Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Effects of ^{60}Co γ-ray irradiation on biological parameters and sterility of *Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae)

Shengjun Jiang
Guizhou University
Chaorong Meng
Guizhou University
Huan Deng
Guizhou University
Hancheng Wang
Guizhou Academy of Tobacco Science
Jianyu Meng
Guizhou Academy of Tobacco Science
Maofa Yang
Guizhou University
Chennan Yu
Guizhou Tobacco Company Guiyang Branch
Shimeng Zhang
zhangshimeng@nwsuaf.edu.cn

Guizhou University

Research Article

Keywords: pupal irradiation, reproductive capacity, infertility, inherited sterility

Posted Date: October 7th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10242074/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Abstract

Spodoptera litura (Fabricius) (Lepidoptera: Noctuidae) is an economically important pest of many crops, but its management still mainly relies on chemical insecticides. The sterile insect technique (SIT) is an environmentally friendly approach based on the mass release of sterile insects. Currently, studies of SIT on *Spodoptera litura* have focused on adult irradiation or X-ray, whereas information on γ-ray irradiation during the pupal stage remains limited. In this study, 8-day-old female and male pupae of *Spodoptera litura* were separately exposed to ^{60}Co γ-ray at doses of 40, 70, 100, and 130 Gy. The effects of irradiation were evaluated on the basis of deformity, adult longevity, flight ability, multiple mating ability, eggs deposited per female, and infertility. The results showed that irradiation had no significant effects on deformity rate, adult longevity, and flight ability. However, the number of eggs laid per female decreased with increasing irradiation dose. In both the parental (F_0) and first filial (F_1) generations, the infertility rate showed a dose-dependent increasing trend. Overall, ^{60}Co γ-ray irradiation at the pupal stage affected the reproductive performance of *Spodoptera litura* and induced higher levels of infertility in subsequent generations. These findings suggest that pupal irradiation has the potential for the application of SIT in *Spodoptera litura*

1 Introduction

Spodoptera litura (Fabricius) (Lepidoptera: Noctuidae) is widely distributed in South Asia, Southeast Asia, and Oceania (Bernays 1998; Bragard et al. 2019). It is a highly polyphagous pest with up to 389 recorded host plant species (Qin et al. 2006), and it can cause severe damage to tobacco, reducing yield by 30%-40% (Rao 2023). Currently, management of *Spodoptera litura* in tobacco production still relies largely on chemical insecticides (Wu et al. 2016). However, increasing insecticide application rates have led to a substantial decline in control efficacy and have promoted resistance to many insecticides (Gandhi et al. 2016; Grace et al. 2024). In addition, intensive insecticide use has increased pesticide residues and reduced tobacco leaf quality, creating further challenges for sustainable pest management. Therefore, the development of environmentally friendly control methods is essential for *Spodoptera litura*

The sterile insect technique (SIT) is an environmentally friendly pest management approach in which insects are sterilized by irradiation and then released in large numbers into target areas to suppress reproduction in wild populations (Bourtzis and Vreysen 2021). In this approach, radiation induces dominant lethal mutations in male germ cells and may also sterilize females, so that matings between irradiated and wild insects produce no viable offspring, ultimately reducing population density. γ-ray irradiation is one of the most common methods for insect sterilization because of its strong penetration ability, high treatment efficiency, and precise control of sterilizing doses. γ-rays used for insect irradiation are mainly generated from radioisotopic sources, particularly cobalt-60 (^{60}Co) and caesium-137 (^{137}Cs). Among these sources, ^{60}Co has been widely used because of its reliable source characteristics, relatively high photon energy, and suitability for standardized irradiation procedures (Bakri et al. 2005; Helinski et al. 2009). Considering its high penetrating ability and capacity to achieve relatively uniform dose delivery, γ-ray irradiation has important applications in insect sterilization, stored-product pest control, and

phytosanitary irradiation treatments (Chen et al. 2011; Hallman and Blackburn 2016). This approach has been applied to several insect pests across different orders, such as *Maruca vitrata* (Seth et al. 2020), *Anthonomus eugenii* (Basso et al. 2024), and *Aedes aegypti* (Khan et al. 2024).

The effectiveness of γ-ray irradiation is generally influenced by several factors, including absorbed dose, developmental stage, age at irradiation, sex, and treatment conditions. An insufficient absorbed dose may fail to induce a stable sterilizing or lethal effect, whereas an excessive dose can cause pronounced somatic damage, thereby affecting adult emergence, longevity, and normal physiological performance. Therefore, suitable dose control is essential for ensuring treatment efficacy and experimental reproducibility (International Atomic Energy Agency 2015).

In Lepidoptera, relatively high radiation doses are generally required to achieve complete male sterility, typically in the range of 350–500 Gy (LaChance and Graham 1984). Females of Lepidoptera are generally more radiosensitive than males (Wei et al. 2025), and doses of 100–200 Gy commonly induce nearly complete sterility (Carpenter et al. 2009; Marec and Vreysen 2019). In addition, the irradiation dose required to induce sterility varies among species. In *Manduca sexta*, irradiation with 100 Gy of γ-rays was sufficient to induce adult sterility, and increasing doses from 0 to 100 Gy progressively reduced egg hatch, pupal development, adult emergence, and adult longevity, with stronger effects in males than in females (Seth and Reynolds 1993). In *Heliothis virescens*, irradiation of pupae approximately 2 day before adult emergence with 350 Gy γ-rays induced about 99% sterility in males, although the sterilizing dose also reduced adult emergence and adult longevity (Flint and Kressin 1967). Eggs deposited per female and male longevity also decreased with increasing irradiation dose (Vinson et al. 1969). In *Spodoptera litura*, previous studies have evaluated the effects of γ-ray irradiation on adult females (Sengupta et al. 2022), and the effects of X-ray irradiation on pupal development, flight, and reproduction have also been reported (Jiang et al. 2022). However, the effects of ^{60}Co γ-ray irradiation on *Spodoptera litura* pupae and the expression of sterility in their progeny remain insufficiently understood. Irradiation of younger pupae can induce sterility at lower doses, but it is also associated with high pupal mortality and deformity rates (Seth and Reynolds 1993). Thus, irradiation of older pupae may be a more appropriate approach for improving pupal survival after treatment.

In this study, we evaluated the effects of ^{60}Co γ-ray irradiation on 8-day-old female and male pupae of *Spodoptera litura* The effects of different irradiation doses on development, survival, and reproduction of *Spodoptera litura* were examined. Furthermore, we assessed the potential of pupal irradiation for suppressing reproduction in this species. The aim was to determine whether irradiation of late-stage pupae could provide a feasible basis for SIT-based management of *Spodoptera litura*

2 Materials and Methods

2.1 Insect rearing

The *Spodoptera litura* colony used in this study originated from individuals collected in Fenggang County (Zunyi City, Guizhou Province, China), and was maintained for a minimum of three generations on an artificial diet consisting of soybean meal, wheat bran and corn leaf powder at the Natural Enemy Mass-Rearing Center of Guizhou University. Insects were maintained within an environmental chamber set to 25 ± 1°C, 70 ± 5% RH, and a photoperiod of 12:12 h (light:dark).

2.2 Effects of irradiation on pupae

Healthy 8-day-old female and male pupae (weighing > 300 mg) were selected and placed separately in transparent boxes (277 × 168 × 68 mm) for irradiation, and wet gauze was provided in each box to maintain humidity. Thirty female pupae and 30 male pupae were exposed to ^{60}Co γ-rays at doses of 40, 70, 100, and 130 Gy at a dose rate of 3.45 Gy/min at an irradiation facility (Guizhou Jinnong Irradiation Technology Co., Ltd.), respectively. The same four doses were used in subsequent experiments 2–5. Each treatment was repeated three times, with unirradiated pupae (0 Gy) serving as the control. After irradiation, pupae were placed individually in plastic rearing boxes with separate compartments (120 × 178 × 130 mm) and maintained until adult emergence. Adult emergence was checked and recorded every 12 h, and deformed adults were counted to calculate the deformity rate. Adults were considered deformed if they failed to expand their wings after emergence.

2.3 Effects of γ-ray irradiation on reproductive performance

Newly emerged adults derived from irradiated pupae were paired with unirradiated virgin adults and transferred to transparent plastic cups (2000 mL) for mating. The mating combinations were as follows: N♀ × N♂ (control), N♀ × T♂, and T♀ × N♂ (N indicates unirradiated individuals, T indicates irradiated individuals). Eggs were collected and counted daily, and honey water was replaced regularly until all adults had died. Fifteen pairs were used for each treatment, and the experiment was repeated three times. The number of eggs laid per female, egg hatchability, and adult longevity were recorded. Additionally, egg infertility was calculated.

2.4 Effects of γ-ray irradiation on mating behavior

Ten pairs of three-day-old virgin females emerged from irradiated pupae and unirradiated virgin males were placed in an oviposition observation device for the analysis of female multiple mating ability. The mated unirradiated males were removed and immediately replaced with new unirradiated virgin males after mating was completed. Mating behavior was observed every 30 min until the females no longer mated or died. The mating history of dead female moths was assessed by counting spermatophores in the spermatheca under a stereomicroscope. The number of lifetime matings per female was recorded. The experiment was repeated three times.

Ten pairs of three-day-old virgin males emerging from irradiated pupae and unirradiated virgin females were placed in an oviposition observation device for the analysis of male multiple mating ability. The mated unirradiated females were removed and immediately replaced with new unirradiated virgin

females after mating was completed. Mating behavior was observed every 30 min until the males no longer mated or died. Successful mating was confirmed by the presence of spermatophores in the spermatheca. The number of lifetime matings per male was recorded. The experiment was repeated three times.Mating behavior observations were conducted in an environmental chamber (120 × 178 × 130 mm) under red light illumination in complete darkness (20:00 to 8:00). In this study, no further mating was defined as the absence of mating for two consecutive scotophases.

2.5 Effects of γ-ray irradiation on flight ability

Flight performance was assessed using a flight mill (SUN-FL, Jinan Chixin Electronic Technology Co., Ltd., Shandong Province, China). Three-day-old adults that developed from irradiated pupae and had intact wings were selected for testing (twelve adults per treatment dose). Insects were placed in 50 mL centrifuge tubes and anesthetized on ice for 1–2 min before testing. They were then carefully removed from the tubes with their wings spread, and the scales on the abdomen and thorax were gently brushed away. The thorax was then attached to the flight mill using a small amount of glue. Each test insect was vertically connected to the flight mill arm at an angle of 90° and allowed to fly continuously for 24 h in darkness at 25 ± 1°C and 70 ± 5% RH. Each treatment was repeated three times.

2.6 Effects of γ-ray irradiation on the F_1 generation

Eight-day-old male pupae were irradiated at four doses (40, 70, 100, and 130 Gy) as described in Section 2.2. Newly emerged male adults were paired with one-day-old unirradiated virgin females. Eggs were collected post-oviposition for viability assessment. First-instar larvae were individually transferred into polystyrene tubes (diameter: 24 mm; height: 95 mm) and reared on the artificial diet until pupation. After F_1 adult emergence, emergence and deformity were quantified. Newly emerged F_1 moths were then paired with unirradiated moths (N♂ × N♀ (control), N♂ × T_1♀, T_1♂ × N♀: T_1 indicates the F_1 generation from crosses between irradiated males and unirradiated females; N indicates unirradiated individuals). Fifteen pairs were included in each treatment, and the experiment was replicated three times. Eggs were collected every 24 h. The number of eggs laid per female, egg hatchability, and adult longevity were recorded. Additionally, egg infertility was calculated.

2.7 Data analysis

The effects of irradiation dose and sex on the deformity rate of irradiated pupae and reproductive parameters of parental adults were analyzed using two-way analysis of variance (ANOVA), with irradiation dose and sex included as the main factors. The effects of different irradiation doses on adult flight ability and developmental parameters of the F_1 generation were analyzed using one-way ANOVA. Prior to ANOVA, normality and homogeneity of variance were checked. Non-normal or heteroscedastic data were log-transformed, and all percentage data were arcsine square-root transformed. Where ANOVA indicated significant differences, Tukey's HSD test was used for post hoc multiple comparisons.

All statistical analyses were performed using SPSS Statistics 26.0 (IBM Corp., Armonk, NY, USA) and GraphPad Prism 10.1.2 (GraphPad Software, Boston, MA, USA).

3 Results

3.1 Effects of irradiation on pupae

Two-way ANOVA revealed that irradiation dose had no significant effect on adult deformity rate in *Spodoptera litura*. Sex also had no significant effect on deformity rate, and the interaction between irradiation dose and sex was not significant (Table 1). The deformity rate of male adults ranged from 15.56% to 17.78% in the treatment groups, which was higher than that of the control group (11.48%), but the difference was not significant. The deformity rate of female adults ranged from 22.78% to 23.61%, which was also higher than that of the control group (15.56%), but the difference was not significant (Fig. 1a). Overall, no clear dose-dependent relationship was observed between irradiation dose and the deformity rate of F_0 female and male adults.

Table 1
Two-way ANOVA of the effects of irradiation dose and sex on adult deformity rate, adult longevity, the number of matings, eggs deposited per female, and infertility rate in F_0 *Spodoptera litura* adults

Parameter	Source of Variation	df	MS	F	P
deformity rate	irradiation dose	4	0.008	0.735	0.579
	Sex	1	0.05	4.351	0.05
	irradiation dose × Sex	4	0	0.017	0.999
adult longevity	irradiation dose	4	5.372	1.708	0.156
	Sex	1	100.278	31.89	P < 0.001
	irradiation dose × Sex	4	0.194	0.062	0.993
the number of matings	irradiation dose	4	7.812	5.029	P < 0.001
	Sex	1	3.2	3.694	0.156
	irradiation dose × Sex	4	0.388	0.392	0.909
eggs deposited per female	irradiation dose	4	1788661.25	37.847	P < 0.001
	Sex	1	329022.72	6.962	0.012
	irradiation dose × Sex	4	6525.67	0.138	0.967
infertility rate	irradiation dose	4	1.07	131.269	P < 0.001
	Sex	1	0.001	0.17	0.683
	irradiation dose × Sex	4	0.015	1.87	0.135

3.2 Effects of γ-ray irradiation on reproductive performance

Two-way ANOVA revealed that irradiation dose significantly affected the number of eggs deposited per female and infertility rate, but had no significant effect on adult longevity. Sex significantly affected adult longevity and the number of eggs deposited per female, but did not significantly affect infertility. No significant interaction between irradiation dose and sex was detected for any of the measured parameters (Table 1).

The number of eggs deposited per female decreased with increasing irradiation dose. In the T♀ × N♂ treatment, females in the irradiated groups deposited 349.40-1377.60 eggs, compared with 1640.20 eggs in the control group. A similar dose-dependent decline was observed in the N♀ × T♂ treatment, in which females in the irradiated groups deposited 465.00-1526.40 eggs, compared with 1473.00 eggs in the control group (Fig. 1b).

Infertility increased with increasing irradiation dose in both crossing treatments. In the T♀ × N♂ treatment, infertility ranged from 45.74% to 85.93% in the irradiated groups, compared with 25.27% in the control group. Similarly, in the N♀ × T♂ treatment, infertility ranged from 39.22% to 90.14% in the irradiated groups, compared with 17.91% in the control group (Fig. 1c).

Irradiation slightly reduced the mean adult longevity of females, from 10.56 days in the control group to 9.22–10.11 days in the irradiated groups; however, the differences among dose treatments were not statistically significant. A similar pattern was observed in males, whose mean adult longevity decreased from 12.89 days in the control group to 11.44–12.11 days after irradiation, with no significant differences among dose treatments. Thus, irradiation at 40–130 Gy had no significant effect on adult longevity in F_0 adults under the conditions of this study, although adult longevity differed significantly between sexes (Fig. 1d).

3.3 Effects of γ-ray irradiation on mating behavior

The two-way ANOVA results indicated that irradiation dose significantly affected the number of matings, whereas sex and the irradiation dose × sex interaction were not significant (Table 1). In males (T♂ × N♂), the mean number of matings decreased from 2.75 in the control group to 2.75, 2.13, 2.00, and 0.75 at 40, 70, 100, and 130 Gy, respectively. Males irradiated at 130 Gy mated significantly fewer times than those in the control and 40 Gy groups. In females (T♀ × N♀), the mean number of matings decreased from 2.38 in the control group to 2.13, 1.63, 1.25, and 0.88 at 40, 70, 100, and 130 Gy, respectively. Females irradiated at 130 Gy mated significantly fewer times than those in the control group (Fig. 1e). Overall, irradiation reduced the number of matings in adults, particularly at the highest dose.

3.4 Effects of γ-ray irradiation on flight ability

One-way ANOVA revealed that irradiation at different doses had no significant effect on flight duration (6.73–8.39 h; F = 0.336; df = 4, 20; P = 0.850), flight distance (12.00-19.01 km; F = 0.926; df = 4, 20; P = 0.469), or flight speed (1.57–2.23 km/h; F = 0.815; df = 4, 20; P = 0.530) in adult females. Similarly, no significant differences were observed in flight duration (7.11–8.67 h; F = 0.275; df = 4, 20; P = 0.891), flight distance (11.57–19.55 km; F = 0.944; df = 4, 20; P = 0.459), or flight speed (1.68–2.47 km/h; F =

1.263; df = 4, 20; P = 0.317) in adult males. These results indicate that, under the conditions of this study, pupal-stage irradiation with 40–130 Gy ⁶⁰Co γ-rays did not significantly impair the flight performance of wing-intact *Spodoptera litura* adults (Table 2).

Table 2
Effects of different γ-ray irradiation doses on the flight ability of F_0 *Spodoptera litura*. Values are means ± SE. Means within a column followed by the same lowercase letter are not significantly different according to Tukey's HSD test ($P < 0.05$)

irradiation dose (Gy)	Duration (h)		Distance (km)		Velocity (km/h)	
	♀	♂	♀	♂	♀	♂
0	7.65 ± 0.81a	7.52 ± 0.76a	15.21 ± 0.81a	19.55 ± 3.07a	2.05 ± 0.16a	2.47 ± 0.26a
40	7.35 ± 1.16a	7.11 ± 1.53a	12.00 ± 4.01a	11.57 ± 3.68a	1.57 ± 0.30a	1.68 ± 0.32a
70	8.39 ± 0.93a	8.67 ± 0.73a	19.01 ± 3.03a	17.27 ± 2.85a	2.06 ± 0.22a	1.97 ± 0.22a
100	7.65 ± 0.61a	8.59 ± 1.94a	16.83 ± 2.14a	14.63 ± 2.60a	2.23 ± 0.31a	1.90 ± 0.27a
130	6.73 ± 1.44a	8.01 ± 1.03a	12.98 ± 3.62a	17.01 ± 3.28a	1.87 ± 0.36a	2.13 ± 0.24a

3.5 Effects of γ-ray irradiation on the F_1 generation

One-way ANOVA revealed that the deformity rate of F_1 adult females ranged from 46.99% to 54.88%, showing no significant difference from the control group (46.24%; F = 1.272; df = 4, 10; P = 0.344). Although the deformity rate of F_1 adult males fluctuated with increasing F_0 irradiation dose, ranging from 48.74% to 61.17%, it was not significantly different from that of the control group (43.45%; F = 3.380; df = 4, 10; P = 0.054; Fig. 2a).

Adult longevity in F_1 adult females ranged from 8.43 to 9.29 days, slightly lower than that in the control group (9.86 days), but the difference was not statistically significant (F = 1.241; df = 4, 30; P = 0.315). Similarly, adult longevity in F_1 adult males ranged from 10.57 to 11.71 days, also lower than that in the control group (12.14 days), with no significant difference detected among treatments (F = 0.877; df = 4, 30; P = 0.489). These results indicate that pupal-stage irradiation of the F_0 generation had no significant effect on adult longevity in F_1 adult females or males (Fig. 2b).

In the T_1♀ × N♂ crosses, eggs deposited per female ranged from 307.63 to 967.63 eggs, which was significantly lower than that in the control group (1441.25 eggs; F = 40.777; df = 4, 35; P < 0.001). Similarly, in the N♀ × T_1♂ crosses, eggs deposited per female ranged from 295.38 to 1065.88 eggs, also significantly lower than that in the control group (1453.75 eggs; F = 49.667; df = 4, 35; P < 0.001; Fig. 2c).

In the T_1♀ × N♂ crosses, F_1 infertility increased significantly with increasing F_0 irradiation dose, ranging from 51.31% to 92.78%, compared with 24.66% in the control group ($F = 248.227$; $df = 4, 35$; $P < 0.001$). In the N♀ × T_1♂ crosses, F_1 infertility also increased significantly with increasing F_0 irradiation dose, ranging from 46.06% to 92.75%, and was significantly higher than that in the control group (25.51%; $F = 187.509$; $df = 4, 35$; $P < 0.001$). Overall, F_1 infertility increased significantly as the F_0 pupal irradiation dose increased (Fig. 2d).

4 Discussion

A key requirement for SIT is the identification of an optimal irradiation dose that induces a high level of sterility while minimizing negative effects on insect quality (Bourtzis and Vreysen 2021). Adult deformity rate and longevity are important indicators for evaluating the quality of pupal irradiation, because deformed sterile insects are unable to search for food or mate successfully and are therefore of little value in SIT programs (Muthu Lakshmi et al. 2023). In the present study, irradiation caused nonsignificant increases in adult deformity rate, as well as reductions in adult longevity in both sexes. This result is generally consistent with that reported by Cagnotti et al. (2016). A similar phenomenon has also been observed in dipteran insects, including *Drosophila suzukii* (Krüger et al. 2018), whereas X-ray doses of 10–400 Gy significantly reduced adult longevity in *Xestia c-nigrum* (Chu et al. 2024). This may result from damage to somatic cells caused by excessively high irradiation doses. Irradiation had only a slight effect on adult emergence and basic survival of *Spodoptera litura* within the dose range tested here, indicating potential for SIT applications in terms of the survival ability and competitiveness of released sterile males under field conditions. In the present study, irradiated females had shorter adult longevity than irradiated males, suggesting that female reproductive capacity may have been more strongly suppressed, although the implications of this effect for release performance require further evaluation.

^{60}Co γ-ray irradiation of pupae did not significantly affect the flight ability of *Spodoptera litura* adults, which is consistent with previous findings for X-ray irradiation in this species (Jiang et al. 2022). In contrast, studies on *Zeugodacus cucurbitae* and *Bactrocera tau* have shown that irradiation can weaken flight ability (Cai et al. 2018; Muthu Lakshmi et al. 2023). This difference may be related to the greater radiation tolerance of lepidopteran insects. However, irradiation had a negative effect on the multiple-mating ability of *Spodoptera litura* in the present study. In both sexes, the number of matings declined as irradiation dose increased, and at 130 Gy, the mean number of matings per adult was less than one. Irradiation at a high dose significantly reduced the number of matings by females, whereas the number of matings by males showed a decreasing trend but did not reach statistical significance.

The number of eggs deposited per female and egg hatchability are important quality parameters for evaluating sterility in SIT. In this study, irradiation significantly reduced the number of eggs deposited per female in the F_0 mating combinations and increased the infertility rate of F_1 eggs. Similar effects have been reported in *Aedes aegypti* and *Ae. albopictus* (Bond et al. 2019). The same pattern was also observed in progeny derived from irradiated male pupae, indicating that irradiation-induced sterility

effects can be expressed in subsequent generations. These results suggest that irradiation of male pupae has potential for inducing inherited sterility. In Lepidoptera, lower irradiation doses that induce F_1 sterility may improve the quality and competitiveness of released moths, whereas higher doses may cause more severe somatic damage (Carpenter et al. 2009). Therefore, the optimal dose is not necessarily the dose that produces the highest sterility, but rather the dose that maximizes inherited sterility while minimizing reductions in insect quality. In the present study, the relatively high deformity rate in the F_1 control group and the relatively high infertility rate of F_2 eggs in the control group may be related to laboratory colony degeneration.

Egg hatch decreased progressively with increasing irradiation dose, which is consistent with findings in *Eldana saccharina* (Walton and Conlong 2016), as did the number of eggs deposited per female. However, the number of eggs deposited in the irradiated-male treatment remained higher than that in the irradiated-female treatment. This result is consistent with the findings of Traut (1977) and suggests that female germ cells are more radiosensitive than male germ cells (Blomefield et al. 2010).

Although further increases in irradiation dose may induce higher sterility, excessive irradiation may further impair the biological quality of irradiated *Spodoptera litura* Considering both sterility induction and adult quality parameters, 70 and 100 Gy maintained relatively high sterility levels while having less effect on adult flight ability, adult longevity, and mating ability. These doses may therefore be suitable candidates for subsequent field-cage trials and evaluations of release competitiveness. Before large-scale release, small-scale field-cage experiments are needed to further assess the feasibility of SIT or inherited sterility programs for *Spodoptera litura*

Declarations

Competing interests

The authors declare that they have no competing interests.

Ethics approval

Not applicable. This study did not involve human participants, human data, human biological material, or vertebrate animals.

Consent to participate

Not applicable.

Author Contribution

A: Conceptualization, data curation, investigation, formal analysis, visualization, writing - original draft, and writing - review and editing. B.C: Investigation. D.E: Conceptualization and funding acquisition. F: Conceptualization, supervision, and writing - review and editing. G: Resources. H: Conceptualization, data curation, funding acquisition, supervision, and writing - review and editing.

Acknowledgments

This research was funded by the China National Tobacco Corporation Project (110202201022(LS-06)), the International Atomic Energy Agency (IAEA) Technical Cooperation Program (CPR5028), the IAEA Coordinated Research Project D41028 (26368), the Hundred-Level Innovative Talent Foundation of Guizhou Province (GCC[2022]0281), and the Guizhou Provincial Key Laboratory for Tobacco Quality Improvement and Efficiency Enhancement (Qian Ke He Ping tai ZSYS [2025]028).

Data Availability

The data supporting the findings of this study are available on figshare through the following private link for peer review: https://figshare.com/s/c328e47638dd5db270df. A reserved DOI has been created: https://doi.org/10.6084/m9.figshare.32834735. The dataset will be made publicly available upon publication.

References

1. Bakri A, Mehta K, Lance DR (2005) Sterilizing insects with ionizing radiation. In: Dyck VA, Hendrichs J, Robinson AS (eds) Sterile insect technique: Principles and practice in area-wide integrated pest management. Springer, Dordrecht, pp 233–268. https://doi.org/10.1007/1-4020-4051-2_9
2. Basso JV, Labbé R, Scott-Dupree C (2024) Assessing the sterility and quality of gamma-irradiated pepper weevils, Anthonomus eugenii (Coleoptera: Curculionidae), toward the development of the sterile insect technique. Pest Manag Sci 80:1692–1701. https://doi.org/10.1002/ps.7898
3. Bernays EA (1998) Evolution of feeding behavior in insect herbivores: Success seen as different ways to eat without being eaten. Bioscience 48:35–44. https://doi.org/10.2307/1313226
4. Blomefield TL, Bloem S, Carpenter JE (2010) Effect of radiation on fecundity and fertility of codling moth Cydia pomonella (Linnaeus) (Lepidoptera: Tortricidae) from South Africa. J Appl Entomol 134:216–220. https://doi.org/10.1111/j.1439-0418.2008.01377.x
5. Bond JG, Osorio AR, Avila N et al (2019) Optimization of irradiation dose to Aedes aegypti and Ae. albopictus in a sterile insect technique program. PLoS ONE 14:e0212520. https://doi.org/10.1371/journal.pone.0212520
6. Bourtzis K, Vreysen MJB (2021) Sterile insect technique (SIT) and its applications. Insects 12:638. https://doi.org/10.3390/insects12070638

7. Bragard C, Dehnen-Schmutz K, Di Serio F et al (2019) Pest categorisation of Spodoptera litura. EFSA J 17:5765. https://doi.org/10.2903/j.efsa.2019.5765
8. Cagnotti CL, Andorno AV, Hernández CM, Carabajal Paladino LZ, Botto EN, López SN (2016) Inherited sterility in Tuta absoluta (Lepidoptera: Gelechiidae): Pest population suppression and potential for combined use with a generalist predator. Fla Entomol 99(Special Issue 1):87–94. https://doi.org/10.1653/024.099.sp112
9. Cai J, Yang H, Shi S, Zhong G, Yi X (2018) Behavioral, morphological, and gene expression changes induced by ^{60}Co γ-ray irradiation in *Bactrocera tau* (Walker). Front Physiol 9:118. https://doi.org/10.3389/fphys.2018.00118
10. Carpenter JE, Marti OG, Wee SL, Suckling DM (2009) Cytological attributes of sperm bundles unique to F_1 progeny of irradiated male Lepidoptera: Relevance to sterile insect technique programs. Fla Entomol 92:80–86. https://doi.org/10.1653/024.092.0113
11. Chen YT, Guo DQ, Wang JJ (2011) Application of irradiation technology in tobacco industry. Chin Tob Sci 32(2):90–95. https://doi.org/10.3969/j.issn.1007-5119.2011.02.020[in Chinese]
12. Chu S, Liu B, Li H, Lu K, Lu Y (2024) Effect of X-ray irradiation on the biological parameters of Xestia c-nigrum. Front Physiol 15:1362991. https://doi.org/10.3389/fphys.2024.1362991
13. Flint HM, Kressin EL (1967) Gamma irradiation of pupae of the tobacco budworm. J Econ Entomol 60:1655–1659. https://doi.org/10.1093/jee/60.6.1655
14. Gandhi BK, Patil RH, Srujana Y (2016) Field resistance of Spodoptera litura (Fab.) to conventional insecticides in India. Crop Prot 88:103–108. https://doi.org/10.1016/j.cropro.2016.06.009
15. Grace ADG, Prasada Rao GMV, Krishnayya PV, Manoj V, Srinivasa Rao V (2024) Insecticide resistance in Spodoptera litura (Fabricius) (Noctuidae: Lepidoptera) to diamide and benzoyl phenylurea insecticides. Int J Trop Insect Sci 44:2287–2292. https://doi.org/10.1007/s42690-024-01318-1
16. Hallman GJ, Blackburn CM (2016) Phytosanitary irradiation. Foods 5:8. https://doi.org/10.3390/foods5010008
17. Helinski MEH, Parker AG, Knols BGJ (2009) Radiation biology of mosquitoes. Malar J 8(Suppl 2):S6. https://doi.org/10.1186/1475-2875-8-S2-S6
18. International Atomic Energy Agency (2015) Manual of good practice in food irradiation: Sanitary, phytosanitary and other applications (Technical Reports Series No. 481). International Atomic Energy Agency, Vienna
19. Jiang S, Fu XW, Jiang SS, Yang XM, Zhao HY, Wu KM (2022) Effect of X-ray irradiation on development, flight, and reproduction of Spodoptera litura. Front Physiol 13:947848. https://doi.org/10.3389/fphys.2022.947848
20. Khan I, Khan GZ, Khan J, Amin M (2024) Assessment of radiation-induced sterility, longevity, and reproductive characteristics of the Aedes aegypti (Diptera: Culicidae) strain of Swat: A step towards the implementation of SIT in Pakistan. J Vector Borne Dis 61:267–274. https://doi.org/10.4103/jvbd.jvbd_131_23

21. Krüger AP, Hoffmann Schlesener DC, Martins LN, Wollmann J, Deprá M, Garcia FRM (2018) Effects of irradiation dose on sterility induction and quality parameters of Drosophila suzukii (Diptera: Drosophilidae). J Econ Entomol 111:741–746. https://doi.org/10.1093/jee/tox349
22. LaChance LE, Graham CK (1984) Insect radiosensitivity: Dose curves and dose-fractionation studies of dominant lethal mutations in the mature sperm of four insect species. Mutat Res 127:49–59. https://doi.org/10.1016/0027-5107(84)90139-8
23. Marec F, Vreysen MJB (2019) Advances and challenges of using the sterile insect technique for the management of pest Lepidoptera. Insects 10:371. https://doi.org/10.3390/insects10110371
24. Muthu Lakshmi BC, Panduranga GS, Rajesh A, Reddy K, Ramanamurthy B (2023) Gamma radiation for sterile insect quality in melon fly, Zeugodacus cucurbitae (Coquillett). Int J Trop Insect Sci 43:949–960. https://doi.org/10.1007/s42690-023-00988-7
25. Qin HG, Wang DD, Ding J, Huang RH, Ye ZX (2006) Host plants of Spodoptera litura. Acta Agriculturae Jiangxi 18(5):51–58. https://doi.org/10.3969/j.issn.1001-8581.2006.05.017[in Chinese]
26. Rao RL (2023) Occurrence characteristics and integrated control measures of Spodoptera litura on tobacco. Agricultural Sci Technol Communication 2023(9):200–202 [in Chinese]
27. Sengupta M, Vimal N, Angmo N, Seth RK (2022) Effect of irradiation on reproduction of female Spodoptera litura (Fabr.) (Lepidoptera: Noctuidae) in relation to the inherited sterility technique. Insects 13:898. https://doi.org/10.3390/insects13100898
28. Seth RK, Patil BV, Khan Z et al (2020) Radiation biology of a serious tropical pigeon pea pest, Maruca vitrata (Fabricius) (Lepidoptera: Crambidae), and potential of radiation-mediated inherited F_1 sterility technique for pest suppression. Int J Radiat Biol 96:532–544. https://doi.org/10.1080/09553002.2020.1707323
29. Seth RK, Reynolds SE (1993) Induction of inherited sterility in the tobacco hornworm Manduca sexta (Lepidoptera: Sphingidae) by substerilizing doses of ionizing radiation. Bull Entomol Res 83:227–235. https://doi.org/10.1017/S0007485300034714
30. Traut W (1977) A study of recombination, formation of chiasmata and synaptonemal complexes in female and male meiosis of Ephestia kuehniella (Lepidoptera). Genetica 47:135–142. https://doi.org/10.1007/BF00120178
31. Vinson SB, Londono RL, Bartlett AC (1969) Effect of gamma radiation on tissues of the tobacco budworm, Heliothis virescens. Ann Entomol Soc Am 62:1340–1347. https://doi.org/10.1093/aesa/62.6.1340
32. Walton AJ, Conlong DE (2016) Radiation biology of Eldana saccharina (Lepidoptera: Pyralidae). Florida Entomologist 99(Special Issue. 136–42. https://doi.org/10.1653/024.099.sp106
33. Wei Z, Chen X, Yang X, Yang X (2025) A review of sterile insect technique in Lepidoptera pest management: Advances and applications. Entomol Generalis 45:1241–1258. https://doi.org/10.1127/entomologia/3696
34. Wu CX, Yang MF, Yao MM, Zeng ZH (2016) Diurnal activity rhythm and time budgets of adult behavior of Spodoptera litura (Fabricius) (Lepidoptera: Noctuidae) after pairing. Acta Phytophylacica

Sinica 43:979–985 [in Chinese]

Figures

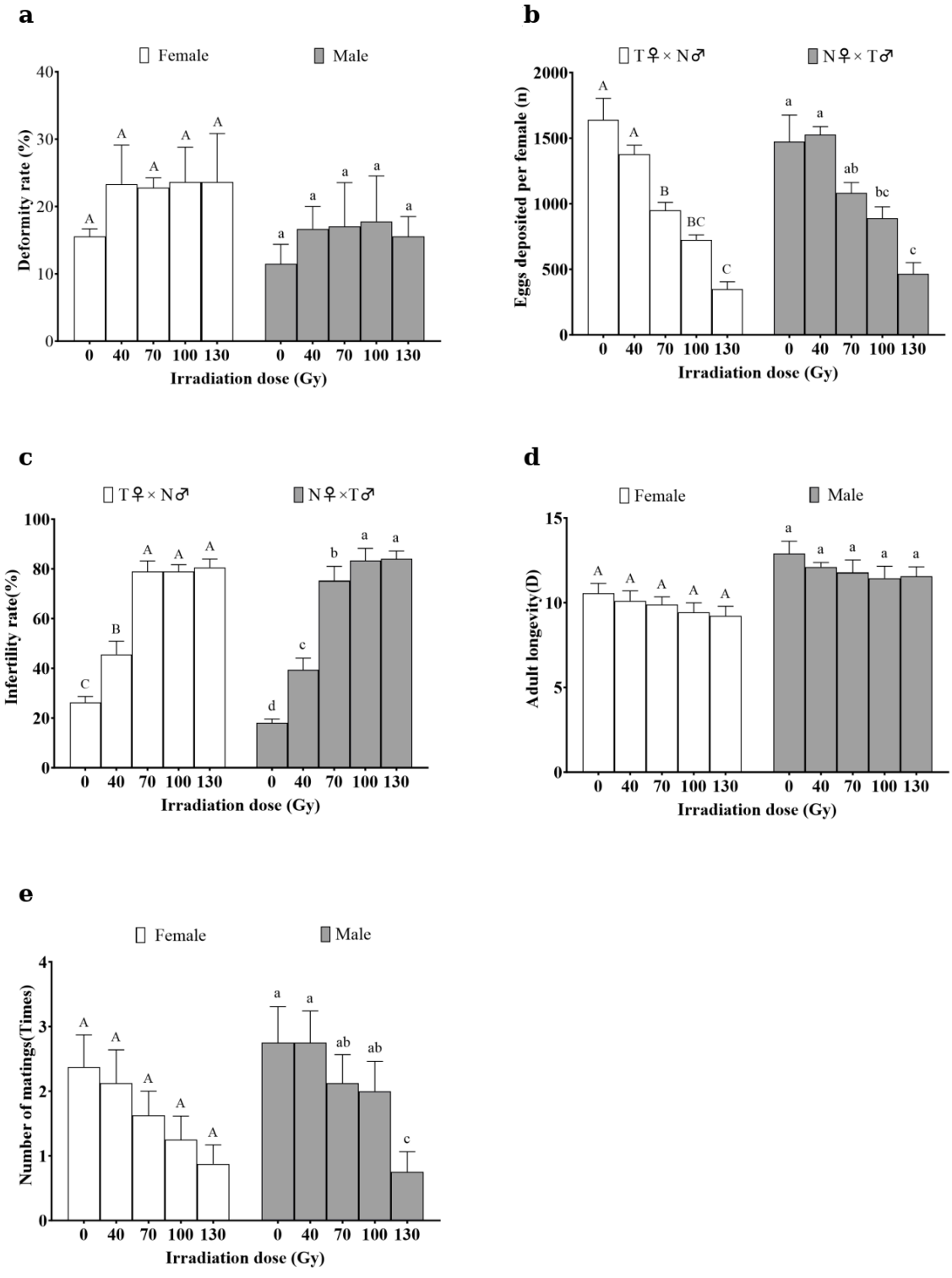


Figure 1

Effects of different γ-ray irradiation doses on the deformity rate (a), mean (± SE) number of eggs deposited per female (b), infertility rate (c), adult longevity (d), and number of matings (e) in parental *Spodoptera litura* adults. The mating combinations were N♀ × T♂ and T♀ × N♂, where N represents unirradiated individuals and T represents irradiated individuals. The N♀ × N♂ group was used as the control (0 Gy). Different lowercase letters indicate significant differences among irradiation doses according to Tukey's HSD test (P < 0.05)

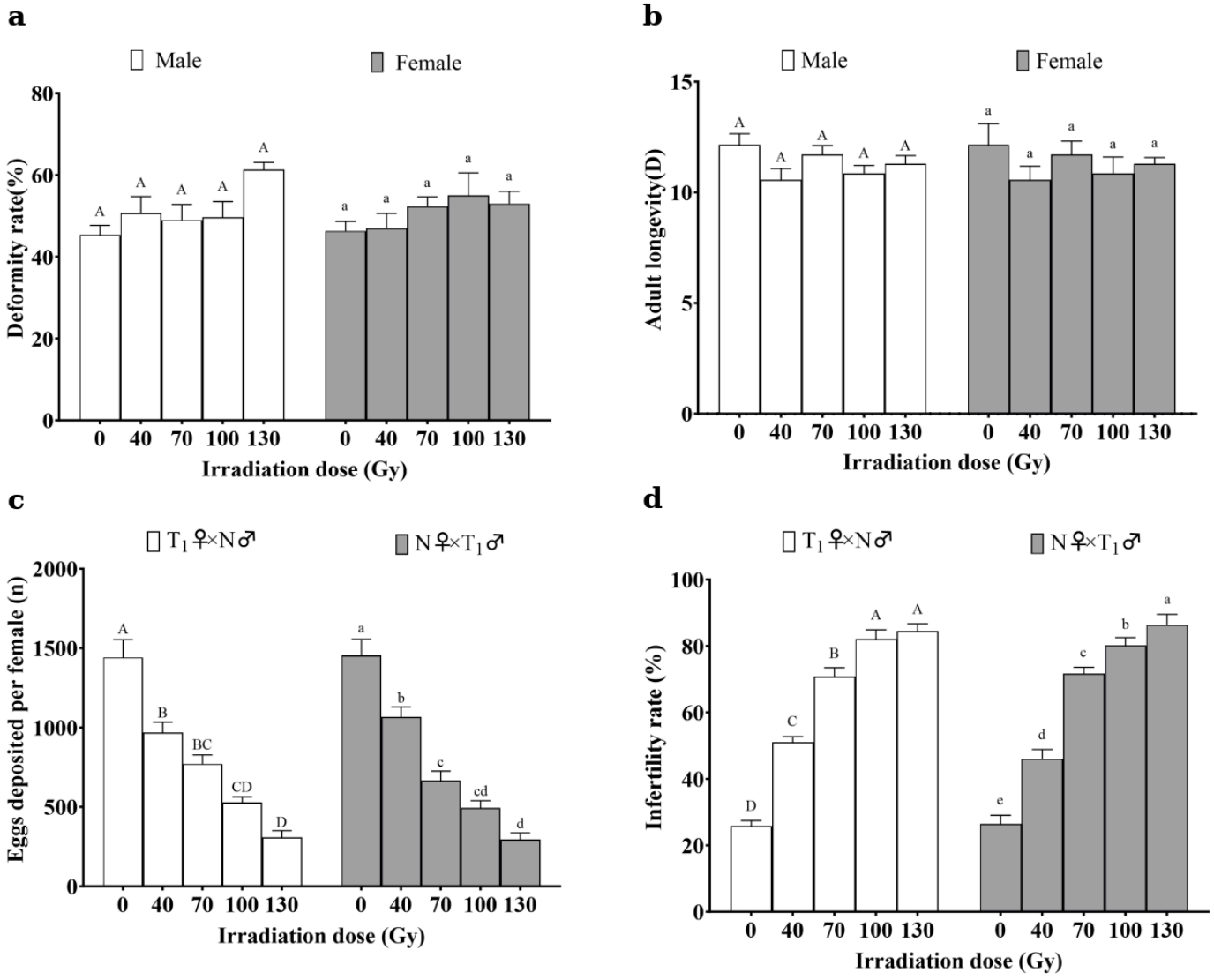


Figure 2

Effects of different γ-ray irradiation doses on the deformity rate (a), mean (± SE) adult longevity (b), number of eggs laid per female (c), and infertility rate (d) of F_1 *Spodoptera litura* adults. The mating combinations were N♀ × T_1♂ and T_1♀ × N♂, with N♀ × N♂ used as the control (0 Gy). N represents normal individuals whose parents were both unirradiated, whereas T_1 represents F_1 individuals derived from irradiated F_0 male pupae. Different lowercase letters indicate significant differences among irradiation doses according to Tukey's HSD test (P < 0.05)