placed in the chambers at  $25 \pm 2$  °C and  $65 \pm 5\%$  RH.

### 2.5. Data collection

After relevant exposure time intervals, cups were opened, and mortality counts were conducted. Mortality signs were considered to be: no movement, body stiffness and shrinkage, and change in color (Husain et al., 2015, 2017b). The mortality observations were continued until all the insects either succeed to develop into the next phase or died.

The mortality data for all stages used in the experiment; were corrected based on control treatment mortality using the given Eq. (1), proposed by Abbott (1925).

$$Mortality_{cor.} = \frac{Mortality_{obs.}(\%) - Mortality_{cnt.}(\%)}{100 - Mortality_{cnt.}(\%)} \times 100\% \quad (1)$$

Where,  $Mortality_{cor.}$  = corrected mortality

$Mortality_{obs.}$  = observed mortality and

$Mortality_{cnt}$  = mortality of controls.

## 2.6. Statistical analysis

The mortality data were tabulated and analyzed to separate the mean differences among the treatment mortality by using a one-way ANOVA (analysis of variance) and Fisher's least significant difference (LSD) test at  $\alpha = 0.05$ . Each treatment group, including control was repeated four times and the average numbers were tabulated from four replicates. Abbott formula was used to correct the treated insects mortality ratio and the statistical analysis were carried out at 5% significance level using the [statistical software R version 3.4.3 \(2017-11-30\)](#).

## 3. Results

### 3.1. Egg hatching

The UV-B (315 nm) radiation was extremely lethal to the immature stages of *C. cautella* as all the immature developmental stages were killed within few minutes to hours. It was observed that UV reduced the hatching rate of *C. cautella*. Eggs were the most sensitive stage, and no hatchability was observed within 30 min post-UV exposure, regardless of the age of the eggs. The eggs, either 1-d or 3-d-old, could not successfully hatch after 30 min of UV treatment. For 1-d-old eggs, the maximum hatchability was recorded after 10 min of exposure ([Table 1](#)). The 3-d-old eggs showed more sensitivity to UV radiation than did the 1-d-old eggs. Maximum rate of egg hatching failure was recorded after 30 min of exposure both for one d and 3-d-old eggs. The differences between egg hatchability compared with that of the control treatments were highly significant ([Table 1](#)).

### 3.2. Larval mortality

The harmful effects of UV on *C. cautella* larval stage are presented in [Table 2](#). In the case of larval mortality, the younger and

older larvae exhibited similar trends. For 12-d-old larvae, mortality was significant when compared with that of the control treatment at 6 h of post-exposure. However, no significant difference was recorded among larval mortalities after 6, 8, 10, and 12 h ([Table 2](#)). Similarly, for 18-d-old larvae, analogous mortality trends were observed. However, for 18-d-old larvae mortality did not reach 100%, which indicated that they were somewhat resistant to UV-B relative to 12-d-old larvae ([Table 2](#)).

### 3.3. Adult emergence from treated pupae

The radiation effect on the pupal stage of *C. cautella* was lethal and mortality was significantly greater than that of the control. Adult emergence failure from UV-irradiated pupae was directly proportional to the radiation exposure interval both for 1-d and for 6-d-old pupae ([Table 3](#)). After 6 h of UV exposure, maximum number of the 1-d-old pupae died before adult emergence, whereas it took 30 h of irradiation to achieve 100% pupal mortality for the 1-d-old pupae. However, for 6-d-old pupae, the situation was quite different, and more than 75% pupae died before adult emergence after 6 h of exposure, whereas no pupae succeeded to emerge as adults after 12 h of exposure ([Table 3](#)). This indicated that the mature pupae were more sensitive than the younger ones and died sooner.

### 3.4. Irradiation effect on adults' biological traits

UV irradiation, adversely affected *C. cautella* biological characteristics, such as fecundity and hatchability as compared to the control treatment. The results indicated that the adult pairs exposed to UV were not able to lay as many eggs as laid by the females in the control treatment ([Table 4](#)). UV irradiation did not cause death of the adults of either sex; in contrast, the irradiated females laid fewer eggs and most of the eggs were either infertile or could not complete their embryonic development. The females

**Table 1**  
Ultraviolet irradiation effects on *Cadra cautella* eggs hatchability (mean  $\pm$  SE).

Eggs age	Exposure (Min.)*	Hatchability (%)	ANOVA parameters			
			N	F	df	P
1-d-old	0 (Control)	87.5 $\pm$ 2.50a	4	330.11	3,15	<0.0001
	10	67.5 $\pm$ 2.50b	4			
	20	27.5 $\pm$ 2.50c	4			
	30	0.00 $\pm$ 0.00d	4			
3-d-old	0 (Control)	95.00 $\pm$ 2.88a	4	87.88	3,15	<0.0001
	10	17.5 $\pm$ 8.53b	4			
	20	5.00 $\pm$ 2.88bc	4			
	30	0.00 $\pm$ 0.00c	4			

In each column, means followed by the same letter (s) are not significantly different, at ( $\alpha = 0.05$ ).

\* The treatment time for eggs was in minutes.

**Table 2**  
Ultraviolet irradiation effect on *Cadra cautella* larval mortality (mean  $\pm$  SE).

Larvae age	Exposure (h)	Mortality (%)	ANOVA parameters			
			N	F	df	P
12-d-old	0 (Control)	2.50 $\pm$ 2.50c	4	57.49	4,19	<0.0001
	6	70.00 $\pm$ 7.07b	4			
	8	71.00 $\pm$ 6.05b	4			
	10	75.00 $\pm$ 2.88b	4			
	12	100.00 $\pm$ 0.00a	4			
	18-d-old	0 (Control)	5.00 $\pm$ 5.00c			
6	72.50 $\pm$ 8.53b	4				
8	90.00 $\pm$ 4.08ab	4				
10	95.00 $\pm$ 2.88a	4				
12	97.50 $\pm$ 2.50a	4				

In each column, means followed by the same letter (s) are not significantly different, at ( $\alpha = 0.05$ ).

**Table 3**  
Ultraviolet irradiation effect on *Cadra cautella* pupal mortality (mean ± SE).

Pupae age	Exposure (h)	Mortality (%)	ANOVA parameters			
			N	F	df	P
1-d-old	0 (Control)	5.00 ± 2.88e	4	28.51	5,23	<0.0001
	6	55.00 ± 8.66d	4			
	12	62.50 ± 4.78dc	4			
	18	77.50 ± 10.30bc	4			
	24	87.50 ± 4.78ba	4			
	30	100.00 ± 0.00a	4			
6-d-old	0 (Control)	10.00 ± 4.08c	4	134.14	5,23	<0.0001
	6	75.00 ± 6.45b	4			
	12	100.00 ± 0.00a	4			
	18	100.00 ± 0.00a	4			
	24	100.00 ± 0.00a	4			
	30	100.00 ± 0.00a	4			

In each column, means followed by the same letter (s) are not significantly different, at ( $\alpha = 0.05$ ).

**Table 4**  
Ultraviolet irradiation effect on *Cadra cautella* adults biological characteristics (mean ± SE).

Adult age	Exposure (d)*	Total laid eggs	Hatchability %	Male life span	Female life span
1-d-old	0 (Control)	206.33 ± 20.57a	94.51 ± 0.78a	6.66 ± 0.33a	7.00 ± 0.00a
	1	88.66 ± 4.09bc	58.89 ± 7.66b	5.33 ± 0.33bc	5.33 ± 0.33c
	2	28.66 ± 15.21c	36.15 ± 18.61bc	5.33 ± 0.33bc	5.66 ± 0.33bc
	3	107.66 ± 38.16b	24.85 ± 10.20 cd	4.33 ± 0.66c	5.33 ± 0.33c
	4	119.00 ± 30.26b	0.00 ± 0.00d	5.66 ± 0.33ab	6.33 ± 0.33ab

In each column, means followed by the same letter (s) are not significantly different, at ( $\alpha = 0.05$ ).

\* Treatment time for adults was in days.

in the control laid 206 eggs, whereas the irradiated females laid, less eggs, after treatment. Egg hatchability in control was much higher. Moreover, the life spans of adult females were also significantly different. UV irradiated pairs lived slightly shorter lives than did the adults in the control treatment (Table 4).

The survival ratios were corrected using Eq. (1), for all exposure times as shown in Table 5. The survival ratio was directly proportional with increase in the exposure time, and 100% mortality of eggs (1-d and 3-d-old), larvae (12-d and 18-d old) and pupae (1-d and 6-d old) was obtained at the minimum exposure times of 29.7, 28.9, 11.9, 11.5, 30.2, 19.8, respectively.

The survival ratio curve for 1-d-old eggs was described by the regression equations:

$$\text{Survival ratio} = 182.1 - 33.4 \times \sqrt{\text{Exposure}}$$

With the coefficient of determination  $R^2 = 0.99$ , where the exposure time in minutes, and survival ratio (%) of 1-d-old eggs and other stages are presented in Table 5. Insects stages data was transformed

using appropriate transformation to achieve normality with significant results,  $p < 0.05$ .

The  $LT_{50}$  and  $LT_{90}$  for treated *C. cautella* stages are presented in Table 6. 1-d-old pupae were the most tolerant life stage to UV radiation with 23.5 h were required to achieve 90% mortality. In contrast, the 6-d-old pupae were the most susceptible life stage to UV irradiation, with 7.6 h were needed to achieve 90% mortality. Different life stages tolerance variation can also be witnessed from the probit lines slope presented in Table 6. The 1-d-old pupae possess minimum slope value, while the 6-d-old pupae showed maximum slope value, which indicated that the shortest exposure time is required to achieve 100% mortality for 6-d-old pupae.

#### 4. Discussion

The present study showed that *C. cautella* eggs were very sensitive to UV-B radiation and there was no hatchability after 30 min of exposure. The reduced hatchability of *C. cautella* eggs has been previously reported for eggs exposed to UV-C for the period of 15 and

**Table 5**  
The ultraviolet irradiation effect on survival ratios of *Cadra cautella* life stages for different exposure times.

Stage	Predictor variables (x)	Parameter value	R <sup>2</sup>	n	Min. time for 100% mortality
1-d-old eggs	Intercept	182.174 ± 4.58	0.998	40	29.745
	$\sqrt{\text{Exposure}}$	-33.402 ± 1.024			
3-d-old eggs	Intercept	57.21 ± 4.631	0.982	40	28.907
	Log (Exposure)	-17.006 ± 1.578			
12-d-old larvae	Intercept	3.07e + 01 ± 4.77e-01	0.997	40	11.996
	$e^{\text{Exposure}}$	-1.89e-04 ± 5.81 e-06			
18-d-old larvae	Intercept	13.331 ± 0.991	0.972	40	11.58
	$\sin(\text{Exposure})$	16.068 ± 1.547			
1-d-old pupae	Intercept	61.0526 ± 2.0156	0.99	40	30.261
	Exposure	-2.0175 ± 0.1013			
6-d-old pupae	Intercept	-10.82 ± 4.20	0.8357	40	19.884 <sup>a</sup>
	1/Exposure	215.15 ± 46.57			

<sup>a</sup> Note: Time for eggs is in minutes whereas, for the larvae and pupae time is in hours.

**Table 6**  
Lethal time of ultraviolet irradiation on different developmental stages of *Cadra cautella*.<sup>a</sup>

Stage	LT <sub>50</sub>	LT <sub>90</sub>	Slope ± SE
1-d-old eggs	14.093	23.912	0.1305 ± 0.0069
3-d-old eggs	7.076	14.279	0.1779 ± 0.0084
12-d-old larvae	5.709	10.461	0.2696 ± 0.0105
18-d-old larvae	4.375	8.814	0.2886 ± 0.0108
1-d-old pupae	6.252	23.594	0.0739 ± 0.0043
6-d-old pupae	3.89	7.696	0.3367 ± 0.0163

<sup>a</sup> Note: Time for eggs is in minutes whereas, for the larvae and pupae time is in hours.

24 min, after which there was only 30 and 12% hatchability, respectively (Faruki et al., 2007; Sorungbe et al., 2016). The harmful effects of UV on other insect species have also been reported and confirmed the sensitivity of eggs to UV light. The eggs of *T. castenium*, *T. confusium*, and *Tyrophagus putrescentiae* mites, were more sensitive than the eggs of *C. cautella* (Faruki et al., 2007; Bakr, 2013). In contrast, the eggs of *C. maculatus*, were not very sensitive to UV and some larvae completed their life cycle even 50 min exposure UV-C for (Heidari et al., 2016).

Ultraviolet irradiation damages the cellular components, such as lipid membranes, proteins, and nucleic acids, as well as induces several other chemical compounds. The question arises why is the egg stage the most sensitive to UV radiation? Some core facts suggest that embryonic development is highly susceptible to stress. When UV light interacts with egg chorion, it damages DNA, as in *Trogoderma granarium* in which UV-C damaged the egg chorion thereby resulting in eggs inner contents leakage (Ghanem and Shamma, 2007; Zhao et al., 2007). We observed that eggs exposed to UV-B were physically shrunken and appeared damaged, whereas, in the control treatment, the eggs were normal and embryonic development proceed and eggs color changed from off-white to golden-yellowish, and even the head capsule of the developing neonates became visible few hours before hatching (personal observation).

UV irradiation had lethal effects and caused larval mortality. Although, no significant differences were observed among larvae of different ages. Nonetheless, the mortality of treated and untreated larvae was significantly different (Table 2). However, the older larvae were somewhat less sensitive and 100% mortality was not achieved with 12 h of exposure. The irradiated larvae were inactive, stopped growing, and had a dark black body color upon death, exhibiting symptoms that were similar to that of sunburns in humans because of solar radiation (Rajpurohit and Schmidt, 2019). In general, the larval and pupal mortalities were directly proportional to exposure times and present results in support with the findings of Faruki et al. (2005). Unlike larvae, the older pupae were more sensitive than the younger and within 6 h, 100% mortality was achieved (Table 3). However, in the case of younger pupae, it took 30 h of exposure to achieve 100% mortality. It is well documented that short wavelength lights (100–315 nm) have deleterious effects on insects by inducing genetic mutations and damaging DNA (Sinha and Häder, 2002; Rastogi et al., 2010; Hori et al., 2014). For example, in *T. castaneum*, UV irradiation influences its metamorphosis through disturbance of the PTTH hormone; thus, the production of ecdysone is inhibited (Wen et al., 2016). Additionally, in mosquitoes, UV-B affected the survival and metabolic rates in *Culex pipiens* and *Aedes albopictus* larvae (Villena et al., 2018).

In general, there was no immediate larval, pupal, or adult mortality at any exposure level. This observation indicated that the epidermis of irradiated larvae was damaged abruptly, which inhibited growth, caused nutrient stress, and turned the larvae greyish to blackish followed by death; thus, the symptoms appeared similar to sunburn in humans (Jagger, 1985; Licht and Grant, 1997;

Solomon, 2008). Because the irradiated larvae remained stunted, it is likely that they stopped feeding and this possibility is supported by the fact that in natural ecosystems UV-B inhibits the feeding of herbivorous insects (Mazza et al., 1999). The harmful effects of UV-C reported for *Oryzaephilus surinamensis*, *T. castaneum*, and the mite, *Acarus siro*, included inhibited development and reduced progeny (Collins and Kitchingman, 2010).

The present research work was carried out at 25 °C which is considered the normal laboratory temperature and we confirmed that UV lamp light did not increase the temperature in the experimental chamber that might have effects on mortality. Moreover, the control treatment was also placed under a normal light to confirm the effects of raised temperature on mortality. There are studies that also confirmed that increased temperature because of blue light did not affect the mortality of model insects. However, the toxic wavelength of visible light is species specific for *Drosophila melanogaster*, *Cu. pipiens*, and *T. castenium* (Hori, et al., 2014; Shibuya et al., 2018). However, the UV radiation effects under different temperatures regimes might have different effects? This question needs to be conducted in the future. The idea of temperature variation is raised because in the date fruit store houses the temperature is usually kept low.

It is easy to record egg failure to hatch, larval mortality, and that of adults; however, in the case of pupal mortality, it is difficult to determine if the pupae are dead or alive. Because the symptoms of dead pupae and the pupae developing to become adults are similar, i.e., the change in color from light brown-to dark brown and black. Nonetheless, to confirm pupal mortality the observations were continued until all the pupae in the control treatments became adults.

## 5. Conclusions

The 100% mortality of eggs (1-d- and 3-d-old), larvae (12-d and 18-d-old) and pupae (1-d- and 6-d-old) was obtained at the minimum exposure times of 29.7 min, 28.9 min, 11.9 h, 11.5 h, 30.2 h, and 19.8 h, respectively. 1-d-old pupae were the most tolerant life stage of *C. cautella* to ultraviolet radiation and the 6-d-old pupae were the most susceptible life stage *C. cautella* to ultraviolet radiation. Ultraviolet radiations (UV-B, 315 nm) proved lethal against the immature developmental stages of *C. cautella*. Although adults did not die immediately, UV-B disrupted their mating behavior and fecundity. After eclosion and mating, *C. cautella* females deposited eggs on food items, and the last instar larvae come out of the food, wandered until pupation, and usually pupated outside the food; consequently, all stages could possibly be directly exposed to UV radiation. In this regard, UV-B might be a safe and economical management strategy to save the dates and other stored food commodities from attack by *C. cautella*.

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## References

- Abbott, W.S., 1925. A method for computing the effectiveness of an insecticide. *J. Econ. Entomol.* 18, 265–267.
- Afreen, F., Zobayed, S.M., Kozai, T., 2006. Melatonin in *Glycyrrhiza uralensis*: response of plant roots to spectral quality of light and UV-B radiation. *J. Pineal Res.* 41, 108–115.
- Aldawood, A.S., 2013. Effect of covering dates fruit bunches on *Ephestia cautella* walker (Lepidoptera: Pyralidae) infestation: population dynamics studies in the field. *Int. J. Agric. Appl. Sci.* 5, 98–100.
- Aldawood, A.S., Rasool, K.G., Alrukban, A.H., Sofan A., Husain, M., Sutanto, K.D., Tufail, M., 2013. Effects of temperature on the development of *Ephestia cautella*

- (Walker) (Pyrilidae: Lepidoptera): a case study for its possible control under storage conditions. *Pak. J. Zool.* 45, 1573–1578.
- Aldryhim, Y.N., Adam, E.E., 1999. Efficacy of gamma irradiation against *Sitophilus granarius* (L.) (Coleoptera: Curculionidae). *J. Stored Prod. Res.* 35, 225–232.
- Alfaro-Viquez, E., Roling, B.F., Krueger, C.G., Rainey, C.J., Reed, J.D., Ricketts, M.L., 2018. An extract from date palm fruit (*Phoenix dactylifera*) acts as a co-agonist ligand for the nuclear receptor FXR and differentially modulates FXR target-gene expression in vitro. *PLoS ONE* 13, e0190210.
- Ayvaz, A., Karabörklü, S., 2008. Effect of cold storage and different diets on *Ephestia kuehniella* Zeller (Lep: Pyralidae). *J. Pest Sci.* 81, 57.
- Bakr, A.A., 2013. Effectiveness of ultraviolet radiation as a physical method in controlling the stored product mite, *Tyrophagus putrescentiae* (Acari: acaridae). *J. Entomol.* 10, 43–48.
- Bouma, W., 1993. Fourth meeting of the parties to the Montreal protocol. *Clean Air: J. Clean Air Soc. Austral. New Zeal.* 27, 11.
- Chao, C.T., Krueger, R.R., 2007. The date palm (*Phoenix dactylifera* L.): overview of biology, uses, and cultivation. *HortScience* 42, 1077–1082.
- Collins, D.A., Kitchingman, L., 2010. The effect of ultraviolet C radiation on stored-product pests. *Julius-Kühn-Archiv* 425, 632–636.
- Faruki, S.I., Das, D.R., Khatun, S., 2005. Effects of UV-radiation on the larvae of the lesser mealworm, *Alphitobius diaperinus* (Panzer) (Coleoptera: Tenebrionidae) and their progeny. *Pak. J. Biol. Sci.* 5, 444–448.
- Faruki, S.I., Das, D.R., Khan, A.R., Khatun, M., 2007. Effects of ultraviolet (254 nm) irradiation on egg hatching and adult emergence of the flour beetles, *Tribolium castaneum*, *T. confusum* and the almond moth, *Cadra cautella*. *J. Insect Sci.* 7, 36.
- Ghanem, I., Shamma, M., 2007. Effect of non-ionizing radiation (UVC) on the development of *Trogoderma granarium* Everts. *J. Stored Prod. Res.* 43, 362–366.
- Ghnimi, S., Umer, S., Karim, A., Kamal-Eldin, A., 2017. Date fruit (*Phoenix dactylifera* L.): an underutilized food seeking industrial valorization. *NFS J.* 6, 1–10.
- Hashem, M.Y., Risha, E.S.M., El-Sherif, S.I., Ahmed, S.S., 2012. The effect of modified atmospheres, an alternative to methyl bromide, on the susceptibility of immature stages of angoumois grain moth *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelechiidae). *J. Stored Prod. Res.* 50, 57–61.
- Heidari, N., Sedaratian-Jahromi, A., Ghane-Jahromi, M., 2016. Possible effects of ultraviolet ray (UV-C) on biological traits of *Callosobruchus maculatus* (Col.: Chrysomelidae). *J. Stored Prod. Res.* 69, 91–98.
- Hori, M., Shibuya, K., Sato, M., Saito, Y., 2014. Lethal effects of short-wavelength visible light on insects. *Sci. Rep.* 4, 7383.
- Husain, M., Rasool, K.G., Tufail, M., Alhamdan, A.M., Mehmood, K., Aldawood, A.S., 2015. Comparative efficacy of CO<sub>2</sub> and ozone gases against *Ephestia cautella* (Lepidoptera: Pyralidae) larvae under different temperature regimes. *J. Insect Sci.* 15, 126.
- Husain, M., Sukirno, S., Mehmood, K., Tufail, M., Rasool, K.G., Alwaneen, W.S., Aldawood, A.S., 2017a. Effectiveness of carbon dioxide against different developmental stages of *Cadra cautella* and *Tribolium castaneum*. *Environ. Sci. Pollut. Res.* 24, 12787–12795.
- Husain, M., Alwaneen, W.S., Mehmood, K., Rasool, K.G., Tufail, M., Aldawood, A.S., 2017b. Biological traits of *Cadra cautella* (Lepidoptera: Pyralidae) reared on khodari date fruits under different temperature regimes. *J. Econ. Entomol.* 110, 1923–1928.
- Isikber, A.A., Oztekin, S., 2009. Comparison of susceptibility of two stored-product insects *Ephestia kuehniella* Zeller and *Tribolium confusum* du Val to gaseous ozone. *J. Stored Prod. Res.* 45, 159–164.
- Jagger, J., 1985. Solar-UV actions on living cells.
- Jurkiewicz, B.A., Buettner, G.R., 1994. Ultraviolet light-induced free radical formation in skin: an electron paramagnetic resonance study. *Photochem. Photobiol.* 59, 1–4.
- Licht, L.E., Grant, K.P., 1997. The effects of ultraviolet radiation on the biology of amphibians. *Am. Zool.* 37, 137–145.
- Mazza, C.A., Zavala, J., Scopel, A.L., Ballaré, C.L., 1999. Perception of solar UVB radiation by phytophagous insects: behavioral responses and ecosystem implications. *Proc. Natl. Acad. Sci. USA* 96, 980–985.
- Navarro, S., 2012. The use of modified and controlled atmospheres for the disinfection of stored products. *J. Pest Sci.* 85, 301–322.
- Ooninx, D.G.A.B., van Keulen, P., Finke, M.D., Baines, F.M., Vermeulen, M., Bosch, G., 2018. Evidence of vitamin D synthesis in insects exposed to UVB light. *Sci. Rep.* 8, 10807.
- Pimentel, M.A.G., Faroni, L.R.D.A., Batista, M.D., de Silva, F.H., 2008. Resistance of stored-product insects to phosphine. *Pesq. Agropec. Bras.* 43, 1671–1676.
- R Core Team, 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN.
- Rajpurohit, S., Schmidt, P., 2019. Latitudinal pigmentation variation contradicts ultraviolet radiation exposure: a case study in tropical Indian *Drosophila melanogaster*. *Front. Physiol.* 10, 84.
- Rastogi, R.P., Richa, K.A., Tyagi, M.B., Sinha, R.P., 2010. Molecular mechanisms of ultraviolet radiation-induced DNA damage and repair. *J. Nucleic Acids* 2010. <https://doi.org/10.4061/2010/592980>.
- Rees, D., 2007. Insects of stored grain: a pocket reference, CSIRO Publishing.
- Shibuya, K., Onodera, S., Hori, M., 2018. Toxic wavelength of blue light changes as insects grow. *PLoS ONE* 13, e0199266.
- Singh, G., Sharma, R.K., 2015. Alternatives to phosphine fumigation of stored grains: the Indian perspective. *Himachal J. Agric. Res.* 41, 104–113.
- Sinha, R.P., Häder, D.P., 2002. UV-induced DNA damage and repair: a review. *Photochem. Photobiol. Sci.* 1, 225–236.
- Solomon, K.R., 2008. Effects of ozone depletion and UV-B radiation on humans and the environment. *Atmos. Ocean* 46, 185–202.
- Sorongbe, A.A., Badmus, H.A., Sulaimon, A.M., 2016. Effect of ultraviolet irradiation on egg hatching of tropical warehouse moth (*Ephestia Cautella*), development of its adult and mortality. *Int. J. Res. Pharma. Bio Sci.* 3, 23–27.
- Villena, O.C., Momen, B., Sullivan, J., Leisham, P.T., 2018. Effects of ultraviolet radiation on metabolic rate and fitness of *Aedes albopictus* and *Culex pipiens* mosquitoes. *PeerJ* 6, e6133.
- Wen, S., Yu, L., He, L., Ma, W.H., Zhu, Z.H., Zhu, F., Wang, X.P., Lei, C.L., 2016. UVB radiation delays *Tribolium castaneum* metamorphosis by influencing ecdysteroid metabolism. *PLoS ONE*. <https://doi.org/10.1371/journal.pone.0151831>.
- Zhao, S., Qiu, C., Xiong, S., Cheng, X., 2007. A thermal lethal model of rice weevils subjected to microwave irradiation. *J. Stored Prod. Res.* 43, 430–434.