J. Entomol. Res. Soc., 16(2): 01-12, 2014 *ISSN:1302-0250*

Effects of Ultraviolet Irradiation on Life Table of Cowpea Weevil, *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae)

Roshanak SEDAGHAT Ali Asghar TALEBI Saeid MOHARRAMIPOUR

Department of Entomology, Faculty of Agriculture, Tarbiat Modares University, P.O. Box: 14115-336, Tehran, IRAN, e-mails: r_sedaghat63@yahoo.com, talebia@modares.ac.ir, moharami@modares.ac.ir

ABSTRACT

The cowpea weevil, *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae) is a serious cosmopolitan pest of stored products throughout the world. In this research, effect of UVC irradiation on egg-hatching, reproduction and population growth parameters of this pest were determined. In the experiments 1, 2 and 3-day-old eggs of *C. maculatus* were exposed to 254nm wavelength (UVC) for different durations at 25±5 ºC and a photoperiod of 10:14 (L: D). The results showed that an increase in time of exposure to UVC-irradiation caused a gradual decrease in the percentage of eggs hatch in all age groups. In all treatments, the older eggs were more sensitive than younger ones. The percentage of hatched eggs was determined to be 95 % in control treatment, while in 1, 2 and 3-day-old eggs it was 7.5, 1.67 and 0.83 %, respectively, at 40 min of exposure to UV- irradiation. All exposure periods of UVC-irradiation in all group of ages caused reduction of reproduction of subsequent adults significantly. The net fecundity rate was estimated to be 79.98±2.34 eggs/female for control and it was lowest (11.07±0.42 eggs/female) in 2-day-old eggs treated by 4 min irradiation. Intrinsic rate of increase (r_m), was 0.14±0.001 day^{-1} in control and decreasing with increasing irradiation time. The lowest value of r_m was observed in 2-day-old eggs treated by 4 min exposure (0.05±0.0012 day^{-1}). Finite rates of increase (λ) decreased with increasing exposure time from 2 to 4 min. The doubling rime (*DT*) and mean generation time (*T*) increased with increasing time of exposure time from 2 to 4 min. The longest mean generation time was recorded in 3-day-old eggs treated for 4 min exposure time (31.72±0.06 days). It may be concluded that UVC-irradiation is a safe and clean method for stored product preservation and storage pest control.

Key words: Callosobruchus maculatus, egg hatching, population growth parameters, reproduction parameters, ultraviolet irradiation.

INTRODUCTION

The cowpea weevil, *Callosobruchus maculatus* (Fabricius) (Coleoptera: Bruchidae) is a cosmopolitan field-to-store pest ranked as the principal post-harvest pest of several pulses, including chickpea, *Cicer arietinum* L. and cowpea, *Vigna unguiculata* (L.) Walp. The adults lay their eggs on the seeds in storage and larval feeding in the cotyledons causes substantial quantitative and qualitative losses (Singh, 1978; Steel *et al*., 1985; Jackai and Daoust, 1986; Ogunwolu and Odunlami, 1996; Pascual-Villalobos Ballesta-Acosta, 2003). Over 90% of the insect damage to cowpea seeds is caused by *C. maculatus* (Caswell, 1981). Commercial quantities of cowpeas are effectively

disinfested by fumigation with methyl bromide or phosphine (Mbata *et al*., 2004). Because of 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, and to freeze its consumption and production, and finally to phase it out by 2015 in developing countries (Clarks, 1998). Uses of other insecticides in stored products are facing restrictions globally. In addition, *chemical* pesticides become less effective as *pests develop resistance to* them (Hagstrum *et al*., 1999; Phillips *et al*., 2000). So, the use of insecticides and its concomitant impact on the environment has necessitated exploration of alternative non-toxic pest control methods. Irradiation has become an established technique for controlling stored product insects because it is residue free (Tuncbilek, 1995). Pszczola (1997) demonstrated the acceptability of irradiation technology as an alternative treatment for food protection because irradiation can extend the shelf life of various fruits and vegetables, and maintain the quality of the product over a longer period of time. Irradiation does not significantly change the quality of the food material or stored seeds (Hasan and Khan, 1998). In the present study, non-ionizing radiation, *i. e.* ultra violet radiation (UVC), was used as a possible method for controlling *C. maculatus*. This study provides new information on the effects of different doses of UVC on life table parameters of *C. maculatus*, which has as yet not been thoroughly studied. Here we examine the effects of different exposure times of eggs to UVC on hatching, reproduction, and population growth parameters of *C. maculatus*. A search of databases for research on UVC and *C. maculatus* did not yield any information on minimum radiation doses for suppressing infestation. Therefore, we have chosen radiation doses arbitrarily to evaluate the effect of UVC doses on the developmental stages of *C. maculatus.*

MATERIALS AND METHODS

Insect cultures

A population of *C. maculatus* was originally collected from stores in Tehran and reared on mung bean, *Vigna radiata* (L.) seeds. The cultures were maintained at temperature of 25±5ºC with a photoperiod of 10:14 (L:D) without humidity control. All experimental procedures were carried out under the same environmental conditions as the culture. The eggs of *C. maculatus* were collected by placing large numbers of beetles on the rearing medium. After 24h the adults were removed and the seeds bearing only one egg were selected. The seeds were kept in a beaker to obtain the eggs of 2 and 3 day- old.

UVC-irradiation technique of eggs

The UVC radiation source was a 15W germicidal lamp, GE15T8 measuring 40 x 2 cm. This lamp produced UVC at a wavelength of 253.7 nm. To determine the effect of UVC on egg hatching, the seeds were placed on a 12 cm distance from the lamp. Eggs were irradiated for 2, 4, 8, 16, 24, 32 and 40 mins. The experiment was conducted using one, two and three-day-old eggs and for each exposure period

120 eggs were irradiated. After exposure, irradiated and non-irradiated eggs of the different age groups were kept separately at 25±5ºC until the death of all individual. Survivorship and life expectancy were calculated by the following formula:

$$l_x = \frac{N_x}{N_o}$$

$$e_x = \frac{T_x}{l_x}$$

Where x is unite of age in days, 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 life expectancy 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 is the fraction of individuals alive during the interval between x and $x + 1$.

Reproduction and population growth parameters

In order to calculate demographic parameters of *C. maculatus*, a large number of 1, 2 and 3-day-old eggs of this pest were irradiated for 2 and 4 minutes. After emerging of adults, 30 (less than 24h old) females and males were differentiated by the method of Bandara and Saxena (1995), paired and introduced into a Petri dish. Each dish containing 5g mung bean. The number of eggs laid by each female was recorded daily until the last female died. The eggs were removed after counting.

Statistical analysis

Standard demographic parameters were calculated 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_o), 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 procedure to estimate the variance for r_m and the other population parameters (Meyer *et al*., 1986). 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 (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_o, 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(all), R_0(all), T_c(all), λ (all) and D_t(all) (Maia *et al*., 2000).

(b) Repeat the procedure described in (a) n times, 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):

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

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, by the following equations (Maia *et al*., 2000):

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

$$VAR_{rm(mean)} = \frac{\sum_{1}^{n} \left(r_{m(j)} - r_{m(all)} \right)^2}{(n-1)}$$

$$SEM_{rm(mean)} = \sqrt{\frac{VAR_{rm(mean)}}{n}}$$

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 Minitab software (MINITAB, 2000). A dendrogram of different age groups of eggs of *C. maculatus* based on reproductive and population growth parameters on different exposure time of UVC-irradiation was constructed after cluster analysis by Ward's method using the statistical software SPSS 13.0 (SPSS, 2004).

RESULTS

Effect of UVC irradiation on egg hatching

UVC-irradiation reduced egg hatch of all age groups. Egg hatching rate increased with increasing exposure periods (Fig. 1). All exposure periods of UVC radiation reduced the hatching of eggs in comparison with control. The percentage of egg hatch was 95 % in control. In one-day-old eggs, egg hatching was 71.93, 64.92, 37.72, 28.95, 22.81, 10.53 and 7.89 % at 2, 4, 8, 16, 24, 32 and 40 min exposure time, respectively. Our results indicated that egg hatching rate decreased as the age of irradiated eggs increased (Fig. 1). In two- day- old eggs, egg hatch rate was 39.16, 13.33, 9.17, 5.83, 3.33, 1.67, 1.67% and in three-day-old eggs was 40.00, 24.17, 9.17, 10.00, 5.00, 2.50 and 0.83% at the mentioned dose, respectively. UVC-irradiation had a sever effect on

the age-specific survivorship rate. The survivorship (l_x) at the first day of life was 95 % in control and 67, 61, 36, 27, 22, 10 and 7% in 1- day-old treated eggs by 2, 4, 8, 16, 24, 32 and 40 min. This parameter was 39, 13, 9, 5, 3, 1, 1 in 2-day-old eggs and 40, 24, 9, 10, 5, 2, 0 % in 3-day-old treated eggs, respectively (Fig. 2). The life expectancy (*ex*) at the first day of life was 48.22 days in control and 35.3, 33.45, 20.74, 17.15, 14.10, 9.48 and 8.49 days in 1-day-old eggs that treated by above mentioned doses. This parameter were calculated to be 24.80, 13.50, 11.23, 5.02, 8.96, 8.24, 9.04 in 2-day-old eggs and 25.02, 16.86, 10.10, 10.41, 8.72, 7.15 and 6.83 days in 3-day-old eggs on the examined doses. The life expectancy at the beginning of adult emergence was 18.97, 20.91, 19.63, 19.76, 21.20, 19.77, 21.27, 18.35 days in 1-day- old eggs, 19.91, 18.29, 14.50, 9.96, 18.25, 19, 7 days in 2-day-old eggs and 21.68, 17.38, 20.12, 18.93, 18.90, 16.50, 17.50 days in 3-day-old eggs at 2, 4, 8, 16, 24, 32 and 40 min exposure time, respectively (Fig.3). Therefore, the results indicated that UVC-irradiation decreased the survivorship and the life expectancy on treated generations in comparison with control.

Effect of UVC irradiation on reproductive parameters

No significant difference was observed on the gross fecundity rate (*i. e*. the mean number of eggs per female per generation) when eggs of different ages were exposed to UVC-irradiation (Table 1). Net fecundity was 79.98±2.34 eggs in control, however decreased significantly by increasing exposure time. The lowest value of net fecundity rate was 52.93±5.08, 11.07±0.42 and 17.96±0.63 in 1, 2 and 3-day-old eggs, respectively (Table 1).

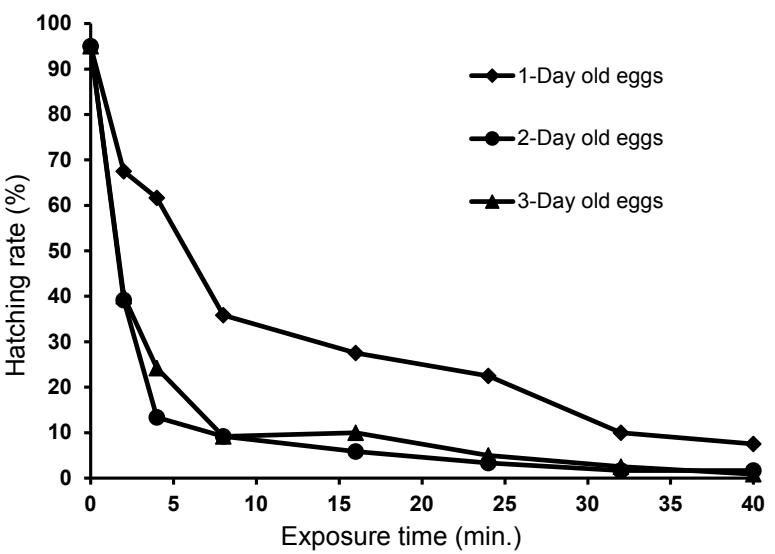

Fig. 1. Egg hatching rate (%) of *C. maculatus* of different ages exposed to various periods to under UVC-irradiation.

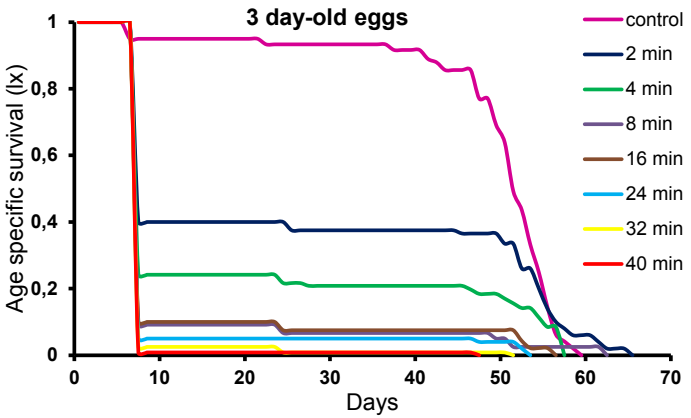

Fig. 2. Age-specific survivorship (l_x) of 1, 2 and 3-day-old eggs of *C. maculatus* under different dose of UVC-irradiation.

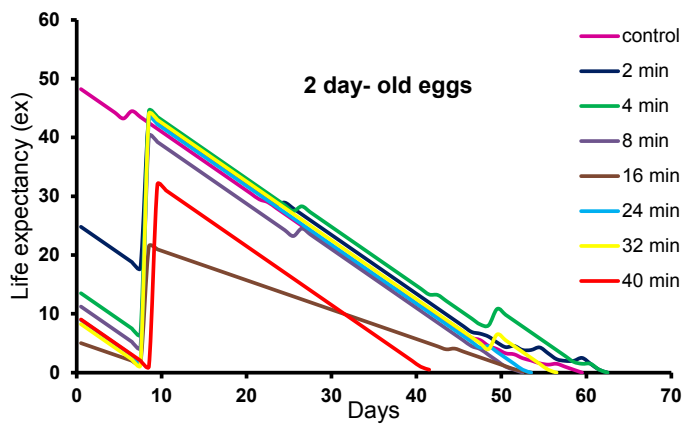

Fig. 3. Life expectancy (*ex*) of 1, 2 and 3-day-old eggs of *C. maculatus* under different dose of UVC- irradiation.

A significant reduction in gross fertility rate of *C. maculatus* was observed when eggs of different ages were exposed to UVC-irradiation. These effects increased with increasing exposure periods (Table 1). The gross fertility was 94.64±2.81 eggs in control. The lowest value of gross fertility rate observed on 2-day-old eggs that were irradiated 4 min (12.7±0.57). Net fertility rate reduced significantly by UV-irradiation (Table 1). The mean number of eggs per female per day was significantly reduced with increasing exposure periods of eggs to UV- irradiation ($P<0.05$). This parameter was 11.36±0.013 in control and it was lowest in 2-day-old eggs, which were irradiated by 4 min. The number of hatched eggs laid per female per day was 10.79±0.012 in control. After 4 mins exposure time of irradiation this parameter decreased to 6±0.007, 1.43±0.002 and 2.45±0.002 in 1, 2 and 3-day-old eggs, respectively. Our results showed that at the same dose of UVC-irradiation, among three different ages of eggs, the 2-day-old eggs were most sensitive.

Table 1. Estimates (±SE) Reproduction parameters of *C. maculatus* under UVC-irradiated time.

Reproduction parameters	Age of eggs irradiated	UVC-irradiated time (min.)		
		0 (control)	2	4
Gross fecundity rate	1	99.68±4.06 a	101.63±2.00 Aa	100.27±4.54 Aa
	2	99.68±4.06 a	89.82±4.28 Ba	95.27±4.47 Aa
	3	99.68±4.06 a	105.97±6.94 Aa	102.22±3.72 Aa
Gross fertility rate	1	94.64±2.81 a	68.49±1.35 Ab	60.24±2.53Ab
	2	94.64±2.81 a	35.12±1.75 Cb	12.70±0.57Cc
	3	94.64±2.81 a	43.46±1.53 Bb	24.47±0.95Bc
Net fecundity rate	1	79.98±2.34 a	60.08±1.31Ab	52.93±5.08 Ab
	2	79.98±2.34 a	32.19±1.47Bb	11.07±0.42 Bc
	3	79.98±2.34 a	57.76±2.03Ab	17.96±0.63 Bc
Net fertility (egg)	1	76.02±2.20 a	40.49±0.88Ab	34.64±2.72 Ab
	2	76.02±2.20 a	12.59±0.57Cb	1.57±0.11 Bc
	3	76.02±2.20 a	23.50±0.83Bb	4.30±0.16 Bc
Mean egg per day	1	11.36±0.013 a	11.20±0.008Ab	10.01±0.01 Ac
	2	11.36±0.013 a	10.75±0.02Bb	8.76±0.01 Cc
	3	11.36±0.013 a	10.74±0.01Bb	10.21±0.008 Bc
Mean fertile egg per day	1	10.79±0.012 a	7.56±0.005Ab	6.00±0.007 Ac
	2	10.79±0.012 a	3.42±0.006Cb	1.43±0.002 Cc
	3	10.79±0.012 a	4.40±0.004Bb	2.45±0.002 Bc

The means in each column with the same upper case letters are not significantly differences within different age groups of eggs and means in each row with the same lower case letters are not significantly different within different exposure time with controls ($P < 0.05$, SNK)

Effect of UVC irradiation on the population growth parameters of *C. maculatus*

Effect of different exposure time of UVC-irradiation on the population growth parameters are 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 *C. maculatus* decreased with increasing exposure time from 2 to 4 mins. The mean generation time (T_c) and doubling time (DT) increased with increasing irradiation time. Net reproductive rate was 38.32±0.1 in control and decreased as the duration of exposure to radiation increased. The lowest value of net reproductive rate among treatments was observed in 2-day-old eggs that treated by 4 min irradiation (5.19±0.21 eggs/female) (table 2). The lowest amount of r_m in 1, 2 and 3-day-old eggs was 0.11±0.0009, 0.05±0.0012 and 0.077±0.0008 day^{-1}, respectively treated by 4 min exposure time while it was 0.14±0.0009 day^{-1} in control. Also changes in amount of λ indicated similar effects of

the irradiation (Table 2). Our results indicated that UVC-irradiation was more effective in 2 and 3 day than 1-day-old eggs. However, no significant difference was observed between R_0, r_m, λ in 2 and 3-day-old eggs by 2 min exposure, while the value of these parameters were lower significantly in 2-day-old eggs irradiated by 4 min exposure time. The lowest r_m, λ and R_0 and highest D_T, T occurred at 2-day-old eggs, suggesting that this is the most sensitive age for controlling of *C. maculatus* by irradiation. Among the emerged adults from the irradiated eggs, a proportion of the individuals were severely deformed in their wings, elytra and bodies (Fig. 4). Deformity was observed at high exposure times (24, 32 and 40 min) in all three age groups of eggs.

Fig. 4. Morphologically deformed adults of *C. maculatus* that emerged from egg irradiated with UVC.

Cluster analysis

The dendogram of reproductive and population growth parameters of *C. maculatus* in different exposure times of UVC- irradiation indicated two distinct clusters (labeled A and B) (Fig. 5). Cluster A included control and 1-day-old eggs and cluster B was included 2 and 3-day-old eggs. There were two and three subgroups in cluster A and B, respectively. The result suggested that cluster A (-day-old eggs) and B are relatively resistant and susceptible, respectively.

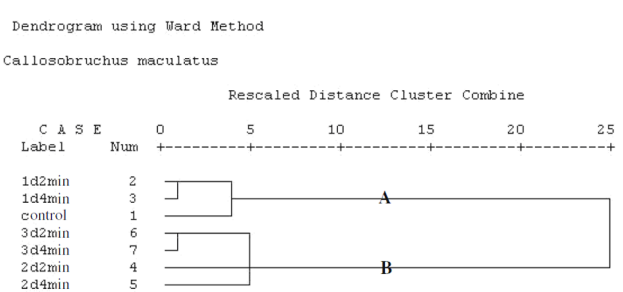

Fig. 5. Dendogram of different dose of UVC and different age of eggs based on reproductive and growth parameters of *C. maculatus*

Table 2. Estimates (±SE) of population growth parameters of C. maculatus under UVC-irradiated time.

Population parameters	Age of eggs irradiated	UVC-irradiated time (min.)		
		0 (control)	2	4
Net reproductive rate (R_o)	1	38.32±0.10 a	30.96±0.61 Ab	27.24±0.80 Ac
	2	38.32±0.10 a	15.26±1.02 Bb	5.19±0.21 Cc
	3	38.32±0.10 a	15.05±0.35 Bb	11.76±0.47 Bc
Finite rate of increase (λ)	1	1.15±0.001 a	1.13±0.0007 Ab	1.12±0.001 Ac
	2	1.15±0.001 a	1.094±0.0028 Bb	1.05±0.0013 Cc
	3	1.15±0.001 a	1.091±0.0008 Bb	1.08±0.0009 Bc
Doubling time (D_T)	1	5.04±0.3 a	5.68±0.03 Bb	6.13±0.03 Ca
	2	5.04±0.3 a	7.72±0.22 Ab	13.32±0.32 Aa
	3	5.04±0.3 a	7.93±0.06 Ab	9.02±0.10 Ba
Mean generation time (T)	1	26.51±0.05 c	28.15±0.05 Cb	29.22±0.08 Ba
	2	26.51±0.05 c	30.01±0.8 Bb	31.68±0.051 Aa
	3	26.51±0.05 c	30.24±0.08 Ab	31.72±0.06 Aa
Intrinsic rate of increase (r_m)	1	0.14±0.0009 a	0.12±0.0006 Ab	0.11±0.0009 Ac
	2	0.14±0.0009 a	0.09±0.0025 Bb	0.05±0.0012 Cc
	3	0.14±0.0009 a	0.097±0.0007 Bb	0.077±0.0008 Bc

The means in each column with the same upper case letters are not significantly differences within different age groups of eggs and means in each row with the same letters are not significantly differences within different exposure time with controls ($P < 0.05$, SNK)

Conclusions and Discussion

Understanding the demographic parameters of the pests is essential in integrated pest management. Our results showed that UVC-radiation was reduced egg hatch, reproductive and population growth parameters of *C. maculatus*. Younger eggs (1-day-old) of *C. maculatus* were more resistant than the older ones, which corroborate with the findings of the other researchers (Calderon and Navarro, 1971; Calderon *et al*. 1985). Seidel *et al.* (1940) found that during early embryonic organization injury to the peripheral parts of the eggs by UV- exposure did not impede the viability of the embryonic regions became more specialized, and different organ fields can no longer replace each other. Thus, damaging of the surface tissue of the eggs can be fatal at the advanced stages of development by non- penetrating radiations like UV-rays. However, our results contrast with the findings of Faruki *et al.* (2007) who observed that the younger eggs of *Cadra cautella* were more sensitive than older ones.

In the present study, mortality gradually increased with increasing dose. This findings agreed with the results of Faruki and Khan (1993) that study on *C. cautella* using UV-rays. They reported that larval mortality was positively correlated with radiation doses. Guerra *et al.* (1968) reported that when eggs of *Heliothis virescens*

and *Heliothis zea* were exposed to UV-rays egg hatch was gradually decreased with increasing time of exposure. Ghanem and Shamma (2007) observed no eggs of *Trogoderma granarium* hatched when eggs of different ages (0, 24 and 48h) were exposed to 3, 8 and 12 minutes UVC- radiation. They reported the eggs chorion was damaged and the inner contents had leaked out. This effect was due to the thinness of chorion and delicacy of the eggs . Accordingly the highest mortality was recorded in embryonic stage. Typically, the embryonic stage of animals is a sensitive to ray (Tilton and Brower, 1983).

Our results clearly showed that UV-radiation reduced Reproductive parameters. Faruki *et al.* (2005) reported that the fecundity and fertility of *Alphitobius diaperinus* were reduced when the 2nd and 3rd instar larvae were irradiated with UV significantly. Hassan *et al.* (1998) observed that fertility of the second generation of treated *Exorista sorbillans* pupa with UV was reduced. Some researchers, reported reduction in fecundity and fertility of treated insect with gamma irradiation (Aye *et al.*, 2008; Ayvaz *et al.*, 2007; Ayvaz and Tunçbilek, 2006). The reduction of fecundity and fertility was due to disturbances of oogenesis and spermatogenesis. Hassan *et al.* (1998) stated that reduction was due to both of active sperms transfer reduced of irradiated males and oocytes production limitation of irradiated females. Insect fertility requires the presence of sufficient quantities of both eupyrene sperm (active sperm) and accessory gland secretions. Reduction in either of them will cause reduction of fertility (Soaur and Makee, 1997). Snow *et al.* (1972) reported that sterilization significantly affects the type and quality of the sperm transferred by treated males. Knipling (1970) suggested that reduction in fertility was due to chromosomal translocations. Radiation did not affect on gross fecundity rate., Adults from irradiated eggs laid more eggs than control, but most of these eggs didn't hatch. Therefore, the emergence of a next generation of *C. maculatus* was strongly inhibited by irradiation. Ayvaz *et al*. (2007) was reported the same result on *Ephestia kuehniella* Zeller. UVC-radiation had a significant effect on the reproductive and population growth rate parameters of *C. maculatus*. No published data are available concerning the effect of UVC-radiation on demographic parameters of *C. maculatus*. However effects of UVC irradiation on intrinsic rate of increase and population growth parameters of *C. maculatus* emphasize its suitability as pest control method. UV rays produced deformities adult at long exposure periods (24, 32 and 40 min). Some of the adults that emerged from treated eggs had incomplete elytra and crumpled wings. Faruki *et al*. (2005) observed that when second and 3rd instar larvae irradiated with UV rays, some of the larvae failed to shed their exuviae during molting. Larval-pupal and pupal-adult intermediate forms were common at each exposure period and showing various morphological deformed characters. Aye *et al*. (2008) reported that *Plodia interpunctella* (Hübner) pupae, which were irradiated by gamma rays, the wings, legs and bodies of a high proportion of emerged adults were severely deformed. Ayvaz and Tunçbilek (2006) irradiated last instar larvae with 200 Gy doses of gamma radiation and none of the adults were normal in appearance.

The present study showed that UVC-radiation caused a significant reduction in egg hatch and reproductive parameters. 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.

Acknowledgements

This research was supported by the Department of Entomology, Tarbiat Modares University. We also extend special thanks to Prof. Myron P. Zalucki who provided some useful comments on the manuscript. We are grateful to Prof. Dr. Abdullah Hasbenli and a reviewer for their comments in the earlier version of this paper.

REFERENCES

Aye, T. T., Shim, J. K., Ha, D. M., Kong, Y. J., 2008, Effect of gamma irradiation on the development and reproduction of *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae). *Journal of Stored Products Research,* 44: 77-81.

Ayvaz, A., Tuncbilek, A. S., 2006, Effect of gamma radiation on life stages of the Mediterranean flour moth, *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae), *Journal of Pest Science*, 79: 215-222.

Ayvaz, A., Albayrak, S., Tuncbilek, A. S., 2007,, Inherited sterility Mediterranean flour moth *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae): Effect of gamma radiation on insect fecundity, fertility and developmental period, *Journal of Stored Products Research*, 43: 234-239.

Calderon, M., Bruce, W. A., Leecsh, L. G., 1985, Effect of UV radiation on eggs of *Tribolium castaneum*. *Phytoparasitica*, 13: 145-147.

Calderon, M., Navarro, S., 1971, Effects of ultra-violet irradiation on the eggs of *Ephestia cautella* (Walk.) (Lepidoptera: Phycitidae). *Journal of Stored Products Research*, 7**:** 309-311.

Carey, J. R., 1993, *Applied Demography for Biologists with Special Emphasis on Insects*, Oxford University Press, New York, 211 .

Caswell, G. H., 1981, Damage to stored cowpeas in Northern Nigeria. Samaru. *Journal of Agriculture Research*, 1:11-19.

Clarks, R., 1998, Methyl Bromide. Protecting the Ozone layer, UNEP IE Series, 6: 40.

Faruki, S. I., Khan, A. R., 1993, Potency of UV-radiation on *Cadra cautella* (Walker) (Lep.: Phycitidae) larvae treated with *Bacillus thuringiensis* var. Kurstaki. *University Journal of Zoology*, Rajshahi University, 12: 73-79.

Faruki, S. I., Das, D. R., Khatun, S., 2005, Effect of UV- radiation on the larvae of the lesser mealworm, *Alphitobius diaperinus* (Panzer) (Col.: Tenebrionidae) and their progeny, *Journal of Biosciences*, 5: 444-448.

Faruki, S. I., Das, D. R., Khan, A. R., Khatun, M., 2007, Effects of ultraviolet (254nm) irradiation on egg hatching and adult emergence of the flour beetles, *Tribolium castaneum*, *T. confusum* and the almond moth, *Cadra cautella*, *Journal of Insect Science*, 7: 1-6.

Ghanem, I.,Shamma, M., 2007, Effect of non-ionizing irradiation (UVC) on the development of *Trogoderma granarium* Everts. *Journal of Stored Products Research*, 43: 362-366.

Guerra, A. A., Ouye, M. T., Bullock, H. R., 1968, Effect of ultraviolet irradiation on egg hatch, subsequent larval development and adult longevity of the tobacco budworm and the bollworm. *Journal of Economic Entomology*, 61: 541-542.

Hagstrum, D. W., Reed, C., Kenkel, P., 1999, Management of stored wheat insect pests. *Integrated Pest Management Reviews*, 4: 127-142.

Hallman, G. J., 2000, Expanding radiation quarantine treatments beyond fruit flies. *Agricultural and Forest Entomology*, 2: 85-95.

Hasan, M., Khan, A. R., 1998, Control of stored-product pests by radiation. *Integrated Pest Management Reviews*, 3: 15-29.

Hassan, M., Jahan, M. S., Khan, A. R., 1998, Effect of uv- radiation on the Uzi-fly, *Exorista sorbillans* Widemann, an endoparasitoid of silkworm, *Bombyx mori* L. *Journal of Insect Science*, 18: 87-91.

Jackai, L. E. N., Daoust, R. A., 1986, Insect pests of cowpea. *Annual Review of Entomology*, 31: 95-119.

Knipling, H. F., 1970, Suppression of pest Lepidoptera by releasing partially sterile males, a theoretical appraisal. *Bioscience*, 20: 456-456.

Maia, A. H. N., Luiz, A. J. B., Campanhola, C., 2000, Statistical inference on associated fertility life table parameter using Jackknife technique, Computational Aspect. *Journal of Economic Entomology*, 93: 511-518.

Makee, H., Saour, G., 2003, Noninherited sterility in irradiated *Phthorimaea operculella* females. *Journal of Applied Entomology*, 127: 489-493.

Mbata, G. N., Phillips, T. W., Payton, M., 2004, Mortality of eggs of stored-product insects held under vacuum: effect of pressure, temperature and exposure time. *Journal of Economic Entomology,* 97: 695-702.

Meyer, J. S., Ingersoll, C. G., Mc Donald, L. L., Boyce, M. S., 1986, Estimating uncertainly in population growth rates: Jackknife vs. bootstrap techniques. *Ecology*, 67: 1156-1166.

MINITAB, 2000, *MINITAB User's Guide*, version 14.1 MINITAB Ltd, UK.

Ogunwolu, E. O., Odunlami, A. T., 1996, Suppression of feed bruchid (*Callsobruchus maculatus* (F.)) development and damage on cowpea (*Vigna unguiculata* (L.)) Walp.) with *Zanthoxylum zanthoxyloides* (Lam.) Waterm. (Rutaceae) root bark powder when compared to neem seed powder and pirimiphos-methyl. *Crop Protection*, 19: 603-607.

Pascual-Villalobos, M. J., Ballesta-Acosta, M. C., 2003, Chemical variation in an *Ocimum basilicum* germplasm collection and activity of the essential oils on *Callosobruchus maculatus*. *Biochemical Systematics and Ecology*, 31: 673-679.

Phillips, T. W., Berberet, R. C., Cuperus, G. W., 2000, *Post-harvest integrated pest management*. In: Francis, F. J. (Ed.), Encyclopedia of Food Science and Technology, 2nd edn. Wiley, New York, 2690-2701.

Pszczola, D. E., 1997, 20 ways to market the concept of food irradiation. *Food Technology*, 51: 46-48.

Saour, G., Makee, H., 1997, Radiation induces sterility in male potato tuber moth *Phthorima operculella* Zeller (Lepidoptera: Gelechiidae). *Journal of Applied Entomology*, 121: 411-415.

Seidel, F., Bock, E., Krause, G., 1940, Die organization des insekteneis. *Naturwiss enschaften*, 28: 433-446.

Singh, S. R., 1978, *Pest of grain legumes and their control in Nigeria*. Singh, S. R., Van Emden, F. H., Taylor, T. A. (Eds.). Resistance to pest of cowpeas in Nigeria. Academic Press, New York,267-296.

Snow, J. W., Young, J. R., Lewis, W. J., Jones, R. L., 1972, Sterilization of adult fall armyworms by gamma irradiation and its effect on competitiveness. *Journal of Economic Entomology*, 65: 1431-1433.

SPSS, 2004, *SPSS User's guide*, version 13.0. SPSS, Chicago.

Steele, W. M., Allen, D., J., Summerfield, R. J., 1985, *Cowpea* (*Vigna unguiculata* (L.) Walp.) In: Summerfield, R. J., Roberts, E. H. (Eds.). Grain legume crops. Collins, London, 537-544.

Tilton, E. W., Brower, J. H., 1983, *Preservation of food by ionizing radiation*. Josephson, Edward S. peterson, Martin S. CRC Press Inc, 269-316.

Tuncbilek, A. S., 1995, Effect of Co gamma radiation on the rice weevil, *Sitophilus oryzae* (L.). *Azeiger fur Schadlingkunde Pflanzenschutz,Umweltschutz*, 68: 37-38.

Yang, T. C. H., Sacher, G. A., 1969, *Effects of X-irradiation on some physiological properties of a developing Tribolium*. In: Argonne National Laboratory Annual Report, 49-50.

Received: May 29, 2012 *Accepted: April 16, 2014*