Field trials in South China to control the diamondback moth, *Plutella xylostella* (Lepidoptera: Plutellidae) using radiation-induced sterility

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Abstract. This paper discusses the control of the diamondback moth, *Plutella xylostella* by the sterile insect technique (SIT). Our studies included mating characteristics, sterility of the F_1 generation, dispersal and recapture of irradiated moths, as well as control of DBM using SIT and F_1 sterility, and an economic evaluation of F_1 sterility to protect cabbage. Male DBM mated an average of 16 times and female DBM mated an average of 4 times. However, irradiated male DBM only mated an average of 7.2 times. Seventy percent of matings occurred from 18:00–24:00 h with an average duration of 80 min. Irradiated male moths and untreated male moths exhibited the same attraction to female moths. After 10 days, most (94.2%) of the released, sterile DBM were recaptured within 40 m of the release site. Only one DBM was recaptured at 120 m from the release site. The area of dispersal was calculated to be 696 m^2 during the first three days. In a field study to control DBM by releases of irradiated insects, the ratio of sterile to wild DBM was 4.7:1. During this study, the egg sterility in the F_1 and F_2 generations was 79.0% and 81.7%, respectively. The developmental times for the F_1 and F_2 generations were 4 and 12 days longer, respectively, than for DBM in the control area. Thus, the number of DBM generations was reduced in the treated field. With successive releases over two generations, the control effectiveness was 80.8% in the F_1 generation and 79.1% in the F_2 generation. The cost of using F_1 sterility to control DBM in a small field was similar to the cost of using pesticides. Therefore, the use of F_1 sterility should be an economically viable control strategy for DBM that also would help protect the environment from the overuse of pesticides.

1. INTRODUCTION

The sterile insect technique (SIT) and radiation-induced inherited sterility (F_1 sterility) have been considered as potential methods for controlling several lepidopteran pests. The diamondback moth (DBM), *Plutella xylostella* (Lepidoptera: Plutellidae), is one of the most important of all lepidopteran pests and causes great economic loss in south China. DBM can reduce production of all mustard family vegetables by 30–50% in some years, and has become resistant to many pesticides. Because of the need to increase the effectiveness of pest control and reduce environmental pollution, we have studied the control of DBM by the SIT and F_1 sterility for many years. These studies have included mating characteristics, sterility of the F_1 generation, release-recapture of sterile DBM, control of DBM by the SIT and F_1 sterility in the field, and an economic evaluation of F_1 sterility to protect cabbage.

2. MATERIALS AND METHODS

2.1. Mating characteristics of DBM

DBM were collected from a suburb of Hangzhou and reared on artificial diet. Mature pupae were irradiated with gamma rays with 250 Gy (dose rate 1.62 Gy/min). The DBM were paired into the following combinations, UF x UM and UF x IM (U= untreated moths; I= irradiated moths), and placed in separate glass containers. Mated female moths were placed in separate containers for oviposition. Data were recorded for the time of day that mating occurred,

mating frequency, duration of copula, time interval between successive matings, fecundity and egg hatch.

2.2. Release-recapture of DBM

The study was conducted in a 12 x 240 m cabbage field that was bordered on one side by a wall. The release site for the DBM was positioned near the centre of the wall at the edge of the field. Traps were positioned in semicircles around the release site. Radii for the semicircles were 10, 25, 40, 60, 80, 100 and 120 m. There were 4, 6, 9, 14, 16, 17 and 4 traps placed in each semicircle, respectively (70 traps total). For each trap, a female DBM was confined in a small cloth bag and positioned above a container holding water and detergent (as a wetting agent). Sterile male moths (2,758) marked with crystal violet were released, and the number of trapped marked males was recorded for 10 days.

Table 1. Fecundity and fertility of 30 female *Plutella xylostella* mated sequentially with the same unirradiated (normal) male moth

Mating Order	No. Eggs Laid	% Egg Hatch
1	105	79.1
2	105	73.3
3	114	86.8
4	111	83.8
5	107	74.8
6	99	70.7
7	62	79.0
8	81	80.2
9	50	78.0
10	46	82.6
11	65	73.9
12	52	90.4
13	20	85.0
14	53	77.3
15	21	71.4
16	58	81.0
17	93	82.8
18	24	83.3
19	1	0
20	21	81.0
21	50	80.0
22	130	77.7
23	23	82.6
24	0	0
25	87	74.7
26	0	0
27	35	85.7
28	48	89.6
29	0	0
30	0	0

Table 2. fecundity and fertility of 14 female *plutella xylostella* mated sequentially with the same irradiated male moth

Mating Order	No. Eggs Laid	% Egg Hatch
1	101	29.0
2	159	33.3
3	106	30.2
4	84	27.4
5	78	32.1
6	112	27.7
7	147	36.1
8	90	21.1
9	80	27.6
10	153	23.5
11	95	29.5
12	78	9.0
13	0	0
14	0	0

2.3. Suppression of wild DBM by releasing irradiated moths

This study was conducted in two isolated cabbage fields: a release field of 0.8 ha, and a control field of 0.067 ha. The densities of DBM in the two fields were similar, reaching 30,000 per ha. Twenty release racks were distributed in the release area, and sterile pupae in mesh-covered plates were positioned on these racks. The plates were positioned 20 cm above the cabbage plants. Ten releases of sterile moths (n = 351,630) were made during two consecutive generations of DBM. The mean ratio of sterile DBM to wild DBM was 4.7:1. The population of DBM was estimated once every 4–5 days by random sampling. Six hundred heads of cabbage were inspected in the release area and 200 heads were inspected in the control area on each sampling date. Samples of DBM eggs were collected from the release and control areas and brought back to the laboratory.

2.4. Economic evaluation of F_1 sterility to protect cabbage production

Two isolated cabbage areas were selected for this study. The sterile DBM were released in a 1 ha area that was not protected with insecticide treatments. The control area was 1 ha and was treated with insecticide for DBM control. Thirty release racks were distributed in the release area allowing for the release of 572,670 sterile moths in the spring and 600,350 sterile moths in the fall. Two crops of cabbage were produced during the year. The commercial value of F_1 sterility to protect the vegetable crop was calculated.

3. RESULTS

3.1. Mating characteristics of DBM

We observed a total of 267 DBM matings. All matings occurred between 18:00 and 06:00 h. Seventy percent of the matings occurred during the period from 18:00 to 24:00 h. Mating duration ranged between 20–205 min. (80 min average). The time between consecutive matings for the same male moth ranged from 5–9,880 min (60 min average).

Table 3. Effects of distance from the release site and time after release on the number of *Plutella xylostella* recaptured

Date	Number of moths captured								% Moths	% Recapture
(day/month)	10m	25m	40m	60m	80m	100m	120 m	Total	Captured	
19/5	19	0	2	1	0	0	0	22	5.8	0.80
20/5	64	6	4	0	0	0	0	74	19.5	2.68
21/5	71	2	3	1	1	2	0	80	21.1	2.90
22/5	14	2	0	4	0	1	0	21	5.5	0.76
23/5	46	19	13	1	0	0	0	79	20.8	2.86
24/5	28	16	5	4	2	1	1	57	15.0	2.07
25/5	9	18	12	0	1	1	0	41	10.8	1.49
28/5	1	1	3	1	0	0	0	6	1.5	0.22
Total	252	64	42	12	4	5	1	380		
% of Total	66.3	16.8	11.1	3.2	1.1	1.3	0.2		100.0	
% Recapture	9.14	2.32	1.52	0.44	0.15	0.18	0.03			13.78

Untreated female moths mated a maximum of 8 times (4 times average). Untreated male moths mated a maximum of 30 times (16 times average), in contrast to irradiated male moths which mated a maximum of 14 times (7.2 times average).

The number of eggs laid by 30 female moths that mated sequentially with the same male moth was similar for the first 6 females (average 107 eggs). However, the number of eggs decreased to an average of 51 for females that were 7 to 12 in the mating order. The fertility of females generally was not affected by the mating sequence (Table 1). Fecundity and fertility of female moths that mated with the same irradiated male were not affected by the sequence of mating (Table 2). Egg hatch ranged from 9.0–36.1%. The sterility of irradiated male moths persisted for 14 matings.

3.2. Release-recapture of DBM

The results showed that 380 marked sterile DBM were recaptured during the first 10 days following release (Table 3). The recapture rate was 13.78%. At a distance of 10 m from the release site 66.3% DBM were recaptured. Only one marked male was trapped 120 m from release site. At a distance of 40 m from the release site 94.2% of the DBM were recaptured during the 10 days following the release, while 92.7% of the recaptured DBM were trapped during the first six days after release. Only 1.5% of the recaptured DBM were trapped during the last 3 days. The dispersion area was calculated to be 216 m^2 on day 5 and 1256 m^2 on day 6.

3.3. Suppression of wild DBM by releasing irradiated moths

A total of 2,502 eggs were collected during the F_1 generation from the release area, and 96 eggs from control area. Nineteen percent of eggs from the release area hatched in the laboratory. The corrected sterile rate of eggs from the release area was 79.0%. During the F_2 generation 1,497 eggs were collected from release area, and 187 eggs were collected from the control area. Only 16.0% of eggs collected from the release area hatched. The corrected sterile rate of eggs from the release area was 81.7% (Table 4).

The highest density of early instar F_1 DBM was 1.17 per m^2 in the release area and 6.10 per m^2 in the control area. As a consequence, the density of early instar DBM in the release area

Table 4. Number of eggs and percent egg hatch for *Plutella xylostella* during two generations following the release of irradiated moths

Treatment	Parameter Measured	F_1	F_2
Release Area	Number of eggs	2502	1497
	Number of Hatched eggs	476	249
	% Egg hatch	19.0	16.0
	Corrected % egg hatch	21.0	18.3
	Corrected sterile rate (%)	79.0	81.7
Control Area	Number of eggs	96	187
	Number of hatched eggs	87	170
	% Egg hatch	90.60	90.90
	Corrected % egg hatch	100.00	100.00
	Corrected sterile rate (%)	0	0

Table 5. Comparison between conventional and F_1 sterility control tactics for protecting cabbage against *Plutella xylostella*

Control method	Cost of pesticide and labor[1]	Cost of irradiated DBM	Cabbage production (kg)	Cabbage value (USD)	Profit (USD)
F_1 sterility	126.50	2891.57	60,000–67,500	6,409	3,158
Pesticide	469.88	-	60,000–67,500	4,337	3,939

[1]The cost of manpower was 3.62 US$/day.

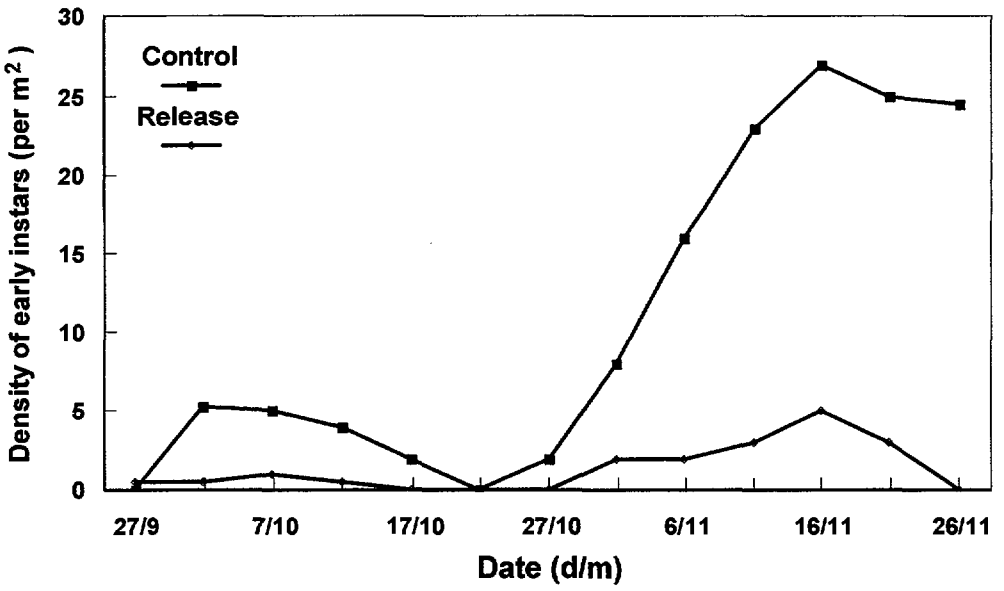

FIG. 1. Effect of sterile Plutella xylostella on density of early instars for two generations following the release of irradiated (250 Gy) moths in a cabbage field.

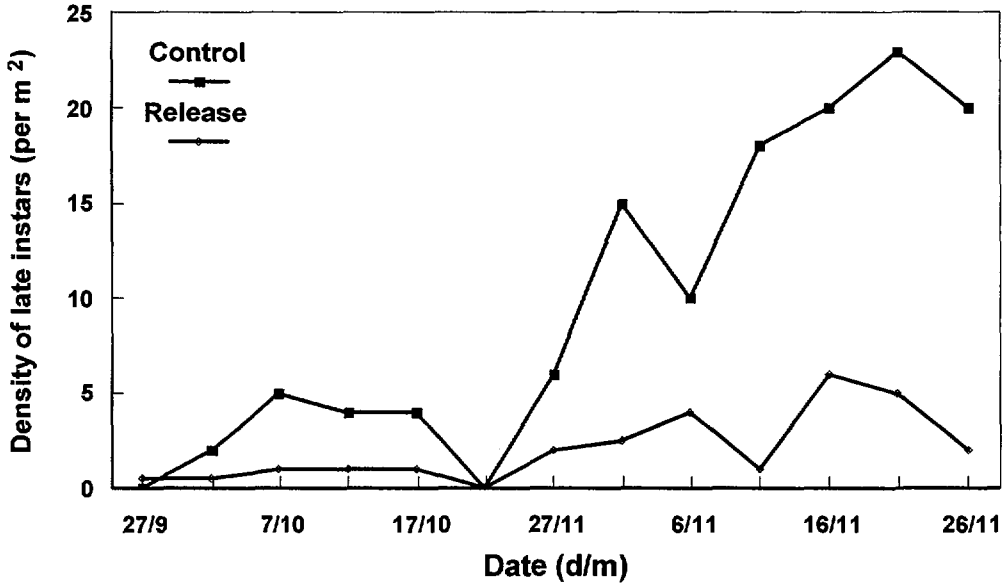

FIG. 2. Effect of sterile Plutella xylostella on density of late instars for two generations following the release of irradiated (250 Gy) moths in a cabbage field.

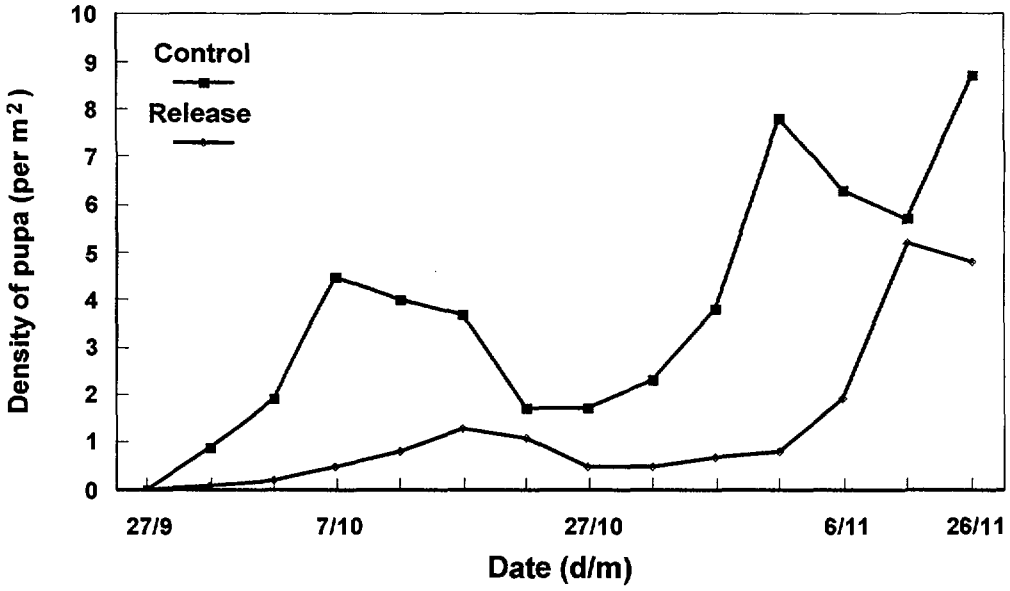

FIG. 3. Effect of sterile Plutella xylostella on density of pupae for two generations following the release of irradiated (250 Gy) moths in a cabbage field.

was only 19.18% of the density of early instars in the control area. Effectiveness of control was calculated at 80.8% during the F_1 generation. The highest density of early instar F_2 DBM larvae was 5.54 per m^2 in release area and 26.50 per m^2 in control area. Therefore, the density of early instars in release area was only 20.91% of the density in the control area. Effectiveness of control was calculated to be 79.1% in the F_2 generation (Figure 1). The

density of late instar DBM was greater in the control area than in the release area. The effectiveness of control based upon late instar DBM densities was calculated at 80.7% (Figure 2). The cabbage in the release area was of marketable quality, but the cabbage in the control area could not be marketed. Peak densities of DBM pupae for F_1 and F_2 generations indicate that the generation time was shorter for the DBM in the control area than for the release area. Also, peak densities of pupae for each generation were lower in the release area than in the control area (Figure 3).

3.4. Economic evaluation of F_1 sterility to protect cabbage production

We compared the calculated commercial value of using F_1 sterility and pesticides to protect cabbage from DBM damage. The cost of using F_1 sterility was about $3,018.00 USD per year and the cost for using pesticides was about $470.00 USD per year. The cabbage yield was 60,000–67,500 kg/ha per year. The value of the cabbage protected with pesticides was about $4,337.00 USD ($0.07 USD/kg), and the value of the cabbage protected with F_1 sterility was $6,409.00 USD ($0.11 USD)(Table 5).

4. DISCUSSION

A dose of 250 Gy was a suitable sterilizing dose for the control of the DBM. The mating behaviour and mating ability of sterile male moths irradiated with dose of 250 Gy was the same as that of untreated male moths. In our field studies, the effectiveness of control for DBM using F_1 sterility was 80.7% in the first generation and 79.1% in the second generation. The developmental time of each DBM generation was longer in the release area than the control area. Thus, the number of generations would be reduced and, therefore, should add to the control effectiveness of releasing sterile moths. Our results showed that the commercial value of using F_1 sterility to control DBM in a small field was similar to using pesticides. Therefore, the use of F_1 sterility should be an economically viable control strategy for DBM that also would help protect the environment from the overuse of pesticides.

ACKNOWLEDGEMENT

This research was supported by FAO/IAEA. We appreciate the help of FAO/IAEA in the past 10 years.