Gamma Irradiation Effect on the Flight Mill Performance of *Dacus dorsalis*[1] and *Ceratitis capitata*[1,2,3]

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Flight mills have often been used to detect the effects of treatment on the flight ability of insects in the laboratory (Henneberry et al., 1968; Skelton and Hunter, 1970; Rowley, 1970; and others), but only few studies have been concerned with the effects of gamma irradiation on insect flight. In one of the earliest studies, Shepard et al., (1968) reported that the flight of 3 to 4-day-old adult fall armyworms, *Spodoptera frugiperda* (J.E. Smith), treated with 40 krad as 6-day-old pupae, was reduced in regard to sustained and total flight times, distances, and peak velocities; also males flew less readily than females. Likewise, Noblet et al., (1968) found that 2-, 5-, and 10-day-old secondary screwworm flies, *Cochliomyia macellaria* (F.), irradiated with 25 krad as 5-day-old pupae (ca. 5.6X greater than the normal dose required to produce 100% sterility) had reduced total and sustained flight distances and spent less time in flight. In contrast, White et al., (unpublished data) reported enhanced (but not significantly different) flight by male codling moths, *Laspeyresia pomonella* (L.), treated with 30 krad. Also, the flight of house flies, *Musca domestica* L., treated as 5-day-old pupae with 4.5 and 7.0 R was not adversely affected when they were tested 2, 5, and 10 days after eclosion (Shepard et al., 1972). Moreover, flight mill research with irradiated oriental fruit flies, *Dacus dorsalis* Hendel, treated with 10 krad (the sterilizing dose) revealed reduced flight velocities by 16-day-old males but enhanced flight times and distances by 12-day-old females (Sharp, unpublished data). We therefore made a more intensive study of the potential effects of irradiation on fruit flies by doubling the dose applied to *D. dorsalis* and by studying the effect of 10 krad (sterilizing dose) on Mediterranean fruit flies, *Ceratitis capitata* (Wiedemann).

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Materials and Methods

The *D. dorsalis* and *C. capitata* pupae treated with irradiation were obtained from colonies reared at the USDA Fruit Fly Investigations Laboratory in Honolulu, Hawaii. Both species were irradiated at ca. 10 a.m. in a pool-type Cobalt-60 gamma irradiator having a dose rate of 3.0-3.5 krad/min. The *D. dorsalis* pupae were irradiated (I) 2 days before adult eclosion with 20 krad. The *C. capitata* pupae were first marked with Calco® blue fluorescent powder; then half were irradiated with 10 krad 2 days before adult eclosion (referred to as I-2), and the other half were allowed to emerge and were irradiated with 10 krad as 2-day-old adults (referred to as I + 2). Flies from the same generation were used as controls (N).

Emergent flies were provided sugar, water, and hydrolyzed protein (Tanaka et al., 1969). Flies exposed to each treatment (ca. 1800) were kept in separate 2.8 dm cubical cages at 24.1 ± 2.6°C and 75.4 ± 2.9% RH with a photoperiod of 13 hour L-11 hour D. Lighting was provided by sunlight and fluorescent tubes.

Normal and irradiated *D. dorsalis* of both sexes were tested on a flight mill system (modified after that described by Chambers and O'Connell (1969)) when they were 1,2,4,8, and 16 days old. The tests with *C. capitata* males (N, I-2, and I + 2) were made when they were 5,10, and 15 days old. Flies were immobilized and fastened to the rotor arms of the mills (Sharp et al., 1974) and were not provided food or water during tests; they were discarded after each test.

The flight mill tests were carried out in a 3.05X3.05X3.05 m cubical room illuminated at a mean of 8.2 X 10^{-13} lumens/cm^2 and maintained at 26 ± 1°C and 57 ± 2% Rh. Data obtained included time in flight and rest; distance flown; velocity, either sustained (based on time in flight) or overall (includes time flying and time at rest); percentage of time in flight; and number of flights/hour. The data were stored on magnetic tape and analyzed by computer (Ashley, et al., in press).

Tests were replicated by using alternate positions on the flight mill system.

Results and Discussion

Dacus dorsalis. No significant differences were found between N and I *D. dorsalis* males in a performance category when they were tested at 1 and 4 days past eclosion or by N and I females tested after they were 1 day past eclosion (Tables 1 and 2). At other ages, some significant effects were noted: 2-day-old I males flew greater distances, had faster overall velocities, and spent more time in flight than N males the same age. Irradiated males at both 8 and 16 days had reduced sustained velocities and peak velocities compared with those of N males at those ages. Females were less adversely affected than males; but irradiated females that were 1 day old had lower peak velocities than other females. When the percentages of flies traversing given distances and flying given percentages of time were tabulated, no N males and only a small percentage of 1- and 2-day-old I males flew greater than 5000 m (Table 3), but young I males flew a greater percentage of time than N males (Table 4). However, overall performance of N flies increased as they aged and finally became somewhat greater than that of I flies (Tables 3 and 4).

The maximum distances were flown by 8-day-old flies: 9700 m by an N male, 8586 by an I male, 9338 m by an N female, and 9945 m by an I female. The maximum sustained velocity for males was the 1.4 m/sec recorded by 16-day-old N and I flies; the maximum for females was the 1.0 m/sec achieved by an 8-day-old N fly and 8- and 16-day-old I flies.

In an earlier test (Sharp, 1972), wingbeat frequencies were reduced in stationary tethered male and female *D. dorsalis* treated with 20 krad 2 days before adult eclosion (Sharp, 1972). However, Sharp (unpublished data) observed little differences in flight ability in flight mill studies with *D. dorsalis* treated with 10 krad and tested when they were adults. Since we observed no marked increase in detrimental effect of increasing the dosage to 20 krad (some statistically significant reductions in performance did occur in some categories at some ages), we conclude that *D. dorsalis* adults have a high capability and a low threshold for flight at the conditions imposed by flight mill tests. Thus pronounced effects due to irradiation with as much as 20 krad cannot be discerned with this system. Other categories of flight performance such as propensity could be affected more markedly by irradiation but would only be discernible by another type of test.

In the present study and in an earlier flight mill study (Sharp et al., 1974), *D. dorsalis* males and females were observed to fly surprisingly great distances even when they were not provided food or water for several hours. This ability was confirmed in field studies by Iwahashi (1972) who found that 9 of 3000 marked *D. dorsalis* moved 50 km among the Ogasawara Islands during ca. 7 days and that others frequently moved ca. 2-4 km. If it is assumed from the present study that *D. dorsalis* males and females fly at a rate of 2500 m per hour, 4 hours per day, they could indeed fly 50 km in 5 days.

Ceratitis capitata. The marking with Calco blue and the irradiation of *C. capitata*, either as pupae 2 days before adult eclosion or as 2-day-old adults, had some effect on flight (Table 5). Normal 5-day-old males flew greater distances and had faster overall flight velocities than other males of the same age, but 5-day-old I-2 made more flights per hour, and the flight ability of I + 2 males was greater (though not significantly) over that of I-2 males. With 10-day-old males, time in flight and distance flown by N and I-2 males was greater than for I + 2 males. There were no marked differences among the 3 treatments when the flies were 15 days old so the data are not shown. Flies were allowed to fly for ca. 129 min. These males were less affected by irradiation (whether -2 or + 2) or by marking. The N, I-2, and I + 2 males at 15 days flew 2214, 2438, and 2524 m, respectively, and flew 70, 82, and 81% of the time at average sustained velocities, respectively, of 0.29, 0.37, and 0.40 m/sec.

Also, the effect of each treatment was compared between 5- and 10-day-old flies. No differences were found between 5-day-old and 10-day-old N males. The 5-day-old I-2 males rested more than 10-day-old I-2 males. The 5-day-old I + 2 males spent more time in flight than the 10-day-old I + 2 ma. with fewer rests and flew greater distances with fewer flights per hour. No statistical comparisons were made between 5- or 10-day-old males and 15-day-old males because the test times for all 15-day-old males were less than the test times for the other 2 ages.

The maximum distances flown by three 5-day-old N males were 7420 m (during 200 min; flying 99% of the time), 6719 m (203 min, 100%), and 5877 m (175 min, 87%). One N 15-day-old male flew an exceptional 8086 m during 132 min, farther than the distance flown by *D. dorsalis* males of the same age in about the same time and nearly as far as the maximum for that species. The 5-, 10-, and 15-day-old I-2 males flew mean distances ranging from 1953 to 2483 m. The maximum distance flown by a 5-day-old I-2 male was 4429 m (198 min, 94%), and the maximum distance flown by a 5-day-old I+2 male was 5781 m (200 min, 100%). Table 6 shows the percentages of males for each treatment that flew a certain distance and that remained in flight a given percentage of time.

DeMurtas (1972a) reported reduced recaptures at a distance of 150 m of released 3-day-old *C. capitata* treated with 7.5 krad and attributed the reduction to irradiation. He also showed (1972b) that *C. capitata* moved 5000 m in the field. In our present studies, a few flies flew greater than 5000 m within 2-3 hours.

Schroeder et al. (1973) noted other detrimental effects to the flight capability of *C. capitata* of irradiation: 10 krad of irradiation 2 days before adult eclosion reduced flight propensity of *C. capitata* males and females 40 and 60%, respectively, compared with that of native flies.

We too found that irradiation of both pupae and adults of *C. capitata* had some deleterious effects, particularly on flight time and distance flown. However, the degree of effect relative to the performance of normal flies varied according to the age of the fly at the time of testing. Irradiation of pupae was less detrimental to flight after 10 days and more detrimental at 5 days; irradiation of adults was less detrimental to flight at 5 days and more so after 10 days. Thus, if sterile *C. capitata* are to have their greatest role in a sterile release program during the first week after release, irradiation of adults may be preferable to irradiation of pupae. Indeed, greater flight ability during this first week may also increase longevity in the field because of improved distribution and greater shelter-and-food-seeking ability.

TABLE 1.—*Effects of 20 krads of gamma irradiation on the flight of* ♂ D. dorsalis.[a,b]

Category	Unirradiated/Irradiated *Age in days*				
	1	*2*	*4*	*8*	*16*
Flight time (min)	30/48	27/50	97/74	104/97	94/89
% of time in flight	31/47	23/50	53/43	66/60	66/63
Total test time (min)	95/95	108/106	180/179	162/162	142/134
Distance flown (m)	986/1406	792/1678	3655/2541	4756/3662	4549/3705
Flights/h	8/14	10/12	9/9	6/6	5/6
$\bar{X}$ sustained flight rate (m/sec)	0.5/0.4	0.6/0.5	0.7/0.6	0.7/0.6*	0.8/0.7*
$\bar{X}$ overall flight rate (m/sec)	0.2/0.2	0.1/0.3*	0.3/0.2	0.5/0.4	0.6/0.4
Peak flight rate (m/sec)	0.6/0.5	0.6/0.6	0.8/0.7	0.8/0.7*	0.9/0.8*

[a]The 2 means for each age and category separated by a slash and followed by * differ significantly at the 5% level. Each mean based on 2 tests, 9 flies/test. Statistical tests based on Student's t-test.
[b]Unirradiated vs. irradiated.

TABLE 2. —*Effects of 20 krads of gamma irradiation on the flight of* ♀ D. dorsalis.[ab]

	Unirradiated/irradiated *Age in days*				
Category	*1*	*2*	*4*	*8*	*16*
Flight time (min)	27/30	86/82	89/101	124/98	69/73
% of time in flight	30/35	60/58	57/66	68/51	63/64
Total test time (min)	83/84	142/143	158/158	190/190	110/103
Distance flown (m)	846/818	3206/3298	3113/3782	5381/4118	3187/3025
Flights/h	7/11	7/5	7/8	6/8	7/8
$\bar{X}$ sustained flight rate (m/sec)	0.5/0.4	0.6/0.6	0.6/0.6	0.7/0.7	0.8/0.7
$\bar{X}$ overall flight rate (m/sec)	0.2/0.2	0.4/0.4	0.4/0.4	0.5/0.4	0.5/0.4
Peak flight rate (m/sec)	0.6/0.5*	0.7/0.7	0.8/0.7	0.8/0.8	0.8/0.8

[a]* differ significantly at the 5% level. Each mean based on 2 tests, 9 flies/test. Statistical tests based on Student's t-test.
[b]Unirradiated vs. irradiated.

TABLE 3. — *Percentage of ♂ and ♀ D. dorsalis flying a given distance.*[ab]

Age in days	*Distance (m)*			
	5000	*3000-4999*	*1000-2999*	*<1000*
			Males	
1	0/6	11/17	17/22	72/56
2	0/6	50/50	39/28	61/56
4	33/33	17/28	28/22	22/33
8	50/17	28/61	6/11	17/11
16	61/24	6/35	17/41	17/6
			Females	
1	0/0	6/0	24/24	71/76
2	28/17	17/33	28/39	28/11
4	11/22	39/33	28/39	28/11
8	56/28	22/28	17/39	11/6
16	12/12	41/35	41/41	6/12

[a]Unirradiated vs. irradiated.
[b]Each percentage based on 18 flies.

TABLE 4. — *Percentage of ♂ and ♀ D. dorsalis flying a given percentage of time.*[ab]

Age in days	*Percentage*				
	100	*80-99.9*	*60-79.9*	*50-59.9*	*<59*
			Males		
1	0/0	6/11	11/28	0/0	83/61
2	0/11	0/22	0/6	0/6	100/56
4	6/0	33/22	6/11	6/6	50/61
8	6/6	33/17	28/33	11/17	22/28
16	6/12	41/29	24/6	0/18	29/35
			Females		
1	0/0	6/6	18/18	0/0	76/76
2	6/17	28/22	22/6	6/0	39/56
4	6/17	17/28	28/17	22/6	28/33
8	6/6	39/11	17/11	11/22	28/50
16	6/6	29/35	24/24	6/6	35/35

[a]Unirradiated vs. irradiated.
[b]Each percentage based on 18 flies.

TABLE 5. —*Effects of irradiation and marking on flight of* C. capitata *5- and 10-day-old males.*[a]

	Treatments					
	5-day-old			*10-day-old*		
Category	*N*	*I-2*	*I+2*	*N*	*I-2*	*I+2*
Flight time (min)	146	135	160 Z	137	138	106 z*
% time in flight	73	66	80 Z	72	74	52 z*
Rest time (min)	52	69 Y	41 z	53	48 y	78 Z
Total test time (min)	199	204	201	190	187	183
Distance flown (m)	3221*	1953	2452 Z	2484	2384	1554 z*
Flights/h	1.8	2.2*	1.6 z	1.8	2.0	2.4 Z
$\bar{X}$ sustained flight velocity (m/sec)	0.33	0.23	0.26	0.29	0.27	0.24
$\bar{X}$ overall flight velocity (m/sec)	0.27*	0.16	0.19	0.22	0.21	0.14
Peak velocity (m/sec)	0.44	0.36	0.39	0.40	0.40	0.38

[a]Each mean based on 12 observations (4 observations/replicate). * denotes within differences at the 5% level among N, I-2, I+2 at 5 or 10 days determined by Duncan's New Multiple Range Test; capital Y and small y in the same 'row' for I-2 at 5 vs. 10 days denote differences at the 5% level. Capital Z and small z in the same 'row' for 1+2 at 5 vs. 10 days denote differences at the 5% level.

TABLE 6. — *Percentage* (N - I-2 - I+2) *of male* C. capitata *flying a given distance or a certain percentage of time.*[a]

Age (days)	*Distance (m)*			
	>5000	*3000-4999*	*1000-2999*	*<1000*
5	25-0-8	25-25-17	33-58-67	17-17-8
10	8-0-0	33-22-25	50-42-33	8-25-42
15	8-0-0	0-33-33	67-42-58	25-25-8

	% time in flight			
	100	*80-99.9*	*60-79.9*	*<59*
5	8-0-17	42-25-23	25-50-33	25-25-17
10	0-8-0	33-33-8	42-33-33	25-25-58
15	8-25-33	42-42-25	25-17-25	25-16-17

[a]Total test time of 15-day-old males in all treatments was less than that of males 5- and 10-day-old males.

SUMMARY

When pupae of *Dacus dorsalis* were treated with 20 krad gamma irradiation 2 days before adult eclosion, the 1- and 4-day-old males and the 2-, 4-, 8-, or 16-day-old females showed no abnormal flight behavior during a test on a flight mill system. However, 2-day-old irradiated males spent more time in flight and flew greater distances than 2-day-old normal males; also, 8- and 16-day-old irradiated males displayed lower sustained and peak flight velocities than normal males of these ages. Peak flight velocities lower than normal were displayed by 1-day-old irradiated females. We conclude that *D. dorsalis* adults have a high capability and a low threshold for flight. Pronounced effects due to irradiation with as much as 20 krad cannot be discerned with this system.

When pupae of *Ceratitis capitata* were marked with Calco® blue and then irradiated with 10 krad 2 days before or 2 days after adult eclosion, normal 5-day-old males flew greater distances and faster than marked, irradiated flies of the same age. Marked males irradiated at 2 days of age and tested at 5 days spent more time in flight, flew greater distances, and stopped less often than similar males tested at 10 days. Marked males irradiated as pupae and tested at 5 days demonstrated flight ability reduced compared to marked males irradiated as adults. At 10 days, differences had either reversed or disappeared. Irradiation of adults may be preferable to irradiation of pupae if sterile *C. capitata* are to have their greatest role in a sterile release program during the first week after release.

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