

Interaction of Substerilizing Gamma Radiation and Thiodicarb Treatment for Management of the Tobacco Caterpillar *Spodoptera litura*

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The F₁ sterility technique (inherited sterility using substerile insects) has been proposed for reproductive suppression of lepidopteran pests. Management of lepidopteran pests using F₁ sterility may be greatly influenced by other possible strategies, including chemical control measures. Within this context, a laboratory investigation was undertaken of the tobacco caterpillar *Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae) to assess the bioefficacy of a substerilizing dose (70 Gy) of gamma radiation on bio-characteristics (*viz.*, adult survival, fecundity, egg hatch, F₁ larval weight, F₁ pupation, F₁ sex ratio); to establish the median lethal dose (LD₅₀) of an oxime carbamate insecticide, thiodicarb (Larvin[®]75 WP), to *S. litura*; and determine the interaction of thiodicarb with the F₁ insects derived from a substerilizing gamma dose. A dose of 70 Gy administered to 7-day-old male pupae reduced the the eclosion by ~ 10%. When the eclosed males (derived from treated pupae) were mated with normal females, the fecundity and fertility were decreased as compared with control (0 Gy). Analysis of body weight of the F₁ larvae showed no significant influence of radiation, *i.e.*, growth was comparable to that of normal progeny, which is a positive factor in the sterile-insect technique. Bioassay on newly molted 6th instar larvae with thiodicarb (Larvin[®]75 WP) showed that the LD₅₀ of the insecticide was 6.76 $\mu\text{g g}^{-1}$ in the combined treatment (radiation to P₁ male pupae + thiodicarb to F₁ larvae), as compared with 28.67 $\mu\text{g g}^{-1}$ in the chemical treatment (thiodicarb), indicating that the toxicity of the insecticide to the F₁ progeny was increased 4.24 times by the radiation treatment, which is a markedly pronounced effect. Further studies of the combined effect of radiation and insecticide on pupation and sex ratio of F₁ progeny showed that pupation was affected more by the combined treatment than by the insecticide alone, whereas the sex ratio was skewed in favor of males in both the combined treatment and the chemical treatment, indicating that thiodicarb was selectively more toxic to females. The possible interaction and potential and the feasible approaches of integrating F₁ sterility and thiodicarb treatment are discussed for management of the lepidopteran pest *S. litura*.

KEY WORDS: *Spodoptera litura*; gamma radiation; F₁ sterility; reproduction suppression; sex ratio; thiodicarb.

INTRODUCTION

Spodoptera litura (Fabricius) is a common defoliator of polyphagous nature, and it has attained an economically serious status in the Indian subcontinent (9,22,26,42). It is

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reported to have developed immense resistance to many of the commonly used insecticides (4,33,43), which has made control of this insect pest extremely difficult. This is considered to be one of the main causes for recent outbreaks in the state of Andhra Pradesh, India (44). Increasing concerns about the effects of chemical pesticides on the environment and insecticide resistance have encouraged entomologists to seek environmentally sound alternative methods to control this pest.

Manipulation of the reproductive potential of insect pest species rather than instant killing, is an environmentally favored approach in protection. Such means may include the mass release of sterile male insects, with an aim of suppressing the reproduction of the endogenous females (7,20), the disruption of pheromone communication between the sexes for interfering with pest reproduction (5), etc. Success in such efforts for suppressing pest populations would lead to the desirable effect of reducing reliance on chemical insecticides.

Lepidopteran insects show high radio-resistance as compared with most other insects (28) and require higher radiation doses for 100% sterilization, which may cause more debilitating effects with enhanced somatic damage and reduced competitiveness of radiated insects. To obviate such a situation, substerilizing doses of radiation have been proposed to be used for inducing inherited sterility to manage the *S. litura* population (35). Inherited sterility in the progeny of treated male lepidopterans was shown to have a potential in suppressing populations of the pests (19,21,28,29). Some attempts have been made to study and employ F₁ sterility for suppression of lepidopteran pests (*Pectinophora*, *Spodoptera*, *Crociodolomia*, *Earias* spp.) in the Indian subcontinent (17,32,36,39,41).

Use of a substerilizing radiation dose to induce inherited sterility in *S. litura* would result in F₁ survivors whose viability and survival might depend upon interaction with prevailing environmental conditions, which could include an insecticide treatment for insect control. In a situation in which insecticide treatment is also being applied, the F₁ survivors with inherited sterility would definitely interact and influence the overall management of the pest. In view of this, the thiodicarb susceptibility of F₁ progeny of *S. litura* treated as male pupae with 70 Gy, was ascertained to understand the compatibility of the F₁ sterility technique and thiodicarb treatment for management of this pest.

MATERIALS AND METHODS

THE TEST INSECT

The test insect used in the present studies, *Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae), was maintained on castor (*Ricinus communis* Linn.) leaves at 27±2 °C, 75 ± 5% r.h. and 12:12, L:D photoperiod under laboratory conditions. To prevent microbial infection (pertaining to bacteria or nuclear polyhedrosis virus) in the culture, the castor leaves were washed with dilute potassium permanganate solution (~ 0.001%), followed by water; the leaves were air-dried. All the glassware used in the experiments was washed thoroughly in detergent, treated with 2% formalin and then dried in an oven at 70 °C for 4 h to check microbial contamination in the insect culture.

Adults of *S. litura* were fed on 10% sucrose solution and kept in Perspex cages (20 × 20 × 20 cm) for mating and oviposition. A fresh castor leaf with its stalk dipped in a small bottle of water, was placed in the cage to serve as an oviposition site. Eggs were collected daily and stored in plastic cups under high humidity for hatching. The neonate larvae were transferred onto tender castor leaves for feeding and further development.

GAMMA IRRADIATION

Stage of the insect for irradiation In the present study 7-day-old male pupae were selected for irradiation, since most of the adult differentiation was over at this age. Due to its non-feeding nature and quiescent stage, the pupae were simple to handle, and could be sterilized with a moderate dosage. In many instances the pupal stage is considered to be the most appropriate one for irradiation, rather than younger stages, because eggs and larvae are radio-sensitive and the radiation levels required to induce sterility in these stages often cause premature death, or result in the development of abnormal adults (31).

Source The test insect was irradiated in a well-type ^{60}Co source (Gamma-5000 irradiator, BRIT, BARC, Trombay; dose rate 9 Gy min^{-1}), at the Institute of Nuclear Medicine and Allied Sciences, Delhi.

Dose used for irradiation The present experiment required the use of gamma radiation at a dose high enough to result in a reasonable range of inherited sterility among the F_1 survivors with satisfactory competence. In view of the observations of Seth (35) during radio-biological studies of *S. litura*, a substerilizing dose of 7 Krad (70 Gy) was chosen for the present investigations, keeping in mind its moderate substerilizing nature and the reasonable level of F_1 survival.

Reproductive performance of irradiated *S. litura* In order to assess the reproductive performance of the treated males (T-males, derived from pupae exposed to 70 Gy), ten individual pairs of T-male \times normal (N)-female were taken as a treated set. The egg-laying capacity and percentage of egg hatch of the mated females were determined; each mated female's data constituted one replicate. The reproductive performance of the T-males was compared with that of N-insects assessed in the similar manner.

INSECTICIDE TREATMENT

Thiodicarb ($\text{C}_{10}\text{H}_{18}\text{N}_4\text{O}_4\text{S}_3$) is an oxime carbamate insecticide, which has recently been introduced into India by Rhône-Poulenc Agro Ltd., Lyon, France, under the trade names Larvin[®] and Semevin[®]. It is primarily an ingestion or stomach toxicant, with relatively little contact toxicity to insects. It has little or no translaminar activity in plants and no fumigant action. Thiodicarb has been found to be a pro-insecticide (10), and is converted in plants, insects and soil into a more toxic compound, methomyl, which is the presumed active metabolite (18). Thiodicarb is a powerful ovicide (14) and a good larvicide (15,30). It also has good adulticidal activity in some lepidopteran pests. In the present investigation, thiodicarb Larvin[®]75 WP was used.

Leaf-disc bioassay An insecticide suspension of 0.1% strength was used in the bioassay studies; it comprised 100 mg of Larvin[®]75 WP (a.i. thiodicarb) mixed with 100 ml of distilled water. The test insects were prepared for bioassay as follows. In the laboratory stock culture, the 5th instar larvae were regularly monitored for head capsule split, which indicated initiation of the process of molting into 6th instar. The 6th instar larvae (L6) were identified by the darker color of the cuticle, and by the prominent, inverted V-shaped frontal suture on the head. The late 5th instar larvae were left undisturbed overnight to undergo molting into 6th instar larvae. These larvae were removed from the castor leaf, kept in plastic boxes, and starved for ~ 3 h, during which time the larvae excreted two or three pellets, indicating that they were successfully preconditioned for bioassay. The

preconditioned larvae were individually weighed and the body weight was recorded. The dosage of insecticide to be administered to each larvae was calculated on the basis of body weight. Another set of the insects from this stock culture was irradiated as pupae with a partial sterilizing gamma dose and their F₁ progeny larvae were prepared in the same manner as in the case of unirradiated insects for insecticide bioassay.

Incorporation of insecticide in leaf discs Castor leaves of the same age and primarily from the same source, were selected. Leaf discs 2.5 cm in diameter were punched out with a metal-puncher, taking care to avoid the midribs. The insecticide suspension was gently stirred and a calculated amount was placed on the disc with a micropipette dispenser so that a thin, uniform insecticide film was formed on the leaf. The insects were treated with seven doses of the insecticide (Larvin), namely, 1, 5, 10, 20, 25, 50 or 100 $\mu\text{g g}^{-1}$; distilled water was applied on the control leaf discs. The leaf disc was air-dried at room temperature and then transferred to a 100-ml-capacity plastic box containing layers of moistened filter papers, to avoid desiccation of leaves (3). The treated leaf section was placed face downwards, to avoid the chance of the insect being in contact with the poison prior to eating it (16). Larval mortality was assessed 48 h after treatment. The moribund larvae were considered as dead for the purpose of calculating percentage mortality.

Statistical analysis The LD₅₀ of Larvin was obtained from the dose mortality data by probit analysis (13). The data obtained for percentage pupa formation, adult emergence, malformation in insects and egg hatch, as well as number of eggs laid, were subjected to analysis of variance followed by Student's t-test or LSD test between treatments (40).

RESULTS

BIOEFFICACY OF GAMMA RADIATION

Effect on pupal eclosion The data reveal that adult emergence after pupal irradiation was 75.5% in the treatment, as compared with 83.3% in the control (unirradiated), the difference being statistically significant (Table 1). Similarly, gamma irradiation was found to induce malformation in 13.4% of the eclosed adults, $P \leq 0.01$ (Table 1).

TABLE 1. Effect of irradiation of male pupae on adult emergence and malformation in *Spodoptera litura* (data are means \pm SE)

Treatment to male pupae	% Adult emergence	% Malformation among emerged adults
70 Gy	75.5 ^a \pm 1.72	13.4 ^a \pm 1.26
0 Gy (control)	83.3 ^b \pm 1.29	2.4 ^b \pm 0.02

Within columns, means followed by a different letter differ significantly at $P \leq 0.01$ (Student's t-test); n=3, each replicate comprising 50 insects.

Effect on fertility of female moths crossed with irradiated males The normal female, when paired with a male which had been treated as a pupa, had an average fecundity of 1744.2 eggs oviposited; egg hatch was 58.7%. For normally mated adults (*i.e.*, control) the number of eggs oviposited per female was 1940.3, and fertility was 93.5%. The results indicated 10.1% reduction in oviposition and 37.24% decline in fertility due to gamma irradiation of pupae (Table 2).

TABLE 2. Egg laying and fertility of a normal female *Spodoptera litura* crossed with a male moth derived from a pupa irradiated with 70 Gy (data are means \pm SE)

Treatment to male pupae	Eggs laid / mated female	% Egg hatch
70 Gy	1744.2 ^a \pm 48.0	58.71 ^a \pm 1.27
0 Gy (control)	1940.3 ^b \pm 31.4	93.53 ^b \pm 1.19

Within columns, means followed by a different letter differ significantly at $P \leq 0.01$ (Student's t-test); n=10.

Effect of gamma radiation on body weight of F₁ larvae The live body weight per freshly molted 6th instar larva in the F₁ generation of *S. litura* treated as a male pupa showed no statistically significant effect on the body weight: 0.279 g as compared with 0.301 g in the control (Table 3).

TABLE 3. Fresh body weight of newly molted 6th instar larvae in the F₁ generation of *Spodoptera litura* moths irradiated as male pupae and crossed with normal females (data are means \pm SE)

Treatment to male P ₁ pupae	Fresh body weight of F ₁ larva (g)
70 Gy	0.279 ^a \pm 0.017
0 Gy (control)	0.301 ^a \pm 0.018

^aNo significant difference at $P = 0.01$ (Student's t-test); n=30.

BIOEFFICACY OF INSECTICIDE ON TREATMENT

The bioassay results after treatment with Larvin, were subjected to probit analysis and the LD₅₀ of the newly molted 6th instar larvae was recorded as 28.67 $\mu\text{g g}^{-1}$ body weight, within 95% fiducial limits. The χ^2 value was 4.51 and the log dose-probit regression equation was $Y = 0.79 X + 3.79$ (Fig. 1). It was observed that after the larvae had fed on the insecticide-coated leaf disc, convulsions and tremors of varying degrees were produced, followed by paralysis. There was copious regurgitation of the gut contents, and cessation of feeding, or limited feeding, was seen especially at higher doses of the insecticide. The symptoms were typical of thiodicarb, a stomach poison. In addition, the treated larvae remained small and shriveled, as compared with the control.

TABLE 4. Effect of thiodicarb (as Larvin) on percentage pupation and sex ratio in the F₁ population of *Spodoptera litura* derived from moths irradiated as male pupae and crossed with normal females (data are means \pm SE)

Features observed	Larvin dose ($\mu\text{g g}^{-1}$)							
	0	1	5	10	20	25	50	100
	Radiation treatment (70 Gy to parent male pupae)							
% Pupation	30.0a	21.4b	13.3c	12.5cd	11.1cd	7.4d	0	0
	± 1.7	± 2.2	± 2.2	± 1.1	± 1.3	± 0.4		
Sex ratio ^z (M:F)	1.2:1	1.4:1	1.4:1	1.6:1	1.8:1	1:0	-	-
	Control (0 Gy)							
% Pupation	94.4a	92.1ab	76.7b	56.6c	26.6d	16.6e	10.7f	0
	± 4.2	± 5.4	± 4.5	± 3.3	± 2.3	± 1.4	± 0.9	
Sex ratio ^z (M:F)	1.07:1	1.00:1	1.09:1	1.12:1	1.66:1	1.50:1	2.00:1	-

Within rows, means followed by a common letter do not differ significantly different at $P < 0.05$ (ANOVA followed by LSD post-test); n=5; a group of 15 insects comprised one replicate.

^zSex ratio of emerged adults was recorded on a group of 75 pupae in each regimen.

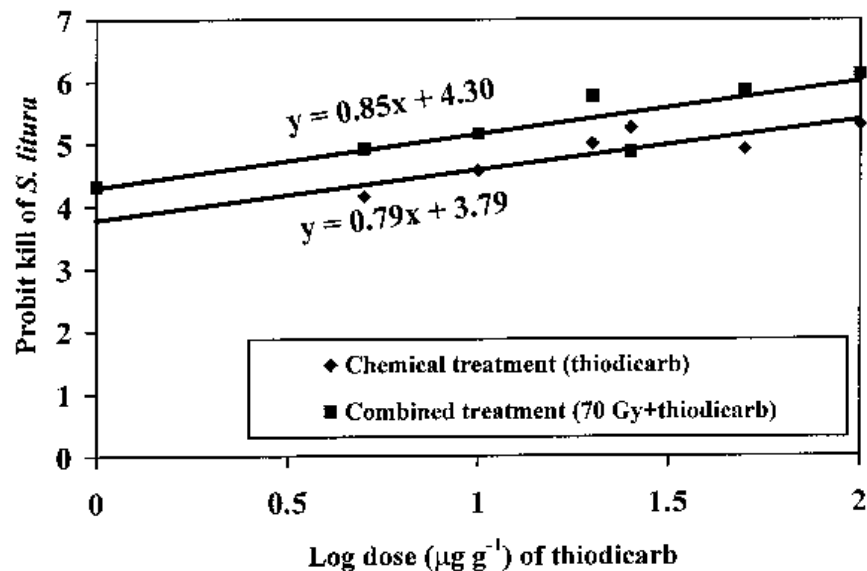


Fig. 1. Bioefficacy of thiodicarb on F₁ progeny of gamma-irradiated male *Spodoptera litura*. Combined treatment LD₅₀ = 6.76 µg g⁻¹; χ^2 = 9.78. Chemical treatment LD₅₀ = 28.67 µg g⁻¹; χ^2 = 4.51.

BIOEFFICACY OF COMBINED TREATMENT

Effect of radiation on insects' susceptibility to thiodicarb In F₁ progeny of the irradiated male parent, the LD₅₀ of thiodicarb (Larvin[®]75 WP) in newly molted 6th instar larvae was 6.76 µg g⁻¹ body weight, within 95% fiducial limits. The LD₅₀ value in the combined treatment (radiation + insecticide) was decreased by 4.24 times compared with the chemical treatment (Fig. 1). The log dose-probit regression equation was $Y = 0.85 X + 4.30$ and the observed heterogeneity was 9.78.

Effect of combined treatment (radiation + insecticide) on pupation and sex ratio At all tested doses of insecticide, pupation percentage was higher in the insecticide treatment (L6 treated with thiodicarb alone), than in the combined treatment (F₁ L6 larvae derived from irradiated parent exposed to thiodicarb). The percentage pupation, however, declined very rapidly up to a dose of 25 µg g⁻¹ in both the regimens, in a dose-dependent fashion (Table 4). The decline in pupation was higher when both treatments were given than in the thiodicarb treatment alone. Observations on the sex ratio of the ensuing pupae showed that it was more skewed in favor of the males in both groups of experiments and furthermore in the combined treatment group (Table 4).

DISCUSSION

The sterile male technique was advocated over 40 years ago by E.F. Knipling, and was used successfully to eradicate the screwworm fly in Curacao islands, southeastern and southwestern USA, Puerto Rico and Mexico. This success inspired many researchers to employ the technique against the most noxious lepidopteran pests of crops. However, insecticides continue to play an important role in pest control all over the world. Often

insecticides are applied with a view to reducing the population levels of the target insect first, followed by the release of sterile males. It would be of great importance to know how the insecticide residues interact with the F₁ progeny of lepidopteran pests which inherited sterility from parent moths (P-moths) irradiated with substerilizing gamma doses. The present work studied the susceptibility to thiodicarb of F₁ progeny of *S. litura* derived from a substerilized male parent and the feasibility of using the F₁ sterility technique in conjunction with an insecticide treatment for the management of this lepidopteran polyphagous pest.

A 70 Gy γ -dose to *S. litura* pupae resulted in a 9.36% reduction in adult emergence as compared with the control, and in 13.39% malformation of the emerged adults. Many workers have studied the feasibility of the sterile insect technique (SIT) for the control of *Spodoptera* species (35,37,45,48) using ionizing radiation on almost all stages, and particularly the older pupae and adults. The data on radiosensitivity of the pupae may help considerably in determining the gamma dose, optimum number of sterilized pupae to be released in a target area, and evaluation of radiation-based genetic techniques (SIT, F₁ sterility technique) for pest management.

The corrected sterility in *S. litura* due to 70 Gy was 37.24%, whereas the reduction in egg laying was 10.1% in comparison with the control. Similar findings have been reported by Li *et al.* (23) in *Ostrinia furnicalis* receiving 25 Krad. When male pupae were irradiated by a substerilizing dose of radiation, the general trend was that fecundity of the mated female and percentage hatching of F₁ eggs declined. The level of decline in reproductive features was found to vary with insect species, age at irradiation, and dose of radiation [refer to observations of Walker *et al.* (46) on *Diatraea saccharalis*, Sallam (34) on *Spodoptera littoralis*, Aguilar *et al.* (2) on *Heliothis virescens*, Bughio (6) on *Chilo partellus*, and Mastro and Schwalbe (24) on *Lymantria dispar*]. Wakid *et al.* (45) found an apparent increase in the egg production and hatch of F₁ larvae when fully mature male pupae of *S. littoralis* – irradiated at 2–16 Krad – were paired with normal females, but irradiation with more than 16 Krad resulted in suppressed egg production and egg fertility. In our study the decrease was seen in these parameters (egg production and egg hatch into F₁ larvae) in the case of *S. litura* due to radiation. Effectiveness of a dose may vary with the attributes of different species and with environmental conditions.

Studies of the effect of gamma-irradiated male parent pupae of *S. litura* on the fresh body weight of newly molted 6th instar larvae in F₁ progeny revealed that there was no significant difference in the parameter between treatment and control. Seth and Sehgal (38) recorded a 23.4% reduction in the dry body weight of 6th instar larvae and a 36.0% reduction in that of pupae of *S. litura*, irradiated as 6th instar larvae in the same generation, at a dose of 7 Krad. However, the stage at irradiation in the present investigations was different, *viz.*, pupa, and fresh body weight of L6 was assessed in the F₁ generation. It appears that the reproductive competitiveness of F₁ progeny with normal population may not decrease, as reproductive viability of F₁ *Spodoptera* can be correlated with its larval body weight, which showed satisfactory growth in the present study. Therefore, these results are of importance in the application of the F₁ sterility technique (modified sterile male technique), where the F₁ progeny of irradiated parents would compete with the wild pest population.

Bioefficacy tests of thiodicarb on *S. litura* showed that the LD₅₀ value of thiodicarb on the 6th instar larvae of normal parent's progeny was 28.668 $\mu\text{g g}^{-1}$ body weight, using a leaf disc bioassay method. In an earlier experiment Yu (47) reported the LD₅₀ value

for technical thiodicarb, applied topically to 4th instar larvae of *Spodoptera frugiperda*, as 58.5 and 2.25 $\mu\text{g g}^{-1}$ body weight in a resistant field strain and a susceptible laboratory strain, respectively. Such differences in response to thiodicarb may be attributed to the difference in species, life-stage treated, method of application, insect strain, formulation of insecticide, etc. To the best of our knowledge, no such work related to the LD₅₀ of thiodicarb has been reported earlier for *S. litura*.

The toxicity of thiodicarb to *S. litura* was increased 4.24-fold when the LD₅₀ values of the combined treatment (radiation + thiodicarb) were compared with thiodicarb treatment alone. This is in agreement with the results of Moustafa and Abdel Salam (27), who administered substerilizing doses (2.5, 5 and 10 Krad) of gamma radiation to male pupae of *S. littoralis* and conducted insecticide bioassays on 4th instar larvae in F₁ progeny. Their results indicated that insecticide susceptibility of larvae increased, not only with thiodicarb but also with chlorpyrifos, deltamethrin, cyanophos and cyfluthrin. Exceptionally, in the case of Empire[®](diflubenzuron + chlorpyrifos), the susceptibility of the larvae was decreased. The present findings are in agreement with those of El-Banby *et al.* (11), who reported similar results in *S. littoralis* with chlorpyrifos. Abdel Salam *et al.* (1) found increased susceptibility of *Tribolium confusum* adults to all the insecticides tested, *viz.*, malathion, formothion, esfenvalerate and Duradin[®](methomyl + flufenoxuron) when the pupae were irradiated 1–2 days before eclosion. However, our results are contradictory to the report of Carpenter and Young (8), who tested the insecticides methomyl and carbaryl on carbaryl-resistant and -susceptible strains of *S. frugiperda* in the F₁ progeny of irradiated adults (10 Krad). Irradiation was found to induce varying degrees of resistance to insecticides in all the tests conducted, and no interaction was evident between radiation treatment and insecticide resistance or between radiation treatment and strain performance. In this context, it should be noted that a change in toxicity of the insecticide to the F₁ progeny of an irradiated parent might depend largely on the differential behavior of a particular insect species and its strain, and on the insecticide used. This was illustrated by Moustafa and Abdel Salam (27), who found that irradiation increased the toxicity of some insecticides towards *S. littoralis*, reduced it in the case of Empire, and led to no change with Deenate[®](methomyl + diflubenzuron) or Delfos[®](chlorpyrifos + Dowco 449). Similarly, varying results were reported by Abdel Salam *et al.* (1) on the toxicity of different insecticides to adults of *T. confusum* irradiated as pupae. These insecticides were more toxic when irradiation was done in a late pupal stage rather than an early one. Similarly, *Callosobruchus maculatus* adults showed more susceptibility to fenvalerate after irradiation, whereas the opposite effect was observed with cypermethrin, under similar conditions (12).

Thus, it may be concluded that the behavior of the F₁ progeny of irradiated males does not follow a fixed pattern, as far as insecticide susceptibility is concerned. This could be attributed to a specific mode of action of different insecticides and to different species-specific reactions of insect pests. However, the data on behavior and susceptibility of F₁ survivors of *S. litura* towards thiodicarb are very important, since they have a bearing on SIT programs, where populations of the F₁ progeny of the released insects are greatly influenced by insecticides and/or insecticide residues. The present investigation demonstrated that the progeny of irradiated insects were more susceptible than the control to thiodicarb, under laboratory conditions. However, considering the fact that the response of insects in the above cases was highly variable, it is suggested that further work needs to be done, to determine the degree of toxicity of the insecticide to all stages of the insect after irradiation.

Laboratory experiments on the effect of combined treatment on pupation and sex ratio of F₁ progeny showed that with increasing doses of insecticide, the percentage pupation decreased. At the toxicant dose nearest to the LD₅₀ value (5 µg g⁻¹ in the combined treatment and 25 µg g⁻¹ in the insecticide treatment), there was 13.3% pupation in the combined treatment compared with 16.6% in the insecticide treatment (Table 4). Furthermore, there was a 78–83% reduction in pupa formation in the combined treatment as compared with that in the insecticide treatment (Larvin at a range of 1–10 µg g⁻¹). The percentage decline in pupa formation was greater in the combined treatment – where gamma radiation of the male parent preceded the insecticide bioassay of the progeny – than in the insecticide only treatment, indicating that gamma radiation exerted a pronounced effect on the insecticide treatment. In the combined treatment the number of larvae surviving until pupation was very low, since only 7.4% of the larvae pupated successfully following the irradiation + thiodicarb treatment with a dose of 25 µg g⁻¹, whereas above this dose there was complete larval mortality. This effect was observed in the radiation control (0 Gy) at the insecticide dose of 100 µg g⁻¹.

It is a general observation that males are more resistant to gamma radiation than females. However, as regards insecticides, the susceptibility of males and females may depend on the insect species and the insecticide used (25). In the present study with thiodicarb and gamma radiation, there is a marked skewing of sex ratio in favor of males. This is in agreement with the findings of Li *et al.* (23) and Bughio (6), who reported similar results on *Ostrinia furnicalis* and *C. partellus*, respectively. Mishra *et al.* (25) reported that the susceptibility of females to carbaryl was higher than that of males in a laboratory population of *Rhyniptia laeviceps*, a beetle pest of millet in India. To the best of our knowledge, no work has been reported on the effect of an oxime carbamate insecticide like thiodicarb on the sex ratio of insects.

A range of substerilizing gamma doses (40–200 Gy), administered to freshly emerged adult moths, has been studied extensively with the F₁ sterility technique for the control of *S. litura* (39). The older pupae (7 days old, as a pharate adult) irradiated in the present investigations might be a feasible stage – due to less somatic damage and convenience in handling – to employ in the inherited sterility technique for lepidopteran pest suppression.

Use of low-range substerilizing gamma doses has been found effective for better mating viability of P₁ and F₁ insects among natural populations, whereas the higher range substerilizing doses could be more effective in P₁ crosses than in F₁ crosses (R.K. Seth, unpublished). When using a higher range substerilizing dose, therefore, integration of thiodicarb treatment could be more effective since less reproductively competitive F₁ insects at this dose would be more sensitive to thiodicarb and suffer high mortality before they reached the adult stage. However, when a low range substerilizing dose is used for F₁ sterility, the thiodicarb treatment might affect the pragmatic impact of the F₁ sterility technique by killing the F₁ larvae, because F₁ adult progeny would not be formed to employ inherited sterility for pest suppression. Furthermore, if needed, the thiodicarb treatment alone could be employed effectively to reduce the natural population to a desired level before the application of F₁ sterility, for efficient use of both techniques.

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