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**Research Article**

# Effect of irradiation on reproductive performance of brinjal shoot and fruit borer, *Leucinodes orbonalis* Guenee (Lepidoptera: Crambidae)

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**ABSTRACT:** An investigation was carried out to assess the effect of ionising radiation (gamma) on the reproductive behaviour of *Leucinodes orbonalis* Guenee. Six-day-old pupae were exposed to 0, 50, 100, 150, 200 and 250 Gy gamma radiation doses and crossed at different combinations. The results indicated that the significantly highest pupal mortality and adult deformity of 21.00 per cent and 39.23 per cent, were recorded at 250 Gy and also this dose induced complete sterility in pupae. Among the crosses, the Normal ♀ × Treated ♂ mating combination has a significant effect on reproductive suppression of brinjal shoot and fruit borer with minimal effect on fecundity of parent and developmental profile of $F_1$ progeny. It induced 67.28 per cent corrected sterility and 84.19 per cent control of reproduction at the dose of 200 Gy. So it was found to be sub sterilising dose for the pupae in inherited sterility to the next generation. Median let belongs to the genus Solanum and family Solanaceae. It is being is being hal doses of 114.06 and 316.28 Gy were required to induce 50 ($LD_{50}$) and 90 ($LD_{90}$) per cent mortality respectively, in the mating combination of Normal ♀ × Treated ♂. The dose of 200 Gy was found to be sub sterilizing dose for the pupae in inheriting sterility to the next generation. It induced 67.28 per cent corrected sterility and 84.19 per cent control of reproduction.

**KEYWORDS:** Corrected sterility, gamma radiations, inherited sterility, *Leucinodes orbonalis*, developmental profile

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## INTRODUCTION

Brinjal (*Solanum melongena* L.) is one of the commonly used vegetables throughout the world and belongs to the genus *Solanum* and family Solanaceae. It is being *Leucinodes orbonalis* (Guenee considered as native to India (Dhaliwal & Aggarwal, 2021). In India, brinjal is cultivated in an area of 7.528 lakh ha with a production of 13023 mt and an average productivity of 17.3 mt/ha. Whereas in Karnataka, it is cultivated in 10720 ha with a production of 291 mt and an average productivity of 27.3 mt/ha (Anonymous, 2023). Insect pests are a prominent contributor among the several biotic and abiotic factors that are causing the yield to decrease. It has been noted that 26 insect pests infest brinjal crops (Dar *et al*., 2015). The most prevalent pests among them are brinjal shoot and fruit borer, *Leucinodes orbonalis* (Guenee), hadda beetle, *Henosepilachna vigintioctopunctata* (Fab.) and *Tetranychus macfarlanei* (Baker and Pritchard) and *Tetranychus urticae* (Koch). According to Hossain *et al*. (2002), the most destructive pest in India is the Brinjal Shoot and Fruit Borer (BSFB), which is regarded as a key limiting factor in the production of brinjal and can result in losses of up to 100% if left unchecked. This is an internal soft tissue feeder that damages fruits and tender shoots from the seedling stage to crop senescence.

The distribution and abundance of pests are influenced by weather parameters that determine the density of the population (Kassi *et al*., 2019). Farmers utilize a combination of conventional insecticides to control *L. orbonalis* without monitoring the incidence level, which causes the development of resistance to several insecticides (Kariyanna *et al*.,2020). Currently, farmers use around 140 times or more insecticides in a single cropping season over 6-7 months, accounting for 32% of the total cost of production to control this pest (Alam *et al*., 2006). The hidden feeding habits of this pest make it difficult to treat with biocontrol agents and insecticides and there are no suitable resistant varieties for the fruit borer or shoot borer available (Yousafi *et al*., 2013).

Therefore, in addition to existing tactics, a novel, environmentally friendly technique is required to manage this pest. The current study is being conducted to manage this pest using the Sterile Insect Technique (SIT). SIT was

one of the earliest biological pest control techniques created for widespread implementation. While the SIT established its name in insect eradication efforts, the scientific community's recognition of its potential as an integral component of Integrated Pest Management (IPM) techniques for suppression, containment, and prevention. It is advisable where eradication of pest populations throughout an area is imperative. To obtain the proper sterile to wild insect over-flooding ratios, the target pest species must be colonized and mass-reared. The implementation of this technology in isolated populations can eventually lead to the extinction of a natural population in some instances. It has been proven effective in controlling a variety of insect pests, such as fruit flies, tsetse flies, moths, and screwworms (Dyck *et al.,* 2005). With this background, we attempted to standardise the gamma radiation dosages to assess the $F_0$ sterility in Brinjal shoot and fruit borer.

## MATERIALS AND METHODS

### Maintenance of brinjal shoot and fruit borer on natural host potato

Infested brinjal fruits were taken from the farmer's field and maintained for pupation in plastic trays (40 cm x 28 cm x 6 cm), covered in muslin cloth and rubber bands. Healthy pupae were collected and sexed out based on the size and location of the genital pore (Padwal & Srivastava, 2017). Adults were fed with a cotton wad soaked in a 10% honey solution that contained 0.01 grams of sorbic acid, 0.02 grams of methyl parahydroxybenzoate, and 10 ml of honey solution with a few drops of multivitamin syrup (ZicovitTM) (Patil, 1990). Muslin cloth was used to cover the jar's open end to facilitate oviposition. The muslin cloth holding the eggs was taken out and changed every day, along with fresh feeding syrup for the adult moths. The eggs inside the muslin cloth were collected and stored until they hatched. Following hatching, the first instar larvae were placed into sterile, peeled, and lined potato tubers (25–30 neonates per 100 g potato). Pupae were gathered, sexed out, and moved to the oviposition jar after pupation. The rearing setup was kept at 27°C, 65±5% relative humidity, and 13L:11D photoperiod (Mannan *et al.,* 2020).

### Irradiation technique and sterilization process

For the present study, cobalt-60 ($^{60}$Co) was used as a radiation source for the exposure of pupae and moths through Gamma Chamber-5000. Six-day-old male and female pupae from pure culture were exposed to gamma radiation in Gamma chamber -5000 having a source strength of 192 TBq and dose rate of 3.342 KGy/hr with different dosages *viz*., 0, 50, 100, 150, 200 and 250 Gy. Plastic vials containing irradiated pupae were kept for adult emergence with normal pupae of the opposite sex in different mating combinations: Normal female × Normal male (Control; NF × NM), Normal female × Treated male (NF × TM), Treated female × Normal male (TF × NM), and Treated female × Treated male (TF × TM).

Three replications were made in each combination, each replication having ten pairs of male and female pupae. These various mating combinations of pupae were kept in separate oviposition jars. The open end of the oviposition jars was covered with a black cloth tied with a rubber band for egg laying, and adults were fed with 10% honey solution. The cloth containing eggs was transferred to transparent plastic containers wrapped in black cloth and tightly protected with a rubber band for egg hatching. Early instar larvae were reared in transparent containers (20 x 10 x 10 cm, l x b x h cm) on potato until pupation later pupae were separated and sexed out and carried out to the further generation. The biological parameters like adult longevity, fecundity, per cent egg hatch, incubation period, larval period, pupal period, per cent pupation, per cent pupal mortality and per cent adult deformity were recorded. The per cent corrected sterility and per cent control of reproduction were calculated by using the following formula.

### Corrected sterility (%)

In the gamma treatment, a lack of hatchability in the eggs was rated as sterility; the percentage of corrected sterility was computed using a formula (Seth and Reynolds, 1993).

$$\text{Corrected sterility (\%)} = \frac{\text{Fertility in control-Fertility in treated}}{\text{Fertility in control}} \times 100$$

### Control of reproduction (%)

The per cent control of reproduction was calculated by using a formula.

$$\text{Control of reproduction (\%)} = \frac{\text{Viablity in control-Viablity in treated}}{\text{Viablity in control}} \times 100$$

### Establishment of median lethal doses of gamma radiations for inducing sterility in *L. orbonalis*

The lethal dose required to induce sterility $LD_{50}$ and $LD_{90}$ values were calculated by using the probit analysis method (Finney, 1971). By calculation, per cent hatchability and per cent mortality were determined. Mortality per cent was corrected using Abbott's Formula (Abbott, 1925).

### Statistical analysis

The data were subjected to arc sin and square root transformation. To determine the impact of each treatment, a completely randomized design with three replications of each treatment was employed in the statistical analysis. The SPSS version 2016 software was used to compare the treatment means using Duncan's Multiple Range Test (DMRT).

## RESULTS AND DISCUSSION

Sterile Insect Technique (SIT) is an eco-friendly management strategy studied in the present investigation for the first time to know the behaviour of this pest towards irradiation and related studies conducted on different insect pests belonging to the same family and other closely related families were compared and discussed with our current results.

### Impact of gamma radiation doses on *L. orbonalis* reproductive behaviour

Six-day-old pupae of brinjal shoot and fruit borer were irradiated at 50, 100, 150, 200 and 250 Gy doses. The sex ratio was not affected at 50, 100 Gy and control but, it was skewed towards males with 0.98: 1, 0.8:1 and 0.76:1 (female: male) in terms of the number of adults eclosed from 150, 200 and 250 Gy irradiated pupae respectively (Table 1). The percentage of adult emergence was 100 per cent in the case of control, 50 and 100 Gy and it was significantly reduced at higher doses of 150, 200 and 250 Gy with 86.67, 84 and 80. 67 percent respectively. Adult longevity of irradiated female moths reduced significantly with the increase in irradiation doses, it was 5.07 days in control and was reduced to 3.63 at 250 Gy. Similarly, the longevity of the irradiated male moth was also reduced, it was 3.19 days in control and was reduced to 2.32 at 250 Gy (Table 1).

Pupal mortality was zero percent in control, 50 and 100 Gy treated pupae and it increased to 13.50, 16.50 and 21 per cent at 150, 200 and 250 Gy, respectively. Similarly, adult deformity showed a positive relation with an increase in irradiation doses, as it was zero per cent in control and increased to 39.23 at 250 Gy gamma radiation doses (Table 1). Our current results are in line with Salem *et al*. (2014) who reported increased per cent pupal, larval mortality and per cent pupal, adult deformity with growing doses by exposing full-grown pupae of *A. ipsilon* to 50, 100 and 150 Gy, respectively. The mortality and deformities ranged from 26.07 to 59.90 per cent.

### Effect of gamma radiation dose on the reproductive behaviour of *L. orbonalis* (normal ♀ × treated ♂)

The radiation dose had a considerable impact on the fertility of female moths, which decreased as the dose increased. Significantly maximum fecundity was noticed in the control with 78.37 eggs/female eggs and significantly least fecundity was found in the control treatment with 31.92 at 250 Gy (Table 2). Significantly highest per cent of egg hatch was seen in control with 75.92 per cent and it was reduced to 67.17, 60.10, 44.67, and 24.84 per cent at 50, 100, 150 and 200 Gy, respectively (Table 2). Egg hatch was zero per cent in the higher dose of 250 Gy. Per percentage of egg hatching affected in the higher dose might be due to the sperm production process in the late pupae. Similarly, radiobiological studies done by Flint and Kressin (1967) revealed that late pupae have a greater number of sperm and fewer spermatids, they exhibit a significant repressive impact on sperm when exposed to radiation which leads to changes in egg hatch. Corrected sterility was found zero per cent in control and 11.51, 20.71, 41.15, and 67.28 per cent at 50, 100,

**Table 1.** Effect of gamma radiation on the reproductive characters of *L. orbonalis* adults

| Irradiation dose (Gy) | Sex ratio (♀/♂ : ♂/♀) | Adult emergence (%)* | Adult longevity (♀)# | Adult longevity (♂)# | Pupal mortality (%)* | Adult deformity (%)* |
|---|---|---|---|---|---|---|
| 0 | 1.00: 1.00 | 100.00 (90)[a] | 5.07 (2.36)[a] | 3.19 (1.92)[a] | 0.00 (0.00)[d] | 0.00 (0.00)[e] |
| 50 | 1.00: 1.00 | 100.00 (90)[a] | 4.83 (2.31)[b] | 3.13 (1.91)[a] | 0.00 (0.00)[d] | 10.00 (18.43)[d] |
| 100 | 1.00: 1.00 | 100.00 (90)[a] | 4.63 (2.26)[c] | 2.89 (1.84)[b] | 0.00 (0.00)[d] | 13.33 (21.34)[cd] |
| 150 | 0.98: 1.00 | 86.67 (68.60)[b] | 4.38 (2.21)[d] | 2.70 (1.79)[c] | 13.50 (21.64)[c] | 20.00 (26.57)[c] |
| 200 | 0.80: 1.00 | 84.00 (66.42)[c] | 4.09 (2.14)[e] | 2.56 (1.75)[d] | 16.50 (23.96)[b] | 30.00 (33.21)[b] |
| 250 | 0.76: 1.00 | 80.67 (63.92)[d] | 3.63 (2.03)[f] | 2.32 (1.68)[e] | 21.00 (26.64)[a] | 39.23 (38.54)[a] |
| **S. Em (±)** | **-** | **0.306** | **0.009** | **0.009** | **0.182** | **0.655** |
| **CD (P=0.01)** | **-** | **1.320** | **1.011** | **1.152** | **2.625** | **4.932** |
| **CV (%)** | **-** | **0.677** | **0.036** | **0.033** | **0.788** | **2.831** |

Sample (n): 50 pupae;

# Figures in the parentheses are $\sqrt{X + 0.5}$ transformed values; *Figures in parentheses are arc sine transformed values and transformed data followed by the same letter within a column are not significantly different at p≤0.01 level.

150 and 200 Gy, respectively. The corrected sterility was 100 per cent at the higher dose of 250 Gy, confirming an absolute positive correlation between the irradiation doses and the corrected sterility. Equally, control of reproduction was estimated to be gradually increasing with a rise in irradiation dose, *i.e.,* zero per cent was recorded in the control and 26.29, 47.84, 67.26 and 84.19 per cent at 50, 100, 150 and 200 Gy, respectively, and it was 100 per cent at the higher dose 250 Gy (Table 2). The changes in reproductive performance observed may be due to the genetic damage caused by irradiation on the sperm of pupa, the sterility induced may be due to the lack of eupyrene sperm transferred during mating by irradiated males.

The findings are consistent with those of Osouli *et al.* (2020), who studied the impact of sterilizing dosages of gamma radiation on European corn borer pupae Ostrinia nubilalis. They stated that, when males were treated at 300 and 350 Gy and mated with unirradiated counterparts, fecundity was reduced to 177.12 and 146.58 in comparison with the control 205.00 per female. Maximum egg hatch was recorded in control treatment with 92.63 per cent and it was reduced to 10.00 and 0.00 per cent at Egg hatch was at 200 and 300 Gy respectively. Similarly, Seth *et al*. (2020) showed that adult males of *Maruca vitrata* (Fabricius) were irradiated at 100, 150, 200 and 250 Gy, the fecundity and egg hatchability reduced significantly with an increase in the dose of gamma irradiation. In addition, Walton *et al*. (2011) exposed *Eldana saccharina* moths to irradiation doses of 150, 200, 250, 300 and 350 Gy. Fertility (egg hatch) decreased dramatically with increasing radiation doses when normal ♀ × treated ♂ was crossed. After 350 Gy of radiation exposure, treated males that mated with untreated females still exhibited 0.19% residual fertility. As a result, increasing ionizing radiation exposures can affect *E. saccharina* fertility.

The outcomes are consistent with those reported by Hilmy *et al.* (1984), who exposed male *Agrotis ipsilon* pupae to doses of 5, 10, and 20 krad. At dose 10, egg production was significantly impacted, and at dose 20, adult emergence was impacted. Al-Izzi *et al.* (1993) found that when male pupae were irradiated and crossed with a normal female, the percentage of embryonated eggs and progeny per female in *Ectomyelois ceratoniae* was reduced to two-thirds as compared to control at 25 and 30 krad. Radiation had a significant impact on the fertility of females as well as the viability and hatching of eggs.

**Effect of gamma radiation doses on the reproductive behaviour of *L. orbonalis* adult when exposed as pupae (treated ♀ × normal ♂)**

Fecundity declined as radiation exposure increased with 67.17, 54.43, 45.37, 36.96, and 29.17 eggs per female at 50, 100, 150, 200, and 250 Gy, respectively, as compared to 78.37 eggs per female in the control groups. (Table 3). The control treatment showed the significantly highest percentage of egg hatching, with 75.92 per cent, and egg hatching decreased to 63.52, 47.27, 28.74, and 19.62 per cent at 50, 100, 150, and 200 Gy, respectively. At 250 Gy, egg hatching was zero per cent, a significant reduction. Damage to the ovarioles' germarium and vitellarium in the resulting female may be the cause of a decrease in fecundity and fertility (Haiba, 1990). A similar detrimental effect of gamma irradiation on per cent corrected sterility and control of reproduction. Percent corrected sterility was zero in control and significantly increased to 16.24, 37.70, 62.13 and 74.14 per cent at 50, 100, 150 and 200 Gy, respectively. Complete sterility was observed at a higher dose of 250 Gy. Similarly, the per cent control of reproduction was zero and it was increased to 28.20, 56.71, 78.08 and 87.81 per cent at 50, 100, 150 and 200 Gy, respectively. Reproduction was completely hampered at 250 Gy (Table 2).

The present results conform with the reports of Bughio (1992) also reported that there was a drastic decrease in fertility of *C. partellus* where irradiated females mated with untreated males it was zero per cent even at 50 Gy irradiated pupae. Similarly, current results are similar with Carpenter *et. al.* (2001) who exposed female cactus moth, *Cactoblastis cactorum* (Berg) (Lepidoptera: Pyralidae) to 50, 100, 200, 300, 400, and 500 Gy, respectively. There was a significant deleterious effect on reproductive performance with an increase in doses in the combination of treated females crossed with untreated counterparts in comparison with irradiated males crossed with unirradiated counterparts. Similar results are documented by Hasaballa (1984) where he exposed female *E. cautella* pupae to radiation at 75 krad which ceased pupae from emerging into adults, while 30 krad resulted in total sterility. Our results in line with reports of Ahmed *et al.* (1985) assessed the impact of irradiation at 25 and 45 krad caused total sterility in both males and females. Increase in irradiation dose, egg laying and fertility were decreased. Female pupae of the Indian meal moth, *P. interpunctella* treated with 26.9 to 31.9 krad radiation, induced absolute infertility, but male pupae at this level only showed partial infertility reported by Judy and Patrick (1987)

**Effect of gamma radiation doses on reproductive behaviour of *L. orbonalis* (treated ♀ × treated ♂)**

Fecundity was significantly maximum with 78.37 eggs/female in the case of control and it was decreased to 69.00, 58.32, 47.99, 39.53 and 30.38 eggs per female at 50, 100, 150, 200 and 250 Gy respectively (Table 3). Similarly, egg hatching was significantly highest at 75.92 per cent in the control treatment, and it decreased from 60.14 to 11.21 per cent as irradiation doses increased from 50 to 200 Gy (Table 3). Egg

**Table 2.** Effect of gamma radiation doses on the reproductive behaviour of *L. orbonalis* adults

| Irradiation dose (Gy) | (Normal ♀ × Treated ♂) | | | | (Treated ♀ × Normal ♂) | | | |
|---|---|---|---|---|---|---|---|---|
| | Fecundity [#] | Egg hatching (%)[*] | Corrected sterility (%) [*] | Control of reproduction (%)[*] | Fecundity [#] | Egg hatching (%)[*] | Corrected sterility (%) [*] | Control of reproduction (%)[*] |
| 0 | 78.37 (8.88) [a] | 75.92 (60.62) [a] | 0.00 (0.00) [f] | 0.00 (0.00) [f] | 78.37 (8.88) [a] | 75.92 (60.62) [a] | 0.00 (0.00) [f] | 0.00 (0.00) [f] |
| 50 | 65.27 (8.11) [b] | 67.17 (55.04) [b] | 11.51 (19.81) [e] | 26.29 (30.83) [e] | 67.17 (8.23) [b] | 63.52 (52.88) [b] | 16.24 (23.76) [e] | 28.20 (32.06) [e] |
| 100 | 51.60 (7.22) [c] | 60.10 (50.83) [c] | 20.77 (27.02) [d] | 47.84 (43.76) [d] | 54.43 (7.41) [c] | 47.27 (43.44) [c] | 37.70 (37.88) [d] | 56.71 (48.86) [d] |
| 150 | 43.58 (6.64) [d] | 44.67 (41.94) [d] | 41.15 (39.90) [c] | 67.26 (55.10) [c] | 45.37 (6.77) [d] | 28.74 (32.41) [d] | 62.13 (52.02) [c] | 78.08 (62.09) [c] |
| 200 | 37.87 (6.19) [e] | 24.84 (29.88) [e] | 67.28 (55.11) [b] | 84.19 (66.58) [b] | 36.96 (6.12) [e] | 19.62 (26.29) [e] | 74.14 (59.44) [b] | 87.81 (69.56) [b] |
| 250 | 31.92 (5.69) [f] | 0.00 (0.00) [f] | 100.00 (90.00) [a] | 100.00 (90.00) [a] | 29.17 (5.45) [f] | 0.00 (0.00) [f] | 100.00 (90.00) [a] | 100.00 (90.00) [a] |
| **S. Em (±)** | **0.026** | **0.556** | **0.921** | **0.573** | **0.026** | **0.556** | **0.921** | **0.573** |
| **CD (P=0.01)** | **1.110** | **2.401** | **3.980** | **2.475** | **0.110** | **2.401** | **3.980** | **2.475** |
| **CV (%)** | **0.621** | **2.424** | **4.130** | **2.080** | **0.621** | **2.424** | **4.130** | **2.080** |

[#] Figures in the parentheses are $\sqrt{X + 0.5}$ transformed values;

[*] Figures in parentheses are arc sine transformed values and transformed data followed by the same letter within a column are not significantly different at p≤0.01 level.

hatching was significantly affected and it was zero at 250 Gy. Unhatched eggs per cent was 24.08 in control versus 100.0 per cent at 250 Gy. There was a strong negative association between the radiation dose, fecundity and the percentage of hatchability, as seen in Table 4, where both are shown to decrease as the radiation dose rises. Corrected sterility was increased as the dose of irradiation increased. The corrected sterility in the case of control was zero and 20.75, 43.90, 70.00 and 85.25 per cent at 50, 100, 150 and 200 Gy, respectively. The sterility was 100 per cent at 250 Gy (Table 3). A similar trend was observed in the control of reproduction, it was zero per cent in the control treatment and 30.21, 58.23, 81.62 and 92.58 per cent at 50, 100, 150 and 200 Gy respectively. In both cases, reproduction ability was completely inhibited at 250 Gy.

The irradiation of both sexes may have resulted in a drastic drop in reproductive performance, with the male being less able to generate and transmit spermatophores than the unirradiated male (El-Sayed and Graves, 1969), sensitivity of female as well (Haiba, 1990), and structural defects such as twisted wings and the merging of tarsal and antennal segments, as well as delayed, incomplete adult emergence (Qureshi *et al.,* 1968). Male and female pupae of *Plodia interpunctella* were exposed to radiation doses of 15, 20, 25, 30, 50, and 70 Gy by Walder & Calkines (1993). Males reached full sterility at 50 Gy, but females reached full sterility at 25 Gy, demonstrating the female's sensitivity to the radiation. The current results are consistent with the reports of Chakroun *et al.* (2017) stated that increasing radiation dose affects the fertility of parents. Males were infertile at 350 Gy. From the eggs laid by females exposed to 300 Gy of radiation, no larvae developed. According to the research, the dose required to fully sterilize a female moth and sub-sterilize a male moth was 300 Gy. Present results are similar to Salem *et al*. (2014) who exposed the pupal stage of greasy cutworm, *Agrotis ipsilon* (Hufn.) to the dose of 50, 100 and 150 Gy and observed complete sterility of both females and males. This suggests that males were more radiation-resistant than females. Furthermore, fertility and fecundity declined with increasing radiation dosage. When both sexes were irradiated and mated together, fecundity and fertility were reduced more than when only one sex was treated. Similarly, Hasaballa (1984) exposed *E. cautella* pupae to radiation doses of 50 and 30 krad, which resulted in 100 per cent infertility in both males and females.

**Effect of gamma radiation on developmental profile and survival of $F_0$ progeny of *L. orbonalis* (normal ♀ × treated ♂)**

The control treatment incubation period recorded was 3.15 days. As the dose increases incubation period was increased to 3.48 and 3.84 days at 150 and 200 Gy, respectively. The average larval period in the control group was 14.65 days, however, at 200 Gy, it was significantly increased to 17.67 days. A similar trend was followed in the case of the pupal period, where it was 7.40 days in control

**Table 3.** Effect of gamma radiation doses on the reproductive behaviour of *L. orbonalis* adults (treated ♀ × treated ♂)

| Irradiation dose (Gy) | Fecundity[#] | Egg hatching (%)[*] | Corrected sterility (%)[*] | Control of reproduction (%)[*] |
|---|---|---|---|---|
| 0 | 78.37 (8.88)[a] | 75.92 (60.62)[a] | 0.00 (0.00)[f] | 0.00 (0.00)[f] |
| 50 | 69.00 (8.34)[b] | 60.14 (50.85)[b] | 20.75 (27.08)[e] | 30.21 (33.33)[e] |
| 100 | 58.32 (7.67)[c] | 42.58 (40.73)[c] | 43.90 (41.49)[d] | 58.23 (49.74)[d] |
| 150 | 47.99 (6.96)[d] | 22.77 (28.50)[d] | 70.00 (56.79)[c] | 81.62 (64.62)[c] |
| 200 | 39.53 (6.32)[e] | 11.21 (19.55)[e] | 85.25 (67.42)[b] | 92.58 (74.20)[b] |
| 250 | 30.38 (5.56)[f] | 0.00 (0.00)[f] | 100.00 (90.00)[a] | 100.00 (90.00)[a] |
| **S. Em (±)** | **0.082** | **0.334** | **0.397** | **0.472** |
| **CD (P=0.01)** | **0.353** | **1.443** | **1.715** | **2.037** |
| **CV (%)** | **1.942** | **1.734** | **1.459** | **1.571** |

[#] Figures in the parentheses are $\sqrt{X+0.5}$ transformed values; [*] Figures in parentheses are arc sine transformed values and transformed data followed by the same letter within a column are not significantly different at p≤0.01 level.

**Table 4.** Effect of gamma radiation on developmental profile and survivability of $F_0$ progeny of *L. orbonalis* (normal ♀ × treated ♂)

| Irradiation dose (Gy) | Developmental period (days) | | | | Pupation (%)[*] | Adult emergence (%)[*] | Adult longevity (♀)[#] | Adult longevity (♂)[#] |
|---|---|---|---|---|---|---|---|---|
| | Egg | Larva | Pupa | Total | | | | |
| 0 | 3.15 ± 0.07[c] | 14.65 ± 0.08[c] | 7.40 ± 0.07[d] | 25.20 ± 0.16[e] | 65.33 (53.94)[a] | 80.00 (63.55)[a] | 5.13 (2.37)[a] | 3.17 (1.91)[a] |
| 50 | 3.23 ± 0.01[c] | 15.04 ± 0.31[c] | 7.77 ± 0.13[c] | 26.04 ± 0.43[d] | 60.33 (50.97)[b] | 71.67 (57.86)[b] | 4.97 (2.34)[a] | 2.93 (1.85)[b] |
| 100 | 3.29 ± 0.03[c] | 16.06 ± 0.33[b] | 7.90 ± 0.02[c] | 27.25 ± 0.28[c] | 52.33 (46.34)[c] | 61.00 (51.36)[c] | 4.73 (2.29)[b] | 2.80 (1.82)[b] |
| 150 | 3.48 ± 0.01[b] | 16.69 ± 0.08[b] | 8.52 ± 0.04[b] | 28.69 ± 0.09[b] | 45.67 (42.51)[d] | 55.67 (48.25)[c] | 4.43 (2.22)[c] | 2.57 (1.75)[c] |
| 200 | 3.84 ± 0.04[a] | 17.67 ± 0.12[a] | 8.88 ± 0.02[a] | 30.39 ± 0.04[a] | 39.17 (38.74)[e] | 43.33 (41.17)[d] | 4.03 (2.13)[d] | 2.47 (1.72)[c] |
| 250 | 0.00[d] | 0.00[d] | 0.00[e] | 0.00[f] | 0.00 (0.00)[f] | 0.00 (0.00)[e] | 0.00 (0.71)[e] | 0.00 (0.71)[d] |
| **S. Em (±)** | **0.039** | **0.199** | **0.076** | **0.222** | **0.604** | **1.066** | **0.010** | **0.013** |
| **CD (P=0.01)** | **0.169** | **0.862** | **0.330** | **0.961** | **2.610** | **4.603** | **0.043** | **0.055** |
| **CV (%)** | **2.387** | **2.588** | **1.961** | **1.680** | **2.700** | **4.224** | **0.855** | **1.355** |

[#] Figures in the parentheses are $\sqrt{X+0.5}$ transformed values; [*] Figures in parentheses are arc sine transformed values and transformed data followed by the same letter within a column are not significantly different at p≤0.01 level.

and a substantial increase was noticed at 50, 100, 150 and 200 Gy with 7.77, 7.90, 8.52 and 8.88 days, respectively (Table 4). The adult longevity was found to be decreased with an increase in the irradiation dose. Female longevity was 5.13 days in control, it was 4.97 days at 50 Gy whereas, it was significantly reduced to 4.73, 4.43 and 4.03 days at 100, 150 and 200 Gy, respectively. Male longevity was 3.17 days in control and it was slightly reduced to 2.93, 2.80, 2.57 and 2.47 days at 50, 100, 150, 200 and 250 Gy, respectively (Table 4). The developmental period and survival of $F_o$ neonates to adulthood were completely inhibited at a higher dose of 250 Gy. The changed genetic information inherited from the treated male parent may be connected to all these variations in the developmental profile of $F_o$ progeny.

The results are in line with the reports of Makee and Saour (2003), who stated that per cent pupation of potato tuber moth *Phthorimaea operculella* was decreased as dose of irradiation dose increased, where the control was 65.33 per cent and decreased to 39.17 per cent at 200 Gy. Similarly, adult emergence also decreased from 80.00 per cent in control to 43.33 per cent at 200 Gy. Similar findings were revealed by Chakroun *et al.* (2017), where the developmental period of *E. ceratoniae* was increased with an increase in the dosage of gamma irradiation. The present findings are also in accordance with Seth *et al.* (2020) who exposed newly emerged adult males of *M. vitrata* at 100, 150, 200 and 250 Gy. Adult longevity, per cent pupation, was decreased and developmental period and per cent adult malformation was increased in the $F_1$ progeny. Our results are in line with Osouli *et al*. (2020), who crossed male pupae of *O. nubilalis* with untreated females. They observed increased incubation, larval and pupal period and decreased per cent pupation with growing doses.

**Effect of gamma radiation on developmental profile and survival of $F_0$ progeny of *L. orbonalis* (treated ♀ × normal ♂)**

As the radiation dose was increased, a noticeable improvement in the developing period was observed. The incubation period was increased as the radiation dose was increased, it was found to be 3.28, 3.33, 3.57 and 3.88 days at 50, 100, 150 and 200 Gy respectively. In the case of control, the incubation period was 3.15 days. Similarly, the average larval period was recorded significantly highest (14.65 days) in control, whereas for 50 and 100 Gy, it was recorded at 14.86 and 15.00 days, respectively. A significant increase in the developmental period of 16.16 and 17.61 days was recorded at 150 and 200 Gy respectively (Table 5). A similar trend was followed in the case of the pupal period. The pupal period was significantly highest with 7.40 days in control, whereas it was noticed with 7.93, 8.28, 8.55 and 8.85 days at 50, 100, 150 and 200 Gy, respectively. The adult longevity was decreased with an increase in the irradiation dose. Female longevity was recorded significantly maximum with 5.13 days in control, at the maximum gamma radiation dose of 200 Gy, it was observed with 3.80 days. Similarly, male longevity was 3.17 in control and it was slightly reduced to 3.03, 3.00, 2.83 and 2.67 days at 50, 100, 150 and 200 Gy, respectively (Table 5).

The developmental period and survival of $F_0$ neonates to adulthood were completely inhabited at a higher dose of 250 Gy. The drastic effect of irradiation was also noticed on the progeny survival rate, as there was a substantial decrease in the number of larvae that successfully pupated as the irradiation dose was increased, where the control was 65.33 per cent and decreased to 59.33, 50.00, 43.00 and 35.00 per cent at 50, 100, 150 and 200 Gy, respectively. Similarly, the pupae that were successfully eclosed into adults also decreased from 80.00 per cent in control to 67.67, 55.67, 47.67 and 31.33 per cent at 50, 100, 150 and 200 Gy, respectively.

The results agree with the reports of Makee and Saour (2003), who stated that when female pupae of potato tuber moth were exposed to a dose of 50 and 150 Gy, this resulted in degeneration and detonation of epithelial cells in the gut of adult females, hence, reducing digestion and absorption resulting in the delayed developmental period (Hesham *et al*., 2003). Our

**Table 5.** Effect of gamma radiation on developmental profile and survivability of $F_1$ progeny of *L. orbonalis* (treated ♀ × normal ♂)

| Irradiation dose (Gy) | Developmental period (days) | | | | Pupation (%) * | Adult emergence (%) * | Adult longevity (♀) # | Adult longevity (♂) # |
|---|---|---|---|---|---|---|---|---|
| | Egg | Larva | Pupa | Total | | | | |
| 0 | 3.15 ± 0.07[b] | 14.65 ± 0.08[c] | 7.40 ± 0.07[a] | 25.20 ± 0.16[d] | 65.33 (53.94)[a] | 0.00 (63.55)[a] | 5.13 (2.37)[a] | 3.17 (1.91)[a] |
| 50 | 3.28 ± 0.02[b] | 14.86 ± 0.28[c] | 7.93 ± 0.26[a] | 26.07 ± 0.18[c] | 61.00 (51.36)[a] | 69.67 (56.59)[b] | 4.83 (2.31)[b] | 3.03 (1.88)[b] |
| 100 | 3.33 ± 0.02[b] | 15.00 ± 0.24[c] | 8.28 ± 0.14[a] | 26.61 ± 0.11[c] | 53.33 (46.92)[b] | 56.33 (48.64)[c] | 4.43 (2.22)[c] | 3.00 (1.87)[b] |
| 150 | 3.57 ± 0.09[b] | 16.16 ± 0.36[b] | 8.55 ± 0.11[a] | 28.21 ± 0.35[b] | 48.33 (44.04)[b] | 47.67 (43.66)[d] | 4.07 (2.14)[d] | 2.83 (1.83)[c] |
| 200 | 3.88 ± 0.07[a] | 17.61 ± 0.19[a] | 8.85 ± 0.10[a] | 30.34 ± 0.16[a] | 39.28 (38.81)[c] | 40.33 (39.42)[e] | 3.80 (2.07)[e] | 2.67 (1.78)[d] |
| 250 | 0.00[c] | 0.00d | 0.00b | 0.00e | 0.00 (0.00)[d] | 0.00 (0.00)[f] | 0.00 (0.71)[f] | 0.00 (0.71)[e] |
| **S. Em (±)** | **0.059** | **0.229** | **0.143** | **0.190** | **1.020** | **0.974** | **0.011** | **0.007** |
| **CD (P=0.01)** | **0.255** | **0.989** | **0.619** | **0.819** | **4.404** | **4.206** | **0.048** | **0.032** |
| **CV (%)** | **3.568** | **3.041** | **3.629** | **1.443** | **4.507** | **4.018** | **0.978** | **0.767** |

# Figures in the parentheses are $\sqrt{X+0.5}$ transformed values; * Figures in parentheses are arc sine transformed values and transformed data followed by the same letter within a column are not significantly different at p≤0.01 level.

results are in line with Osouli *et al*. (2020), who observed increased incubation, larval and pupal period and decreased per cent pupation with increasing doses of irradiation to the female pupae of *O. nubilalis.*

**Effect of gamma radiation on developmental profile and survival of $F_1$ progeny of *L. orbonalis* (treated ♀ × treated ♂)**

As the radiation dose increased, there was a significant improvement in the developmental phase. The incubation period was increased as the dose of gamma radiation increased, it was recorded with 3032, 3.39, 4.08 and 4.22 days at 50,100,150, and 200 Gy respectively. In control, it was recorded with 3.15 days. The average larval period was significantly highest at 150 and 200 Gy with 16.96 and 18.19 days respectively. Whereas, it was 15.05, 15.75 and 14.65 days at 50, 100 Gy and control respectively (Table 6). The pupal duration showed the same trend with 7.40 days in the control treatment and a significant increase was noticed at 50, 100, 150, and 200 Gy, with 7.87, 8.15, 8.92, and 9.15 days respectively. As the irradiation dose was increased, adult longevity was decreased. Female adult longevity was significantly highest with 5.13 days in the control sample and 3.73 days in the 100, 150, and 200 Gy groups. Male longevity was 3.17 days in the case of control, it was slightly reduced to 2.93, 2.77, 2.53 and 2.48 days at 50, 100, 150 and 200 Gy, respectively (Table 6). The developmental period and survival of $F_0$ neonates to adulthood were completely inhabited at a higher dose of 250 Gy.

The drastic effect of irradiation was also noticed on the progeny survival rate, as there was a substantial decrease in the number of larvae that successfully pupated as the irradiation dose was increased, where the control was 65.33 per cent and decreased to 59.33, 50.00, 43.00 and 35.00 per cent at 50, 100, 150 and 200 Gy, respectively. Similarly, the pupae that were successfully eclosed into adults also decreased from 80.00 per cent in control to 67.67, 55.67, 47.67 and 31.33 per cent at 50, 100, 150 and 200 Gy, respectively (Table 7). The drastic changes in the developmental profile of progeny were more pronounced here, because of irradiation of the both sexes.

The changed genetic information inherited from the treated male and female parent may be connected to all these variations in the developmental profile of $F_1$ progeny. Our results conform with the reports of Boshra and Mikhaiel (2006) noted that as the dose of irradiation increased, the egg, larval and pupal duration of *Ephestia calidella* (Guenee) also increased. Similar findings were revealed by Chakroun *et al.* (2017), where the adult longevity of *E. ceratoniae* was decreased with an increase in the dosage of gamma irradiation in the subsequent generations. Our results are similar to Osouli and Atapour (2018) where five-day-old male and female pupae of the Citrus Leaf Miner (CLM), *Phyllocnistis citrella* Stainton, exposed to 100, 200, 300, 350, 400 and 450 Gy and crossed. They observed a drastic decrease in longevity of adults in the case of female longevity it reduced to 4.41 days at 450 Gy from 7.11 in control and

**Table 6.** Effect of gamma radiation on developmental profile and survivability of $F_1$ progeny of *L. orbonalis* (treated ♀ × treated ♂)

| Irradiation dose (Gy) | Developmental period (days) | | | | Pupation (%) * | Adult emergence (%) * | Adult longevity (♀) # | Adult longevity (♂) # |
|---|---|---|---|---|---|---|---|---|
| | Egg | Larva | Pupa | Total | | | | |
| 0 | 3.15 ± 0.07$^{c}$ | 14.65 ± 0.08$^{c}$ | 7.40 ± 0.07 | 25.20 ± 0.16 | 65.33 (53.94)$^{a}$ | 80.00 (63.55)$^{a}$ | 5.13 (2.37)$^{a}$ | 3.17 (1.91)$^{a}$ |
| 50 | 3.32 ± 0.01$^{b}$ | 15.05 ± 0.34$^{c}$ | 7.87 ± 0.09 | 26.23 ± 0.41 | 59.33 (50.38)$^{b}$ | 67.67 (55.35)$^{b}$ | 4.70 (2.28)$^{b}$ | 2.93 (1.85)$^{b}$ |
| 100 | 3.39 ± 0.01$^{b}$ | 15.75 ± 0.37$^{c}$ | 8.15 ± 0.15 | 27.28 ± 0.51 | 50.00 (45.00)$^{c}$ | 55.67 (48.25)$^{c}$ | 4.30 (2.19)$^{c}$ | 2.77 (1.81)$^{c}$ |
| 150 | 4.08 ± 0.04$^{a}$ | 16.96 ± 0.31$^{b}$ | 8.92 ± 0.14 | 29.96 ± 0.46 | 43.00 (40.97)$^{d}$ | 47.67 (43.66)$^{d}$ | 4.10 (2.14)$^{c}$ | 2.53 (1,74)$^{d}$ |
| 200 | 4.22 ± 0.01$^{a}$ | 18.19 ± 0.30$^{a}$ | 9.15 ± 0.15 | 31.56 ± 0.45 | 35.00 (36.27)$^{e}$ | 31.33 (34.04)$^{e}$ | 3.73 (2.06)$^{d}$ | 2.48 (1.73)$^{d}$ |
| 250 | 0.00$^{d}$ | 0.00$^{d}$ | 0.00 | 0.00 | 0.00 (0.00)$^{f}$ | 0.00 (0.00)$^{f}$ | 0.00 (0.71)$^{e}$ | 0.00 (0.71)$^{e}$ |
| **S. Em (±)** | **0.037** | **0.275** | **0.117** | **0.381** | **0.766** | **0.910** | **0.017** | **0.010** |
| **CD (P=0.01)** | **0.161** | **1.188** | **0.506** | **1.644** | **3.308** | **3.931** | **0.071** | **0.043** |
| **CV (%)** | **2.139** | **3.547** | **2.933** | **2.820** | **3.512** | **3.863** | **1.461** | **1.068** |

# Figures in the parentheses are $\sqrt{X + 0.5}$ transformed values; * Figures in parentheses are arc sine transformed values and transformed data followed by the same letter within a column are not significantly different at p≤0.01 level.

**Table 7.** Predictive lethal doses of gamma irradiation for inducing sterility in *L. orbonalis*

| Treatment | $LD_{50}$ values in Gy. | $LD_{90}$ values in Gy. | Regression equation Y= a + bx | Calculated $\chi^2$ value | Table $\chi^2$ value |
|---|---|---|---|---|---|
| Normal ♀ × Treated ♂ | 114.06 | 316.28 | Y= 0.31 + 2.73x | 2.85 | 5.99146 |
| Treated ♀ × Normal ♂ | 102.87 | 274.19 | Y= 1.05 + 3.01x | 3.35 | |
| Treated ♀ × Treated ♂ | 87.56 | 257.43 | Y= 0.95 + 2.93x | 2.65 | |

the case of male longevity, it reduced to 3.52 days at 450 Gy from 5.67 days in control.

**Predictive lethal doses of gamma irradiation for inducing sterility in *L. orbonalis***

The results depicted that a dose of 102.87 Gy was needed to kill half the eggs laid by females eclosed from irradiated pupae when six-day-old female pupae were treated and crossed with the normal male, whereas 90 per cent mortality was noted at 274.19 Gy (Table 7). Similar to this, when the female and male pupae that had been treated were crossed, the dosage was drastically reduced to 87.56 Gy and 257.43 Gy, respectively, to destroy 50 and 90 per cent of the eggs produced. Contrarily, when a male from an irradiated pupa was crossed with a normal female, a relatively higher dosage of 114.06 Gy was needed to induce 50 per cent sterility, while 316.28 Gy was needed to kill 90 per cent of the offspring. The aforementioned findings showed that females were more radiosensitive than males since, in crosses where the female was exposed to radiation, even a small dose was sufficient to cause 50 per cent egg mortality. However, a greater dosage was needed for males to cause a similar level of mortality in the next generation.

The results are in line with Sarika (2018) where, they exposed males of *Pectinophora gossypiella to gamma irradiation and determined LD50 and LD90 values as 90.99 and 275.75 Gy, respectively. As the dose of irradiation increased, a reduction in the per cent hatchability and an increase in the per cent sterility was observed.* Present findings are also in line with Supreeth (2020), who exposed three-day-old pupae of fall armyworm, *Spodoptera frugiperda* to dosages of 50, 100, 150 and 200 Gy and determined *LD50 and LD95 values as 101.31 and 283.77 Gy, 100.31 and 259.60 Gy and 104.18 and 260.01 Gy in treated* ♂ × normal ♀, treated ♂ × treated ♀ and treated ♀ × normal ♂ combinations. Milcheva (2005) determined $LD_{50}$ of the larger wax moth. 50 per cent sterility was produced in female and male pupae at 77 and 152 Gy, respectively.

♂ - Male; ♀ - Female; The above table indicates the ($LD_{50}$) and ($LD_{90}$) values were calculated according to the method of Finney (1971); In the regression equation x is the independent variable, y is the dependent variable, a is intercept and b is slope.

Progeny from irradiated pupae were badly affected during the developmental duration at greater doses of irradiation. This may be the result of the imbalanced hormonal changes brought on by irradiation, which might have had an impact on certain metabolic pathways, such as phenol-oxidase. This might be the reason for the longer developmental period. Lethal dominant mutation brought on by radiation may have resulted in complete sterility at higher dosages, while inherited sterility was brought on by sublethal doses.

## CONCLUSION

The reduction of fecundity and per cent egg hatch increased gradually by increasing the irradiation dose and also irradiation has a positive effect on sterility; with an increase in irradiation dose, the per cent control of reproduction also significantly increased. The incubation period, larval and pupal period were significantly affected and prolonged at 100, 150 and 200 Gy, but the longevity of adults was slightly reduced at higher dosages. Complete sterility was observed at 250 Gy when six-day-old pupae were irradiated by gamma radiation in all mating combinations. Similarly, $LD_{50}$ values indicated the sensitivity of females towards irradiation dose as compared to the males, and the lowest $LD_{50}$ values were observed when both sexes were irradiated and crossed. Based on the *L. orbonalis* reproductive capabilities, it was evident that a dose of 200 Gy resulted in 67.28 per cent sterility and can therefore be used as a sub-sterilizing dose. Additionally, this dose had the least impact on the $F_1$ progeny developmental profile, with lower mortality and higher viability.

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