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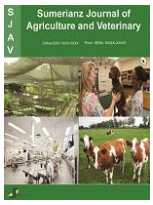


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# Effects of UV Radiation on Egg Hatching Population Growth and Reproductive Parameters of Indianmeal Moth *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae)

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## Abstract

In this research, three age groups of *Plodia interpunctella* (Hübner) eggs (1-, 2- and 3-day-old eggs) were exposed to ultraviolet irradiation (UVC) with 254nm wavelength for 0.5, 1, 1.5, 2, 4, 8, 16, 24, 32 and 40 minutes, under controlled conditions. The effect of UVC-irradiation on reproduction and population growth parameters investigated for eggs irradiated for 0.5, 1 and 1.5 minutes. The percentage of egg hatching decreased with increase in UVC exposure time, while for each exposure time, the older eggs were more sensitive than the younger ones. The results indicated that different exposure times of UVC-irradiation could affect the reproduction and population growth parameters. 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. Both the intrinsic rate of increase ($r_m$) and the net reproductive rate ($R_0$) decreased with increasing 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 obtained in 1, 2 and 3-day-old eggs which were treated with 1.5 min exposure time. The results showed that UVC-irradiation is an appropriate technique for controlling *P. interpunctella*.

**Keywords:** UVC-irradiation; *Plodia interpunctella*; Life table; Reproduction; Population parameters.

## 1. Introduction

Indian meal moth (*P. interpunctella*) is distributed world-wide and is a serious stored products pest of grain seeds [1-3], flour and other milled products [1] as well as dried fruits and nuts [4-6].

In recent years, it was considered as the most important pest of stored pistachios in Iran which causes severe qualitative and quantitative losses [5]. Larvae are able to penetrate and infest a wide range of packaged foods [7, 8] and also can have a great economic impact due to direct product loss and indirectly to factors such as the cost of pest control and loss of sales from consumer complaints [9, 10].

Fumigation and other chemical insecticides are widely used to protect stored commodities from insect infestations and contamination, but their use leads to the problem of undesirable residues [11] and development of resistance [12, 13]. Moreover, the injudicious use of synthetic pesticides and its concomitant impact on the environment have necessitated the exploration of alternative non-toxic pest control methods; Therefore, many alternatives such as low temperature storage, heat treatment [9, 14, 15], pheromone-baited traps [16, 17], change in photoperiod [5], use of essential oils [18-21] as well as natural enemies [22-26] have been suggested as replacements for chemical fumigants.

Due to free residual advantages over chemical fumigation [27], irradiation has become an established technique for controlling stored grain insects [28]. Pszczola [29], demonstrated the acceptability of irradiation technology as an alternative treatment for food protection. Irradiation foods may be more acceptable to those that are sensitive to chemical treatments [30]. As irradiation can extend the shelf life of various fruits and vegetables [31], and also it can maintain the quality of the product over a longer period of time [32]. Horne and Sutton [33], mentioned that irradiation dose not significantly change the quality of the food material or stored seeds.

The Ultraviolet (UV) portion of the spectrum is widely used as germicide and also as an attractant for insects [34], in the physiological studies of embryos [35, 36] and for the surface disinfection of insect eggs from pathogens [37].

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UVC-irradiation is generally less harmful to living organisms than the ionizing radiation as they penetrate only the surface layer of cells [38]. A number of investigators have considered the possibility of using UV-irradiation to control, or at least to suppress the development of various species of stored product insects such as *Heliothis virescens* F. and *H. zea* (Boddie) [37], *Ephestia cautella* (Walker) [39, 40], *Tribolium castaneum* Duval [41, 42], *Alphitobius diaperinus* (Panzer) [43], *T. confusum, T. costaneum, Cadra cautella* (Walker) [44-46], *Trogoderma granarium* Everts [47], *Sitophilus zeamais* (Motschulsky) [48], *Mythimna separate* [49] and *Rhyzopertha dominica* (Fab.) [50].

Fertility life tables are appropriate to study the dynamics of animal populations [51], especially arthropods, as an intermediate process for estimating parameters related to the population growth potential, also called demographic parameters [52].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 effect of UVC-irradiation on demographic parameters of the Indian meal moth. Knowledge of this subject may provide a better view in the pest control.

# 2. Materials and Methods

## 2.1. Insect Culture

Eggs of *P. interpunctella* were collected from Iranian Pistachio Research Institute in Rafsanjani, adjacent to Kerman, Iran. Eggs were transferred to plastic containers with rearing medium (pistachio) at temperature of 25± 5 °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.

## 2.2. Developmental Time and Life Table

In order to determine the life table parameters, 50 pairs (males and females) of adults were selected from culture and they were transferred to mating containers (15.cm diameter, 30cm 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, 40 minutes. After exposure times, the irradiated and non-irradiated control eggs of different age groups were transferred separately to plastic containers at 25±5ºC until hatching**.** For easy observation of the first and second instar larvae, pistachio were cut into pieces (about 2 × 3 mm)**.** Developmental stages were checked daily by a stereomicroscope, and meanwhile the developmental periods and mortality of eggs, larvae, pupae and adults were recorded. This experiment continued until the death of all members of each cohort. Two important life table parameters (survivorship and life expectancy) were calculated using Eq. (1) [52]:

$$l_x = \frac{N_x}{N_o} \qquad e_x = \frac{T_x}{L_x}$$

Eq. (1)

Where *x* is unite of age, *lx* 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: $T_x = \Sigma L_x$**,** where $L_x$ gives the number of days lived by the average individual within a cohort in the interval *x* to *x+1*.

## 2.3. Reproduction and Population Growth Parameters

To calculate the demographic parameters of *P. interpunctella* 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 these 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± 5 °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. The sex ratio of emerged adults was determined. Reproduction and population growth parameters of *P. interpunctella*, were constructed according to Carey [53], Carey [54]. The factors that are essential for calculating the population parameters include: the age of females in days (*x*), the number of females alive at age *x* (*lx*), and the mean number of eggs laid per female alive per day (*mx*).

## 2.4. UVC-Irradiation Technique of Eggs

The UVC-irradiation source was a 15W germicidal lamp, GE15T8 measuring 40 x 2 cm. This lamp produced UVC at a wave length of 253.7 nm. For irradiation**,** the petri dishes were placed on a surface 12cm 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.

## 2.5. Data Analysis

Demographic parameters were calculated from daily records of mortality, fecundity and fertility of cohorts of *P. interpunctella* females. 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 [intrinsic rate of increase ($r_m$), net reproductive rate ($R_o$), mean generation time ($T_c$), finite rate of increase ($\lambda$) and doubling time ($D_T$)] were all calculated using the formulae suggested by Carey [53]. The statistical differences in $R_0$, $T_c$, $\lambda$, $D_T$ and $r_m$ values were tested using jackknife procedure to estimate the variance for $r_m$ and the other population parameters [55]. This procedure is used mostly to estimate variance and bias of estimators. It is based on repeated recalculation of the required estimator, missing out each sample in turn [52]. It is used to quantify uncertainty associated with parameter estimates, as an alternative to analytical procedures, in cases for which the last ones require very complicated mathematical derivation [52]. Algorithms for jackknife estimation of the means and variances are described only for $r_m$. similar procedures were used for the other parameters ($R_0$, $T_c$, $\lambda$ and $D_T$). The steps for the application of the method are the following [52]: (a) Estimation of $r_m$, $R_0$, $T_c$, $\lambda$ 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 $r_m$(all), $R_o$(all), $T_c$(all), $\lambda$ (all) and $d_t$(all) [52]. (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 $r_m(i)$, $R_o(i)$, $T_c(i)$, $\lambda$ ($i$) and $D_T(i)$ [52]. (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 (Eq. 2) [52]:

$$r_{m(j)} = n \times r_{m(all)} - (n-1) \times r_{m(i)} \quad \text{Eq. (2)}$$

d) After calculating all the n pseudo-values for $r_m$, jackknife estimate of the mean ($r_m$(mean)), variance (VAR $r_m$(mean)) and standard error (SEM $r_m$(mean)) calculated, respectively, using Eq. (3) [52]:

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

$$SEMr_{m(mean)} = \sqrt{\frac{VAR(r_{m(mean)})}{n}} \quad \text{Eq. (3)}$$

The differences in development, reproduction, and population parameters were compared using one-way analysis of variance (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 Minitab software.

# 3. Results

## 3.1. Developmental Time and Life Table

The effects of different exposure periods of UV-irradiation on the duration of the developmental stages of *P. interpunctella* (male and female) are presented in Table 1.

**Table-1.** Estimates (± SE) of biological parameters of *P. interpunctella* under UVC-irradiated time

| Biological parameters | Age of eggs irradiated | Sex | UVC-irradiated time (min.) | | | | |
|---|---|---|---|---|---|---|---|
| | | | 0 (control) | 0.5 | 1 | 1.5 | 2 |
| Incubation period | 1 | Female | 4.10±0.05$^{ab}$ | 5.00±0.00$^{da}$ | 5.00±0.00$^{ba}$ | 5.00±0.00$^{ba}$ | 5.00±0.00$^{aa}$ |
| | | Male | 4.20±0.05$^{ab}$ | 5.00±0.00$^{da}$ | 5.00±0.00$^{ba}$ | 5.00±0.00$^{ba}$ | 5.00±0.00$^{aa}$ |
| | 2 | Female | 4.10±0.05$^{ac}$ | 6.00±0.00$^{cb}$ | NH | 7.00±0.00$^{aa}$ | NH |
| | | Male | 4.20±0.05$^{ac}$ | 6.00±0.00$^{cb}$ | 6.40±0.00$^{ab}$ | 7.00±0.00$^{aa}$ | NH |
| | 3 | Female | 4.10±0.05$^{ab}$ | 7.67±0.00$^{aa}$ | NH | NH | NH |
| | | Male | 4.20±0.05$^{ab}$ | 7.00±0.00$^{ba}$ | NH | NH | NH |
| Larval period | 1 | Female | 37.90±0.64$^{ac}$ | 48.48±1.41$^{ba}$ | 41.68±1.41$^{abc}$ | 41.50±0.82$^{bbc}$ | 45.00±2.86$^{aab}$ |
| | | Male | 38.37±0.69$^{ab}$ | 43.80±0.98$^{bab}$ | 41.86±1.88$^{aab}$ | 41.78±0.86$^{bab}$ | 56.33±3.93$^{aa}$ |
| | 2 | Female | 37.90±0.64$^{ac}$ | 45.29±0.99$^{bb}$ | NH | 54.00±1.73$^{aa}$ | NH |
| | | Male | 38.37±069$^{ac}$ | 45.37±1.05$^{bb}$ | 43.60±2.11$^{abc}$ | 56.33±3.93$^{aa}$ | NH |
| | 3 | Female | 37.90±0.64$^{ab}$ | 57.00±3.46$^{aa}$ | NH | NH | NH |
| | | Male | 38.37±069$^{ab}$ | 48.00±4.16$^{ba}$ | NH | NH | NH |
| Pupal period | 1 | Female | 9.39±0.25$^{ab}$ | 14.48±0.51$^{aa}$ | 9.58±0.53$^{bb}$ | 8.62±0.68$^{ab}$ | 8.80±0.73$^{ab}$ |
| | | Male | 9.90±0.28$^{ab}$ | 14.20±0.59$^{aa}$ | 8.71±0.67$^{bb}$ | 10.22±0.98$^{ab}$ | 10.50±1.31$^{ab}$ |
| | 2 | Female | 9.39±0.25$^{aa}$ | 8.21±0.38$^{ba}$ | NH | 8.25±0.75$^{aa}$ | NH |
| | | Male | 9.90±0.28$^{ab}$ | 9.33±0.30$^{bb}$ | 14.40±0.60$^{aa}$ | 10.67±0.67$^{ab}$ | NH |
| | 3 | Female | 9.39±0.25$^{aa}$ | 9.67±1.20$^{ba}$ | NH | NH | NH |
| | | Male | 9.90±0.28$^{aa}$ | 9.67±0.88$^{ba}$ | NH | NH | NH |
| Adult longevity | 1 | Female | 9.95±0.48$^{aa}$ | 9.09±0.91$^{aa}$ | 7.73±0.45$^{aa}$ | 9.75±1.10$^{aa}$ | 7.80±1.20$^{aa}$ |
| | | Male | 9.03±0.32$^{aa}$ | 8.72±0.54$^{aa}$ | 7.36±0.43$^{aab}$ | 9.11±0.96$^{aa}$ | 6.33±0.92ab |
| | 2 | Female | 9.95±0.48$^{aa}$ | 8.79±0.76$^{aa}$ | NH | 11.33±0.88$^{aa}$ | NH |
| | | Male | 9.03±0.32$^{aa}$ | 7.60±0.77$^{aa}$ | 7.60±0.75$^{aa}$ | 9.67±0.33$^{aa}$ | NH |
| | 3 | Female | 9.95±0.48$^{aa}$ | 7.67±1.85$^{aa}$ | NH | NH | NH |
| | | Male | 9.03±0.32$^{aa}$ | 9.67±1.45$^{aa}$ | NH | NH | NH |
| Whole life span | 1 | Female | 61.34±0.73$^{ac}$ | 77.05±1.43$^{aba}$ | 63.68±1.30$^{bbc}$ | 64.87±0.61$^{cbc}$ | 66.60±2.58$^{ab}$ |
| | | Male | 61.51±0.63$^{ac}$ | 71.72±0.91$^{bca}$ | 62.50±1.61$^{bc}$ | 66.11±0.71$^{cb}$ | 66.17±1.68$^{ab}$ |
| | 2 | Female | 61.34±0.73$^{ac}$ | 68.29±1.25$^{cb}$ | NH | 79.33±0.88$^{ba}$ | NH |
| | | Male | 61.51±0.63$^{ac}$ | 68.67±1.03$^{cb}$ | 72.00±2.05$^{ab}$ | 83.67±3.67$^{aa}$ | NH |
| | 3 | Female | 61.34±0.73$^{ab}$ | 82.00±2.89$^{aa}$ | NH | NH | NH |
| | | Male | 61.51±0.63$^{ab}$ | 74.33±4.33$^{bca}$ | NH | NH | NH |

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

## 3.2. Male's Developmental Time

The results of this research showed that during all the periods that the eggs were exposed to UV- radiation; their incubation period was significantly higher than that of the controls (Table 1). There were significant differences between larval period in 1, 2 and 3-day-old eggs which were treated with 2, 0.5 and 1.5, 0.5 min exposure time in comparison to controls respectively (Table 1). Irradiation had significant effect on the developmental time of pupae in 1 and 2-day-old eggs which were treated with 0.5- and 1-min exposure time in comparison to controls respectively (Table 1). However, the duration of adult longevity of males was affected by 2 min exposure time in 1-day-old eggs in comparison to controls. Adult longevity of males was not significantly different (P>0.05) at 2 and 3-day-old eggs (Table 1). Also, in all age groups of eggs, whole life span increased in comparison to controls (Table 1).

## 3.3. Female's Developmental Time

Due to the irradiation of eggs, their incubation period in all age groups was significant in comparison to that of controls (Table 1). This study has shown that the comparison of larval period among different exposure periods of irradiation at three age groups of eggs indicated a significant difference only at 0.5- and 2-min exposure time in 1-day-old eggs (Table 1). The duration of pupal period was affected by 0.5 min exposure time in 2-day-old eggs in comparison to controls (Table 1). Furthermore, there were no significant differences between adult longevity of controls and irradiation adult in 1, 2 and 3-day-old eggs (Table 1). In all age groups of eggs, Whole life span of females increased in comparison to controls (Table 1).

Moreover, adult longevity of *P.interpunctella* between males and females was not significantly different in eggs at each exposure. Interestingly, the results suggest that the effects of ultraviolet (UVC) on adult longevity of male and females were similar in all age groups of eggs. Also, whole life span of eggs increased in comparison to that of the control (Table 1). Present study (for both sexes) revealed that irradiation showed higher effect on incubation period of eggs than other development stages.

At all age groups of eggs, mortality was high in embryonic stage. Moreover, our results indicated that all the periods of exposure to UVC-irradiation reduced hatching eggs. An increase in the time of exposure to irradiation caused a gradual decrease in the percentage of hatching in all age groups of eggs. Also, the hatching rate decreased for each exposure duration as the age of irradiated eggs increased from 1 to 3 days (Figure 1). The percentage of hatching eggs of *P. interpunctella* decreased from 71.33% at 0.5 min to 0.67% at 8 min exposure time in 1-day-old eggs, from 35% at 0.5 min to 1.67% at 4 min exposure time in 2-day-old eggs and from 31.67% at 0.5 min to 1.67% at 2 min exposure periods in 3-day-old eggs, no hatching eggs occurred at higher exposure times. The life expectancy (*ex*) of newly laid eggs was estimated to be 52.52 (control), 38.93, 20.89, 13.30, 9.98, 6.00 (1-day old eggs), 21.22, 10.48, 9.15, 6.64 and 8.25 (2-day old eggs) days and the life expectancy values of newly emerged

adults were 15.47 (control), 11.87, 11.76, 8.33, 11.68, 6.00 (1-day old eggs), 14.40, 8.83, 13.67, 8.50 and 7.50 (2-day old eggs) days at 0.5, 1, 1.5, 2 and 4 min exposure time, respectively. In 3-day-old eggs, this parameter in first day of life showed 10.58, 10.43, 6.14 and 3.52 days and at the beginning of adult emergence 8.25, 4.50, 7.50 and 6.50 days which were treated with 0.5, 1, 1.5 and 2 min UVC-irradiation, respectively (Figure 3). Age-specific survivorship rate ($l_x$) of 1, 2 and 3-day-old eggs that were exposed to different periods of UVC-irradiation are presented in figure 2. This figure indicates that UVC-irradiation had a pronounced effect on the Age-specific survivorship of *P. interpunctella*.

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

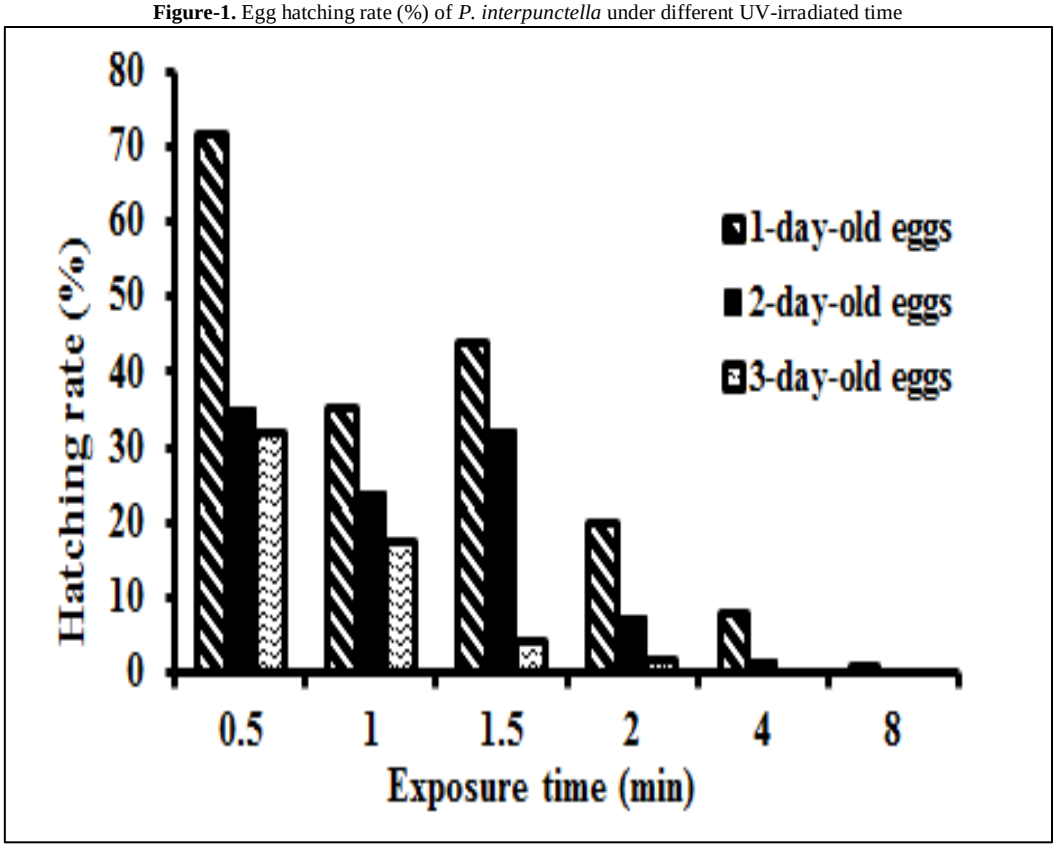
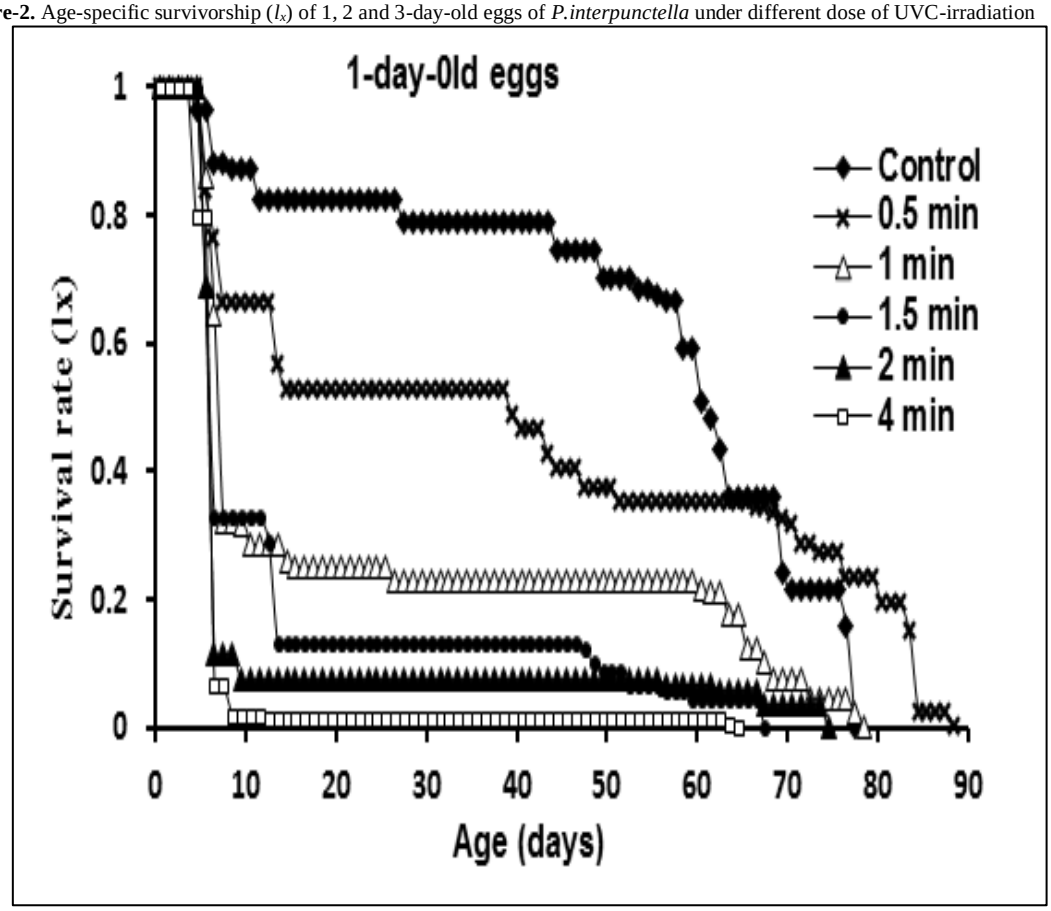
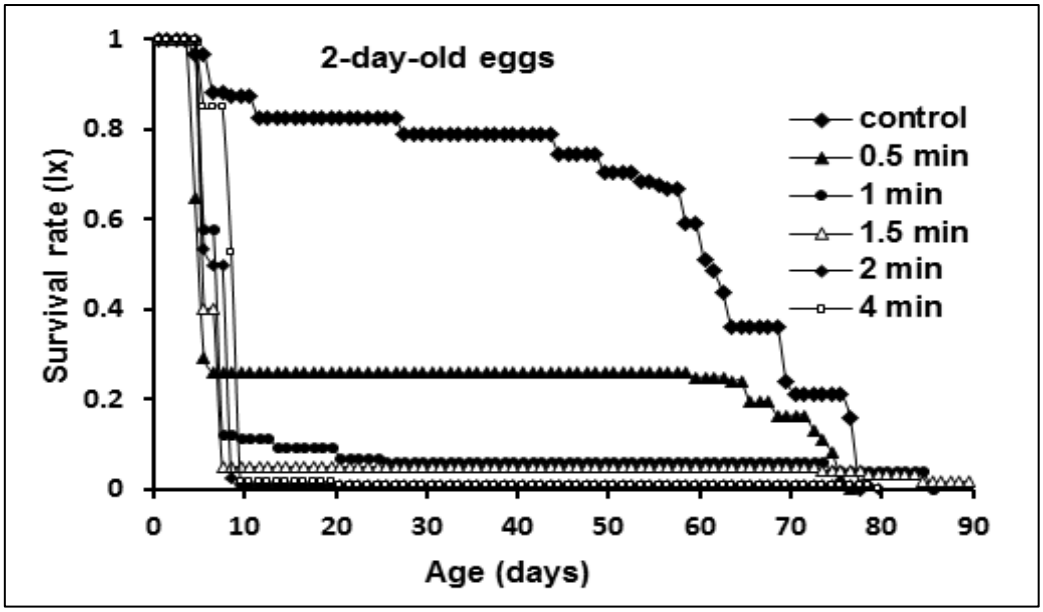



**Figure-2.** Age-specific survivorship ($l_x$) of 1, 2 and 3-day-old eggs of *P.interpunctella* under different dose of UVC-irradiation





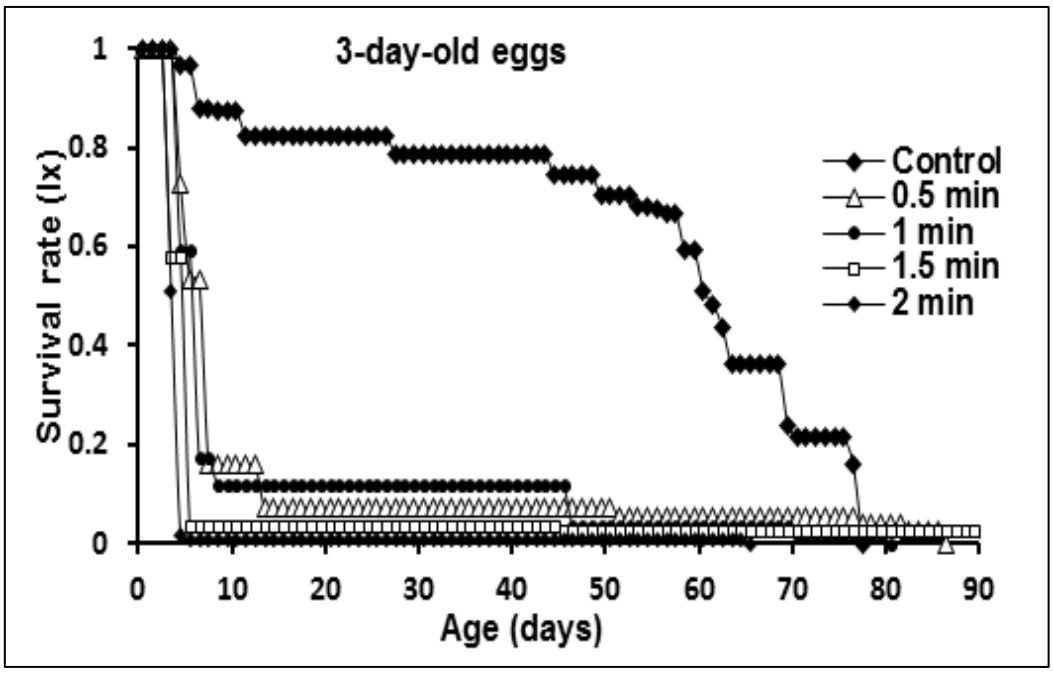
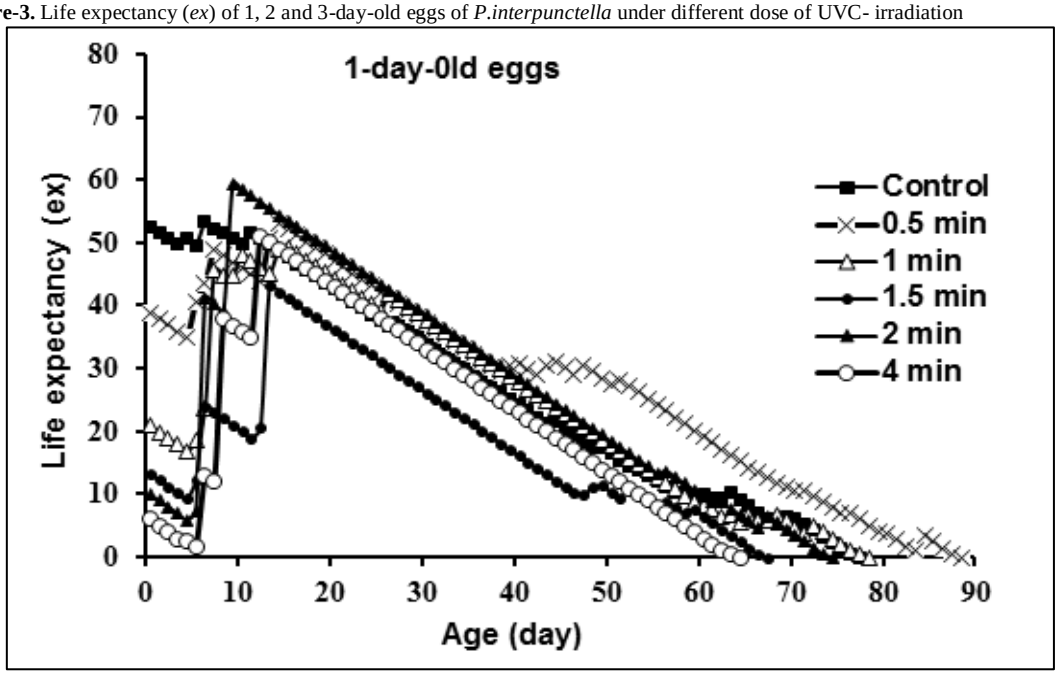
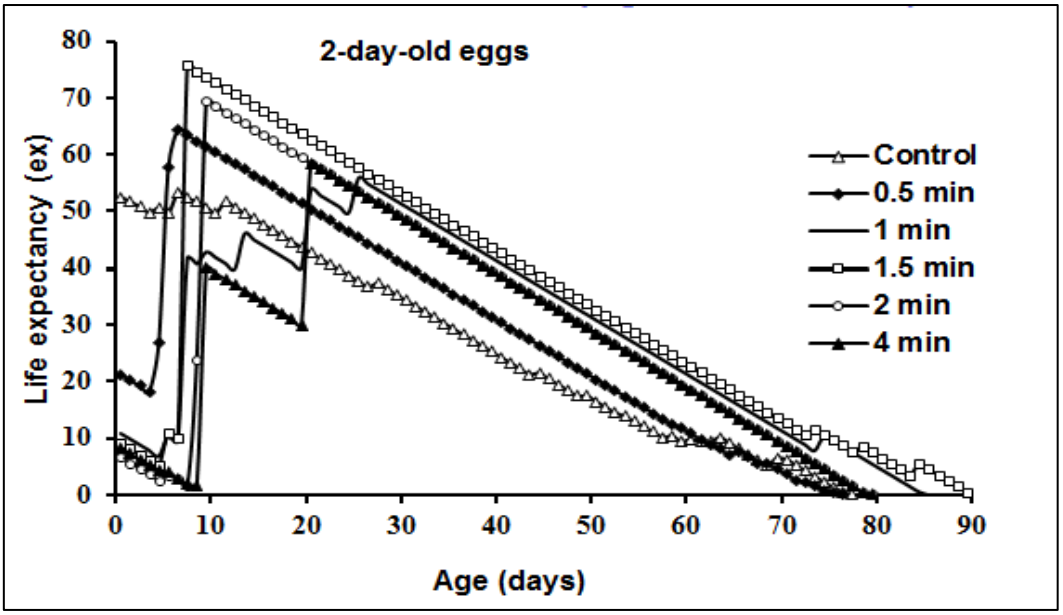
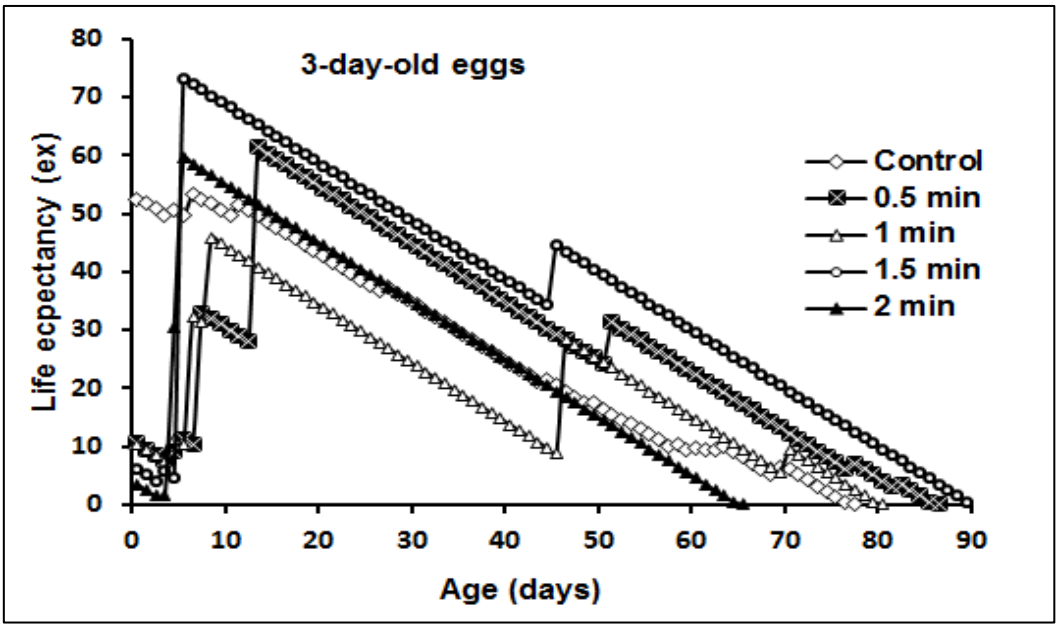




**Figure-3.** Life expectancy (*ex*) of 1, 2 and 3-day-old eggs of *P.interpunctella* under different dose of UVC- irradiation






## 3.4. Reproduction and Population Growth Parameters

The results suggest that in comparison to controls, the reproductive parameters at all age groups of eggs were significantly affected by different duration of UVC-irradiation. The lowest value of gross fecundity rate and gross fertility rate were obtained in 1-day-old eggs by 1 min exposure time (58.96±6.65 for gross fecundity rates and 20.83±2.32 for gross fertility rates, respectively) and in 2 and 3-day-old eggs which were treated with 1.5 min exposure time (41.32±6.44 and 19.47±1.93 eggs for gross fecundity rates and 12.70±2.77 and 0.81±0.08 eggs for gross fertility rates, respectively) (Table 2). The highest value of net fecundity rates was observed in 1-day-old eggs which were treated with 1.5 min exposure time (26.82±0.38 eggs/female). No significant difference was observed between value net fecundity in this age group which were treated with 0.5- and 1.5-min exposure time. The highest value of net fecundity was for 2 and 3-day-old eggs which were treated with 0.5 min exposure time (17.24±1.84 and 0.84±0.13 eggs for net fecundity rates respectively) (Table 2). 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 (17.58±2.50, 6.03±0.64 and 0.27±0.04 eggs for net fertility rates, respectively) (Table 2). The number of hatched eggs laid per female per day decreased from 7.07±0.04 at 0.5 min to 3.68±0.03 at 1.5 min exposure time in 1-day-old eggs, from 3.38±0.02 at 0.5 min to 1.70±0.011 at 1.5 min exposure time in 2-day-old eggs and from 3.45±0.06 at 0.5 min to 0.13±0.001 at 1.5 min exposure periods in 3-day-old eggs (Table 2). Furthermore, the net fecundity rates and net fertility rates decreased for each exposure duration as the age of irradiated eggs increased from 1 to 3 days (Table 2).

**Table-2.** Estimates (±SE) Reproduction parameters of *P. interpunctella* under UVC-irradiated time

| Reproduction parameters | Age of eggs irradiated | UVC-irradiated time (min.) | | | |
|---|---|---|---|---|---|
| | | 0 (control) | 0.5 | 1 | 1.5 |
| Gross fecundity rate | 1 | 140.85±15.13$^{a}$ | 92.55±10.50$^{ab}$ | 58.96±6.56$^{bb}$ | 79.98±8.17$^{ab}$ |
| | 2 | 140.85±15.13$^{a}$ | 107.42±11.1$^{ab}$ | 58.77±6.40$^{bc}$ | 41.32±6.44$^{bc}$ |

| | | | | | |
|---|---|---|---|---|---|
| | 3 | 140.85±15.13$^{a}$ | 85.46±7.56$^{ab}$ | 99.13±13.85$^{ab}$ | 19.47±1.93$^{cc}$ |
| Gross fertility rate | 1 | 133.34±14.32$^{a}$ | 70.20±8.40$^{ab}$ | 20.83±2.32$^{ac}$ | 35.19±3.59$^{ac}$ |
| | 2 | 133.34±14.32$^{a}$ | 37.60±3.89$^{bb}$ | 14.20±1.55$^{ac}$ | 12.70±2.77$^{bc}$ |
| | 3 | 133.34±14.32$^{a}$ | 27.16±2.50$^{bb}$ | 17.28±2.36$^{abc}$ | 0.81±0.08$^{cc}$ |
| Net fecundity rate | 1 | 48.17±7.56$^{a}$ | 24.64±3.51$^{ab}$ | 11.01±1.77$^{ac}$ | 26.82±0.38$^{ab}$ |
| | 2 | 48.17±7.56$^{a}$ | 17.24±1.84$^{bb}$ | 3.10±0.48$^{bc}$ | 1. 95±0.37$^{bc}$ |
| | 3 | 48.17±7.56$^{a}$ | 0.84±0.13$^{cb}$ | 0.73±0.13$^{bb}$ | 0.53±0.07$^{bb}$ |
| Net fertility (egg) | 1 | 45.60±7.15$^{a}$ | 17.58±2.50$^{ab}$ | 3.89±0.62$^{ac}$ | 11.72±0.15$^{abc}$ |
| | 2 | 45.60±7.15$^{a}$ | 6.03±0.64$^{bb}$ | 0.75±0.11$^{bb}$ | 0. 63±0.12$^{bb}$ |
| | 3 | 45.60±7.15$^{a}$ | 0.27±0.04$^{cb}$ | 0.13±0.02$^{bb}$ | 0.02±0.003$^{cb}$ |
| Mean egg per day | 1 | 10.02±0.05$^{a}$ | 9.91±0. 05$^{ba}$ | 5.20±0.04$^{cc}$ | 8.37±0. 08$^{ad}$ |
| | 2 | 10.02±0.05$^{a}$ | 9.66±0.05$^{bb}$ | 7.40±0.05$^{bc}$ | 5. 22±0.03$^{bd}$ |
| | 3 | 10.02±0.05$^{b}$ | 10.95±0.03$^{aa}$ | 9.42±0.08$^{ac}$ | 3.35±0.02$^{cd}$ |
| Mean fertile egg per day | 1 | 9.49±0.05$^{a}$ | 7.07±0. 04$^{ab}$ | 1.84±0.01$^{ad}$ | 3.68±0. 03$^{ac}$ |
| | 2 | 9.49±0.05$^{a}$ | 3.38±0.02$^{bb}$ | 1.79±0.013$^{bc}$ | 1. 70±0.011$^{bd}$ |
| | 3 | 9.49±0.05$^{a}$ | 3.45±0.06$^{bb}$ | 1.63±0.02$^{cc}$ | 0.13±0.001$^{cd}$ |

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)

The population growth parameters of *P. interpunctella* are shown in table 3. At all age groups of eggs, intrinsic rate of increase ($r_m$), finite rate of increase ($\lambda$), and the net reproductive rate ($R_0$) of *P. interpunctella* decreased with increasing the time of exposure from 0.5 to 1.5 min. Meanwhile, the mean generation time ($T_c$) and doubling time ($D_T$) increased within this irradiation range. 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 (0.037±0.003, 0.035±0.002 and 0.033±0.001 respectively) and the lowest value was obtained by 1.5 min exposure time (0.031±0.007, 0.008±0.002 and 0.016±0.001 respectively) (Table 3). In comparison to the controls, there were significant differences between the net reproductive rates (*Ro*) in 1, 2 and 3-day-old eggs which were treated with the exposure periods. The highest rate of $R_0$ was recorded in 1, 2 and 3-day-old eggs which were treated with 0.5 min exposure time (7.51±1.18, 5.59±0.62 and 0.42±0.13 respectively) and the lowest value was observed by 1.5 min exposure time (1.75±0.38, 0.64±0.10 and 0.13±0.02 respectively) (Table 3). Also change in the amount of $\lambda$ indicated similar effects of the irradiation (Table 3). The doubling time ($D_T$) increased from 18.69±1.45 at 0.5 min to 22.50±1.74 at 1.5 min exposure time in 1-day-old eggs, from 19.81±1.13 at 0.5 min to 87.50±4.04 at 1.5 min exposure time in 2-day-old eggs and from 20.76±0.96 at 0.5 min to 43.55±2.01 at 1.5 min exposure periods in 3-day-old eggs (Table 3). The lowest and the highest rate of mean generation time ($T_c$) were recorded in 1-day-old eggs which were treated with 1 and 0.5 min exposure time (44.99±0.16 and 54.84±0.19 days respectively).The lowest amount of mean generation time ($T_c$) was observed in 2 and 3-day-old eggs which were treated with 0.5 min exposure time (49.49± and 86.87± days respectively) and the highest value was obtained by 1.5 min exposure time (86.16±0.32 and 97.65±0.11 days respectively) (Table 3). However, the intrinsic rate of increase ($r_m$), finite rate of increase ($\lambda$) and the net reproductive rate ($R_0$) of *P. interpunctella* decreased for each exposure duration as the age of irradiated eggs increased from 1 to 3 days.

**Table-3**. Estimates (±SE) of population growth parameters of *P. interpunctella* under UVC-irradiated time

| **Population parameters** | **Age of eggs irradiated** | **UVC-irradiated time (min.)** | | | |
|---|---|---|---|---|---|
| | | **0 (control)** | **0.5** | **1** | **1.5** |
| Net reproductive rate ($R_o$) | 1 | 14.59±2.14$^{a}$ | 7.51±1.18$^{ab}$ | 4.05±0.63$^{abc}$ | 1.75±0. 38$^{ac}$ |
| | 2 | 14.59±2.14$^{a}$ | 5.59±0.62$^{ab}$ | 0.72±0.38$^{bc}$ | 0. 64±0.10$^{bc}$ |
| | 3 | 14.59±2.14$^{a}$ | 0.42±0.13$^{bb}$ | 0.34±0.08$^{bb}$ | 0.13±0.02$^{bb}$ |
| Finite rate of increase ($\lambda$) | 1 | 1.062±0.003$^{a}$ | 1.037±0.003$^{ab}$ | 1.032±0.003$^{ab}$ | 1.007±0.004$^{ac}$ |
| | 2 | 1.062±0.003$^{a}$ | 1.035±0.002$^{ab}$ | 0.997±0.002$^{bc}$ | 0.995±0.002$^{bc}$ |
| | 3 | 1.062±0.003$^{a}$ | 0.993±0.002$^{bb}$ | 0.998±0.0024$^{bb}$ | 0.979±0.001$^{cc}$ |
| Doubling time ($D_T$) | 1 | 11.46±0.53$^{b}$ | 18.69±1.45$^{aab}$ | 22.07±1.78$^{ba}$ | 22.50±1.74$^{ba}$ |
| | 2 | 11.46±0.53$^{c}$ | 19.81±1.13$^{ac}$ | 75.23±3.48$^{ab}$ | 87. 50±4.04$^{aa}$ |
| | 3 | 11.46±0.53$^{c}$ | 20.76±0.96$^{ab}$ | 31.90±1.47$^{bab}$ | 43.55±2.01$^{ca}$ |
| Mean generation time ($T$) | 1 | 44.65±0.36$^{c}$ | 54.84±0.19$^{ba}$ | 44.99±0.16$^{bc}$ | 49.33±0.11$^{cb}$ |
| | 2 | 44.65±0.36$^{d}$ | 49.49±0.31$^{cc}$ | 81.84±0.07$^{ab}$ | 86. 16±0.32$^{ba}$ |
| | 3 | 44.65±0.36$^{d}$ | 86.87±0.44$^{ab}$ | 81.6±0.40$^{ac}$ | 97.65±0.11$^{aa}$ |
| Intrinsic rate of increase ($r_m$) | 1 | 0.06±0.003$^{a}$ | 0.037±0.003$^{ab}$ | 0.031±0.003$^{ab}$ | 0.031±0.007$^{ab}$ |
| | 2 | 0.06±0.003$^{a}$ | 0.035±0.002$^{ab}$ | 0.009±0.002$^{bc}$ | 0.008±0.002$^{ac}$ |
| | 3 | 0.06±0.003$^{a}$ | 0.033±0.001$^{ab}$ | 0.022±0.005$^{abbc}$ | 0.016±0.001$^{ac}$ |

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)

## 4. Discussion

Understanding the demographic parameters of a pest is essential to develop an integrated pest management strategy [56, 57]. These parameters provide population growth rate of an insect pest in the current and next generations [58, 59]. No published data are available concerning the effect of UVC-radiation on *P. interpunctella*

demographic parameters. The results revealed the obvious effects of UVC-radiation on the developmental time, mortality and survival rate, net fecundity and fertility and percentage of eggs hatchability of *P. interpunctella.*

The eggs of *T. castenium, T. confusium* [41, 44] the mite *Tyrophagus putrescentiae* [60] and *Cadra cautella* [40], were sensitive to UV light. In contrast, the eggs sensitivity and duration of different life stages of *C. maculatus,* were not significantly affected at different exposure times [61].

Moreover, we showed that older eggs were more sensitive to UV-radiation than younger eggs, and this corroborates with the findings of Calderon and Navarro [39], Calderon, *et al.* [41], Faruki, *et al.* [44] who reported that older eggs (2 and 3 day-old) of *Ephestia Cautella, Tribolium castaneum* and *T. confusum,* were more sensitive to UV-rays than younger eggs.

The work of Seidel, *et al.* [62], may give a possible explanation of higher sensitivity of older eggs to UVC-irradiation than the younger eggs. They found that during early embryonic organization, injury to the peripheral parts of the eggs by UV-exposure did not impede the viability of the activation centre. As development proceeds, the embryonic regions became more specialized and different organ fields can no longer be replaced with each other. Thus, the damage to the surface tissue of the eggs can be fatal at the advanced stages of development by non-penetrating radiations like UV-rays.

In the present test, the mortality of the irradiated eggs was directly proportional to the dose of radiation; in other words, mortality gradually increased with increasing the exposure period. This result agreed with the result of Faruki, *et al.* [44], working with *T. castaneum* using UV-rays mentioned that egg mortality was positively correlated with radiation doses. Guerra, *et al.* [37], that when eggs of *Heliothis virescens* and *H. zea* were exposed to UV-rays of short wavelength (2537 Aº) the percentage of egg-hatch gradually decreased with the increase in the time of exposure, and no hatch occurred after an exposure of 20 minutes. According to our results, that embryonic development was highly susceptible to stress and 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 [63]. The detrimental effects of Ultraviolet irradiation involve a highly orchestrated series of events which damages the cellular and chemical components and are amplified by interaction with egg chorion [47], thereby resulting in eggs inner contents leakage [64], and by oxidative damage to DNA, lipids, proteins, and many metabolites [65].

A significant increasing in incubation period of eggs was observed when the eggs of different ages, were exposed to UV irradiation. These results agreed with the findings of Ayvaz, *et al.* [66] who reported that incubation period of *Ephestia Kuehniella and Carda cautella* increased with increasing exposure periods. Also we showed that both larval and pupal mortality were directly proportional to exposure times and were more sensitive to adults and present results in support with the findings of Guerra, *et al.* [37] and Faruki, *et al.* [43]. However, no significant difference in adult longevity was observed. Because the final stage of insect development is the adult stage and irradiation has no effect on adult longevity. Research findings indicated that females had longer longevity than males by different exposure duration. This result is corroborating with the findings of Aye, *et al.* [67] , who reported that adult longevity of females of *E. Kuehniella* was longer than adult longevity of males by irradiation gamma rays. Since only a limited number of females are able to remain, the increase in the longevity in favor of females may be an important adaptation for the pest to maintain its generation when exposure duration is high.

The data show that at all age groups of eggs, intrinsic rate of increase ($r_m$), finite rate of increase ($\lambda$) and the net reproductive rate ($R_0$) of *P. interpunctella* decreased with increasing time of exposure from 0.5 to 1.5 min while the mean generation time ($T_c$) and doubling time ($D_T$) increased within this irradiation range. As the age of irradiated eggs increased from 1 to 3 days, the $r_m$, finite $\lambda$ and $R_0$ of *P. interpunctella* decreased for each exposure duration. The intrinsic rate of increase ($r_m$) is an index of population increase and is intensively used in population growth models and the prediction of population dynamics. This parameter is a product of different biological parameters including fecundity, reproductive rate, immature mortality, sex ratio, and developmental rate. The highest and lowest value of intrinsic rate of increase ($r_m$) and the net reproductive rate ($R_0$) were observed in 1, 2 and 3-day-old eggs which were treated with 0.5- and 1.5-min exposure time respectively. Low value of $r_m$ indicates that the exposure duration is more effective than other exposure times for control of pest. The results clearly indicate that all life table parameters ($R_0$, $r_m$, $T_c$, $D_T$, and $\lambda$) are affected significantly by different exposure duration.

UVC-radiation had a significant influence on the reproductive parameters of *P. interpunctella* (Tables 2). In three age groups of eggs, the net fecundity rates and net fertility rates decreased as the time of exposure increased from 0.5 to 1.5 min. However, the lowest value of both parameters was obtained in 2 and 3-day-old eggs which were treated with highest dose (1.5 min exposure time). Due to low grass fecundity in 1-day-old eggs which were treated with 1 min exposure time, their net fecundity rates and net fertility rates were recorded less than those of the 1-day-old eggs which were treated with 1.5 min exposure time. Moreover, 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. Faruki, *et al.* [43], recorded that the fecundity and fertility of *Alphitobius diaperinus* eggs resulting from UV-irradiated 2nd and 3rd instar larvae reduced significantly. Hasan, *et al.* [68], observed the reduced fertility in the eggs of the Uzi fly, *Exorista sorbillans* developing from UV-irradiated pupae. It has been shown that the gamma radiation can affect on fecundity and fertility of *P. interpunctella* eggs resulting from UV-irradiated pupae [67]. Ayvaz, *et al.* [66] reported reduced fecundity and fertility in eggs of $F_1$ and $F_2$ progeny of *E. kuehniella* resulting from gamma radiation adults.

The reduced fecundity and fertility of adults indicate that the disturbances in oogenesis and spermatogenesis, and on the other hand reduction in accessory gland secretions and number of eupyrene sperm (active sperm) will cause low fertility in insects [69]. Marec and Vreysen [70], suggested the reduced fertility resulting from chromosomal translocation. Wendell Snow, *et al.* [71] report that sterilization significantly affects the type and quality of the sperm transferred by treated males. In the present study, irradiation *P. interpunctella* eggs of various

ages with UVC-irradiation determined the effect of doses and age on reproduction and population growth parameters.

## 5. Conclusion

The significantly reduced hatching, fecundity, fertility and intrinsic rate of increase ($r_m$) of eggs resulting from UVC-irradiation eggs revealed that UVC-irradiation is promising, 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)**.** However, much more comprehensive research is needed.

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