Influence of Gamma-Irradiation on Flight Ability and Dispersal of Conopomorpha sinensis (Lepidoptera: Gracillariidae)

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Influence of gamma-irradiation on flight ability and dispersal of *Conopomorpha sinensis* (Lepidoptera: Gracillariidae)

Ke Zhang, Haohao Fu, Shaowen Zhu, Zhibin Li, Qun-fang Weng and Mei-ying Hu**

Abstract

Assessment of quality of male insects has been done primarily in area-wide integrated pest management (AW-IPM) programs that have a sterile insect technique (SIT) component. Routine monitoring of sterile male quality needs to be carried out both in the mass-rearing facility and in the field. Simple bioassays, which can be conducted in the laboratory or under semi-field conditions, would be potential surrogates for laborious field tests that are usually very costly. In the laboratory, a flight mill system was used to assess the quality of males of the litchi stem-end borer, *Conopomorpha sinensis* (Lepidoptera: Gracillariidae), in terms of flight distance, flight duration and speed. Flight distance, duration, mean speed and greatest speed of non-irradiated adult males were 13,926 m, 29,365 s, 0.42 m/s, and 1.01 m/s, respectively, during a 24 h period. Although the values of these parameters of non-irradiated males were greater than corresponding values for moths irradiated with 150 and 200 Gy, there were no significant differences between the various treatments and the non-irradiated control group. These data suggest that irradiation with 150 and 200 Gy did not significantly affect the flight ability of male litchi stem-end borers. This study also included 2 field release and recapture experiments. The data of the field experiments indicated that recapture rates, dispersal distances, and dispersal directions of the 150 and 200 Gy irradiated males were not significantly different from those of non-irradiated males. These data indicate that the ability of litchi stem-end borer males irradiated with doses of 150 and 200 Gy to disperse in the field was not impaired in comparison with non-irradiated males.

Key Words: irradiation; sterile insect technique; release/recapture; flight mill; dispersal

Resumen

La evaluación de la calidad de los insectos machos estériles o parcialmente estériles se ha hecho principalmente en relación con programas de manejo de plagas integrado en toda la área (MIP-TA) que tienen un componente de técnica del insecto estéril (TIE). El monitoreo rutinario de la calidad de los machos esteriles necesita ser realizado tanto en las instalaciones de cría masiva como en el campo. Bioensayos simples, que pueden ser realizados en el laboratorio o en condiciones de semi-campo, serían sustitutos potenciales para las pruebas laboriosas de campo para monitorear el desempeño de los machos estériles en el campo que por lo general son costosos. En el laboratorio, se utilizó un sistema de molino de vuelo para evaluar la calidad de machos del barrendador del tallo de litchi (*Conopomorpha sinensis*; Lepidoptera: Gracillariidae) en términos de distancia, tiempo y velocidad de vuelo. La distancia del vuelo, la duración del vuelo, el promedio de la velocidad y la mayor velocidad de vuelo de los machos adultos no irradiados fueron 13,926 m, 29,365 s, 0.42 m/s, y 1.01 m/s, respectivamente, dentro de un período de 24 h. Aunque los valores de estos parámetros de los machos no irradiados fueron mejores que los de las polillas que habían sido irradiadas con 150 y 200 Gy, no hubo diferencia significativa entre los diferentes tratamientos y el grupo control no tratado. Estos datos sugieren que la irradiación con 150 Gy y 200 Gy no afectó significativamente la capacidad de vuelo de los machos del barrenador del tallo de litchi. Este estudio también incluyó 2 experimentos de liberación de campo y recaptura. Los datos de los experimentos de campo indicaron que la tasa de recaptura, la distancia de dispersión, y la dirección dispersión de las polillas tratadas con 150 Gy y 200 Gy no fueron significativamente diferentes de las de los machos no irradiados. Esto indica que la capacidad de dispersión en el campo de los machos del barrenador del tallo de litchi irradiados con dosis de 150 y 200 Gy no difieren significativamente de los de los machos no irradiados.

Palabras Clave: irradiación; técnica del insecto estéril; liberar/recaptura; molino de vuelo, dispersión

The litchi stem-end borer, *Conopomorpha sinensis* Bradley (Lepidoptera: Gracillariidae) is an important pest of litchi, *Litchi chinensis* Sonn. (Sapindales: Sapindaceae) and longan, *Dimocarpus longan* Lour. (Sapindales: Sapindaceae). Litchi stem-end borers not only damage the fruit, but also damage the shoots and young leaves due to larval boring and feeding. This results in a large number of dropped fruits ("dung fruits"), fallen flowers and dieback (FAO 2002). The adult moths become active soon after sunset (18:00–18:30 h), although a few moths may become active as early as 16:30 h on dark rainy d. Adult moths cease to be active near the dawn, and they remain quiescent during the photophase (Cai et al. 2011). As the litchi stem-end borer larvae are interval feeders, they are difficult to control with chemical pesticides. Also, in organic litchi production, most chemicals are strictly prohibited, which makes control by traditional methods very difficult (Tsang et al. 2007, 2011).

The sterile insect technique (SIT) is a method of pest control based on area-wide releases of sterile males in a ratio of sterile to wild males of the same species that is sufficiently great to drasti-

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cally reduce the fertility of the targeted field population. The SIT depends greatly on the production of good quality sterile males that can locate and compete for wild females of the wild target population. Since the New World screwworm, *Cochliomyia hominivorax* (Coquerel) (Diptera: Calliphoridae) was eradicated from the Island of Curacao in 1954 using this technology, the SIT has received increased attention.

Many lepidopteran species are destructive pests of annual and perennial crops, forests, and stored products throughout the world. Because lepidopteran species are usually more radiation resistant than most other insect species (Dyck et al. 2005), a fully sterilizing radiation dose would be so great that it would reduce the quality of the irradiated males and reduce their ability to disperse in the field and compete for wild females. To increase the competitiveness of irradiated Lepidoptera, Proverbs (1962) investigated the potential of using sub-sterilizing doses of radiation on the codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), and discovered that at less than fully sterilizing doses, the sons of irradiated males were fully sterile. This discovery of inherited (IS) or F_1 sterility promoted numerous investigations in many Lepidopteran pests.

Inherited sterility is a derivative of the SIT that is applicable to lepidopteran pests (Proverbs 1962; LaChance 1985; Carpenter et al. 2005; Kean et al. 2008), and—when compared with full sterility, provides several advantages for lepidopteran pest control. As explained by Carpenter et al. (2005), lepidopteran females are usually more radio-sensitive than males of the same species. Therefore in many cases it is possible to find a radiation dose that induces complete sterility in females but only partial sterility in males. Thus large numbers of irradiated males and females can be released in the field, but the released females cannot produce progeny that can damage the crop. However, when the partially sterile parental generation males mate with wild females the radiation induced deleterious genes are inherited by the F_1 generation. As a result the F_1 egg hatch is reduced and the F_1 offspring tend to be both sterile and predominantly male. Because the F_1 progeny are produced in the field they tend to be better adapted and distributed to compete for wild mates. The advantages of IS derive from the lowering of the radiation dose, which allows the release of more competitive and longer living males. In addition adult F_1 males tend to be stronger fliers that mate more frequently and are more competitive than moths irradiated with greater radiation doses (Carpenter 2000).

In a previous study, females irradiated with 200 Gy did not oviposit when mated with non-irradiated males (Fu et al. 2016), indicating that 200 Gy was the lowest fully sterilizing dose for females, and 200 Gy was confirmed to be the dose needed to induce complete sterility in the F_1 generation offspring from the parental cross untreated female (UF) × treated male (TM). Radiation-induced partial sterility of the litchi stem-end borer was shown to be inherited in at least 3 consecutive generations beginning with the parental males that were irradiated with 150 Gy as pupae shortly before emergence. There were no significant differences in longevity between the parental generation and the F_1 generation when the male in the parental generation was irradiated with 150 Gy. Therefore, 150 Gy applied before emergence could be used to irradiate moths for large scale release programs, although a dose of 200 Gy may be more appropriate for use in SIT/IS programs. Very little work has been done on quality control aspects of *C. sinensis*, however, many workers have reported on various quality parameters used for other lepidopteran pests (Rogers & Winks 1993; Bloem et al. 1997; Vreysen & Hendrichs 2005). This study was carried out to assess the effect 150 and 200 Gy irradiation on the flight ability of male litchi stem-end borers in the laboratory and to assess their dispersal ability in the field.

Materials and Methods

SOURCE OF INSECTS AND PROCEDURE FOR MARKING MALES WITH DIFFERENT FLUORESCENT DYES

The litchi stem-end borers were collected from litchi orchards at the Guangdong Academy of Agricultural Sciences, Hainan, Maoming and Zengcheng, China. We gathered infested fallen fruit and collected the pupae from leaves on trees and fallen leaves. These insects were used to establish a laboratory colony (according to the procedure described by Fu et al. (2016) in this issue) that provided moths for the experiments.

After irradiation the male adult moths were marked with 1 of 3 fluorescent dyes (Kunyou Illumination Technology Co., Ltd. Jinan, China) to distinguish non-irradiated from irradiated males after recapture in the release-recapture experiment. The effect of the fluorescent dye on the longevity of adult male moths was first assessed. One d old adult males were marked with 3 different fluorescent dyes (blue, orange and green) with 30 males in each color treatment. Adult males without dye were used as the control. Their longevities were observed and recorded.

RADIATION SOURCE

The experimental material was irradiated in a ^{60}Co source (Nordion Inc., Ottawa, Ontario, Canada) located at the Guangzhou Furui High-Energy Technology Co., Nansha District, Guangzhou, Guangdong Province, China. The dose rate was 3.2 Gy/min.

FLIGHT MILL AND TETHERED FLIGHT

The flight performance of *C. sinensis* adults was tested using a 26-channel, computer monitored flight mill system at the Institute of Plant Protection (Zhengzhou, China). Mature pupae of uniform size were irradiated with either 150 or 200 Gy. Adult males which emerged from these irradiated pupae were anesthetized with CO_2 for 30 s when 1 d old. By means of a drop of cyanoacrylate Super Glue (Yuyao Kexing Adhesive Co., Zhejiang, China) placed on the ventral side of the mesothorax, each male was attached to the end of the flight mill arm. The flight mill was placed in a dark room at 30 ± 2 °C and 75–85% RH. One tethered flight test took 24 h to complete, i.e., from 21.00 h to 21.00 h of the next day.

The software system recorded the time of flight initiation and cessation, as well as the number of mill revolutions every 5 s during the assay period. If flight stopped for ≥ 1 min, it was considered the end of a flight. Based on the number of mill revolutions over a given time period, total flight distance and duration, average speed, as well as distance and duration of each flight were computed for each individual using a custom-made software package (Cheng et al. 1997).

WEATHER CONDITIONS DURING FIELD RELEASE STUDIES

Weather data during the release trials were obtained from a station of the Guangdong Meteorological Service 5 km from the release orchard.

RELEASE AND RECAPTURE EXPERIMENT

Irradiation and Marking

Mature pupae of uniform size were irradiated with either 150 or 200 Gy. Each of the adult males that emerged from these irradiated pupae was dyed when 1 d old with 1 of the 3 different fluorescent dyes to identify the 3 treatments (non-irradiated control was blue, 150 Gy was orange, and 200 Gy was green).

Sex Pheromone Bait and Triangle Traps

The sex pheromone used to bait the traps and the triangle traps were provided by Zhangzhou Enjoy Agriculture Technology Co., Ltd., China. The traps were open on both sides and had an adhesive cardboard insert on the bottom of the trap to capture adult males that entered the trap. The sex pheromone attractant was placed in a small plastic cup inside the trap.

Release and Recapture

Two release-recapture experiments were conducted to assess the dispersal ability of adult males. The releases were carried out in a litchi orchard of the South China Agricultural University, Guangzhou, Guangdong Province, China. The litchi orchard had a rectangular shape with dimensions of 60 m (E-W) × 160 m (S-N). The release point was located at the intersection of the 2 diagonals of the orchard rectangle. Twenty-four traps were deployed and hung in litchi trees and aligned according to 8 compass directions—with radial angles of 45°—at 5, 15 and 30 m from the release point. An additional 6 traps were deployed at 80 m distances to the S, N, SW, SE, NW and NE. The release point of adult males, the position of each trap, and the number of traps were the same throughout the experimental period.

The first experiment was conducted from 3 to 11 Jul, and the second from 20 to 28 Jul 2013. In each experiment a total of 500 dyed male adults of each treatment (150 and 200 Gy) and of the non-irradiated control were released into the orchard around 16:30–17:00 h. During the 5 d after the release, the triangle traps were checked every 24 h. The adhesive cardboard base was removed and replaced with a new one if moths were trapped and the cardboard base was taken to the laboratory to record the catch. Normally the color of dye on the surface of the captured male could be readily determined with the aid of a UV lamp.

DATA ANALYSIS

For each individual *C. sinensis* male, flight activity was characterized by total flight distance, flight duration, average flight speed, number of flights, mean duration of flights, and distance and duration of the longest flight. Flight parameters were analyzed using a two-way analysis of variance (ANOVA), with wind direction, temperature, relative humidity, and dye as factors. Flight data of individual tests were analyzed and calculated using the Matlab software package (MathWorks, Inc., Natick, Massachusetts, USA). All other data were analyzed with SPSS Version 19.0 (SPSS Inc., Chicago, Illinois, USA) software. The meteorological data were presented as mean values for each 24 h period.

Results

INFLUENCE OF IRRADIATION ON FLIGHT ABILITY OF ADULT MALE LITCHI STEM-END BORERS

The flight distance, flight time, mean speed, and the greatest speed of non-irradiated adult litchi stem-end borer males were 13,926 m, 29,365 s, 0.42 m/s, and 1.01 m/s, respectively, during a 24 h period using the flight mill system in the laboratory. The values of each of these parameters were greater for the non-irradiated control males as than for the irradiated males, but the differences were not significantly different (Table 1). The flight mill data did not reveal any significant physiological deterioration as the result of either the 150 or 200 Gy treatment on the flight parameters of adult litchi stem-end borer males.

EFFECT OF FLUORESCENT DYES ON LONGEVITY OF ADULT MALE LITCHI STEM-END BORERS

The observed mean longevity of each treatment was in the range of 13–15 d (Table 2). Analyses using the proportional hazard model indicated that none of the dyes significantly increased the hazard of dying (Table 2) in comparison with the unmarked control. Even after 11 days, the survival rates in all treatments were greater than 90%, but survival in all treatments declined steeply soon thereafter (Fig. 1).

RELEASE AND RECAPTURE EXPERIMENTS

Recaptures of *Conopomorpha sinensis* Males

Weather conditions during the first release experiment were favorable with almost no precipitation, and steady light winds (1.6–1.9 m/s) mostly from the SE (Table 3) under a mostly clear sky. In the first release experiment, a total of 1,500 adult male moths were released, and a total of 87 males (5.8%) were recaptured. The recapture rates of the non-irradiated control males, and males irradiated with either 150 or 200 Gy in the first release experiment were 6.2%, 5.4%, and 5.8%, respectively. The irradiation treatments (150 and 200 Gy) had no significant effect on the recapture rates as compared with the non-irradiated control (χ^2 = 0.29; *P* = 0.86) (Table 4).

Weather conditions during the second release experiment were somewhat turbulent with precipitation on all 5 d of the experiment, and light but variable winds (0.8–2.0 m/s) of quite variable directions fluctuating mostly between SE and NE under a mostly cloudy sky (Table 3). In the second release experiment, a total of 1,500 males were released, and a total of 123 males (8.2%) were recaptured. The results were similar to those of the first release in that no significant differences were found in recapture rates of the males irradiated either with either 150 or 200 Gy and the non-irradiated control males (χ^2 = 1.49; *P* = 0.48) (Table 4).

Table 1. Flight parameters of *Conopomorpha sinensis* males tethered on a flight mill system. The males were non-irradiated or irradiated either with 150 or 200 Gy and allowed to fly for 24 h. If a flight stopped for ≥ 1 min, it was considered the end of that flight.

Radiation dose (Gy)	Number of tested insects	Flight distance ± SE (m)	Flight duration ± SE (s)	Mean flight speed ± SE (m/s)	Maximum speed ± SE (m/s)
0 (control)	8	13,926 ± 1,419 a	29,365 ± 2,970 a	0.4175 ± 0.026 a	1.0075 ± 0.067 a
150	8	11,732 ± 2,254 a	24,934 ± 3,636 a	0.4073 ± 0.019 a	1.0119 ± 0.064a
200	8	9,257 ± 1,116 a	26,328 ± 2,180 a	0.4088 ± 0.022 a	0.656 ± 0.019 a

Note: Mean values in the same column followed by the same letters are not significantly different at *P* = 0.05 level according to the Duncan's multiple ranger test (DMRT)

Table 2. The influence of fluorescent dyes on longevity in the laboratory of adult *Conopomorpha sinensis* males.

Color of fluorescent dye	Mean longevity (days) ± SE	Proportional hazard model T_i	SE	Wald chi-square	*P*
None (control)	14.1 ± 1.6	—	—	—	—
Orange	14.2 ± 2.0	−0.045	0.366	0.015	0.902
Blue	13.7 ± 2.1	−0.130	0.366	0.126	0.723
Green	13.9 ± 2.0	0.062	0.366	0.029	0.865

Dispersal Direction and Dispersal Distance

The maximum distances that the adult males dispersed were 30 m and 80 m in the first and second release experiments, respectively. Most of the recaptured males (67.8% in the first experiment and 62.8% in the second experiment) were caught in traps located only 5 m from the release point. The number of recaptured males decreased exponentially with distance from the release point (Fig. 2).

A Kruskal-Wallis test indicated that there were no significant differences in the dispersal distances of males of the 2 treatment groups as compared with the non-irradiated control males in the first (W = 0.00, P = 1) and second experiment (W = 0.2, P = 0.905). In view that no effect of irradiation could be detected with respect to recapture rate and dispersal distance, all data in each experiment was analyzed by regression analysis. The analysis indicated a median dispersal distance of 11.3 m and an arithmetic mean of dispersal distance of 8.7 m in the first release experiment. In the second experiment the median dispersal distance was estimated at 10.6 m and the arithmetic mean of the dispersal distance was estimated at 15.6 m (Table 4).

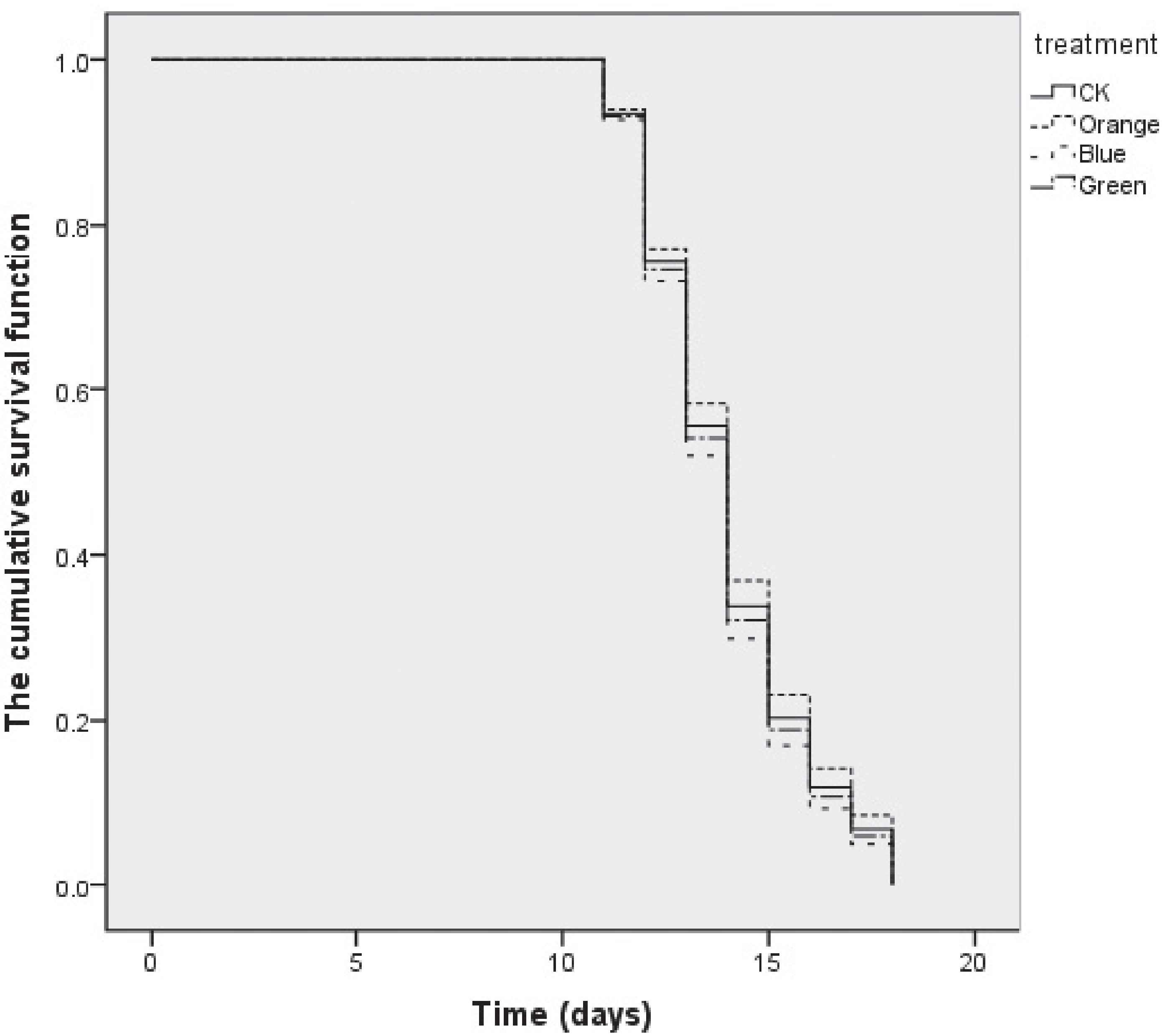

Fig. 1. Survival (days) of non-irradiated *Conopomorpha sinensis* males either dyed with 1 of 3 different fluorescent colors or undyed (control) in the laboratory. Each treatment involved 30 males.

Table 3. The weather conditions during the field release experiments with *Conopomorpha sinensis* adult males in a litchi orchard of the South China Agricultural University, Guangzhou, China. Meteorological data were obtained from a station of the Guangdong Meteorological Service located 5 km from the release orchard. The data presented are the mean values for each 24 h period.

	Day of release				
	1st	2nd	3rd	4rth	5th
First Experiment					
Mean temperature (°C)	28.8	28.9	29.3	30.2	29.0
Max/min temperature (°C)	34.0/24.9	35.0/26.2	34.8/26.9	34.6/27.2	33.2/26.8
Dominant wind direction	SE	SE	SSE	SE	SSE
Mean speed of wind (m/s)	1.6	1.9	1.6	1.8	1.9
Rainfall (mm/d)	0.1	0.0	0.0	0.0	0.0
Second Experiment					
Mean temperature (°C)	27.1	26.7	27.7	28.5	28.8
Max/min, temperature (°C)	32.1/24.5	31.0/24.2	33.7/23.3	35.2/25.0	35.0/25.2
Dominant wind direction	SE	ESE	SE	NE	ENE
Mean speed of wind (m/s)	2.0	1.5	0.8	0.9	1.0
Rainfall (mm/d)	16.6	18.5	0.2	8.6	0.8

Litchi stem-end borer males dispersed in all directions, but in both experiments most males were recaptured in 3 directions (S, W and SW) (Fig. 3). These dispersal directions were similar to the wind directions in each experimental period (Table 3). The dispersal direction was not significantly different for the males of the 2 treatment groups as compared with the non-irradiated control males; for the first release (P = 0.50) and for the second release (P = 0.80). Analyzed percentages of recaptured males in each treatment and experiment were significantly different among the 8 directions (Table 5).

Discussion

Our study showed an average flight speed of non-irradiated male litchi stem-end borers of 0.42 m/s, as measured in a flight mill system in the laboratory. This recorded speed was lower than the one observed for 1 d old Asian corn borers, *Ostrinia furnacalis* (Guenée) (Lepidoptera: Crambidae), i.e., 1.01 m/s at 24 °C and 70–75% RH (Lu et al. 2005), but similar to the one observed for 1 d old pink bollworms, *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae), i.e., 0.54 m/s at 28 °C and 80% RH (Wu 2006). In addition, the greatest total flight distance flown by a *C. sinensis* male using the flight mill system was 13.93 km.

The flight ability of released sterile insects is an important factor for the success of the SIT/IS. Although we cannot expect that the flight performance of insects with a flight mill will accurately reflect their performance under field conditions, the flight mill does provide standardized and quantitative estimates of the insect's intrinsic flight capacity (Taylor et al. 1992). Within the known limitations of the system (Armes & Cooter 1991; Beerwinkle et al. 1995; Riley et al. 1997), flight mills have been used to examine insect flight activity as a function of age, sex, size, mating status, and physiological state (Colvin & Gatehouse

Table 4. Analysis of parameters of field release experiments with adult *Conopomorpha sinensis* males in a litchi orchard of the South China Agricultural University, Guangzhou, China.

	First experiment			Second experiment		
Dose (Gy)	0	150	200	0	150	200
No. of males released	500	500	500	500	500	500
No. of males recaptured	31	27	29	39	47	37
Recapture rate (%)	6.2	5.4	5.8	7.8	9.4	7.4
Effect of irradiation on the recapture rate[a]	χ^2 = 0.293 df = 2 P = 0.864			χ^2 = 1.488 df = 2 P = 0.475		
Arithmetic mean of dispersal distance(m)[b]	9.2	8.89	8.10	14.10	15.96	16.49
Effect of irradiation on the dispersal ability[c]	W = 0.000 P = 1			W = 0.2 P = 0.905		
Regression coefficient[d]	−1.283			−2.964		
P[e]	0.000			0.002		
Correlation coefficient (r)	0.965			0.788		
Estimates of mean dispersal distance (m)[f]	11.33			10.61		

[a]Comparison of the recapture rates across 3 treatments; Chi-square test
[b]Sum of dispersal distance of every recaptured male per number of recaptured males
[c]Comparison of the dispersal distances across 3 treatments; Kruskal-Wallis test
[d]Regression analysis of the number of male individuals on distance from released point
[e]Test of significance for regression; P is probability
[f]Median dispersal distance calculated by the regression

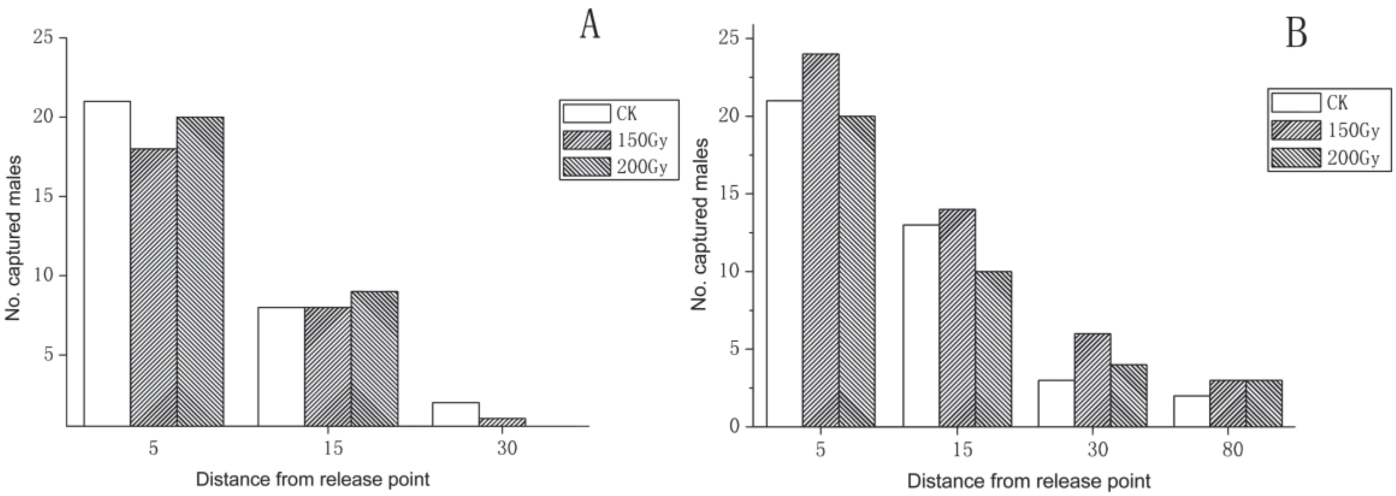

Fig. 2. Numbers of adult *Conopomorpha sinensis* males recaptured in traps deployed at various distances (m) from the release point in 2 release/recapture experiments in a litchi orchard of the South China Agricultural University, Guangzhou, China. The males were either non-irradiated or irradiated either with 150 or 200 Gy. A: First release, B: Second release.

1993; Rankin et al. 1994; Lu et al. 2007; Sarvary et al. 2008; Tsang et al. 2011), as well as lipid utilization in flight (Williams & Robertson 2008).

Irradiation of adult litchi stem-end borer males with either 150 or 200 Gy did not impair their flight ability as measured with a flight mill. Bloem et al. (2006) reported that the mobility of adult *C. pomonella* males was significantly influenced by an interaction of radiation and ambient temperature, but that the relatively low dose of 150 Gy had little effect on the flight activity of the codling moths. In contrast wind tunnel studies with the light brown apple moth, *Epiphyas postvittana* Walker (Lepidoptera: Tortricidae), indicated that either 100 or 250 Gy reduced upwind flight by 14% and 46%, respectively (Suckling et al. 2011). Previous studies had shown that relatively low doses of gamma irradiation did not significantly affect the flight ability of *C. sinensis*, and the results of this study are consistent with the previous studies.

Li et al. (2009) reported that 80.5% of litchi stem-end borer adults in 1 experiment flew 3–7 m, with an average flight distance of 4.97 m and a maximum distance of 12 m. These data are similar to the results of our release recapture experiment, where 59.1% of the released adult males were recaptured in traps that were located at 5 m from the release point, and the median dispersal distance as obtained with the regression analysis was about 11 m. However, we need to recognize that the released males were recaptured in traps baited with the female's sex pheromone, and it is very likely that the released males would have dispersed much longer distances if pheromone sources had been absent.

In the 2 release experiments, the main dispersal direction of the adult male litchi stem-end borers corresponded with the main wind direction, and it was skewed toward the west. We hypothesize that there are 2 other possible factors that may have affected the results. First, our study site was located on an east-west slope, and the experimental area was surrounded by trees except on the north-eastern side. This topography may have enhanced the effect of the wind. Second, the odor of vegetation including oleander, *Nerium indicum* Mill. (Gentianales: Apocynaceae) and wax apple, *Syzygium samarangense* Merr. & Perry (Myrtales: Myrtaceae) outside of the study area may have affected the dispersal direction. Generally, these factors—as well as the effect of some artificial lights to which insects may display a negative

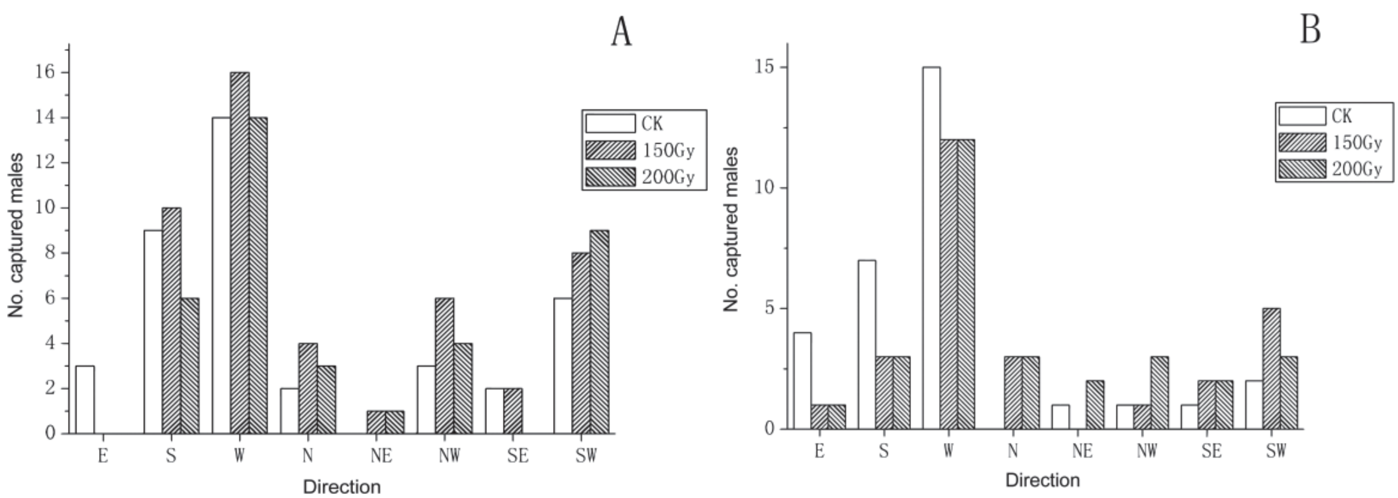

Fig. 3. Frequency distributions of the dispersal directions of adult *Conopomorpha sinensis* males in 2 release/recapture experiments in a litchi orchard of the South China Agricultural University, Guangzhou, China. The males were either non-irradiated or irradiated either with 150 or 200 Gy. A: First release, B: Second release.

Table 5. Tests of dispersal direction of adult *Conopomorpha sinensis* males in field release experiments in a litchi orchard of the South China Agricultural University, Guangzhou, China.

	Test of dispersal direction			Comparison of dispersal direction across 3 treatments
	0 Gy	150 Gy	200 Gy	
First experiment	$P < 0.01$[b]	$P < 0.01$[b]	$P = 0.009$[b]	$P = 0.496$[b]
Second experiment	$P < 0.01$[b]	$\chi^2 = 37.708$, $P = 0$ df = 7[a]	$P < 0.01$[b]	$P = 0.800$[b]

[a]Chi-square test
[b]Fisher exact test

phototaxis (Li et al. 2008)—may combine to affect the dispersal direction (Kumano et al. 2009).

In the present study, we demonstrated that irradiating adult litchi stem-end borer males with either 150 or 200 Gy did not affect their flight ability as measured with a flight mill in the laboratory, nor did these levels of gamma irradiation affect their dispersal ability in the field as measured in 2 release recapture studies. It is clear that operational and commercial insect pest management programs with a SIT component can only be successful when there is consistent production and release of sterile insects of high biological quality and performance (Calkins & Parker 2005). Effective quality assurance tests for monitoring and providing feedback on the performance of insects during each step of production, handling and release are crucial to insure quality control and success of these programs (Huettel 1976; Singh & Ashby 1985; Calkins & Parker 2005). Additional studies are needed to evaluate the quality and performance of litchi stem-end borers released in the field, and to develop mass rearing and mass handling procedures.

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