phase. Possibly the females do not release pheromone during the latter hours of the scotophase even though they do adopt the calling posture. Female *Plodia interpunctella* (Hübner) that call during the scotophase release ca. 13 times more sex pheromone than those that call during the photophase (Nordlund and Brady 1974). There may also be a female receptivity rhythm as in *Ephestia cautella* (Walker) (Barrer and Hill 1977).

The increased response of male TPW in the olfactometer when overhead illumination was provided is apparently caused by the overhead orientation of the stimulus rather than the increase in intensity. It is very possible that this phenomenon would be observed in other species since the dorsal light response is a well-known orientation mechanism in flying and swimming animals (Fraenkel and Gunn 1961).

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MATING COMPETITIVENESS IN THE LABORATORY OF IRRADIATED MALES AND FEMALES OF *EPHESTIA CAUTELLA*[1]

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Abstract

Males or females of the almond moth, *Ephestia cautella* (Walker), a serious pest of stored commodities, were irradiated (I) with either 35 krad (a partially sterilizing dose) or 50 krad (a sterilizing dose) and combined with pairs of untreated (U) adults at I:U ratios of 1, 5, 10, 15, or 25. Doses

[1]Lepidoptera: Pyralidae.

of 35 and 50 krad reduced egg hatch to 9.0 and 0%, respectively, when the ratio was 25 I males per U pair; egg hatch was 1.6 (35 krad) and 2.6% (50 krad) when the ratio was 25 I females per U pair. Both males and females were slightly less competitive after treatment with 35 krad than after treatment with 50 krad (based on percentage egg hatch). Treated females were more competitive at both doses than treated males; treated females were competitive at all release ratios. The I males were competitive with U males except at the lowest release ratio. Thus, irradiated adults were judged sufficiently competitive for field trials to be justified.

Ephestia cautella (Walker), the almond moth, is a cosmopolitan pest of stored food commodities. It severely damages many different products and is probably the most destructive stored-product pyralid moth. In many situations it is the only species of moth present, and the relatively isolated populations within commodity storage structures make the species amenable to control with the sterile insect release technique (SIRT). Amuh (1971) advocated the use of the SIRT for control of the almond moth, and the suggestion has been repeated by various investigators. In spite of the fact that radiosensitivity and sterilization doses have now been well defined (Calderon and Gonen 1971, Cogburn et al. 1973, Gonen 1975, Brower 1979), no serious effort has been made to apply the technique for population control. One possible reason is the lack of any information concerning the mating competitiveness of irradiation sterilized adults of this species. Reduced mating competitiveness is considered a serious obstacle to field application of the SIRT (North and Holt 1968). The present study was designed to determine mating competitiveness of irradiated males and females of the almond moth.

Materials and Methods

Moths were obtained from laboratory stock cultures reared in 3.8-liter jars on the complete diet described by Silhacek and Miller (1972). Throughout the experiments, cultures and test insects were maintained at 27±1°C and 60±5% RH with a 12-h photophase (0600-1800). Upon emergence, unmated moths were collected in No. 000 gelatin capsules, segregated by sex, and aged 24 h before irradiation. Moths were treated in a ^{60}Co irradiator with a source strength of ca. 700 Ci and a dose rate of ca. 722 rad/min. Doses utilized were 35 krad (a partially sterilizing dose) and 50 krad (essentially a fully sterilizing dose) (Brower 1979). All controls were unirradiated moths at the same age.

Immediately after treatment, irradiated (I) moths of 1 sex were placed with untreated (U) moths of the same sex in 1.9-liter jars; then U moths of the opposite sex were added. Screen tops were attached, and the jars were inverted over open petri dishes. Irradiated males and I females were tested separately for sexual competitiveness. Moth density was kept similar by using the following numbers and ratios (I:U:U): 10:10:10 (1:1:1), 20:4:4 (5:1:1), 20:2:2 (10:1:1), 30:2:2 (15:1:1), and 25:1:1. Three days after the insects were placed in jars, eggs that had fallen through the wire mesh into the petri dishes were removed. One hundred eggs from each collection were placed in petri dishes on black construction paper disks surrounded by rearing medium for hatched larvae. Egg hatch was determined after 10 days (an egg was scored as hatched only if the larva was successful in emerging completely from the chorion). Medium containing the hatched larvae from each petri dish was added to ca. 200 g of medium in a 0.47-liter jar with the lid sealed with a double layer of filter paper. As soon as emergence of F_1 adults started, jars were examined 3 times/week, and adults were removed and counted until emergence was completed. There were 10 replications of each sex, dose, and I:U:U ratio.

Natural egg infertility of the untreated (U) population and egg infertility of U females paired with only I males and I females were also determined. The expected egg infertility calculated from the I:U release ratios was corrected for control egg infertility and for egg fertility in the I samples because of the residual fertility of the substerilized males. Competitiveness values (indicated by C.V.) for the I males were then calculated by dividing the percentage actual infertility by the percentage corrected expected infertility using the same reasoning as Fried (1971). Because I females laid infertile eggs and the presence of these eggs would bias the observed percentage egg hatch, the following equation was used to estimate a corrected expected percentage infertility for females:

$$\text{Corr. exp. \% infertility} = \frac{x\,(\text{No. I}\ ♀)\,(v) + y\,(\text{No. U}\ ♀)\,(w)}{x\,(\text{No. I}\ ♀) + y\,(\text{No. U}\ ♀)} \times 100\%$$

where:

x = No. of eggs of I ♀ x U ♂,
y = No. of eggs of U ♀ x U ♂,
v = Fraction of infertile eggs laid by I ♀, and
w = Fraction of infertile eggs laid by U ♀.

Competitiveness values (C.V.) for I females were calculated by dividing the percentage observed egg infertility by the percentage corrected expected infertility. Total progeny per U ♀ was calculated by multiplying the number of progeny per 100 eggs by the mean number of eggs per female.

Results

MALES—35 KRAD. The mean number of eggs laid per female when confined with various ratios of males irradiated with 35 krad was not significantly different from the mean number of the control except at 1 ratio (Table 1). When the numbers of eggs laid by females at the different male ratios were compared, there were significant differences between some of them. Only 8.2% of the control eggs were infertile, but the addition of I males increased infertility to 39.7% at the lowest ratio (1 I ♂ : 1 U ♂ : 1 U ♀). As the ratio of I males to U males increased, the percentage of infertile eggs also increased to 95.0% at a ratio of 15 I ♂ : 1 U ♂ : 1 U ♀ (Table 1). Because 35 krad is not a fully sterilizing dose for adult males, some eggs produced by U females paired with I males were fertile (1.9%). Thus, sexual competitiveness of adult males irradiated with 35 krad was good at all ratios (0.75-1.0 was considered competitive), though it was generally better at the higher ratios of I males (Table 1). The mean number of progeny/100 eggs was 80.9 for the controls; this decreased to 5.0 for the 25 I ♂ : 1 U ♂ : 1 U ♀ ratio. The number of replicates that produced no progeny also increased markedly as the I:U ratio increased.

MALES—50 KRAD. There were no significant differences between the various ratios in the number of eggs per female when males were irradiated with 50 krad, except the 10 I ♂ : 1 U ♂ : 1 U ♀ ratio which was less (Table 1). Also,

TABLE 1. NUMBER OF EGGS, PERCENTAGE EGG INFERTILITY, NUMBER OF F_1 PROGENY/100 EGGS, AND TOTAL COMPETITIVENESS OF MALES OF THE ALMOND MOTH IRRADIATED WITH 35 OR 50 KRAD AND PLACED WITH UNTREATED INSECTS AT THE RATIOS SHOWN.

Ratio I♂:U♂:U♀	x̄ no.* eggs/♀	x̄ % egg infertility	Expected % infertility	C.V.	x̄ no. F_1 progeny	% of control	Expected %	% with no progeny	Calculated no. progeny/U♀
				35 KRAD					
0:1:1	194.2 ab	8.2	—	—	80.9	100	100	0	157.1
1:1:1	205.1 b	39.7	53.2	0.75	52.8	65.3	50	0	108.3
5:1:1	233.1 c	80.2	83.1	.97	15.2	18.8	16.7	40	35.4
10:1:1	155.8 a	77.2	89.9	.86	19.5	24.1	9.1	60	30.4
15:1:1	164.8 a	95.0	92.4	1.03	2.9	3.6	6.3	90	4.8
25:1:1	154.8 a	91.0	94.6	.96	5.0	6.2	3.9	80	7.7
1:0:1	185.8 ab	98.1	—	—	0	0	—	100	0
				50 KRAD					
0:1:1	235.7 b	8.2	—	—	82.5	100	100	0	194.5
1:1:1	236.7 b	37.1	54.1	.69	57.2	69.3	50	0	135.4
5:1:1	221.8 b	80.8	84.7	.96	15.6	18.9	16.7	40	34.6
10:1:1	175.6 a	99.5	91.7	1.09	0	0	9.1	100	0
15:1:1	208.8 b	88.8	94.2	.94	9.5	11.5	6.3	80	19.8
25:1:1	239.2 b	100	96.4	1.04	0	0	3.9	100	0
1:0:1	227.7 b	100	—	—	0	0	—	—	—

*Means followed by the same letter are not significantly ($P < 0.05$) as determined by Duncan's multiple range test.

there was no difference in the number of eggs when I males and U males were confined separately with U females. At this dose, egg infertility increased from 37.1% at a 1 I ♂ : 1 U ♂ : 1 U ♀ ratio to 99.5% at a 10 I ♂ : 1 U ♂ : 1 U ♀ ratio to 100% at the 25 I ♂ : 1 U ♂ : 1 U ♀ ratio (Table 1). Competitiveness values for the various ratios ranged from 0.69 to 1.09. The average number of progeny per 100 eggs decreased from 82.5 in the U + U controls to 0 in the 10 I ♂ : 1 U ♂ : 1 U ♀ and 25 I ♂ : 1 U ♂ : 1 U ♀ ratios.

FEMALES—35 KRAD. Females irradiated with 35 krad and paired with U males did not produce significantly ($P < 0.05$) fewer eggs than mated U females (Table 2). Virgin I females produced significantly fewer eggs than mated females; many of the females at the higher I female ratios probably did not mate since females greatly outnumbered males. The mean number of eggs per female at higher ratios was much less than that for mated U ♀ though significantly greater than the mean number produced by virgin females. Females irradiated with 35 krad and paired with U males had an egg fertility of 0.6%. Egg infertility increased from 54.9% at the 1 I ♀ : 1 U ♀ : 1 U ♂ ratio to a high of 98.4% at the 25 I ♀ : 1 U ♀ : 1 U ♂ ratio (Table 2). Sexual competitiveness of I females was better than that of U females at a 1 I ♀ : 1 U ♀ : 1 U ♂ ratio and slightly better at the higher ratios (Table 2). The number of progeny produced decreased concurrently with an increase in the ratio, and only 0.8 progeny/100 eggs were produced at a 25 I ♀ : 1 U ♀ : 1 U ♂ ratio (Table 2).

FEMALES—50 KRAD. Females irradiated with 50 krad and paired with U males laid fewer eggs (139.4) than mated U females (235.7, Table 1) but significantly more eggs than virgin I females (26.3) (Table 2). Except for the 1 I ♀ : 1 I ♀ : 1 U ♂ ratio, all ratios produced numbers of eggs between these 2 values, and these numbers did not differ significantly from either extreme. Mean percentage egg infertility increased from 54.9% at the 1 I ♀ : 1 U ♀ : 1 U ♂ ratio to 99.5% at the 10 I ♀ : 1 U ♀ : 1 U ♂ ratio but declined to 97.4% at the 25 I ♀ : 1 U ♀ : 1 U ♂ ratio (Table 2). The calculated competitiveness values for all ratios averaged 1.1; that is, the females were fully competitive. The number of progeny produced depended on the release ratio and ranged from a high of 41.4 to a low of 0.7 (Table 2). Most of the cages with the 3 higher ratios produced no progeny.

DISCUSSION

Control of the almond moth by using the SIRT is feasible according to models by Brower and Tilton (1975). Mating competitiveness of irradiated adults had not been determined previously, and this study provides the needed data. Both males and females irradiated as adults have an adequate level of sexual competitiveness to be effective in a sterile insect release program. Males could be used in one warehouse and females in another, thus doubling the efficiency of the program without increasing the number of insects that must be reared. Alternatively, males and females could be irradiated and released together. Ahmed et al. (1976) showed that such an alternative was feasible for the closely related Indian meal moth, *Plodia interpunctella* (Hübner). Moreover, Brower (1978) summarized the work on competitiveness of irradiated adults of the Indian meal moth and concluded that irradiated females were fully compentive but irradiated males

TABLE 2. NUMBER OF EGGS, PERCENTAGE EGG INFERTILITY, NUMBER OF F_1 PROGENY/100 EGGS, AND TOTAL COMPETITIVENESS OF FEMALES OF THE ALMOND MOTH IRRADIATED WITH 35 OR 50 KRAD AND PLACED WITH UNTREATED INSECTS AT THE RATIOS SHOWN.

Ratio I♀:U♀:U♂	$\bar{x}$ no.* eggs/♀	$\bar{x}$ % egg infertility	Expected % infertility	C.V.	$\bar{x}$ no. F_1 progeny	% of control	Expected %	% with no progeny	Calculated no. progeny/U♀
				35 KRAD					
0:1:1	194.2 d	8.2	—	—	80.9	100	100	0	157.1
1:1:1	134.2 c	54.9	49.1	1.10	38.7	47.8	50	0	102.3
5:1:1	80.5 b	88.0	81.4	1.08	9.8	12.1	16.7	30	47.4
10:1:1	74.0 b	94.3	89.4	1.06	3.5	4.3	9.1	50	28.5
15:1:1	52.1 b	95.1	92.5	1.03	3.5	4.3	6.3	70	29.2
25:1:1	42.1 b	98.4	95.1	1.04	.8	1.0	3.9	90	8.8
1:0:1	158.2 c	99.4	—	—	0	0	—	100	—
1:0:0	17.7 a	100	—	—	—	—	—	—	—
				50 KRAD					
0:1:1	235.7 d	8.2	—	—	82.5	100	100	0	194.5
1:1:1	153.5 c	54.9	42.3	1.30	41.4	50.2	50	0	127.1
5:1:1	76.1 b	83.2	76.8	1.08	14.5	17.6	16.7	30	66.3
10:1:1	53.4 b	99.5	86.7	1.15	.6	.7	9.1	90	3.5
15:1:1	76.0 b	99.2	90.7	1.09	.6	.7	6.3	80	7.3
25:1:1	50.4 b	97.4	94.2	1.03	1.3	1.6	3.9	90	20.9
1:0:1	139.4 c	100	—	—	0	0	—	100	—
1:0:0	26.3 a	100	—	—	—	—	—	—	—

*Means followed by the same letter are no significantly different ($P < 0.05$) as determined by Duncan's multiple range test.

were slightly less competitive at 35 krad and 10-20% less competitive at 50 krad. Overall, results with the Indian meal moth were very similar to these reported here for the almond moth though irradiated almond moth males, if anything, were more nearly competitive. Stress factors encountered in the field could reduce the actual competitiveness of sterile insects. However, irradiated almond moths were judged sufficiently competitive for field testing.

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