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Effects of gamma radiation on mortality and sterility of some stored-product beetles

(Kesan sinaran gama terhadap kematian dan pemandulan beberapa spesies kumbang dalam hasil pertanian yang disimpan)

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Key words: gamma radiation, insect control, mortality, sterility, stored products

Abstrak
Keberkesanan sinaran gama sebagai kaedah kawalan serangga telah dikaji terhadap lima spesies kumbang yang terdapat dalam hasil pertanian yang disimpan. Objektif utama adalah untuk menilai dos yang berkesan bagi membunuh dan memandulkan serangga sepenuhnya pada julat dos ujikaji 0.05–1.0 kGy. Pemandulan sepenuhnya tercapai pada dos 1.0 kGy bagi spesies *Lasioderma serricorne* dan *Oryzaephilus surinamensis* dan 0.05 kGy bagi *Tribolium castaneum*. Pengurangan pembiakan yang melebihi 93% populasi dari generasi F_1 diperoleh bagi spesies *Sitophilus zeamais* dan *Rhizopertha dominica*, tanpa perbezaan antara semua dos yang diuji. Penyinaran terhadap *S. zeamais* jantan dewasa menunjukkan teknik kawalan serangga secara pemandulan jantan tidak berkesan. Kematian 100% tercapai dengan penyinaran terhadap biji beras yang mengandungi larva *S. zeamais*. Kematian berlaku pada peringkat larva di dalam biji atau setelah menjelma sebagai dewasa, walaupun 0.6%–11% daripada larva berupaya menyempurnakan edaran hidup mereka ke peringkat dewasa. Jumlah kumbang dewasa yang keluar dari biji beras yang disinar menurun dengan peningkatan aras dos sinaran yang digunakan. Kematian 100% kumbang dewasa dicapai 4–7 minggu selepas didedahkan pada sinaran pada aras 0.2 kGy atau kurang, dan 1–3 minggu pada aras yang melebihi dos ini.

Abstract
The effects of gamma radiation on mortality and sterility of five species of beetles in a stored product were studied. The dosages used ranged from 0.05 kGy to 1.0 kGy. Complete sterilization was achieved at 1.0 kGy for *Lasioderma serricorne* and *Oryzaephilus surinamensis* and at 0.05 kGy for *Tribolium castaneum*. For *Sitophilus zeamais* and *Rhizopertha dominica*, more than 93% reduction of F_1 progenies was observed, with random variations among all the tested dosage levels. Irradiation of male *S. zeamais* adults showed that insect control by male sterility technique is not effective. Developing *S. zeamais* larvae in rice kernels were completely killed either within the kernel or after emergence as adults at all the tested dosages. However, 0.6% to 11% of the treated larvae within the kernels managed to complete their development into adults, with the number of emergents inversely proportional to the dosage levels. Complete mortality of the treated adults of all storage beetle species tested was obtained after 4–7 weeks below 0.2 kGy and 1–3 weeks above 0.2 kGy.

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Introduction

Irradiation as a physical process in the treatment of food has a wide application in food preservation. It can be applied for insect disinfestation, microbial disinfection and in delaying physiological processes in cereals, pulses, fruits, vegetables and many other fresh or dried agricultural products (Loharanu 1985). A type of ionizing radiation that has been extensively experimented for controlling insects in stored products is the gamma ray and its potential application has been extensively reviewed (Watters 1972, 1979; Tilton 1975, 1979; Evans 1985).

Variations in insect response to a particular radiation dosage occur due to differences in climate, food, storage method, and tolerance acquired resulting from repeated applications of control measures (Cornwall 1966). The occurrence of different strains of the same insect species resulting from the influence of the above factors justifies the needs to verify any new insect control technique under the local conditions.

Currently, there is a dearth of information on the effectiveness of ionizing radiation against insects found during storage in Malaysia. This paper reports part of a programme to determine the feasibility of controlling storage insects by gamma radiation. The objective of this study was to establish the time taken to induce complete mortality of five common beetle species in various stored products and to elucidate the effective minimum dosages to cause sterility of the insects.

Materials and methods

Radiation source and dosage

The gamma radiation was obtained from a Cobalt-60 source (Gamma-cell GL4000A) at the Nuclear Energy Unit (NEU), Prime Minister's Department, Bangi. Dosimetric measurements were performed using a Fricke dosimeter. The dosage rate of the Cobalt-60 source at the time of irradiation was approximately 0.095 kGy/min. The maximum dosage currently recommended by WHO/FAO for the treatment of grain is 1.0 kGy. For this study, dosages of 0 (untreated control), 0.05, 0.1, 0.2, 0.4, 0.6, 0.8 and 1.0 kGy were chosen to determine the minimum dosage to sterilize local strains of five beetle species and the time taken to induce 100% mortality on irradiated adults.

Insects and treatments

The five insect species used were beetles *Sitophilus zeamais, Rhizopertha dominica, Lasioderma serricorne, Tribolium castaneum* and *Oryzaephilus surinamensis*. All the test insects were obtained from laboratory cultures reared in a controlled environment chamber maintained at 30 °C and 70% RH. Both *S. zeamais* and *R. dominica* were reared on whole-grains whereas *L. serricorne* was reared on crushed cocoa beans and *O. surinamensis* on oatmeal. Adults, 1–10 days old, were routinely removed from the rearing jars every week to be used in all the tests. For *R. dominica, L. serricorne, T. castaneum* and *O. surinamensis*, 1 280 adults of each species, regardless of sex, were counted in batches of 40 insects into 32 plastic vials each measuring 4.5 cm x 7 cm with perforated opening and containing 5–10 g of respective insect media. There were four replications for each of the test doses and the control. *Sitophilus zeamais* was chosen for detailed evaluation to determine the minimum lethal and sterility dosages on irradiated paired male and female adults, irradiated male adults only and the sterility dosage for larva developing within rice kernels. The same dosages above were used in these experiments. For the test on paired parents, 10 pairs of the 1–10 day old adults were counted into each vial and subsequently irradiated. In the test on sterilizing male parent only, 10 adult males were irradiated with various

Table 1. Time taken to achieve complete mortality of irradiated adults of five species of storage beetles

Dosage (kGy)	Mean (weeks)				
	S. zeamais	*R. dominica*	*L. serricorne*	*T. castaneum*	*O. surinamensis*
0.05	4.7a	7.7a	2.0a	4.2a	10.1a
0.1	3.7b	6.5a	2.3a	2.6ab	2.9b
0.2	2.6c	3.1b	2.3a	2.7a	2.3b
0.4	2.6c	2.6b	2.3a	2.6ab	2.1bc
0.6	2.6c	2.1b	2.3a	1.8b	1.7bc
0.8	2.6c	1.4b	2.3a	1.9b	1.4c
1.0	2.6c	1.1b	2.0a	1.7b	1.4c

Means followed by different letters are significant at $p = 0.09$

dosages and then introduced to 10 non-irradiated females for each replicate. Adults *S. zeamais* were individually sexed by examining the proboscis (Halstead 1962). In the tests on irradiation of the larva, 1 920 infested milled rice kernels with varying larval instars within, were collected from culture jars 18–20 days after introduction of adult weevils. The infested kernels were then randomly transferred into 32 vials each with 80 kernels. Twenty-eight of these vials were irradiated. There were four replications per dosage and four vials were kept as untreated control.

After irradiation, the insects were maintained in the rearing chamber at 30 °C and 70% RH. In tests on adult insects, the mortality of irradiated insects was recorded every 3–4 days until all the irradiated insects were dead. Subsequently, the number of fresh adults that emerged were recorded and removed weekly for 10 weeks, until no adults emerged for 1 week. The number of days required to achieve 100% mortality of the adult served as a measure of efficiency of the treatment dosages. Differences in the efficacy among the tested dosages were statistically analysed using Duncan's multiple range test. The reduction in reproductive performance, based on number of progenies in F_1 generation obtained between irradiated and control doses, served as a basis of comparison among the treatments for effective sterilizing dosage. The mortality values of irradiated adults were adjusted for control by using the Abbott's formula.

Results and discussion

The relative effectiveness of gamma radiation at various dosage levels to induce mortality and sterility to the five species of storage beetles is shown in *Table 1* and *Table 2* respectively. Since none of the dosages used in this test caused 100% immediate mortality, relative efficacy of the doses was measured in terms of time taken to induce 100% mortality of the initial irradiated population.

***Sitophilus zeamais* (Mots.)**

The irradiated weevils showed no difference between dosages of 0.2 to 1.0 kGy, based on time to achieve 100% mortality. At these dosages, about 2.6 weeks were required to induce complete mortality to the treated paired adults. The dosage levels below 0.2 kGy took a longer time whereby about 4.7 weeks and 3.7 weeks elapsed before all insects were dead at 0.05 kGy and 0.1 kGy respectively. The extended period to induce total mortality probably enabled the mating and subsequent reproduction of new F_1 adults at an average of 0.1 to 0.8 adult per paired parents among all tested dosages. However, the reduction in reproductive potential ranged from 92% to 98% compared to 'control'. These findings

Table 2. Effectiveness of gamma irradiation to suppress insect reproduction (F_1 generation) at various treatment doses

Dosage (kGy)	No. F_1 adults per 40 unsexed insects								No. F_1 adults per paired parent			
									S. zeamais			
	R. dominica		*L. serricorne*		*T. castaneum*		*O. surinamensis*		(Both parent irradiated)		(parent only irradiated)	
	No. F_1	Reduction (%)	No. F_1	Reduction[+] (%)	No. F_1	Reduction (%)	No. F_1	Reduction (%)	No. F_1	Reduction (%)	No. F_1	Reduction (%)
Control	24.7	–	24.4	–	7.1	–	0.7	–	10.6	–	66.7	
0.05	1.2	95.1	3.3	98.6	0	100	0.1	85.7	6.5	93.8	6.2	62.2
0.1	2.2	91.0	0	100	0.1	98.5	0	100	1.5	98.5	18.0	73.0
0.2	5.2	78.9	0	100	0	100	0	100	7.0	93.3	62.2	7.0
0.4	6.2	74.8	0	100	0	100	0	100	3.2	96.9	45.0	29.5
0.6	0.8	96.7	0.3	99.8	0	100	0	100	6.2	94.1	71.5	0
0.8	0.8	96.7	0	100	0	100	0	100	8.5	91.9	50.1	24.8
1.0	0.7	97.1	2.3	99.0	0	100	0	100	8.5	91.9	48.0	28.0

[+] % Reduction $= \frac{\text{Control} - \text{treatment}}{\text{Control}} \times 100$

Table 3. Emergence and mortality of *S. zeamais* adults from gamma irradiation rice kernels

Dosage (kGy)	Av emergence/ 80 kernels (%)	Mortality (%)	Reduction in emergence (%)
Control	18.5a	0	–
0.1	8.7b	100	52
0.2	2.7bc	100	60.4
0.4	2.5cd	100	86.3
0.6	1.5d	100	92.1
0.8	0.5d	100	98.7
1.0	0.2d	100	97.4

Means followed by different letters are significant at $p = 0.01$

concurred with earlier investigations (e.g. Brower and Tilton 1972) that the time required to induce 100% mortality was 4 weeks at dosages between 0.3 kGy and 0.5 kGy. However, the incomplete sterility for dosages up to 1.0 kGy as shown in this test did not agree with their findings that 0.1 kGy was adequate to induce total sterility.

The number of adults that emerged from the larvae within the irradiated rice kernels and the percentage mortality of these newly emerged adults are shown in *Table 3*. None of the tested dosage levels were able to completely prevent the metamorphic development of the larvae into adult, as shown in *Table 3*. The mortality of the larvae within the kernel could not be determined, as these were hidden within the rice kernels. Some larvae which developed into adults died before emerging from the rice kernels. These non-emerging adults were not considered as fully-developed adults and were thus not counted as new emergences. At 0.05 kGy, about 9% of the larvae developed and emerged from the kernels as adults but the number decreased to 0.2% at 1.0 kGy with the number proportionately reduced with increment in dosage levels. This represented 52% to 98% reduction in adult emergences compared with the number of emergences in kernels held as control. Although the adults managed to emerge, all of them died shortly within 1–2 days after emergence at the tested dosage levels. None of the new adults were able to produce progenies. The results indicated that, depending on dosage levels, some of the developing larvae of the irradiated maize weevils were able to complete their development to adult, but the effect of the gamma rays tended to shorten the life-span of the new adults.

The tests to verify the effective dosage to induce male sterility by irradiating male parent only showed less than 30% reduction in the F_1 generation compared to 90% obtained by irradiating both parents.

Rhizopertha dominica (F.)

Irradiation dosages showed definite pattern of increasing effectiveness with corresponding increase in dosage levels. However, the differential time to achieve 100% kill at dosages of 0.2 kGy and above was not significant. This finding is comparable with previous finding (Tilton et al. 1966) that the time required to kill 100% of the treated adults was reduced from 4 weeks to 1 week when irradiation dosage was increased from 0.1 kGy to 1.0 kGy. However, their observation on achieving complete sterility at 0.13 kGy was contrary with these findings as none of these tests induced total sterility. The reduction in reproduction, based on number of progenies produced, ranged from 75% to 97% compared to non-irradiated 'control' adults.

Lasioderma serricorne **(L.)**

The post-treatment mortality was about the same for all the seven dosage levels whereby complete mortality was achieved after 2–2.3 weeks. The life span of the treated insects from this study was shorter than previously reported (Tilton et al. 1966) where the tested dosage levels of 0.13–1.0 kGy required 5–7 weeks. The minimum dosage required to induce total sterility i.e. 0.25 kGy, as shown in the same report, was also higher than that observed in this study, i.e. 0.1 kGy.

Tribolium castaneum **(H.)**

Comparison of the mortality times for the different treatment doses showed no significant differences among the tested dosages. Nevertheless, all dosages induced complete suppression against reproduction of F_1 generation insects with the exception of 0.1 kGy. Both the mortality and sterility results were comparable with two earlier findings which showed that 3–4 weeks were required to achieve 100% mortality. Similarly, Watters and MacQueen (1967) and Brower and Tilton (1973) reported that dosage levels of 0.1–0.2 kGy was sufficient to completely sterilize the insect.

Oryzaephilus surinamensis **(L.)**

The results on mortality dosages showed a pattern of increasing effectiveness proportionate with increment of dosage levels. At 0.05, 0.1–0.4 and 0.6–1.0 kGy, the mortality time required was 10, 2–3 and 1.5 weeks respectively. The adult beetles were effectively sterilized at a minimum dosage of 0.1 kGy, and no reproduction was observed at the higher dosage levels. These results were comparable to the previous findings based on treatment dosage of 0.5 kGy which required 2.4 weeks to totally disinfest the unsexed adults (Cornwall et al. 1957). Brower and Tilton (1972) studies on response by different sexes showed that male insects were more tolerant to irradiation than the females, requiring 10 weeks and 2–3 weeks, at 0.3–0.5 kGy levels, respectively. The latter's report also showed that the dosage level needed to completely sterilize the insect was 0.2 kGy, which is slightly higher than that observed in this investigation.

These findings on the effectiveness of gamma irradiation to cause mortality and induce sterility to the five storage beetles generally agreed with results obtained by other researches reviewed in this report. Although the exact dosage levels varied, these investigations also concurred that gamma radiation as a method of insect control is best applied at dosages sufficient to cause immediate reproductive sterilization, although several weeks may be taken to produce complete mortality. These findings also showed that complete sterilization of irradiated adult of *L. serricorne*, *T. castaneum* and *O. surinamensis* was achieved at the highest dosage level of 0.1 kGy. At the same dosage level, reduction in reproduction by more than 93% was observed for *R. dominica* and *S. zeamais*. Complete sterilization was not obtained on the letter two insects even by increasing the dosages up to 1.0 kGy. Evans (1985), in his review on efficacy of gamma radiation on stored product insects observed that 0.2 kGy was needed to cause immediate total sterility for the above five beetle species using population found in USA. In the same report, he noted that some storage beetles in Australia, including *L. serricorne*, required up to 0.4 kGy. However, these findings that the time required to cause complete mortality was 4–7 weeks at dosages up to 0.2 kGy, and 1–3 weeks above this dosage were comparable to the findings by earlier workers (Evans 1985). Although dosages ranging from 2.5 kGy to 5 kGy are required to cause 100% mortality within 24 h, such dosages may cause changes in the treated food (Evans 1984).

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