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Effect of Gamma Radiation on the Sterility and Quality of Male Peach Fruit Fly, *Bactrocera zonata* (Saunders) (Diptera: Tephritidae)

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ABSTRACT

The sterile insect technique is widely used in integrated programs against tephritid fruit flies. The peach fruit fly, *Bactrocera zonata* (Saunders) is a serious pest of fruits in many parts of the world. The pest species has been recently recorded in Egypt. Referring to its significant yield losses, recorded on a wide range of fruits, a strong emphasis for developing effective measures to suppress/ eradicate the pest population in infested areas was suggested. In the present study, effect of gamma radiation on adults' emergence, female fecundity, pupal size, flight ability, sex ratio, male sterility and male mating competitiveness was studied under laboratory conditions. Pupae were irradiated (^{60}Co) 48 hrs before adult emergence (in an air atmosphere) with 10, 30, 50, 70 or 90 Gy. Results indicated that adults' emergence and egg hatching decreased with increasing radiation dose. Exposure of pupae to 90 Gy resulted in a total sterility of eggs laid by non-treated females crossed with treated males. Insignificant difference in the radiation effect on female fecundity was found. Moderate affects on sex ratio and pupal size were recorded, as they decreased gradually by increasing doses. No considerable effect on flying capability of adults, particularly at a lower height of tubes (5 and 10 cm) was observed. Irradiated males with 30 and 70 Gy successfully competed with non-irradiated ones. According to obtained results, taking into consideration a necessity to compromise between male sterility and competitiveness, the more suitable irradiation dose was $\leq$ 70 Gy.

Key words: Gamma radiation, sterile insect technique, *Bactrocera zonata*, Biological parameters.

INTRODUCTION

The peach fruit fly, *Bactrocera zonata* (Saunders) (Diptera: Tephritidae), is a serious polyphagous pest attacks over fifty cultivated and wild plant species in many parts of the world (White and Elson-Harris, 1992). This fruit fly is native to Asia and occurs mainly in Southeast Asia, India, Pakistan, Mauritius, Moluccas Islands, Reunion Island, Sri Lanka and Thailand. At present, *B. zonata* in particular, is a significant horticultural pest in India and Pakistan (Qureshi *et al.*, 1991).

B. zonata was recorded for the first time in Egypt in 1998 (El-Minshawy, 1999). Today it has been well established in most of the Egyptian provinces and causes severe damages to a wide range of fruits such as; guava, peach, mango and apricot (Khan *et al.*, 2005). Development of the pest's population in Egypt proves its potential to establish populations in a relative short time and to compete successfully in new environments. particularly in the Mediterranean climate (Duyck *et al.*, 2004). Annual losses due to the peach fruit fly were estimated by 190 million € in Egypt (EPPO, 2005). Despite the species has not been yet introduced to the European continent, it has been included in the A1 list of pests. as a quarantine pest (EPPO, 2005).

In Egypt, *B. zonata* populations are typically managed by trapping, partial or complete spraying, bait spraying/ collection and deep burial of fallen fruits (EPPO, 2005). Traditional pest control measures using chemical insecticides experience have disadvantages such as; residual problems and inability of insecticides to penetrate infested fruits to kill larvae inside. Moreover, the public demand for insecticide-free fresh fruits is encouraging the use of environment-friendly methods of pest control.

The sterile insect technique (SIT) is a promising environment-friendly method for controlling or eradicating a number of insect pests (Parker and Mehta, 2007). SIT usually reduces growth rate of a target population by saturating wild females with released mass-reared sterilized males (Dyck *et al.*, 2005). It is rapidly becoming one of the major components of integrated pest management programs for the control of the Mediterranean fruit fly, *Ceratitis capitata* (Dyck *et al.*, 2005). Sterilization of males is carried out by gamma radiation depends greatly on the production of good quality sterile males that are released into target wild populations. The quality of sterile males is assured through a system of bioassays of quality parameters that primarily reflect the male's ability to survive, interact with its environment, locate, mate and fertilize females of target wild populations (Collins *et al.*, 2009).

Effect of gamma radiation on development, morphology and anatomy of the peach fruit fly were studied by Shehata *et al.*, (2006) and Younes *et al.*, (2009), in addition, the influence of radiation dose on selected biological aspects of the peach fruit fly was evaluated by (Draz *et al.*, 2008).

The present study aimed to analyze the effect of gamma radiation on selected quality control parameters of *B. zonata* under laboratory conditions.

MATERIALS AND METHODS

Insects rearing techniques

B. zonata: a laboratory culture of *B. zonata* was developed from pupae collected from infested mango fruits at Ismailia city (Egypt). The collected pupae were placed in a cage (75 x 28 x 28 cm) covered with muslin fabric and placed over a plastic dish (40 cm in a diameter) filled with tap water (1 litre). Enclosed adults were provided with a diet consisted of protein hydrolysate and sugar (1:3, w/w), a water soaked cotton clump in a small cup served as a water source. Females laid their eggs through muslin fabric (cage sides) and the eggs fell down to tap water in the plastic dish. The deposited eggs were collected daily.

Larvae were reared according to (Qureshi *et al.* 1974) in plastic trays (15 × 5 × 3 cm). After complete pupation, the sand was sieved; the pupae were collected and transferred into the rearing cages to start a new generation. The rearing of *B. zonata* and all experiments were conducted in a controlled chamber at 25 ± 2°C, 65 – 75% RH and a photoperiod of 12/12h (L/D).

Treatment of gamma radiation

Samples of 7-day-old pupae were obtained from the laboratory culture and hold in plastic container and irradiated using a ^{60}Co source (Gammacell irradiator, model 4000A) located at the Atomic Energy Authority, Gamma Irradiation Unit, Nasr City, Cairo, Egypt. The gamma irradiation was carried out at a dose rate of 66 Gy/min. Five different doses in air atmosphere were used for the treatment (10, 30, 50, 70 and 90 Gy). After irradiation, the pupae were confined in separate rearing cages for emergence of adults. In the control, non-irradiated pupae were maintained at the same manner.

Adults' emergence and sex ratio

Emergence of adults was determined by placing the irradiated pupae in a Petri dish inside the rearing cages. 500 pupae in 5 replicates (5 x 100 pupae) per dose and the control (non-irradiated) were randomly selected and evaluated for emergence. Each batch of pupae was placed in a separate rearing cage, adults' emergence was checked daily and number of emerged flies was recorded. Emerged adults from all the irradiation treatments and the control were collected, temporarily paralysed by chilling and then sexed. The sex ratio was calculated.

Female fecundity and Egg hatchability

Female fecundity and egg hatchability were estimated trough two mating trials: (i) non-irradiated females and irradiated males; (ii) non-irradiated females and non-irradiated males. For each mating trial 25 virgin females and 25 males were released into a rearing cage. The females were obtained from the laboratory culture while the males were obtained from the pupae exposed to the 5 different doses of gamma-radiation 10, 30, 50, 70 and 90 Gy. Each mating trial was replicated 4 times for each dose. Eggs laid by females were counted daily from day one until all the flies had died. Female fecundity was estimated as the number of eggs laid / the number of alive females in the cages. 1000 samples of eggs laid by the females were collected and held in Petri dishes on fine black cloth placed on a moist cotton pad. Three days later, the egg hatching was observed daily for 5 consecutive days. Percentage of egg hatchability for each mating trial (4 x 250 eggs (n = 1000) was determined using a light-stereo microscope.

Flight ability test

Flight ability of adults emerged from pupae exposed to the different doses of gamma radiation was estimated, using a black plastic tube (9 cm in a diameter), placed on a Petri dish bottom inside the rearing cage. One hundred pupae were centred in the bottom of the Petri dish for 24 h after irradiation and a black tube was placed on the Petri dish bottom, thus the pupae were confined in the tube. The black tube was lightly covered with unscented talcum powder, except for lower 10 mm, to prevent the flies from walking out. All flies that emerged and flew from the tube were removed from the cage daily to minimise fly-back (or fall-back) into the tubes. The removed adults were separated by sex. After all emerged flies flew from the tubes or died, the dead flies and non-emerged pupae were counted, about 3 days after emergence. The flight ability based on a number of flies escaping from the black tube, test black tubes of 5 different heights were used: 5, 10, 15, 20, 25 and 30 cm. The experiment was conducted 4 times per each tube height with 100 pupae for each replicate (n = 400). In the control, non-irradiated pupae (4 x 100) were used (FAO/IAEA/USDA, 2003). This experiment was done with the same batch of pupae treated with gamma radiation.

Pupal size

7-day-old pupae obtained from the mating trials were used to determine pupal size. 4 x 25 pupae (n = 100) were weighed individually using a microbalance (Mettler, d = 0.1 mg) to get a mean weight. In addition, length and diameter of individual pupae were measured (FAO/IAEA/ USDA, 2003).

Sterility and sexual competitiveness of males

Samples of 7-day-old pupae were irradiated with doses of 30 and 70 Gy for sterility and sexual competitiveness test. To evaluate sterility of irradiated males, emerged adults were sexed and 20 irradiated males and 20 non-irradiated females were released in a rearing cage. In the control, 20 non-irradiated males and 20 non irradiated females were used. 4 replicates, with 20 males and 20 females were carried out for both doses and the control. The flies were allowed to mate and feed. Eggs laid by females were collected daily for 10 days and a sample of 250 eggs was used each day per a replicate for a percent hatchability evaluation.

To evaluate competitiveness of sterile males, a competition experiment between irradiated (30 and 70 Gy) or non-irradiated males for mating with non-irradiated females was studied in 4 mating trials:

(*i*) 10 irradiated males / 0 non-irradiated males / 10 non-irradiated females
(*ii*) 50 irradiated males / 10 non-irradiated males / 10 non-irradiated females
(*iii*) 100 irradiated males / 10 non-irradiated males / 10 non-irradiated females
(*iv*) 0 irradiated males / 10 non-irradiated males / 10 non-irradiated females

In all mating trials, 4 replicates were conducted per dose and percent egg hatching (observed egg hatch - EH_o) was evaluated as above. For the mating trials (*ii*) and (*iii*) expected egg hatching (EH_e) was also calculated using the formula by Fried (1971):

$$EH_e = \frac{N(H_{nn}) + S(H_{sn})}{N + S}$$

where:
N = number of non-irradiated males
S = number of irradiated males
H_{nn} = % EH_o for the mating trial (*iv*)
H_{sn} = % EH_o for the mating trial (*i*)

Total competitiveness value (CV) for irradiated males was calculated according to the Fried's formula (Fried 1971):

$$CV = \frac{(H_a - H_b)}{(H_b - H_c)} \times \frac{N}{S}$$

where:
H_a = rate of egg hatching (non-irradiated females mated with non-irradiated males)
H_b = rate of egg hatching (at a given ratio of irradiated vs. non-irradiated males in the presence of non-irradiated females)
H_c = rate of egg hatching (non-irradiated females mated with irradiated males)
N = number of non-irradiated males
S = number of irradiated males

This experiment was conducted with the same batch of pupae irradiated by gamma rays.

Data analysis

Obtained data were subjected to analysis of variance (ANOVA) and correlation coefficient with the honestly significant difference value calculated as Tukey's statistic at $\alpha = 0.05$ (SAS Institute 2002). The chi-square test was used to test the null hypothesis (1*df*, $P = 0.05$) that there is no significant difference between the expected (EH_e) and observed (EH_o) egg hatching in the competitiveness test. If the hypothesis could not be rejected, the observed and expected values were significantly different.

RESULTS AND DISCUSSION

Effects of gamma radiation on adults' emergence, sex ratio of emerged adults, egg hatching, female fecundity and pupal size of *B. zonata* are shown in Table (1). Obtained results indicated that adults' emergence decreased with increasing radiation dose. It ranged between 68 and 82.2% in the treatments. Statistically, significant differences were recorded in emergence of adults developed from pupae treated with different doses of gamma radiation ($F_{5,24}$ = 10.70, $P < 0.01$). Correlation coefficient was (r = -0.80, $P < 0.01$). Adults' emergence in the control (0 Gy) reached 88.7% and was significantly greater ($P < 0.05$) than the emergence percentages at the doses of 50, 70 and 90 Gy (Table 1).

Sex ratio (males/ total) was moderately affected by gamma radiation. The sex ratio was unaffected at the lowest dose (10 Gy). It was as the same as those for non-irradiated pupae (0.50). At the doses of 50, 70 and 90 Gy, the proportion of emerged males significantly decreased ($P < 0.05$) when compared with the control and the least dose10 Gy. At the high dose of 90 Gy the sex ratio decreased to 0.44, the lowest ratio observed in the experiment (Table 1).

Fertility of the females of *B. zonata*, evaluated after treatment with the different doses of gamma radiation was determined by egg hatching %. Results showed that inseminating non-irradiated females with sterile males (developed from irradiated pupae) did not affect the production of eggs, but it seriously hampered hatchability of eggs. Treatment of pupae at 10 Gy reduced egg hatching to 52.9%, and declined to 39.1% at 30 Gy, 20.0% at 50 Gy and 5.5% only at 70 Gy. Exposure of the pupae to 90 Gy produced a total sterility of eggs. According to Tukey's HSD test, the differences in percentages of egg hatching among the treatments were highly significant ($F_{5,18}$ = 558.63, $P < 0.01$).

Table (1): Effect of different doses of gamma radiation on adult emergence, sex ratio, egg hatching, female fecundity and pupal size of the peach fruit fly, *Bactrocera zonata* under laboratory conditions.

Radiation dose (Gy)		0 (control)	10	30	50	70	90
Adult emergence (%)		88.7 ± 2.12 a*	82.2 ± 5.94 ab	80.0 ± 4.66 ab	74.7 ± 6.12 bc	74.5 ± 5.36 bc	68.0 ± 4.74 c
Sex ratio (males/total)		0.50± 0.006 a	0.50 ± 0.01a	0.45 ± 0.006 b	0.46 ± 0.01b	0.46 ± 0.03 b	0.44 ± 0.02 b
Egg hatching (Corrected %)		93.2 ± 6.02a (100)	52.9 ± 8.67 b (56.7)	39.1± 8.76 c (41.9)	20.0 ± 9.72 d (21.4)	5.5 ± 6.97e (5.9)	0.0 f (0.0)
Total eggs/female		413 ± 14.4 a	455 ± 43.8 a	414 ± 39.02 a	407 ± 29.9 a	401 ± 30.8 a	398 ± 29.5 a
Pupal size	Weight (mg)	10.34 ± 0.6 a	10.18 ± 0.6 a	9.5 ± 0.77 ab	8.74 ± 0.33 b	8.7 ± 0.45 b	-
	Length (mm)	4.82 ± 0.18 a	4.7 ± 0.14 ab	4.42 ± 0.18 bc	4.2 ± 0.22 c	4.1 ± 0.22 c	-
	Diameter (mm)	2.08 ± 0.08 a	2.0 ± 0.14 ab	1.95 ± 0.08 ab	1.87 ± 0.09 b	1.84 ± 0.04 b	-

* Values (± SD) followed by the same letter within a row are insignificantly different at the 5% level (Tukey's HSD test).

The percentage was declined by increasing the doses of gamma radiation and there was a strong negative relationship (r = -0.94, $P < 0.01$) between the dose of gamma radiation and the egg hatchability of *B. zonata*. From these results it could be concluded that the doses below 90 Gy do not prevent egg hatching, and had no effect on female fecundity. Data showed a positive correlation coefficient (r =0.351, $P > 0.05$).

Pupal size (weight, length and diameter) gradually decreased by increasing the dose. Statistically significant differences among the doses ($F_{4,20}$ = 8.002, $P < 0.01$ for weight; $F_{4,20}$ = 11.52, $P < 0.01$ for length; $F_{4,20}$ = 4.40, $P < 0.01$ for diameter) were recorded.

Pupal irradiation with doses ≤ 70 Gy did not prevent egg hatching of *B. zonata*. However, when the dose increased to 90 Gy, egg hatching was completely suppressed. These results are in accordance with those of Shehata *et al.* (2006) who reported that the dose of 60-90 Gy having the most deleterious effect on male gonads of *B. zonata*. As well, were the studies of Resilva *et al.*, (2007) on *Bactrocera philippinensis* as the most effective irradiation ranged between 67-74 Gy, (90-100 Gy) *on Anastrepha fraterculus* (Wiedemann) and (70-90 Gy) on *Bactrocera cucurbitae* (Coquillett) and *B. zonata* (Allinghi *et al.*, 2007).

In some other studies on different insect species, a dose to induce 100% sterility of tephritid males is often a bit lower ranging from 40 to 60 Gy, For example, 40 Gy for *B. cucurbitae* (Nahar *et al.*, 2006), 50 Gy for *Anastrepha suspense* Loew (Walder and Calkins, 1993) and *B. zonata* (Draz *et al.*, 2008), or 60 Gy for *Anastrepha obliqua* (Macquart) (Toledo, 1993).

In general, sterility dose differs according to the type and irradiator cells, genus of flies and laboratory strain age. Mean sterility doses are different among families of Diptera ranging from 20 to 160 Gy (Bakri *et al.*, 2005). In the present study, the percentage of egg hatching of *B. zonata* negatively correlated with the radiation dose and this relationship was also observed in other tephritid species recorded by (Dyck *et al.*, 2005). As mentioned above, based on anatomical observations of radiation effects on male gonads, doses ranged between 60 and 90 Gy are considered sub-sterilizing and sterilizing for *B. zonata* (Shehata *et al.*, 2006).

The percentage of adults' emergence decreased with increasing the dose, however a significant decrease was only observed for ≤ 50 Gy. Obtained results showed lower emergence rate by about 10% for each dose than those for *B. zonata* presented recently by Draz *et al.* (2008). It can be concluded that even high doses did not have strong deleterious effects on the pupal viability. At the dose of 70 Gy, nearly 3/4 of exposed pupae maintained their viability and produced adults.

Pupal size is a valuable indicator of overall viability of pupae and correlates with size of the resulting adult flies. The larger male tephritids are, in general, stronger fliers, live longer, have higher mating propensity and produce longer refractory periods in female flies than the smaller males (Calkins and Parker, 2005). Pupal size is usually measured either by diameter or weight (Calkins and Parker, 2005) and the values may vary depending upon an insect strain and a rearing system. Obtained data demonstrated significant effect of radiation on weight and dimensions of pupae. The pupae were significantly smaller at doses equal to and over 30 Gy when compared with the control (0 Gy). Draz *et al.*, (2008) recorded the effect of gamma rays on deformation of *B. zonata* pupae and occurrence of deformed pupae in the populations.

Greater variability of sex ratios (males/ total) for

B. zonata treated with gamma radiation was observed by Draz *et al.* (2008). They recorded highest sex ratio (0.60) at 30 Gy, followed by 0.56 and 0.47 for the doses 50 and 10 Gy, respectively. Percentage of males in rearing colonies of tephritid species should generally be within the range of 45-55% for bisexual strains (FAO/IAEA/USDA, 2003). Monitoring sex ratios is especially important when dealing with genetic sexing strains, because sex ratios change with genetic recombination. Obtained results showed no considerable deviation from natural sex ratio.

Results of flight ability showed inconsiderable effect of the tested gamma doses (10, 30, 50, 70 or 90 Gy) on flying capabilities of adults, particularly at lower heights of tubes ($F_{5,24} = 2.25$, $P > 0.05$ for 5 cm tube height and $F_{5,24} = 1.67$, $P > 0.05$ for 10 cm). However, there were significant differences at higher tubes ($F_{5,24} = 4.547$, $P < 0.01$ for 15 cm, $F_{5,24} = 8.044$, $P < 0.01$ for 20 cm, $F_{5,24} = 13.787$, $P < 0.01$ for 25 cm and $F_{5,24} = 6.095$, $P < 0.01$ for 30 cm). Generally, flier percentage decreased with increasing the tube height (Table 2).

Reductions in the flight ability due to irradiation and/or rearing have been recorded by many researchers (Resilva *et al.*, 2007). Obtained data are in accordance showed significant effects of irradiation on flying capability at greater tube heights (≥ 15 cm) and higher doses (≤ 50 Gy). Sharp and Little (1982) stated that flight ability of adults may also be adversely affected during the pupal stage at a critical time in their development. Therefore, flight ability evaluation is a part of routine quality control tests of sterile mass-reared tephritid fruit flies.

Observed and expected egg hatching percent of different sex ratios and the estimated total competitiveness values of treated males are presented in Table (3). When the ratio of irradiated males (males developed from irradiated pupae) increased, the percentage of egg hatching of non-treated females declined. However, the decline was not as great as that from the ratio 1:0:1 (the absence of non-irradiated males). The percentage of egg hatching decreased, depending on the sex ratio; 65.7 and 50.5% for the dose 30 Gy and 25.1 and 16.8% for the dose 70 Gy. Statistically, significant differences in percentages of egg hatching among the sex ratios of both doses ($F_{5,18} = 68.58$, $P < 0.01$ for 30 Gy and $F_{5,18} = 568.26$, $P < 0.01$, for 70 Gy). Observed values of hatched eggs were greater than

Table (2): Flight ability of the peach fruit fly, *Bactrocera zonata* emerged from pupae irradiated with different doses of gamma radiation under laboratory conditions.

Radiation dose (Gy)	Fliers (%)					
	Tube height (cm)					
	5	10	15	20	25	30
0 (control)	80.2 ± 2.5 a	68.7 ± 5.77 a	58.0 ± 1.30 a	38.0 ± 2.26 a	19.5 ± 1.19 b	7.5 ± 0.53 a
10	73.7 ± 6.90 ab*	67.0± 6.27 ab	56.7 ± 2.43 a	37.2 ± 2.43 ab	19.5± 1.92 a	6.2 ± 1.38 a
30	71.0 ± 5.90 ab	67.5 ± 5.15 ab	53.7 ± 5.25 ab	36.2 ± 2.05 ab	16.5 ± 2.20 a	5.5 ± 1.19 ab
50	72.2 ± 8.53 ab	63.0 ± 3.92 ab	52.0 ± 6.27abc	32.7 ± 3.88 bc	16.5 ± 2.44 a	5.5 ± 1.60 ab
70	66.2 ± 4.43 b	62.7 ± 6.06 ab	49.2 ± 4.92 bc	28.0 ± 1.69 c	12.7 ± 1.16 b	4.0 ± 0.75 bc
90	68.0 ± 4.07 b	59.2 ± 3.24 b	45.0 ± 2.61 c	27.7 ± 4.55 c	10.2 ± 1.75 b	2.7 ± 2.05 c

* Values (± SD) followed by the same letter within a column are insignificantly different at the 5% level (Tukey' HSD test).

Table (3): Sterility and sexual competitiveness of the peach fruit fly, *Bactrocera zonata* males emerged from pupae treated with gamma radiation (30 or 70 Gy) under laboratory conditions.

Rad. dose	Sterility and competitiveness parameters	Sex ratio (S♂: N♂: N♀)[1]			
		0:1:1	1:0:1	5:1:1	10:1:1
30 Gy	EH_o (%)[2]	93.2a[5]	39.1d	65.7b	50.5c
	EH_e (%)[3]	-	-	48.1	44.0
	χ^2 (1 *df*; $P = 0.05$)[6]	-	-	6.20	1.71
	CV[4]	-	-	0.21	0.37
70 Gy	EH_o (%)	93.2a	5.5d	25.1b	16.8c
	EH_e (%)	-	-	20.1	13.5
	χ^2 (1 *df*; $P = 0.05$)	-	-	0.78	0.93
	CV	-	-	0.69	0.68

[1]S♂ - males emerged from irradiated pupae, N♂ and N♀- males and females emerged from non-irradiated pupae
[2]% egg hatch observed in experiments
[3]% egg hatch calculated according to Fried (1971)
[4]CV – total competitiveness value (Fried 1971)
[5]Values followed by the same letter within a row are not significantly different at the 5% level (Tukey's HSD test)
[6]χ^2 values - boldface values indicate significant ($P = 0.05$) difference between observed and expected egg hatch

those of the expected ones in all variants. However, a significant difference (1 *df*; $P = 0.05$) was observed only for the 5:1:1 sex ratio and the 30 Gy dose. Values of the Fried's competitiveness coefficient (*CV*) ranged from 0.21 to 0.69. While at the 70 Gy dose, they were nearly equivalent for both sex ratios. The competitiveness at 30 Gy was 1.85 times greater at the higher portion of sterile males in the trial. The results declared that the males treated with higher doses of gamma radiation were more competitive.

Competitiveness (*CV*) of the irradiated males with the non-irradiated ones for mating the non-irradiated females indicated that the competitiveness coefficient of *B. zonata* ranged from 0.21 to 0.69 depending upon the dose and ratio of irradiated/non-irradiated males. Values for the Fried's competitiveness coefficient range from 1 to 0. Values of 1 indicate an equivalent level of competitiveness between irradiated and non-irradiated males, while values close to zero indicate superior competitiveness of the non-irradiated males (Fried, 1971). Values between 0.2 and 0.4 are normal for sterile laboratory males and values less than 0.2 are a reason for concern about the male competitiveness (FAO/IAEA/USDA, 2003). The total competitiveness values obtained suggest that irradiated males successfully competed with non-irradiated males. The values correspond with results of other authors (Lux *et al*., 2002). In competitiveness test doses of 90 Gy was not used as higher doses of gamma radiation, usually significantly affect quality of insects (Bakri *et al*., 2005 and Parker and Mehta, 2007). Also, SIT programs depend on releases semi-sterile males, not completely sterile ones.

Optimal doses of gamma radiation for sterilization have been determined for many fruit species (Collins *et al*., 2009). In choosing an optimal dose for sterilization, a balance needs to be reached between the levels of sterility and mating competitiveness of males (Parker and Mehta, 2007). Insects that receive very low dose are not sufficiently sterile and those that receive very high dose may be uncompetitive, reducing the effectiveness of the SIT by requiring a greater number of sterile insects must be released. (Pereira *et al*., 2007) declared that the irradiation process negatively affects the total competitiveness of males, and thereby increase the effectiveness of the SIT, was to reduce the sterilizing dose (Shelly *et al*., 2005).

According to present results and taking into consideration a necessity of a compromise between sterility and competitiveness, the best irradiation range of *B. zonata* pupae treated 48 h before emergence should be 70 Gy.

Since male competitiveness in the field is a complex of many factors such as; survival rate, mating propensity, mating compatibility, post-mating and other factors, that have not been studied here, they remain to be studied under semi-field and field conditions.

Generally the results obtained in the present study recommend the use of the doses $\leq$ 70 Gy and applied 48h before adult emergence to induce sub-sterilization for males of *B. zonata*.

REFERENCES

Allinghi, A.; Gramajo, C.; Willink, E. and Vilardi, J. 2007. Induction of sterility in *Anastrepha fraterculus* (Diptera: Tephritidae) by gamma radiation. Fla. Entomol., 90: 96-102.

Bakri, A.; Heather, N.; Hendrichs, J. and Ferris, I. 2005. Fifty years of radiation biology in entomology: Lessons learned from IDIDAS. Ann. Entomol. Soc. Am., 98: 1-12.

Calkins, C. O. and Parker, A. G. 2005. Sterile insect quality. In: Dyck VA, Hendrichs J, Robinson AS (eds). Sterile Insect Technique: Principles and Practice in Area-wide Integrated Pest Management. Springer, Dordrecht, pp 269-296.

Collins, S.; Weldon, C.; Banos, C. and Taylor, P. 2009. Optimising irradiation dose for quality and sterility of Queensland fruit flies, *Bactrocera tryoni* (Froggatt). J. Econ. Entomol., 102: 1791-1800.

Draz, K. A., El-Aw, M. A. M.; Hashem, A. G. and El-Gendy, I. R. 2008. Influence of Radiation Dose on Some Biological Aspects of the Peach Fruit Fly, *Bactrocera zonata* (Saunders) (Diptera: Tephritidae). Aust. J. Basic. Appl. Sci., 2: 815-822.

Duyck, P. F.; Sterlin, J. F. and Quilici, S. 2004. Survival and development of different life stages of *Bactrocera zonata* (Diptera: Tephritidae) reared at five constant temperatures compared to other fruit fly species. Bull. Entomol. Res., 94: 89-93.

Dyck, V. A.; Hendrichs, J. and Robinson, A. S. 2005. Sterile Insect Technique: Principles and Practice in Area-wide Integrated Pest Management. Springer, Dordrecht, 787 pp.

El-Minshawy, A.M., Al-Eryan, M.A.S. and Awad, A.I. 1999. Biological and morphological studies on the guava fruit fly, *Bactrocera zonata* (Diptera: Tephritidae) found recently in Egypt. 8th Nat. Conf. of Pests and Diseases of Vegetables and Fruits in Ismailia, Egypt, 71-82.

EPPO, 2005. *Bactrocera zonata*. Data sheets on quarantine pests. Bull OEPP/EPPO Bull 35: 371-373.

FAO/IAEA/USDA, 2003. Manual for Product Quality Control and Shipping Procedures for Sterile Mass- Reared Tephritid Fruit Flies. Version 5.0. International Atomic Energy Agency, Vienna, Austria.

Fried, M. 1971. Determination of sterile-insect competitiveness. J. Econ. Entomol., 64: 869–872.

Khan, M. A.; Ashfaq, M.; Akram, W. and Lee, J. J. 2005. Management of fruit flies (Diptera: Tephritidae) of the most perishable fruits. Entomol. Res., 35: 79-84.

Lux, S. A.; Vilardi, J. C.; Liedo, P.; Gaggl, K.; Calcagno, G. E.; Munyiri, F .N.; Vera, M. T. and Manso, F. 2002. Effects of irradiation on the courtship behaviour of medfly (Diptera: Tepritidae) mass reared for the sterile insect technique. Fla. Entomol., 85: 102-112.

Nahar, G.; Howlader, A. J. and Rahman, R. 2006. Radiation sterilization and mating competitiveness of melon fly, *Bactrocera cucurbitae* (Coquillett) (Diptera: Tepritidae) male in relation to sterile insect release method. Pak. J. Biol. Sci., 9: 2478-2482.

Parker, A. and Mehta, K. 2007. Sterile insect technique: A model for dose optimization for improved sterile insect quality. Fla. Entomol., 90: 88-95.

Pereira, R.; Silva, N.; Quintal, C.; Abreu, R.; Andrade, J. and Dantas, L. 2007. Sexual performance of mass reared and wild Mediterranean fruit flies (Diptera: Tephritidae) from various origins of the Madeira islands. Fla. Entomol., 90: 10-14.

Qureshi, Z. A.; Hussain, T. and Siddiqui, Q. H. 1991. Relative preference of mango varieties by *Dacus zonatus* and *D. dorsalis*. Pak. J. Zool., 23: 85–87.

Qureshi, Z. A.; Mohammad, A.; Bughio, A. R.; Shahid, H. 1974. Rearing, reproductive behaviour and gamma sterilization of fruit fly, *Dacus zonatus* (Diptera: Tephritidae). Entomol. Exp. Appl., 17: 504-510.

Resilva, S. S.; Obra, G. B.; Zamora, N. F. and Gaitan, E. G. 2007. Development of quality control procedures for mass produced and released *Bactrocera philippinensis* (Diptera: Tephritidae) for sterile insect technique programs. Fla. Entomol., 90: 58-63.

SAS Institute Inc. 2002. SAS/STAT User's guide, version 9.1. SAS Institute Inc. Cary, North Carolina, USA.

Sharp, J. L. and Little. H. F. 1982. Effect of mechanical disturbance on median dorsal flight muscle development of *Anastrepha suspensa.* Ann. Entomol. Soc. Am., 75: 146-149.

Shehata, N. F.; Younes, M. W. F. and Mahmoud, Y.A. 2006. Anatomical effects of gamma-ray on the peach fruit fly, *Bactrocera zonata* (Saund.) male gonads. J. Appl. Sci. Res., 2: 510-513.

Shelly, T. E.; Edu, J. and Pahio, E. 2005. Lack of an irradiation effect on the mating performance of mass-reared males of the Mediterranean fruit fly. Fla. Entomol., 88: 547-548.

Toledo, J. 1993. Optimum dosage for irradiating *Anastrepha obliqua* pupae to obtain highly competitive sterile adults. In Aluja M, Liedo P (eds) Fruit Flies: Biology and Management. Springer Verlag, New York. pp 301-304.

Walder, J. M. M. and Calkins, C. O. 1993. Effects of gamma radiation on the sterility and behavioural quality of the Caribbean fruit fly, *Anastrepha suspensa* (Loew) (Diptera: Thephritidae). Scientia Agrícola 50: 157-165.

White, I. M. and Elson-Harris, M. M. 1992. Fruit Flies of Economic Significance: Their Identification and Bionomics. CABI International, Wallingford.

Younes, M. W. F.; Shehata, N. F. and Mahmoud, Y. A. 2009. Histopathological effects of gamma irradiation on the peach fruit fly, *Bactrocera zonata* (Saund.) female gonads. J. Appl. Sci. Res., 5: 305-31.