Effect of ultra violet irradiation on life table of Mediterranean flour moth, *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae)

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Ali Mirshekar^{1*} , Akram Bakhshi² , Ali Asghar Talebi² , Yaghoub Fathipour²

Article Info

Accepted:
29 Feb. 2020

Keywords:

Ephestia kuehniella,
Physical control,
Population growth
parameters,
Reproductive
parameters

ABSTRACT

Three age groups of eggs of the stored grain pests, *Ephestia kuehniella* (1, 2, and 3 days old) were exposed to ultraviolet irradiation with 254 nm wavelength (UV-C) for different exposure times (0.5- 40 min.) under controlled conditions to determine irradiation effect on egg-hatching. The effect of UVC-irradiation on reproduction and population growth parameters was investigated for eggs irradiated for 0.5, 1 and 1.5 minutes. An increase in time of exposure to irradiation caused a gradual decrease in percentage of hatching off eggs in all age groups of eggs. In all treatments, the older eggs were more sensitive to UV-rays than younger ones. The results indicated that different exposure periods of UV-irradiation could affect the reproduction and population growth parameters. The highest value of net fertility rates was observed in 1, 2, and 3-days-old eggs which were treated with 0.5 min exposure time (26.69 ± 4.66 , 5.99 ± 0.57 and 1.55 ± 0.16 eggs/female, respectively). Both the intrinsic rate of increase (r_m) and the net reproductive rate (R_0) decreased with increasing the exposure time from 0.5 to 1.5 min while the mean generation time (T_c) and doubling time (D_T) increased within this irradiation range. The lowest amount of r_m was determined in 1, and 2 days-old eggs at 1.5 min and in 3-day-old eggs at 1 min exposure times (0.037 ± 0.0025 , 0.004 ± 0.0016 and 0.006 ± 0.0008 day⁻¹, respectively). UVC-irradiation may be used as an alternative approach to control of stored product pests.

INTRODUCTION

The Mediterranean flour moth *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) is one of the major pests in industrial flour mills in temperate climates, as well as in the storage worldwide (Pires et al. 2018). Moth larvae produce webbing that blocks machinery and pipes; presence of larvae and webbing in the end product is unacceptable to consumers. Typically, control of this pest is undertaken by regular space treatment of the infested area with a pesticide (Trematerra and Gentile 2010).

In many countries, the fumigant methyl bromide has been applied on a regular basis as the main control method for this pest (Piccirillo and Piccirillo 2010). Since methyl bromide causes depletion of the ozone layer, the parties to the

Montreal Protocol have agreed to phase out methyl bromide by 2010 in developed countries (Gareau 2010) and finally the amount of methyl bromide production or import was reduced incrementally until it was phased out in 2005 (Besri 2010). Use of other insecticides in stored products have restrictions globally. In addition, chemical pesticides use leads to the development of resistance in certain insect species (Roditakis et al. 2015). So, the deleterious effects of insecticides on the environment and human health, forced to find other safe alternative control approaches.

Irradiation has become a promising technique for controlling stored product insects because of its pollution free to the environment (Hallman 2013). The application of irradiation technology as an alternative to insecticides in stored products has been well established. Irradiation treatment prolonged the fruit and vegetable shelf life over a longer period of time; however, radiated products show no significant alter in the quality of the material or stored seeds (Singh et al. 2016). The Ultraviolet irradiation is extensively used as germicide (Turtoi 2013), an attractant for insects

1- Department of Plant Protection, Faculty of Agriculture University of Zabol, P.O. Box: 35856-98613, Zabol, Iran.

2- Department of Entomology, Faculty of Agriculture, Tarbiat Modares University, P.O. Box: 14115-336, Tehran, Iran.

* E-mail: mirshekar@hotmail.com

(Barghini and Medeiros 2012), also used in the physiological studies of embryos (Ozáez et al. 2016). Arthur et al. (2015) stated that UV-rays are generally less harmful to living organisms than the ionizing radiation as they penetrate only the surface layer of cells. A number of investigators have considered the possibility of using UV-rays to control, or at least to suppress the development of various species of stored product insects such as *Ephestia kuehniella* (Zeller) (Azizoglu et al. 2011), *Oryzaephilus surinamensis* (Linnaeus), *Tribolium castaneum* (Herbst), *Acarus siro* (Linnaeus) and *Tyrophagus putrescentiae* (Schränk) (Collins and Kitchingman 2010), *Trichogramma euproctidis* (Girault) (Tuncbilek et al. 2012) and *Sitophilus zeamais* (Motschulsky) (Hassan et al. 2019).

Fertility life tables are appropriate to study the dynamics of animal populations, especially arthropods, as an intermediate process for estimating parameters related to the population growth potential, also called demographic parameters (Price et al. 2011). The development of effective management strategies requires broad understanding of the pest biology and population parameters. Therefore, the objective of the present study was to evaluate the effects of different exposure times of UVC on egg-hatching, reproduction, and population growth parameters of *E. kuehniella*. A large number of studies have been conducted to evaluate UV-rays on different pests of stored products worldwide. A thorough search of literature on UVC and *E. kuehniella* did not revealed any report about the lowest radiation doses for suppressing infestation. Therefore, in this study the different radiation doses and exposure times was investigated to evaluate the effect of UVC doses on the developmental stages of *E. kuehniella*. Understanding this subject may provide a better view of the pest control.

MATERIALS AND METHODS

The laboratory experiments were carried out at the Department of Entomology, Faculty of Agriculture, Tarbiat Modares University, Tehran, Iran, from 2018 to 2019. Prior to the project implementation, Eggs of *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) were collected from the Iran's Pistachio Research Institute, Rafsanjan, Iran and transferred to plastic containers with rearing medium (Flour) at temperature of $25 \pm 5^\circ\text{C}$, and a photoperiod of 10:14 (L: D), without humidity control. A hole (5 cm diameter) was cut at the center of top cup of the plastic container and covered by fine nylon mesh for ventilation.

The UVC irradiation source was a 15W germicidal lamp, GE15T8 measuring 40×2 cm. This lamp produced UVC at a wave length of 253.7 nm. For irradiation, the Petri dishes were placed on a surface 12 cm from the lamp, as the eggs were in

front of the lamp. Exposure period was determined using a stop watch. At the end of the exposure period, the UV-lamp was turned off and the eggs were removed immediately.

In order to determine the life table parameters, a number of adults were selected from mass cultures and they were transferred to mating beakers (20 cm diameter, 30 cm height). The top of the beaker was covered with a netted cloth. The beakers with moths were placed on Petri dishes for an easy collection of the eggs. On the following day, 1-day-old eggs were collected. Some of these eggs were kept in Petri dishes to obtain 2- and 3-day-old eggs. The experiment was conducted for one-day, two-day and three-day eggs similarly, and 150 eggs were irradiated for each exposure period. Eggs were irradiated for 0.5, 1, 1.5, 2, 4, 8, 16, 24, 32 and 40 minutes. After exposure, the irradiated and non-irradiated control eggs of different age groups were transferred separately to plastic containers at $25 \pm 5^\circ\text{C}$ until hatching. This experiment continued until the death of all members of each cohort. Two important life table parameters (survivorship and life expectancy) were calculated by the following formula:

$$l_x = \frac{N_x}{N_o}, \quad e_x = \frac{T_x}{l_x},$$

where x is unit of age, l_x is age-specific survival rate or the fraction of individuals of the initial cohort alive at age x , N_x is number alive at age x , N_o is starting number of individuals in the cohort, e_x is the expectation of life at age x , T_x is the number of time units lived by the cohort from age x until all individuals die: $T_x = \sum L_x$, where L_x gives the number of days lived by the average individual within a cohort in the interval x to $x+1$ (Carey 1993).

To calculate the demographic parameters of *E. kuehniella* a large number of one-day, two-day and three-day eggs were selected and were irradiated for 0.5, 1, 1.5 minutes (since mortality was high in other exposure duration, these parameters were not calculated for other exposure times), after irradiation, the eggs were placed individually into plastic containers with rearing medium until pupae formation. Healthy pupae were segregated sexually and were maintained separately until adult exclusion. After adult emergence, 30 pairs (male and female) were selected and each pair was placed in a plastic beaker at temperature of $25 \pm 5^\circ\text{C}$, and a photoperiod of 10:14 (L:D). The number of eggs laid by each female was recorded daily until the last female died. After counting, the eggs were removed. Reproduction and population growth parameters of *E. kuehniella* were constructed according to Carey (1993, 2001). The factors that are essential for calculating the population

parameters including the age of females in days (x), the number of females alive at age x (l_x), and the mean number of eggs laid per female alive per day (m_x).

Standard life table parameters were computed from daily records of mortality, fecundity and fertility of a cohort of *C. maculatus* at each UVC-irradiation period. The reproduction (gross fecundity and fertility rates, net fecundity and fertility rates, mean number of eggs and fertile eggs per female per day) and population parameters including intrinsic rate of increase (r_m), net reproductive rate (R_0), mean generation time (T_c), finite rate of increase (λ) and doubling time (D_T); were calculated using formulae suggested by Carey (1993). The statistical differences in R_0 , T_c , λ , D_T and r_m values were tested using jackknife method to estimate the variance for r_m and the other population parameters (Meyer et al. 1986). This method is used mostly to determine variance and bias of estimators. It is based on a repeated recalculation of the required estimator, missing out each sample in turn (Maia et al. 2000). It is used to quantify uncertainty associated with parameter estimates, as an alternative to analytical procedures which require very complicated mathematical derivation (Maia et al. 2000).

Algorithms for jackknife estimation of the means and variances are described only for r_m . Similar procedures were used for the other parameters (R_0 , T_c , λ and D_T). The steps for the application of the method are the following (Maia et al. 2000): (a) Estimation of r_m , R_0 , T_c , λ and D_T considering the survival and reproduction data for all the n females, referred to as true calculation. At this point, called step zero, estimates obtained are denoted as $r_m(\text{all})$, $R_0(\text{all})$, $T_c(\text{all})$, $\lambda(\text{all})$ and $D_T(\text{all})$ (Maia et al., 2000). (b) Repeat of the procedure for n times was described in part (a), each time excluding a different female. In so doing, in each step i , data of $n - 1$ females are taken to estimate parameters for each step, now named $r_m(i)$, $R_0(i)$, $T_c(i)$, $\lambda(i)$ and $D_T(i)$ (Maia et al., 2000). (c) In each step i , pseudo-values are calculated for each parameter, subtracting the estimate in step zero from the estimate in step i , for instance, the pseudo-values of r_m , $r_m(j)$, was calculated for the n samples using the following equation (Maia et al., 2000):

$$r_{m(j)} = n \times r_{m(\text{all})} - (n - 1) \times r_{m(i)}$$

d) After calculating all the n pseudo-values for r_m , jackknife estimate of the mean $r_m(\text{mean})$, variance $\text{VAR } r_m(\text{mean})$ and standard error $\text{SEM } r_m(\text{mean})$ calculated, respectively, by the following equations (Maia et al. 2000):

$$r_{m(\text{mean})} = \frac{\sum_{j=1}^n r_{m(j)}}{n}$$

$$\text{VAR } r_{m(\text{mean})} = \frac{\sum_{j=1}^n (r_{m(j)} - r_{m(\text{all})})^2}{n - 1}$$

$$\text{SEM } r_{m(\text{mean})} = \sqrt{\frac{\text{VAR}(r_{m(\text{mean})})}{n}}$$

The differences in development, reproduction and population parameters were compared using one-way ANOVA. If significant differences were detected, multiple comparisons were made using the Student-Newman-Keuls (SNK) at $P < 0.05$. Statistical analysis was carried out using software *Minitab*, version 14.1 (Minitab User's Guide, Minitab Ltd. UK).

RESULTS AND DISCUSSION

UVC-irradiation reduced egg hatch of all age groups. Egg hatching rate increased with increasing exposure periods (Figure 1).

Figure 1. Egg hatching rate (%) of *Ephestia kuehniella* under different UV-irradiated time

All exposure periods of UVC radiation, reduced the hatching of eggs in comparison with control. The percentage of egg hatch was 81.67% in control. In one-day-old eggs, egg hatching was 70.83, 45.83, 31.67, 18.33, 4.17, 3.33 and 2.5 % at 0.5, 1, 1.5, 2, 4, 8 and 16 min exposure time, respectively. Our results indicated that egg hatching rate decreased as the age of irradiated eggs increased. In two-day-old eggs, egg hatch rate was 55.83, 39.17, 24.17, 5.83% at 0.5, 1, 1.5 and 2 min exposure time, in three day old eggs was 18.33 and 10% at 0.5 and 1 min exposure time, respectively. In all age groups of eggs, no hatching eggs occurred at higher exposure times. UVC-irradiation had a severe effect on the age-specific survivorship rate.

The survivorship (l_x) at the first day of life was 71.68% in control and 56.03, 20.17, 19.17, 7.63, 2.5, 2.5 and 0.83% in 1-day-old treated eggs by 0.5, 1, 1.5, 2, 4, 8 and 16 min exposure time. This parameter was 8.69, 3.39, 1.68 and 0.83% in 2-day-

old eggs at 0.5, 1, 1.5 and 2 min exposure time and 6.69, 1.96% in 3-day old eggs that treated by 0.5 and 1 min exposure time, respectively (Figure 2).

Figure 2. Age-specific survivorship (l_x) of 1, 2 and 3-day-old eggs of *E. kuehniella* under different dose of UVC-irradiation

The life expectancy (e_x) at the first day of life was 57.02 days in control and 46.14, 24.75, 18.79, 11.83, 5.96, 5.79 and 4.93 days in 1-day old eggs that treated by 0.5, 1, 1.5, 2, 4, 8 and 16 min exposure time. This parameter was calculated to be 12.52, 7.08, 6.23, 6.11 days in 2-day-old eggs at 0.5, 1, 1.5, 2 min exposure time and 7.55, 3.66 days in 3-day-old at 0.5 and 1 min exposure time eggs, respectively. The life expectancy at the beginning of adult emergence was 14.33 days in control and 13.27, 12.16, 13.33, 14.28, 4.83, 6.83, 6.50 days in 1-day-old eggs by above mentioned doses and 6.42, 9.50, 5.50 and 3.50 days in 2-day-old eggs at 0.5, 1, 1.5 and 2 min exposure time and 8.06, 12.00 days in 3-day-old eggs at the examined doses, respectively (Figure 3). Therefore, the results

indicated that UVC-irradiation decreased the survivorship and the life expectancy on treated generations in comparison with control. Among the emerged adults from the irradiated eggs, a proportion of the individuals were severely deformed in their wings, elytra and bodies (Figure 4). Deformity was observed at high exposure times in all three age groups of eggs.

Figure 3. Life expectancy (e_x) of 1, 2 and 3-day-old eggs of *Ephesia kuehniella* under different dose of UVC-irradiation

The results suggest that in comparison to controls, the reproductive parameters of all age groups of eggs were significantly affected by different duration (Table 1).

Although in comparison to controls, no significant difference was observed on the gross fecundity rate (i.e. the mean number of eggs per female per generation) when 2 and 3 day-old eggs were exposed to UVC irradiation, there was significant reduction in value of gross fecundity rate in 1 day-old eggs that treated by UVC-irradiation. Net fecundity rate was 74.84 ± 10.16 eggs in control, however decreased significantly by

Figure 4. Morphologically deformed adults of *Ephestia kuehniella* that emerged from egg irradiated with UVC

increasing exposure time. The lowest value of net fecundity rate was 15.87 ± 2.01 and 1.69 ± 0.24 in 1 and 2 day old eggs, respectively that treated by 1.5 min exposure time and 1.80 ± 0.24 in 3 day old eggs that treated by 1 min exposure time (Table 1). A significant reduction in gross fertility rate of *E. kuehniella* was observed when eggs of different ages were exposed to UVC-irradiation. These effects increased with increasing exposure periods. The gross fertility was 114.42 ± 11.51 eggs in control. The lowest value of gross fertility rate observed on 3-day-old eggs that were irradiated 1 min (12.17 ± 1.21). Net fertility rate reduced significantly by UV-irradiation. The highest value of net fertility rates was observed in 1, 2 and 3-day-old eggs which were treated with 0.5 min exposure time (26.69 ± 4.66 , 5.99 ± 0.57 and 1.55 ± 0.16 eggs, respectively). The number of hatched eggs laid per female per day decreased from 8.71 ± 0.05 at 0.5 min to 3.65 ± 0.02 at 1.5 min exposure time in 1-day-old eggs, from 8.34 ± 0.02 at 0.5 min to 3.92 ± 0.06 at 1.5 min exposure time in 2-day-old eggs and from 2.84 ± 0.02 at 0.5 min to 1.13 ± 0.06 at 1 min exposure periods in 3-day-old eggs. Furthermore, the net fecundity rates and net fertility rates were decreased for each exposure duration as the age of irradiated eggs increased from 1 to 3 days.

Effect of different exposure time of UVC-irradiation on the population growth parameters of *E. kuehniella* is presented in Table 2. At all age groups of eggs, intrinsic rate of increase (r_m), finite rate of increase (λ) and the net reproductive rate (R_0) of *E. kuehniella* decreased with increasing exposure time. The mean generation time (T_c) and doubling time (DT) increased with increasing irradiation time. Net reproductive rate was 38.10 ± 4.95 in control and decreased as the duration of exposure to radiation increased. The lowest value of net reproductive rate was 6.68 ± 0.90 and 0.73 ± 0.09 in 1- and 2-day old eggs that treated by 1.5 min exposure time and 0.70 ± 0.09 in 3day old eggs that treated by 1 min exposure time, respectively (Table 2). The highest amount of r_m was observed in 1, 2 and 3-day-old eggs which were treated with 0.5 min exposure time (0.066 ± 0.0039 , 0.021 ± 0.0019 and 0.015 ± 0.0020

respectively) while it was $0.072 \pm 0.0026 \text{ day}^{-1}$ in control. Also changes in amount of λ indicated similar effects of the irradiation. The doubling time (DT) increased from 10.51 ± 0.37 at 0.5 min to 18.68 ± 1.34 at 1.5 min exposure time in 1-day-old eggs, from 33.97 ± 2.41 at 0.5 min to 153.38 ± 9.66 at 1.5 min exposure time in 2-day-old eggs and from 44.63 ± 2.21 at 0.5 min to 119.55 ± 5.91 at 1 min exposure periods in 3-day-old eggs. The lowest amount of mean generation time (T_c) was observed in 1, 2 and 3-day-old eggs which were treated with 0.5 min exposure time (42.09 ± 0.14 , 56.14 ± 0.19 and 52.76 ± 0.25 days respectively). However, the intrinsic rate of increase (r_m), finite rate of increase (λ) and the net reproductive rate (R_0) of *E. kuehniella* decreased for each exposure duration as the age of irradiated eggs increased from 1 to 3 days.

Understanding the demographic parameters of a pest is essential to develop an integrated pest management strategy; these parameters provide population growth rate of an insect pest in the current and next generations (Kakde et al. 2014). Irradiation has been recommended as a safe method for food preservation and as suitable alternative to chemical fumigants (Hallman and Blackburn 2016). The present study showed that *E. kuehniella* eggs were very sensitive to UV-C radiation and there was no hatchability after 16 min of exposure. The harmful effects of UV on fertile eggs of other insect species have been observed and confirmed the sensitivity of eggs to UV light (Alwaneen et al. 2019); In contrast, the eggs of, *C. maculatus*, were not very sensitive to UV and some larvae completed their life cycle even 50 min exposure to UV-C radiation (Heidari et al. 2016).

Our findings revealed that younger eggs (1-day-old) of *E. kuehniella* were more resistant than the older ones, which corroborates with the findings of Sedaghat et al. (2014) who reported that older eggs (2 and 3 day-old) of *Tribolium castaneum*, *T. confusum* and *C. maculatus* were more sensitive to UV-rays than younger eggs.

Ultraviolet irradiation damages the cellular components, such as lipid membranes, proteins, and nucleic acids, as well as induces several other

Table 1. Estimates ($\pm$ SE) reproduction parameters of *Ephestia kuehniella* under UVC-irradiated time

Reproduction parameters	Age of eggs	UVC-irradiated time (min)			
	irradiated	0 (control)	0.5	1	1.5
Gross fecundity rate	1	140.11 $\pm$ 14.09a	100.34 $\pm$ 10.58b	116.93 $\pm$ 6.51ab	101.32 $\pm$ 12.07b
	2	140.11 $\pm$ 14.09b	111.32 $\pm$ 7.90c	163.92 $\pm$ 11.94a	161.14 $\pm$ 12.30ab
	3	140.11 $\pm$ 14.09b	166.75 $\pm$ 9.72a	117.83 $\pm$ 12.75b	NH
Gross fertility rate	1	114.42 $\pm$ 11.51a	71.07 $\pm$ 7.49b	53.59 $\pm$ 2.98c	32.08 $\pm$ 3.82c
	2	114.42 $\pm$ 11.51a	62.15 $\pm$ 4.41b	64.20 $\pm$ 4.68b	38.94 $\pm$ 4.97c
	3	114.42 $\pm$ 11.51a	30.57 $\pm$ 1.78b	12.17 $\pm$ 1.21c	NH
Net fecundity rate	1	74.84 $\pm$ 10.16a	37.67 $\pm$ 6.58b	23.04 $\pm$ 2.50c	15.87 $\pm$ 2.01d
	2	74.84 $\pm$ 10.16a	10.73 $\pm$ 1.03b	4.32 $\pm$ 0.52c	1.69 $\pm$ 0.24d
	3	74.84 $\pm$ 10.16a	8.45 $\pm$ 0.87b	1.80 $\pm$ 0.24c	NH
Net fertility rate	1	61.12 $\pm$ 8.30a	26.69 $\pm$ 4.66b	10.56 $\pm$ 1.14c	0.34 $\pm$ 0.07d
	2	61.12 $\pm$ 8.30a	5.99 $\pm$ 0.57b	1.69 $\pm$ 0.20c	0.41 $\pm$ 0.06d
	3	61.12 $\pm$ 8.30a	1.55 $\pm$ 0.16b	0.18 $\pm$ 0.02c	NH
Mean eggs per day	1	13.78 $\pm$ 0.04a	12.29 $\pm$ 0.07c	13.39 $\pm$ 0.04b	11.52 $\pm$ 0.06d
	2	13.78 $\pm$ 0.04d	14.90 $\pm$ 0.03c	15.06 $\pm$ 0.05b	16.25 $\pm$ 0.04a
	3	13.78 $\pm$ 0.04b	15.46 $\pm$ 0.04a	11.33 $\pm$ 0.06c	NH
Mean fertile eggs per day	1	11.25 $\pm$ 0.01a	8.71 $\pm$ 0.05b	6.14 $\pm$ 0.02c	3.65 $\pm$ 0.02d
	2	11.25 $\pm$ 0.01a	8.34 $\pm$ 0.02b	5.92 $\pm$ 0.06c	3.92 $\pm$ 0.06d
	3	11.25 $\pm$ 0.01a	2.84 $\pm$ 0.02b	1.13 $\pm$ 0.06c	NH

The means in each column with same letters are not significantly differences within different of age groups of eggs and means in each row with same letters are not significantly differences within different exposure time with controls ($P < 0.05$, SNK); NH = eggs no hatched.

chemical compounds synthesis. In the embryonic development of insect eggs, specialization of different embryonic organs does not occur; thus, exposure to non-penetrating radiations like UV-rays, do not damage the surface tissue of the eggs and can be fatal only at the advanced stages of egg development (Hori et al. 2014). However, our results contrast with the findings of Alwaneen et al. (2019) who observed that the younger eggs of *Cadra cautella* (Walker) were more sensitive than older ones.

In the present study, mortality gradually increased with increasing dose. Our finding corroborates with the results of Abbas et al. (2011) working with *Plodia interpunctella* (Hübner) that the developmental periods and the growth indices of the adults, significantly decreased with

increasing dose of radiation which were also administered to the eggs, larvae and pupae.

When UV-C light interacts with egg chorion, its damaged DNA thereby results in eggs inner contents leakage. This effect was due to the thinness of chorion and delicacy of the eggs (Güven et al. 2015).

According to our results, the highest mortality was recorded in embryonic stage. Typically, the embryonic stage of an animal is a period of higher radio sensitivity and the insects are no exception. The hatching rate and survivorship rate decreased as the age of irradiated eggs increased from 1 to 3 days for each exposure duration. Thus, the value of reproductive parameters in concert with these parameters decreased with the increase in the age of irradiation. Tariq et al. (2015) revealed that fecundity and oviposition rates of adults of

Table 2. Estimates ($\pm$ SE) of population growth parameters of *Ephestia kuehniella* under UVC-irradiated time

Population parameters	Age of eggs irradiated	UVC-irradiated time (min)			
		0 (control)	0.5	1	1.5
Net reproductive rate (R_0)	1	38.10 $\pm$ 4.95a	16.07 $\pm$ 2.80b	8.735 $\pm$ 0.63c	6.68 $\pm$ 0.90d
	2	38.10 $\pm$ 4.95a	3.35 $\pm$ 0.34b	0.74 $\pm$ 0.09c	0.73 $\pm$ 0.09c
	3	38.10 $\pm$ 4.95a	2.08 $\pm$ 0.23b	0.70 $\pm$ 0.09c	NH
Finite rate of increase (λ)	1	1.075 $\pm$ 0.002a	1.060 $\pm$ 0.002b	1.043 $\pm$ 0.002c	1.038 $\pm$ 0.003c
	2	1.075 $\pm$ 0.002a	1.021 $\pm$ 0.001b	0.996 $\pm$ 0.007c	0.996 $\pm$ 0.001c
	3	1.075 $\pm$ 0.002a	1.014 $\pm$ 0.002b	0.995 $\pm$ 0.002c	NH
Doubling time (D_T)	1	9.30 $\pm$ 0.46d	10.51 $\pm$ 0.37c	16.32 $\pm$ 0.92b	18.68 $\pm$ 1.34a
	2	9.30 $\pm$ 0.46d	33.97 $\pm$ 2.41c	91.11 $\pm$ 6.46b	153.38 $\pm$ 9.66a
	3	9.30 $\pm$ 0.46c	44.63 $\pm$ 2.21b	119.55 $\pm$ 5.91a	NH
Mean generation time (T)	1	50.81 $\pm$ 0.42b	42.09 $\pm$ 0.14c	51.25 $\pm$ 0.18b	51.76 $\pm$ 0.17a
	2	50.81 $\pm$ 0.42d	56.14 $\pm$ 0.19c	80.67 $\pm$ 0.34b	87.05 $\pm$ 0.23a
	3	50.81 $\pm$ 0.42c	52.76 $\pm$ 0.25b	75.07 $\pm$ 0.26a	NH
Intrinsic rate of increase (r_m)	1	0.072 $\pm$ 0.003a	0.066 $\pm$ 0.004a	0.042 $\pm$ 0.002b	0.037 $\pm$ 0.002b
	2	0.072 $\pm$ 0.003a	0.021 $\pm$ 0.002b	0.008 $\pm$ 0.001c	0.004 $\pm$ 0.002c
	3	0.072 $\pm$ 0.003a	0.015 $\pm$ 0.002b	0.006 $\pm$ 0.001c	NH

The means in each column with same letters are not significantly differences within different of age groups of eggs and means in each row with same letters are not significantly differences within different exposure time with controls ($P < 0.05$, SNK); NH = eggs no hatched.

Dialeurodes citri (Ashmead) (Homoptera: Aleyrodidae) significantly decreased with increasing exposure time and reported that the longevity of adults of both sexes and the cumulative survival of F1 immatures were decreased with increased exposure time. Also, they showed that the developmental time of immature stages prolonged which indicates a positive correlation with exposure time and concluded that exposure to UV light significantly inhibited egg hatching, larval development, pupation, and adult emergence. Similar results were observed by Zhang et al. (2011) which reported that adult longevity of *Helicoverpa armigera* (Hübner) decreased with increasing exposure time for both sexes also they mentioned that exposure to UV-A for longer periods caused a decline in cumulative survival of F1 immature stages, but no significant differences were found in egg hatch, pupation and eclosion. The results clearly indicate that all life table parameters (R_0 , r_m , T_c , D_T , and λ) are affected significantly by different exposure duration. No published data are available concerning the effect of UVC-radiation on demographic parameters of *E.*

kuehniella. UV rays produced deformed adults at long exposure periods. Some of the adults that emerged from treated eggs had crumpled and small wings. The findings of this research indicated that UVC-radiation was safe and effective for the control of storage pests. Thus, UVC-irradiation can be used with other control methods such as insecticides and biological control in integrated pest management (IPM) of stored products pests.

CONCLUSIONS

The following conclusions were drawn from this study regarding the effects of ultra violet irradiation on life table of Mediterranean flour moth: 1. UVC-radiation caused a significant reduction in egg hatch, fecundity, fertility and intrinsic rate of increase (r_m) of adults resulting from UVC-irradiation eggs. 2. UVC-radiation has obvious effects on the developmental time, mortality, survival of different life stage of *E. kuehniella*. 3. Older insect eggs of *E. kuehniella*, were more sensitive to UV-radiation than younger eggs.

ACKNOWLEDGMENTS

This research is supported by Department of Entomology at Tarbiat Modares University (Tehran, Iran).

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

ORCID

Ali Mirshekar: <http://orcid.org/0000-0001-7571-8576>

Akram Bakhshi: <http://orcid.org/0000-0001-6451-9897>

Ali Asghar Talebi: <http://orcid.org/0000-0001-5749-6391>

F Yaghoob Fathipour: <http://orcid.org/0000-0002-7963-5409>

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