Andhra Pradesh J Agril. Sci : 9(3): 227-232, 2023

RADIATION BIOLOGY OF FALL ARMYWORM, *Spodoptera frugiperda* (J.E. Smith)

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Date of Receipt: 27-07-2023 Date of Acceptance: 28-09-2023

ABSTRACT

Maize (*Zea mays* L.) is 3rd most important cereal crop next to rice and wheat sharing about 2% of world's maize production. Maize is called as "Queen of cereals" due to its productivity potential over other cereal crops. Fall armyworm is a serious pest of maize known to feed on more than 350 plant species belonging to cereals, millets, cotton and vegetables. The use of insecticides as a sole tool in the management of insect pests has potential drawbacks such as the development of insecticide resistance, persistence of pesticide residues on crop produce, outbreak of secondary insect pests and pest resurgence. Determination of the optimum dose of gamma radiation for male sterilization without compromising the quality of adults in terms of adult emergence, adult longevity and survival of sterile males is crucial in the successful application of SIT. Exposure of mature pupae of *Spodoptera frugiperda* to gamma radiation (Co-60 source) at doses ranging from 25 to 100 Gy had least negative impacts on adult emergence and deformation. Further increase in radiation doses ranged between 125-200 Gy significantly decreased the adult emergence with increase in percentage of deformation. The longevity of adult moths from the pupae irradiated at 25, 50 and 75 Gy was 8.67, 8.33 and 7.5 days respectively and on par with control. The longevity of irradiated males at 100 and 125 Gy was 6.00 and 5.00 days, respectively. Whereas males irradiated at 150, 175 and 200 Gy lived up to 4.33, 3.67 and 2.50 days respectively. Males exposed to gamma radiation showed an inverse relationship between the percentage of survival and radiation doses. At 25 and 50 Gy, survival rates were 72.33% and 67.50%, respectively and were significantly different from the control (76.20%). No significant difference was found at 75Gy and 100 Gy with survival rates of 61% and 59%, respectively. Percentage of survival of male moths from the pupae irradiated at 125, 150, 175 and 200 Gy significantly reduced to 47.00%, 41.00%, 26.80% and 21.50% respectively.

KEYWORDS: Fall armyworm, Gamma radiation, Quality parameters, Adult longevity.

INTRODUCTION

Maize (*Zea mays* L.) is 3rd most important cereal crop next to rice and wheat sharing about 2% of world's maize production. Maize is called as "Queen of cereals" due to its productivity potential over other cereal crops. In India, the area under cultivation of maize is 9.9 million ha with an annual production of 30 million tonnes during 2020-2021 (www.indiastat.com, 2021) contributing nearly 10% to the national food basket. In Andhra Pradesh, the area under cultivation of maize is 0.09 lakh ha with an annual production of 0.31 lakh tonnes (www.indiastat.com, 2021). Maize is used as a basic raw material in thousands of industrial products including starch, oil, protein, food sweeteners, cosmetics and pharmaceuticals.

Fall armyworm is a serious pest of maize native to tropical and subtropical regions of America. It is also known to feed on more than 350 plant species belonging to cereals, millets, cotton and vegetables. In India, FAW was first reported on maize in the Shivamogga district of Karnataka during May-June, 2018 by Sharanabasappa *et al*. (2018). Later in the year 2019, FAW was reported in Andhra Pradesh, Telangana, Maharastra, Tamil Nadu, Bihar, Chattisgarh, Gujarat, Odisha, West Bengal and Madhya Pradesh (Vishwakarma *et al*., 2020). Fall armyworm attacks maize plants at all phases of crop development, but it is most common during the whorl stage, which lasts up to 45 days after sowing. Early instars feed by scraping and skeletonizing the upper epidermis of leaves resulting in short pin holes (window pane) on leaves. The damage by the late instars (4th instar onwards) results in extensive defoliation of leaves and the presence of faecal pellets in whorls. Due to this pest, maize production in India reduced by 5-10% equivalent to 0.04 to 0.075 million tonnes (Suby *et al*., 2020). Farmers and commercial growers depend predominately on the use of synthetic insecticides for controlling this insect Pest. The use of insecticides as a sole tool in the management of insect pests has potential drawbacks such as the development of insecticide resistance, persistence of pesticide residues on crop produce, outbreak of

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secondary insect pests and pest resurgence (Togbe *et al*., 2014). Hence, it is necessary to explore other alternative methods that are ecologically safe.

SIT (Sterile Insect Technique) is a species specific, non-polluting and environmental friendly method of insect control that relies on mass production and sterilization of target insects by radiation and systematic release of sterile males into the target environment to induce sterility in a wild population (Knipling, 1979). It is a method of pest control that uses radiation to generate mutations or chromosomal abnormalities in germ cells, resulting in reproductively sterile adult insects (Reichard, 2002). Determination of the optimum dose of gamma radiation for male sterilization without compromising the quality of adults in terms of adult emergence, adult longevity and survival of sterile males is crucial in the successful application of SIT. Because, high doses of radiation increase the sterility but decrease the mating competitiveness of sterile males. Whereas lower doses may not induce enough sterility (Calkins and Parker, 2005; Collins *et al.,*2008). To induce the desired level of sterility with the least negative impacts on sexual performance of sterile insects, the radiation dose must be optimized. An optimum dose of gamma radiation should not interfere with the ability of sterile males to compete with wild males for their wild female mates in the released Environment (Dyck *et al*., 2005). Hence the quality of sterile males must be assessed by studying the effects of gamma radiation on quality parameters *viz.,* Adult emergence, Adult longevity and Survival under food stress which primarily reflects the male's ability to survive, interact with its environment, locate, mate and fertilize females of target wild populations (Collins *et al.,* 2008; Collins *et al.,* 2009).

MATERIAL AND METHODS

The studies on the effect of different doses of gamma radiation on biological parameters of Fall armyworm, *Spodoptera frugiperda* were conducted during 2021-22 at Insectary, Department of Entomology, S.V. Agricultural College, Tirupati.

Mass Rearing and Maintenance of *Spodoptera frugiperda*

The initial culture of Fall armyworm was obtained by collecting egg masses and early instar larvae from farmer's fields and the College farm of S.V. Agricultural College, Tirupati. Each larva was reared separately in small plastic containers provided with an artificial diet (Barreto *et al*., 1999) to avoid cannibalism up to the sixth instar under controlled laboratory conditions. Pupae were collected and transferred to adult rearing cages (30×30×30cm) provided with 10% honey solution (Cotton swabs) as an adult diet and water-soaked cotton swabs in 100 ml conical flasks as a source of water. The composition of an artificial diet used in the experiment has given in Table 1.

Gamma Radiation Treatment

Pupae required for irradiation were obtained by rearing the larvae on artificial diet (Barreto *et al.,* 1999). Male and female pupae were differentiated by observing the distance between the genital opening and anal slit. The distance between the genital opening and anal slit is more in females (Plate 2). The male pupae (7- 8 days old) were taken in plastic Petri plates provided with blotting paper at the base and the inner sides were lined with non-absorbent cotton to avoid damage to the pupae. Petri plates containing male pupae were exposed to gamma radiation (Cobalt 60 source) at 0, 25, 50, 75, 100, 125, 150, 175 and 200 Gy at a discharge rate of 9 kGy/hr using a gamma chamber installed at ICAR-Indian Institute of Horticultural Research, Bengaluru, Karnataka.

Quality Parameter Tests of Parental Generation

Male pupae after exposure to different doses of gamma radiation were brought to the Insectary and confined to adult rearing cages (30 × 30 × 30 cm) in three replications for each dose. The quality parameter tests *viz.,* Adult emergence (%), deformation (%), adult longevity (days) and survival under food stress (%) of parental generation were recorded as follows;

Adult emergence

Fifty irradiated male pupae from each dose were taken in a glass petri dish and kept in an adult emergence

Table 1. Diet composition for *Spodoptera frugiperda* (Barreto *et al.,* 1999)

S. No.	Ingredient	Per litre of diet
1	Besan flour	240.0 g
2	Corn flour	240.0 g
3	Yeast	72.0 g
4	Ascorbic acid	7.3 g
5	Sorbic acid	2.4 g
6	Methyl paraben	4.4 g
7	Agar	20.0 g
8	Formaldehyde 10%	6.0 ml
9	Vitamin mix	10.0 ml
10	Distilled water	1.0 lit

cage (30 × 30 × 30 cm) provided with adult diet (10% honey solution) and water. After the complete ceasing of adult emergence (up to 5 days from the day of emergence), the number of adults emerged out of 50 pupae were worked out and expressed in percentage. Fifty unirradiated male pupae were also maintained as control and a similar procedure was followed.

Adult emergence (%) =

$$\frac{\text{Number of adults emerged}}{\text{Total number of pupae kept for adult emergence}} \times 100$$

Deformation

Fifty irradiated male pupae from each dose were taken in a glass petri dish and kept in an adult emergence cage provided with an adult diet and water. After the complete ceasing of adult emergence, the number of deformed pupae, partially emerged adults and deformed moths with defective wings and other appendages were recorded and expressed as per cent deformation. Fifty unirradiated male pupae were maintained as untreated control and similar procedure was followed.

Adult longevity

A study on adult longevity of irradiated males from each dose including control was conducted by confining freshly emerged moths to adult rearing cages (30×30×30 cm) provided with an adult diet and water. Cages were checked for adult mortality and the average longevity of adult moths was worked out and expressed in days.

Survival under food stress

It was conducted by confining 10 freshly emerged adult male moths from irradiated pupae at different doses into separate adult rearing cages without adult diet and

Table 2. Effect of gamma radiation on biological parameters of parental generation of Fall armyworm

Radiation dose (Gy)	Adult Emergence (%)*	Deformed adults (%)*	Adult longevity (Days)**	Survival under food stress (%)*
0 (Control)	88.00^{a} (69.74±1.02)	3.00^{e} (9.87±0.98)	9.00^{a} (3.16±0.09)	76.20^{a} (60.78±0.38)
25	83.13^{ab} (65.74±0.79)	4.10^{e} (11.53±1.32)	8.67^{a} (3.10±0.05)	72.33^{b} (58.24±0.21)
50	79.46^{bc} (63.05±1.07)	5.00^{de} (12.87±0.76)	8.33^{a} (3.05±0.04)	67.50^{c} (55.26±1.63)
75	75.90^{cd} (60.59±1.02)	7.50^{de} (15.78±1.35)	7.50^{a} (2.90±0.13)	61.00^{d} (51.34±0.34)
100	71.00^{d} (57.41±1.09)	9.00^{d} (17.43±0.57)	6.00^{b} (2.64±0.10)	59.00^{d} (50.16±0.37)
125	58.70^{e} (50.00±1.53)	13.80^{c} (21.73±1.29)	5.00^{bc} (2.44±0.00)	47.00^{e} (43.26±0.66)
150	36.30^{f} (36.99±1.99)	17.00^{c} (24.29±1.18)	4.33^{c} (2.30±0.15)	41.00^{f} (39.80±0.67)
175	27.00^{g} (31.25±1.49)	27.20^{b} (31.39±1.29)	3.67^{cd} (2.15±0.07)	26.80^{g} (31.15±0.93)
200	20.30^{h} (26.71±1.46)	35.90^{a} (36.77±1.52)	2.50^{d} (1.86±0.07)	21.50^{h} (27.61±0.54)
ANOVA	F=144.28; C.D.= 3.96.	F=60.98; C.D.=3.54.	F=24.84; C.D.=0.29.	F=242.02; C.D.= 2.26.

Figures in the parenthesis are transformed values ± standard errors.
*Arc sine transformation; ** Square root transformation

water. The number of moths that were survived after 48 hrs of commencement of test was recorded and expressed as per cent survival under food stress. A similar procedure was followed for control using unirradiated adult moths of the same age.

RESULTS

The pupae required for irradiation were obtained by rearing the larvae of Fall armyworm on an artificial larval diet. The mature male pupae (7-8 days old) were exposed to different doses of gamma radiation (Cobalt 60 source) at 25, 50, 75, 100, 125, 150, 175 and 200 Gy using a gamma chamber (GC- 5000, BRIT and AERB) at ICAR-Indian Institute of Horticultural Research, Bengaluru, Karnataka. Observations on quality parameters such as adult emergence, deformation, adult longevity and survival under food stress in parental generation were recorded (Table 2).

Adult Emergence

The percentage of adult emergence from the irradiated pupae were decreased with an increase in gamma radiation doses. Adult emergence of *Spodoptera frugiperda* at different doses (25 Gy to 200 Gy) ranged from 83.13% to 20.30%. The percentage of adult emergence at 25 Gy (83.13%) was statistically on par with the control (88.00%). Adult emergence at 50 Gy and 75 Gy are 79.46% and 75.90 %, respectively and were significantly different from control. 71.00% of adults were emerged from pupae irradiated at 100 Gy. Further increase in radiation doses; 125, 150, 175 and 200 Gy, emergence of adults drastically decreased to 58.70%, 36.30%, 27.00% and 20.30% respectively and were significantly different. A drastic reduction in adult emergence was recorded at higher doses of gamma radiation *i.e.* 125 Gy and onwards.

Deformation

Deformation includes deformed pupae/adults, partially emerged adults, adults with defective wings, legs and other appendages as a result of exposure to gamma radiation. The formation of deformed pupae/adults ranged from 4.10 to 9.00% at radiation doses ranging from 25 to 100 Gy. Percentage of deformation at 25, 50 and 75 Gy were statistically on par with control. Deformation at 100 Gy (9.00%) was on par with radiation doses ranging from 25 to 75 Gy. The percentage of deformation was increased with increase in gamma radiation doses at 125 (13.80%), 150 (17.00%), 175 Gy (27.20%) and 200 Gy (35.90%) compared to the remaining doses of gamma radiation.

Adult Longevity

Longevity is the duration of irradiated males survived provided with an adult diet and water. Adult longevity of unirradiated males was 9 days. The longevity period decreased with an increase in radiation dose. The longevity of adult moths from the pupae irradiated at 25, 50 and 75 Gy was 8.67, 8.33 and 7.5 days respectively and on par with control. The longevity of irradiated males at 100 and 125 Gy was 6.00 and 5.00 days, respectively, which are on par with each other. Whereas males irradiated at 150, 175 and 200 Gy lived up to 4.33, 3.67 and 2.50 days respectively. Adult longevity of male moths was reduced by 50% at higher doses of 150 Gy onwards.

Survival under food stress

It is the percentage of adults survived up to 48 hours without an adult diet and water. Males exposed to gamma radiation showed an inverse relationship between the percentage of survival and radiation doses. At 25 and 50 Gy, survival rates were 72.33% and 67.50%, respectively and were significantly different from the control (76.20%). No significant difference was found at 75Gy and 100 Gy with survival rates of 61% and 59%, respectively. Percentage of survival of male moths from the pupae irradiated at 125, 150, 175 and 200 Gy significantly reduced to 47.00%, 41.00%, 26.80% and 21.50% respectively.

It was found that radiation doses (up to 100 Gy) had least negative impacts on Quality parameters of male moths. Whereas at radiation doses ranging from 125 to 200 Gy, the Quality parameters such as adult emergence, deformation, adult longevity and survival under food stress were severely affected.

Discussion

Method of controlling insects using gamma radiation in support of autocidal biological control is one of the safest methods having no adverse effects on the environment. Since the discovery that mutation could be induced in insects by X-ray treatment, entomologists thought of sterilizing large numbers of insects and releasing them, whenever the insects are abundant as a means of pest control. The success of SIT program in inducing reproductive sterility in subsequent generations depends on the comparative competitiveness of the released sterile insects and the native populations. Hence, studying the effects of gamma radiation on biological parameters of Fall armyworm is very important in identifying the radiation dose that induce optimum sterility with least negative impacts on Quality parameters such as Adult emergence, deformation, adult longevity and survival under food stress of Fall armyworm.

Exposure of mature pupae of *Spodoptera frugiperda* to gamma radiation (Co-60 source) at doses ranging from 25 to 100 Gy had least negative impacts on Adult emergence and deformation. Further increase in radiation doses ranged between 125-200 Gy significantly decreased the adult emergence with increase in percentage of deformation. percentage of adult emergence was 71.00% at 100 Gy with deformation of <10% (i.e. 9.00%). Whereas further increase in radiation dose from 100 to 125 Gy; adult emergence was drastically reduced to 58.70% with increased percentage of deformation (13.80%). Similar results were reported by Hilmy *et al.* (1984) and Ibrahim and El-Naggar (2001) that irradiation of six-day old male pupae of *Spodoptera littoralis* at above 100 Gy significantly decreased the adult emergence and at 200 Gy adult emergence was completely inhibited.

An inverse relation between the radiation dose and adult emergence was also reported by Salem *et al.* (1983) who exposed pupae of *Ephestia kuehniella* to different doses of gamma radiation and they found that the rate of adult emergence was negatively correlated with increase in radiation doses. The present findings were concurrent Boshra and Mikhaiel (2006) who irradiated male pupae of *Ephestia calidella* at 200, 400, 600 and 800 Gy of gamma radiation and found that adult emergence decreased to 85.9, 68.8, 40% and 11.2% respectively. Similarly, Dhoubi and Abderahmane (2002) irradiated male pupae of carob moth, *Ectomylois ceratoniae* at 500 Gy and found that the percentage of adult emergence was reduced to 6% at 500 Gy.

In the present study, radiation doses at 125 Gy onwards significantly increased the percentage of deformation in *Spodoptera frugiperda.* These results are corroborated with earlier reports by Hasaballa *et al*. (1985) and El-Sinary (1987) who worked on *Spodoptera littoralis* reported that increasing doses of gamma radiation increased the percentage of deformation and they also reported that complete lethality was obtained at higher doses; 350 and 400 Gy. Our results are inclined with Seth *et al.* (2020) who studied the radiation biology of *Maruca vitrata* and found that radiation doses; 100, 150 and 200 Gy resulted in adult emergence of 60.70, 51.10 and 14.00% ,where adult emergence was severely affected at 150 and 200 Gy. There was no emergence of adult at 250 Gy. They also reported that percentage of malformed adults increased at 150 Gy(24.50%) and 200 Gy (100%) when compared to 100 Gy (11.20%). Adult emergence and deformed adults at unirradiated control were 72.00% and 2.58% respectively. These findings are very close with our research results.

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