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Efficacy of gamma irradiation against *Sitophilus granarius* (L.) (Coleoptera: Curculionidae)

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Abstract

The lethal and sterilizing responses to gamma irradiation of eggs, larvae, pupae, and three-day- and four-week-old adults of *Sitophilus granarius* were investigated. Doses were 0, 10, 30, 50, 70, 100, 300 and 500 Gy. Eggs and larvae were unable to develop to adults following doses of 30–500 Gy. Emergence of adults from irradiated eggs and larvae occurred at a dose of 10 Gy. Pupae developed to the adult stage following doses of 10–70 Gy. A dose of 70 Gy at the pupal and four-week-old adult stages caused sterility. Three-day-old adults were most tolerant of irradiation and required 100 Gy for sterility. The percentage of damage to wheat grains caused by pre-adult stages following various irradiation doses was determined.

Keywords: Sitophilus; Stored grain; Physical control; Irradiation; Sterility

1. Introduction

Fumigants and other insecticides are widely used to control insects in stored grain but residues and development of resistance in certain species have been of some concern (Champ and Dyte, 1976). Furthermore, fumigation is being increasingly restricted for environmental reasons. Methyl bromide is to be phased out by 1 January 2005 in developed countries (Anon., 1997) and phosphine has an extended application time which makes it unsuitable for many disinfestation requirements. As options become more limited, countries can be expected to increasingly turn to irradiation as an alternative treatment (Pszczola, 1997). Moreover, the

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residue-free advantages of irradiation disinfestation over chemical fumigation have been demonstrated repeatedly (Tuncbilek, 1995a).

Curculionids were observed to be sensitive to irradiation (Tilton and Brower, 1987). Brown et al. (1972) found that 10 Gy was sufficient to cause sterility in adults of *Sitophilus granarius* (L.). Tuncbilek (1995b) observed that adult mortality of *S. granarius*, following irradiation, was considerably increased by raising the temperature post-irradiation. Zewar and Abdel-Salam (1988) found that irradiation of *S. granarius* at 160 Gy decreased food consumption rates measured after five weeks by 92.4, 99.3 and 100% on wheat, sorghum and rice, respectively.

Our objective was to study the effects of gamma irradiation on *S. granarius*. Since the immature stages of *S. granarius* develop within cereal grains, a preliminary study was conducted to determine the development time from egg to adult emergence under the experimental conditions.

2. Materials and methods

S. granarius has been reared on wheat grains over several years at the Entomology Laboratory of the Department of Plant Protection, College of Agriculture, King Saud University, under controlled conditions of $28 \pm 2°C$ and $65 \pm 5\%$ r.h. The insects were maintained under these conditions before and during all tests and observations. Jars (11×7 cm) and dishes (9×1.5 cm) were used in the current studies.

2.1. Biological study

Sixteen replicates were used in the biological study. Twenty adults were placed in jars containing 100 g of wheat. Adults were removed after 48 h. Progeny were counted and removed daily from first emergence till completion. The period from oviposition to adult emergence was recorded.

2.2. Irradiation

This study determined the effects of gamma irradiation on *S. granarius* eggs, larvae, pupae, and three-day- and four-week-old adults. Doses of 0 (control) 10, 30, 50, 70, 100, 300 and 500 Gy were used on four replicates at each dose. Controls were subjected to the same disturbance as the tested insects including transfer to the irradiator and return. A semi-commercial irradiation facility, ^{60}Co source, at King Faisal Specialist Hospital and Research Center was used for the irradiation. The dose rate was 933 rads/min (0.56 kGy/h). The absorbed dose was monitored by ferric sulfate dosimeters. The max–min ratio of doses used were 1.127, 1.071, 1.034, 1.031, 1.087, 1.063 and 1.047, respectively.

One thousand adult weevils were isolated from a stock culture by sieving and were placed on 15 kg of wheat grains (9.5% m.c.) for ovipositing. Adult weevils were removed by sieving after 48 h. Samples of 100 g of wheat infested in this way were taken randomly and placed in jars. Grains infested with eggs and larvae were irradiated at 1 and 14 days, respectively, after removal of the adult weevils from grains. Grains containing pupae were irradiated three days before the first adult emergence was expected. Four weeks after the first adult emergence in the controls, 100 kernels were selected randomly from each replicate, and the number of damaged grains containing an adult emergence hole was counted. Ten adults, per replicate, that emerged from irradiated eggs, larvae, and pupae were transferred by a fine brush to dishes containing 20 g of wheat. These adults were observed for survival and progeny as an indication of reproductive ability.

Twenty of three-day- and four-week-old adults were placed in jars with 100 g of wheat. After irradiation, ten adults from each jar were transferred by a fine brush to dishes containing 20 g of wheat. These adults were observed for survival and progeny as an indication of reproductive ability.

Analyses of variance of the data were carried out according to the statistical analysis system (SAS). Significance was measured at $P < 0.05$.

3. Results

The biological study of *S. granarius* under laboratory conditions showed that the first adults emerged from grains 32 days after oviposition. Moreover, 58% (150.1 ± 10.8) of adults emerged in the first three days.

Mortality following irradiation of eggs was relatively high. No adults emerged at doses of 30–500 Gy and no damage occurred to wheat kernels. At 10 Gy, adults emerged but with a significant decrease in survival compared to the control, 257.7 ± 9.4, (Table 1). Damage to wheat grains from weevils was 4.3% which was significantly less than in controls (Table 2). Moreover, the replacement rate after treatment at 10 Gy was 0.2, significantly less than in the control (Table 3).

Mortality following irradiation of larvae was high at all doses of irradiation. No adults emerged from larvae irradiated at 30–500 Gy and there were no externally damaged grains. At 10 Gy, adults emerged from irradiated grains containing larvae but there was a significant decrease in survival compared with controls (Table 1). Damage was relatively high (10.8%) but

Table 1
Adult survivorship at 7–42 days from eggs and larvae of *Sitophilus granarius* gamma irradiated at doses from 10–500 Gy[a]

		% survival of adults emerged from irradiated eggs and larvae (means ± S.E.)					
Dose (Gy)	Stage	7 days	14 days	21 days	28 days	35 days	42 days
0		100 a	100 a	100.0 a	100 a	92.5 ± 4.8 a	90.0 ± 4.1 a
10	Egg	55.0 ± 6.5 c	42.0 ± 4.8 c	17.5 ± 4.8 c	0.0 c	0.0 c	0.0 b
	Larva	75.0 ± 6.5 b	70.0 ± 5.8 b	57.5 ± 4.8 b	32.5 ± 4.8 b	15.0 ± 2.9 b	0.0 b
30–500	Egg	0.0 c	0.0 c	0.0 c	0.0 c	0.0 c	0.0 b,c
	Larva	0.0 c	0.0 c	0.0 c	0.0 c	0.0 c	0.0 b

[a] Means with the same letters in same column were not significantly different. $n = 10$, number of individuals per replicate.

Table 2
Percentage (means ± S.E.) of wheat grains damaged by *Sitophilus granarius* following gamma irradiation at doses from 10–500 Gy[a]

Doses (Gy)	Stages irradiated		
	Egg	Larva	Pupa
0	19.3 ± 2.6 a	19.3 ± 2.7 a	19.0 ± 0.9 a
10	4.3 ± 1.5 b	10.8 ± 1.4 b	14.0 ± 1.2 b
30	0.0c	0.0 c	10.0 ± 0.9 c
50	0.0c	0.0 c	7.3 ± 0.5 d
70	0.0c	0.0 c	4.0 ± 0.4 e
100	0.0c	0.0 c	2.3 ± 0.8 e
300–500	0.0c	0.0 c	0.0 f

[a] Means with the same letters in same column were not significantly different.

significantly less than in controls. Adults which developed from larvae irradiated at a dose of 10 Gy were able to reproduce with a replacement rate of 1.8 (Table 3).

Pupae were more tolerant of irradiation than egg or larval stages. No adults emerged from pupae irradiated at a dose of 500 Gy. Adults which emerged from pupae irradiated at a dose of 100 Gy died immediately after emergence with 2.3% of damaged grains. Total mortality was achieved 21 and 42 days after adult emergence from pupae irradiated at doses of 70 and 10–50 Gy respectively (Table 4). The percentage of damage to wheat grains decreased significantly with increasing doses (Table 2). Doses of 70 and 100 Gy resulted in complete sterility in adults which emerged from irradiated pupae, whereas adults which emerged from pupae irradiated at doses 10–50 Gy were able to produce progeny but with significant reduction in replacement rate with increasing dose (Table 3).

Three-day-old adults showed the highest tolerance of irradiation (Table 5). Doses of 10, 30, 50, 70, 100, 300 and 500 Gy caused 100% mortality in young adults 49, 42, 42, 35, 28, 14 and

Table 3
Replacement rate (means ± S.E.) of *Sitophilus granarius* following gamma irradiation at doses from 10–500 Gy[ab]

Doses (Gy)	Stages irradiated				
	Egg	Larva	Pupa	Young adult	Old adult
0	5.7 ± 0.8 a	5.7 ± 0.3 a	7.2 ± 0.4 a	3.2 ± 0.2 a	2.4 ± 0.1 a
10	0.2 ± 0.9 b	1.8 ± 0.6 b	3.6 ± 0.5 b	2.5 ± 0.4 b	1.6 ± 0.2 b
30	0.0 b	0.0 c	0.4 ± 0.1 c	0.5 ± 0.1 c	0.4 ± 0.1 c
50	0.0 b	0.0 c	0.2 ± 0.2 c	0.2 ± 0.04 c	0.2 ± 0.1 cd
70	0.0 b	0.0 c	0.0 c	0.2 ± 0.2 c	0.0 d
100–500	0.0 b	0.0 c	0.0 c	0.0 c	0.0 d

[a] Means with the same letters in same column were not significantly different.
[b] Replacement rate = no. progeny ÷ no. parental adults.

Table 4
Adult survivorship at 7–42 days from pupae of *Sitophilus granarius* gamma irradiated at doses from 10 to 500 Gy[a]

	% survival of adults emerged from irradiated pupae (means ± S.E.)					
Dose (Gy)	7 days	14 days	21 days	28 days	35 days	42 days
0	100 a	100 a	100 a	97.0 ± 2.5 a	95.0 ± 2.9 a	87.5 ± 7.5 a
10	95.0 ± 5.0 a	85.0 ± 2.9 b	77.5 ± 4.8 b	60.0 ± 4.1 b	37.0 ± 2.5 b	0.0 b
30	85.0 ± 2.9 b	80.0 ± 4.1 b	70.0 ± 4.1 c	60.0 ± 4.1 b	35.0 ± 5.0 b	0.0 b
50	65.0 ± 2.9 c	57.0 ± 4.9 c	45.0 ± 2.9 d	32.0 ± 2.5 c	12.5 ± 2.5 c	0.0 b
70	17.5 ± 2.5 d	10.0 ± 4.1 d	0.0 e	0.0 d	0.0 d	0.0 b
100–500	0.0 e	0.0 e	0.0 e	0.0 d	0.0 d	0.0 b

[a] Means with the same letters in same column were not significantly different. $n = 10$, number of individuals per replicate.

7 days after irradiation, respectively. Doses of 100, 300 and 500 Gy caused complete sterility in young adults, whereas adults which were exposed to doses of 10, 30, 50 and 70 Gy were able to produce progeny but with significant reduction in the replacement rate with increasing dose (Table 3).

Four-week-old adults were more susceptible to irradiation than young adults (Table 6). Doses of 300 and 500 Gy caused immediate mortality in these adults. Doses of 70 and 100 Gy caused 100% mortality 14 and 21 days post-irradiation, whereas doses of 10, 30, 50 Gy required 28 days to cause 100% mortality. Four-week-old adults which were exposed to 70–500 Gy were unable to produce progeny. However, adults which received 10–50 Gy produced progeny but with a significant reduction in the replacement rate with increasing dose (Table 3).

Table 5
Adult survivorship of three-day-old adults of *Sitophilus granarius* gamma irradiated at doses from 10 to 500 Gy[a]

	% survival of adults after treatment (means ± S.E.)						
Dose (Gy)	2 days	7 days	14 days	21 days	28 days	35 days	42 days
0	100 a	100 a	100 a	98.8 ± 1.3 a	96.3 ± 2.4 a	95.0 ± 2.9 a	86.3 ± 2.4 a
10	100 a	100 a	86.0 ± 2.4 b	78.8 ± 4.7 b	62.5 ± 3.2 b	36.3 ± 4.3 b	2.5 ± 2.5 b
30	100 a	93.8 ± 2.4 a	85.0 ± 3.4 b	63.8 ± 2.4 c	43.8 ± 4.3 c	26.3 ± 2.4 c	0.0 b
50	96.3 ± 2.4 ba	86.3 ± 2.4 b	75.0 ± 2.0 c	56.3 ± 2.4 d	43.8 ± 3.4 c	16.3 ± 3.1 d	0.0 b
70	92.5 ± 3.0 b	80.0 ± 2.9 b	32.0 ± 4.8 d	21.3 ± 2.4 e	10.0 ± 3.5 d	0.0 e	0.0 b
100	85.0 ± 2.9 c	65.0 ± 3.5 c	10.0 ± 3.5 e	2.5 ± 2.5 f	0.0 e	0.0 e	0.0 b
300	67.5 ± 3.2 d	32.5 ± 3.2 d	0.0 f	0.0 f	0.0 e	0.0 e	0.0 b
500	36.3 ± 2.4 e	0.0 e	0.0 f	0.0 f	0.0 e	0.0 e	0.0 b

[a] Means with the same letters in same column were not significantly different. $n = 10$, number of individuals per replicate.

Table 6
Adult survivorship of four-week-old adults of *Sitophilus granarius* gamma irradiated at doses from 10 to 500 Gy[a]

	% survival of adults after treatment (means ± S.E.)				
Dose (Gy)	2 days	7 days	14 days	21 days	28 days
0	100 a	100 a	100 a	95.0 ± 2.0 a	90.0 ± 2.0a
10	88.8 ± 2.4 b	80.0 ± 3.5 b	63.8 ± 7.2 b	46.3 ± 3.1 b	0.0 b
30	81.3 ± 2.4 c	58.8 ± 5.9 c	37.5 ± 4.8 c	30.0 ± 6.8 c	0.0 b
50	80.0 ± 2.0 c	46.3 ± 3.1 d	16.3 ± 5.9 d	10.0 ± 3.5 d	0.0 b
70	72.5 ± 3.2 d	42.5 ± 5.9 d	7.5 ± 2.5 ed	0.0 e	0.0 b
100	61.3 ± 4.3 e	21.3 ± 3.1 e	0.0 e	0.0 e	0.0 b
300–500	0.0 f	0.00 f	0.0 e	0.0 e	0.0 b

[a] Means with the same letters in same column were not significantly different. $n = 10$, number of individuals per replicate.

4. Discussion

The most effective grain disinfestation fumigant, methyl bromide, will be banned in some countries and phased out in others commencing in 1999 (Anon., 1997). The alternative fumigant phosphine is widely used on grain but requires a relatively long duration of exposure 5–12 days compared to 12–24 h for methyl bromide (Bell, 1979). Thus, phosphine cannot achieve the quick response of methyl bromide needed for situations such as grain found to be infested during loading into a ship. Irradiation requires very short exposure times and is limited only by the throughput rate. Irradiation leaves minimal residues consistent with the growing consumer preference for foodstuffs free of chemical residues.

Lower doses of irradiation do not cause immediate death of adults, but low doses can prevent an increase in the population by lethal effects on the immature stages, sterilization of adults and a reduction in adult longevity (Buscarlet, 1982). Thus, irradiated adults will die before most grain shipments reach their final destinations. Cornwell (1966) stated that the presence of irradiated adults does not imply continuing infestation because the adults should be sterile and incapable of reproducing. Moreover, Zewar and Abdel-Salam (1988) found that the rate of food consumption of live adults, irradiated at a dose of 250 Gy, decreased considerably. Brown et al. (1972) found that no adults emerged from treated eggs and larvae of *S. granarius* at doses of 50–100 Gy whilst Tilton et al. (1966) found that of 150 larvae of *Sitophilus oryzae* treated at 132 Gy + 10% two emerged as adults.

The results obtained from our study and others show agreement in the sensitivity of *S. granarius* to irradiation, with eggs and larvae the most sensitive stages. Eggs and larvae treated at a dose of 10 Gy developed to the adult stage but not at doses of 30–50 Gy.

The pupal stage showed more tolerance of irradiation than eggs or larvae. No adults emerged from pupae irradiated at doses of 100–500 Gy. Furthermore, a dose of 70 Gy was sufficient to produce sterility in adults which emerged from treated pupae. However, Brown et al. (1972) found that the emergence of adults from irradiated pupae occurred after doses as high as 200 Gy and a dose of 50 Gy on pupae was adequate to cause sterility.

Tilton et al. (1966) found that for *S. oryzae* adults were most tolerant, followed by the pupae, larvae and then eggs. Jefferies (1962) found that a dosage applied to adults of *S. granarius* sufficient to cause complete sterility, would also cause sterility if applied to other stages. Moreover, Cornwell and Bull (1960) reported that resistance to radiation increased slightly through the life cycle of any insect. Young adults would not produce progeny when treated with doses of 100 Gy or above. The same results were found by Brown et al. (1972). Tuncbilek (1990) found that a dose of 80 Gy caused complete sterility to adults of *S. granarius*. We found that three-day-old adults exhibited the most tolerance of irradiation followed by pupae.

Our study is the first to explore the effects of irradiation on young and old adults of *S. granarius*. Old adults showed less resistance to irradiation and a dose of 70 Gy was adequate to sterilize the old adults. This finding is contrary to the report of Cornwell and Bull (1960) who found that the older an insect within any given stage, the greater its resistance to irradiation. Whilst their statement is applicable to pre-adult stages, it does not take into account the effect of senility apparently responsible for our findings.

The effect of temperature and grain moisture content on the efficacy of radiation were not studied. High temperature (30°C) during radiation did not increase the rate of adult mortality of granary weevils (Pendlebury, 1966). Moreover, the degree of sterilization induced by radiation was not affected by temperature (Tilton and Brower, 1987).

The use of multiple doses and stages has enabled us to identify a minimum treatment of 100 Gy which would be effective against *S. granarius* in wheat under operational conditions. This is the treatment required to ensure zero replacement which equates to sterility and then death of all adults within a shipping transit time of 28 days. For shorter times a higher minimum dose might be required.

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