Radiation disinfestation of used packagings: irradiation trials with electron beams

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Abstract

Used bags, sacks and other packagings are often infested with insect and mite pests of stored products. Such packagings provide a source of infestation for products entering storage.

Cleaning of reused packages is the most important preventive method. After use, bags and sacks should be carefully beaten with a mechanical or hand beater. When pests are found, the packages should be disinfested with hot air or hot water. Larger numbers of bags are usually fumigated in a special chamber. Irradiation is a potential substitute for chemical fumigation.

This paper describes trials of radiation disinfestation of used bags. Information on the use of electron beams for pest disinfestation of jute and PVC plastic bags is given. Of the irradiation parameters, absorbed dose is the most important. Kill rates equivalent to chemical insecticides are obtained by high doses of ionising radiation. Control of insect and/or mite infestation of the reused packagings may be obtained by ionising radiation applied at 2–3 kGy. These doses result in complete mortality of stored product pests within a few days.

The radiation must penetrate the product to sufficient depth. Gamma rays and X-rays penetrate treated products easily, but penetration by radiation is much lower, depending on the electron energy employed. The results of this study indicate that bags made of PVC may be disinfested with electron beams when treated as separate units or in batches up to 50 bags. Penetration of jute bags is lower than plastic bags. Jute bags should be irradiated with electrons in batches containing no more than 30 bags.

Introduction

Packages which are repeatedly used contain often the remains of previously packed agricultural commodities and stored product pests. These pests include various developmental stages of beetles (Coleoptera), moths (Lepidoptera), mites (Acarina) and others. Insect and mite pests may feed and reproduce on these remains. When the packages infested with stored product pests are used for packaging of new product lots or units, the pests present infest them easily and soon produce severe damage to the product.

Cleaning of repeatedly used packages is the most important preventative method. After use, bags and sacks should be carefully beaten with a mechanical or hand beater. This should be done outside the storehouse. After beating of external and internal side of sacks, they should be checked for insect pests at their folds and joints (Golebiowska and Nawrot 1976). When pests are found, the packages should be disinfested with hot air or hot water. Larger numbers of bags are usually fumigated in a special fumigation chamber.

Until now, fumigation with chemicals such as methyl bromide or phosphine is the most effective method for disinfestation (Bond 1984). However, fumigation has many limitations including the lack of penetration of the fumigant into the product in sufficient concentration; undesirable residues; increased resistance of surviving pests to the chemical leading to higher dose requirements; potential fire hazard with some fumigants (Moy 1988). Therefore, there is a need for alternatives to chemical methods of disinfestation.

Disinfestation by radiation is potentially a feasible substitute for chemical fumigation. Irradiation, in the form of gamma radiation or accelerated electron beam, is technically efficacious, economically feasible and can be safely used for disinfesting a wide variety of materials and agricultural products (Moy 1988).

The purpose of this paper is to present information on the use of electron beams for disinfesting packages. Trials of radiation disinfestation of sacks (bags) made of juta or polyvinyl chloride are described and discussed.

Radiation disinfestation of used bags by electron beams

Pre-irradiation treatment of packages

After each use, the packages were carefully beaten with a hand beater, and the remains of the previous products removed. After this treatment, packages were stored in clean, pest-free storehouses. To minimise pest contamination, packages were kept at low temperature and humidity.

Before the irradiation treatment, the empty bags were handled as separate units or as groups of 10, 20, 30, 40, and 50 units. No special precautions were undertaken during transport of these bags to and from the irradiation facility.

Irradiation of packages

Irradiation facility and its operation

Irradiation treatments were performed at the Pilot Plant for Electron Beam Food Processing, having a licence granted by Panstwowa Agencja Atomistyki, an office of the Polish Government responsible for atomic energy matters. This plant is used for food irradiation, and is equipped with a small research accelerator Pilot 1 (10 MeV, 1 kW), and with an industrial unit Elektronika (10 MeV, 10 kW) (Table 1). Elektronika 10–10 has a vertical installation position and 90° bending of the beam by 270° magnet. This industrial unit is also equipped with e-/X conversion target, and therefore is suitable for irradiation of high density products. A conveyor supplies materials under the horn of an accelerator with programmed and constant velocity which permits achievement of the desired radiation dose. Total length of the conveyor is

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Table 1. Technical characteristics of the Pilot 1 and Elektronika 10-10 accelerators

Parameters	Pilot 1	Elektronika 10-10
Electron energy	8-10 MeV	5-10 MeV
Mean beam current	0.1 mA	1 mA
Mean power in the beam	0.7-1.0 kW	10 kW
Pulse duration	4 μs	2-7 μs
Pulse frequency	50-300 Hz	25-400 Hz
Scanning frequency	2998 MHz	1887 MHz

approximately 70 m, and its width is 60 cm (Migdal et al. 1993).

This facility employs an accelerated electron beam generated by an accelerator operated at or below an energy level of 10 MeV according to the guidance provided in the following publications: Codex General Standard for Irradiated Foods (worldwide standard). Codex Alimentarius Commission Codex Stan. 106–1983; Recommended International Code of Practice for the Operation of Irradiation Facilities Used for the Treatment of Food. Codex Alimentarius Commission, CAC/RCP 19–1979.

It is not possible to distinguish irradiated from unirradiated packages by inspection. Therefore, physical barriers were used for keeping the irradiated and non-irradiated products separate. Thus, the irradiation procedure included the following stages: (a) storage of packages to be irradiated in a room ('dirty' area) near the irradiator chamber; (b) irradiation — passage of packages through ionising radiation field; (c) storage of irradiated packages in a room ('clean' area) separated from the room with materials to be irradiated.

Records of the operation of the irradiation facility were collected and packages that had been irradiated were identified by lot numbers.

Irradiation conditions

Radiation disinfestation of used packages was performed under conditions usually employed at the Pilot Plant for Electron Beam Food Processing for irradiating various materials at ambient temperatures. The irradiation area was well-ventilated to minimise ozone build-up in order to prevent formation of an explosive mixture of ozone and dust.

Dose of ionising radiation for disinfestation of packages

Of the irradiation process parameters, the most important is the amount of ionising energy absorbed by the target material, termed here the 'absorbed dose'. The unit of absorbed dose is the Gray (Gy). One Gy is equal to the absorption of one joule per kilogram (1 Gy = 100 rads). The absorbed dose should be the minimum dosage required to accomplish the desired disinfestation.

Depending on the dosage used, the ionising radiation induces the following effects in insects and mites: death, 'knock-down' (apparent death, followed by recovery), reduced longevity, delayed moulting, inhibition of development, reduction of food consumption, sterility, reduction of egg hatch, etc. (Ignatowicz and Boczek 1984; Ignatowicz 1988; Tilton and Brower 1983). Younger developmental stages of the stored-product pests are more susceptible to ionising radiation than older stages and adults (Ignatowicz 1988; Tilton and Brower 1983; Watters 1968). Usually, the females are considerably more sensitive to the effects of irradiation than males of the same species. Radio tolerance of stored-product pests depends also on the species involved, e.g. the bulb mite, *Rhizoglyphus echinopus* (F. et R.), seems to be more resistant to gamma radiation than the mould mite, *Tyrophagus putrescentiae* (Schrank) (Ignatowicz 1988). The lifespan of adult stored-product insects varies from a few days for moths to a few weeks for dermestids (Dermestidae) and bruchids (Bruchidae) to a year or more for the tenebrionids (Tenebrionidae). As a general rule, the short-lived species require much greater doses of radiation to significantly shorten their longevity than do the long-lived species (Tilton and Brower 1983).

Usually, higher doses are required for a lethal effect than for the induction of sterility in target pests (Ignatowicz and Brzostek 1990).

Control of stored-product insects and mites with chemical insecticides (e.g. malathion and pyrethroids) results in a rapid kill of these pests. When used properly, fumigants disinfest the products within a few days (the exposure time of infested product to fumigant ranges from 1 to 10 days, depending mostly on the temperature) (Bond 1984). When disinfestation by radiation processing is considered to be a feasible substitute for chemical control, the irradiation treatment should result in pest mortality within a few days.

Before the trials of radiation disinfestation, the doses of ionising radiation to be used were determined by the following experiment. Adults of the grain weevil (*Sitophilus granarius* (L.)) and the rice weevil (*S. oryzae* (L.)), of unknown age, were isolated from laboratory cultures maintained on wheat grains at 25°C and 60–70% r.h. Insects (more than 100 insects/treatment) were irradiated with gamma rays (dose rate 30 or 116 Gy/minute) at doses ranging from 1.0 to 2.6 kGy. After the treatment, the number of live and dead insects was recorded daily. Those insects that did not move or respond when touched gently with a small probe were considered dead.

The results obtained are presented in Figures 1 and 2 and in Table 2. It is seen that lethal effects of radiation, used at low doses, are not as pronounced as those achieved with chemical insecticides or fumigants. Small to moderate doses (e.g., up to 0.4 kGy) have a little effect on the longevity of treated pests. However, the general effect of radiation at higher doses is to shorten the mean lifespan of the treated population. The mean post-radiation longevity is usually inversely related to the size of radiation dose. A long period between irradiation and death of insects and mites is characteristic at doses up to 1 kGy. At 1.6 kGy complete mortality of these pests occurs within 1–2 weeks, depending on susceptibility of the species to ionising radiation. A dose higher than 2 kGy is needed to produce complete mortality within a few days (Table 2). Similar observations have been made by others (e.g. Baker et al. 1954; Cornwell 1966; Ignatowicz 1990; Ignatowicz and Brzostek 1990; Tilton and Brower 1973; Tilton and Stuard Nelson 1984; Watters and MacQueen 1967).

Table 2. Time to achieve 100% mortality (days) by irradiated adults of stored product pests; dose rate - 116 Gy/minute

Dose (kGy)	Time to achieve 100% mortality (days)		
	S. granarius	*S. oryzae*	*T. confusum*
2.6	2	1	4
2.4	4	2	5
2.2	4	2	2
2.0	5	3	6
1.8	4	3	8
1.6	6	4	7
1.4	5	4	10
1.2	5	4	12
1.0	6	4	13

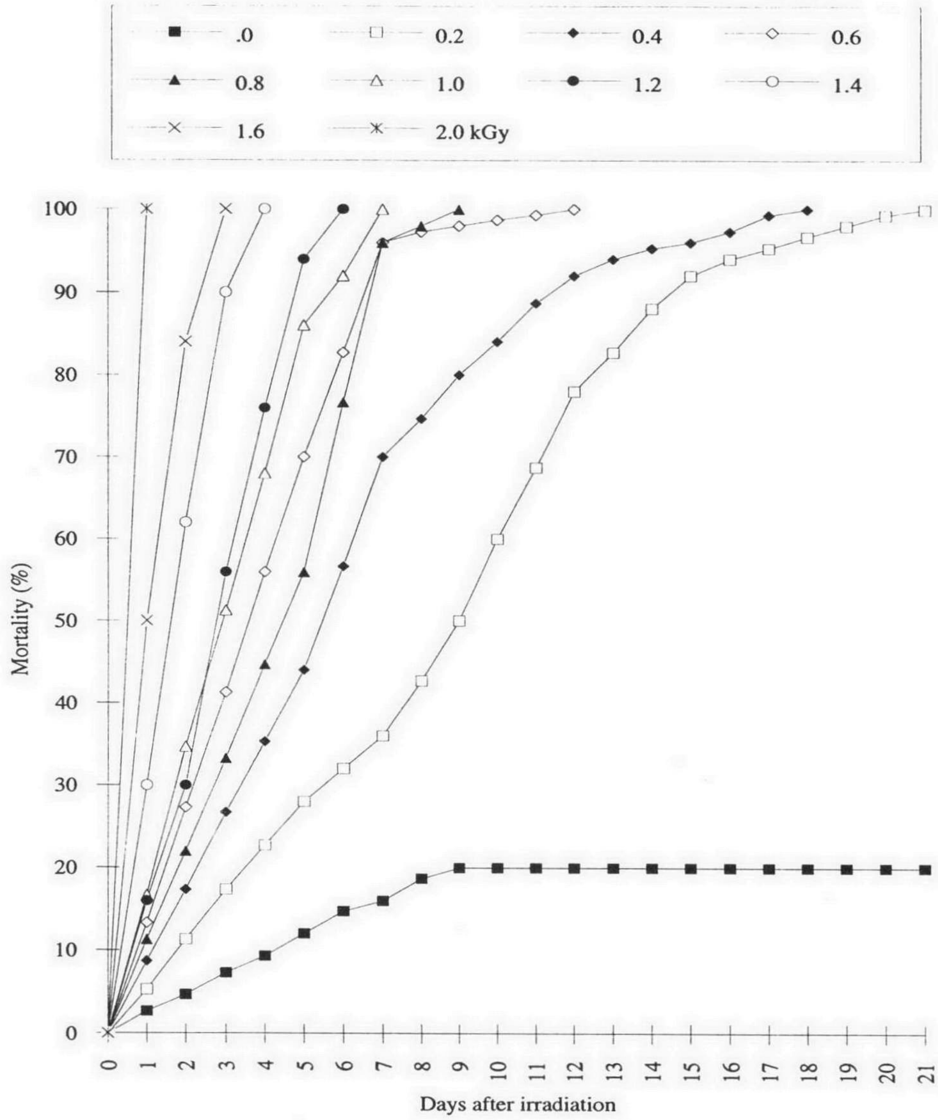

Fig. 1. Mortality of the granary weevil adults treated with gamma radiation; dose rate—ca.30 Gy/minute.

Therefore, the equivalent effect to chemical insecticides in killing pests may be obtained by very high doses of ionising radiation. Control of insect and/or mite infestation of used packages may be secured by ionising radiation applied at 2–3 kGy. These doses result in a complete mortality of stored product pests within a few days (Table 2), and these doses were employed in the trials of radiation disinfestation of used bags.

The ionising radiation which may be employed in irradiating packages is limited to: gamma rays from the radionuclides 60 Co or 137 Cs; X-rays generated from machine sources operated at or below an energy level of 5 MeV; or electrons generated from machine sources operated at or below an energy level of 10 MeV.

Gamma-rays and X-rays are electromagnetic radiations, which are converted into fast electrons in the medium through which they pass by Compton scattering, photoelectric absorption and pair-production. The reactions in the material irradiated with gamma-rays or X-rays are brought about mainly by the fast electrons thus formed, so the reactions caused by gamma-rays or X-rays and those by electron beams from an accelerator are essentially the same. An important difference between gamma-rays and accelerated electrons is dose rate. The dose rates of gamma-rays from commercial Co-60 sources are 1–100 Gy/minute, while those of electron beams from electron accelerators are 10^3–10^6 Gy/second. Another important difference between these types of ionising radiation is penetration capacity in materials. The penetration capacity of gamma-rays is much higher than that of accelerated electrons. The penetration capacity of accelerated electrons increases with their energy and the electrons at 10 MeV can penetrate ca. 4 cm of material if its density is 1 g/cm^3. The energy which the electrons transmit to the material is different, depending upon the depth in the material. The energy gradually increases with the distance from the surface and then rapidly decreases, while the energy which gamma-rays give to the material decreases with the depth (Hayashi 1991).

The radiation must penetrate the packagings to a sufficient depth. Gamma rays and X-rays penetrate the treated products easily, but electron radiation penetrability is much lower, depending on the electron energy employed. An irradiator generating electron radiation may be also employed, especially for packages created as separate units or as small batches. Results of the following experiments provide information on the number of bags in batches which could be successfully disinfested with electron beams.

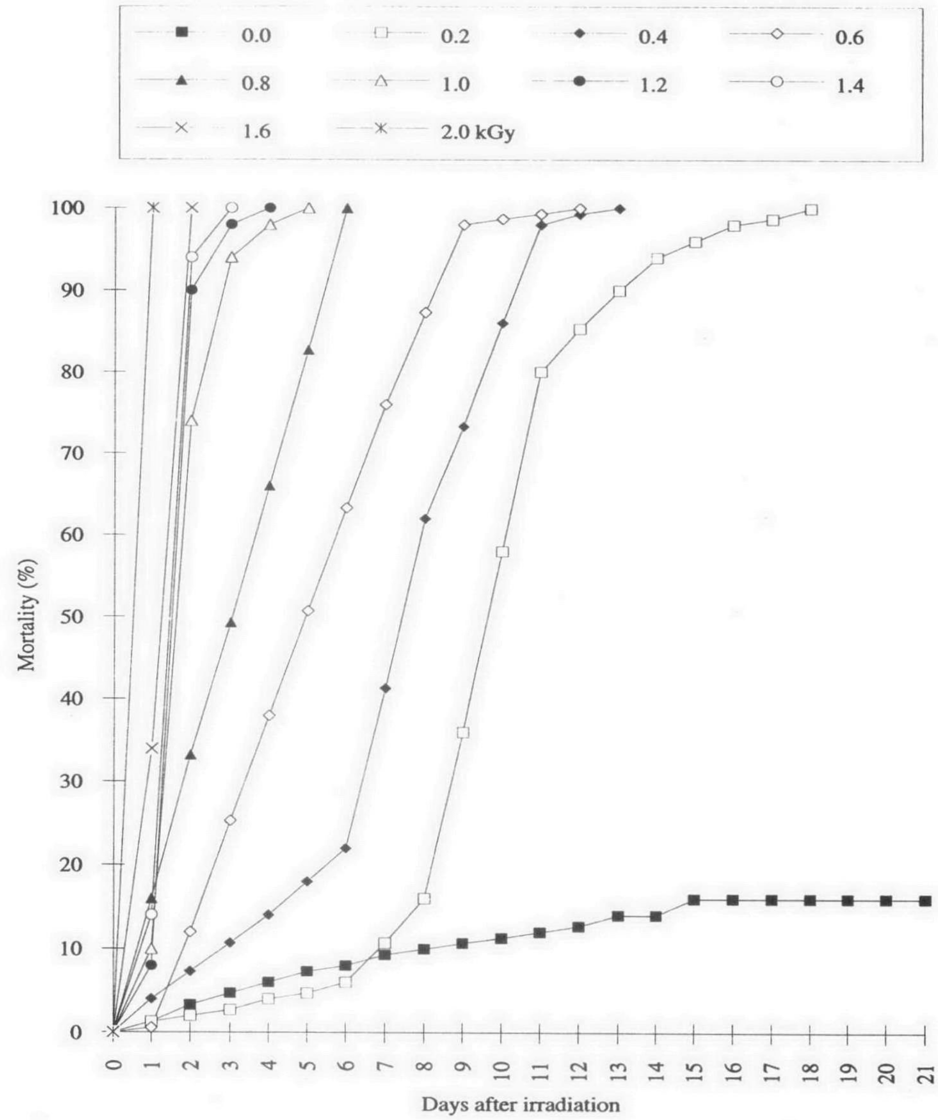

Fig. 2. Mortality of the rice weevil adults treated with gamma radiation; dose rate—ca. 30 Gy/minute.

Experiment 1. Batches of 13 jute bags infested with the granary or rice weevils were treated with electron beams at the following doses: 1.06, 2.31 and 3.02 kGy. After the irradiation treatment, about 200 adults of the pests were isolated from the 1st, 4th, 8th and 12th bag, and placed with wheat grains into Petri dishes. Their mortality was observed daily. Alanine dosimeters were placed on the 1st bag, between the 4th and 5th bags, between the 8th and 9th bags, and between the 12th and 13th bags. These dosimeters did not recover any significant change of the dosage of ionising radiation in particular sectors of the bag batches (Table 3).

Weevils isolated from jute bags treated with 3.02 kGy were not walking, and only a few of them (less than 3%) moved their mouthparts, antennae, or legs. After a 3-day period, all insects were dead. After the irradiation treatment with 2.31 kGy, some insects were not walking, while others were walking slowly. All insects were moving their mouthparts, antennae and legs. Therefore, all insects were considered alive. The rice weevil seems to be more susceptible to electron beams than the grain weevil. Complete mortality of rice weevils was noted on the 6th and 7th day post-treatment, while grain weevils were dead after 10–12 days. Weevils isolated from the 1st bag lived somewhat longer (up to 18 days) than those isolated from 8th or 12th bag (Figs 3 and 4). Effects of a dose of 1.06 kGy on mortality of the granary and rice weevils were less pronounced. After the treatment, all insects were walking, although their locomotory activity (speed) was affected by irradiation. Complete mortality of the rice weevil was recorded on 10th or 12th day post-treatment, whereas granary weevils were dead on the 16th–19th day post-treatment. There was no effect of the thickness of bag batches on the penetrability of electrons and on the mortality of weevils (Figs 5 and 6).

Results obtained suggest that irradiators generating electron radiation may be employed for disinfestation of bags delivered for treatment as separate units or as small batches. A dose of 1.06 kGy is too low for radiation disinfestation of jute bags, as the treated weevils are alive for more than 22 days after the treatment.

Experiment 2. Batches of 50 jute or plastic bags infested with the granary or rice weevils were treated with electron beams at 2.3 and 2.8 kGy doses. Alanine dosimeters were placed on the 1st bag and under the 50th bag of the batch. After the treatment, about 200 insects were isolated from the first

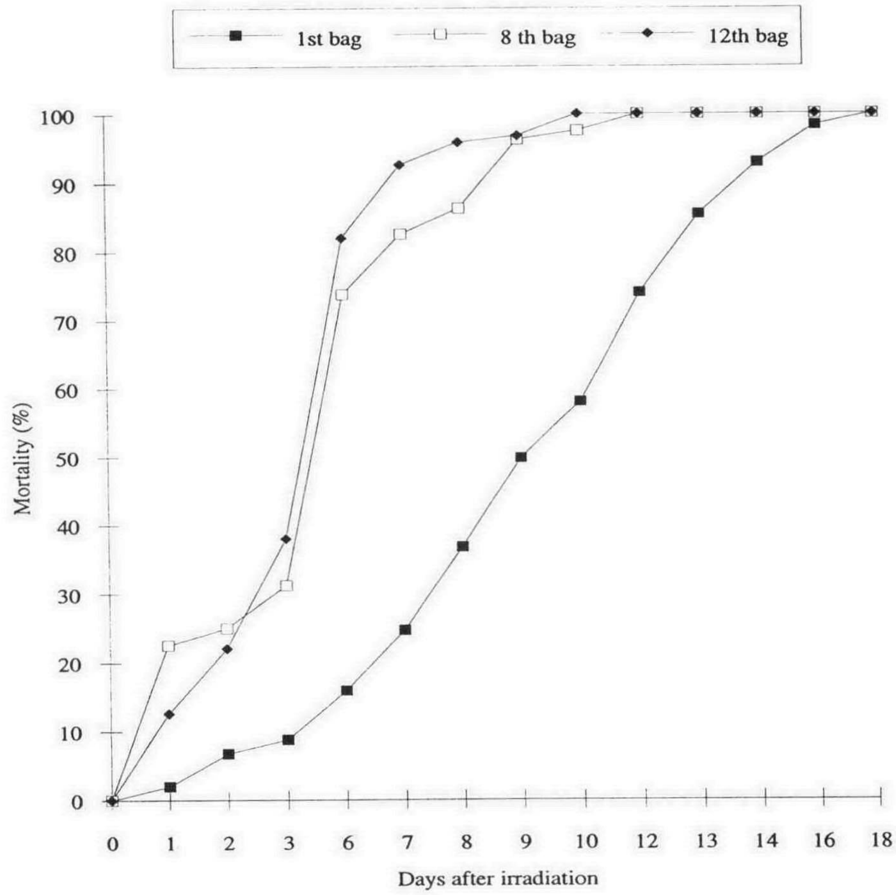

Fig. 3. Mortality of the granary weevil adults isolated from the 1st, 8th and 12th bag of a group of 13 jute bags, which were disinfested with electron beams at a dose of 2.31 kGy.

(upper layer) and last bag (lower layer) of the batch. Insects were placed in Petri dishes with wheat grains, and their mortality was recorded daily.

Alanine dosimeters indicated the changes in dosage of electron radiation with depth in irradiated bags. Under the 50th jute bag, the dose was by ca. 35–40% less than that noted on the 1st bag. Electron beams penetrated the plastic bags easily. A batch of 50 plastic bags reduced the dose slightly (only by 1.4–4.8%) (Table 3). Electron radiation used at a dose of 2.3 or 2.8 kGy caused the rapid mortality of weevils isolated from the 1st bag. However, insects isolated from the lower layer of the bag batch, i.e., from the 50th bag were alive for more than 10 days. Mortality of weevils irradiated in plastic bags was more pronounced than in jute bags. Complete mortality of the grain weevils and the rice weevils treated with a 2.8 kGy dose was observed within a 10-day period after the treatment. Only insects infesting the lower layers of bag batches died later (Table 4 and 5).

Results of this experiment suggest that batches of jute bags should be limited to less than 50 bags, while for radiation disinfestation of plastic bags, batches of 50 bags may be presented for treatment.

Experiment 3. Batches of 20, 30 and 50 jute or plastic bags were treated with a 3 kGy dose of electron radiation. Alanine dosimeters were placed on the first bag and under the last bag. After the treatment, about 100 granary or rice weevils were isolated from the first and last bag of the batch. Irradiated insects were placed into Petri dishes, and their mortality was recorded daily.

Disinfestation of jute bags with electron radiation was successful only for batches of 20 and 30 bags. Grain weevils isolated from the 50th bag were alive for many days. During this period, these pests were feeding on wheat grains and mating. The rice weevils were more susceptible to radiation; a significant proportion of them died during 2 weeks after the treatment. Disinfestation of plastic bags with fast electrons was successful for batches containing up to 50 bags. Complete mortality of insects isolated from plastic bags was noted on the day following treatment.

Results of the experiments indicate that bags made of polyvinyl chloride may be disinfested with electron beams when treated as separate units or in batches containing up to 50 bags. Jute bags can be irradiated with electrons in batches containing up to 30 bags.

Dosimetry

The control of the irradiation procedure so as to deliver a prescribed dose entails a number of considerations, important among which is dosimetry, the method for measuring dose. Alanine dosimeters or dosimeters made of polymethyl methacrylate and produced in U.K. under the name 'Red Perspex' were successfully used when packages were irradiated. Dosimetry methods described in the manuals and papers on dosimetry procedures of IAEA (1977), Holm and Berry (1970), and McLaughlin et al. (1982) were followed.

Table 3. Penetrability of electron beams through batches of jute or plastic bags

Material irriadiated	Desired dose of electron radiation (kGy)	Thickness of bag batches	Actual dose of electron radiation as determined by an alanine dosimeter
Jute bags	3.0	1 bag	3.02
		8 bags	3.02
		12 bags	3.02
	2.0	1 bag	2.31
		8 bags	2.31
		12 bags	2.31
	1.0	1 bag	1.06
		8 bags	1.06
		12 bags	1.06
Jute bags	2.8	1 bag	2.84
		50 bags	1.65
	2.3	1 bag	2.31
		50 bags	1.50
Plastic bags	2.8	1 bag	2.84
		50 bags	2.80
	2.3	1 bag	2.31
		50 bags	2.20
Jute bags		1 bag	2.95
	3.0	20 bags	2.70
		30 bags	1.86
		50 bags	0.60
Plastic bags		1 bag	2.98
	3.0	20 bags	2.83
		30 bags	2.70
		50 bags	2.68

Post-irradiation treatment of packages

After treatment, irradiated packages were stored in dry, cool conditions to avoid development of moulds which may be suppressed by the irradiation treatment, but not destroyed completely.

Appropriate measures to prevent reinfestation were undertaken because irradiation results in no lasting protection against the subsequent insect and mite infestation.

In a case of reinfestation, the subsequent irradiation of the same packages is possible because radiation doses for pest disinfestation are much lower than doses causing the impairment to the packaging material (W. Pekala and H. Kubera, unpublished data). The total absorbed dose of two or more treatments, however, should not exceed the maximum dose permitted, above which irradiation produces impairment of functional properties of the packages.

After the treatment of packages, each batch was labelled by a paper sticker or equivalent. This labelling not only identifies the packages as irradiated, but also serve to inform the client as to the purpose and benefits of the treatment. Additionally, documents with a protocol of irradiation treatment accompanied any movement of each batch or unit of irradiated packages.

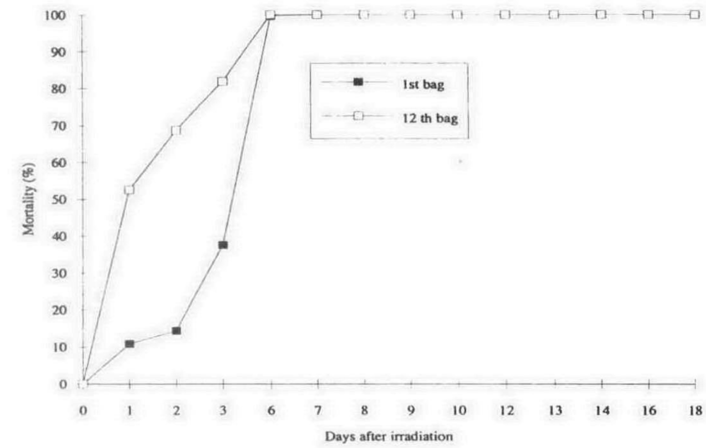

Fig. 4. Mortality of the rice weevil adults isolated from the 1st and 12th bag of a group of 13 jute bags, which were disinfested with electron beams at a dose of 2.31 kGy.

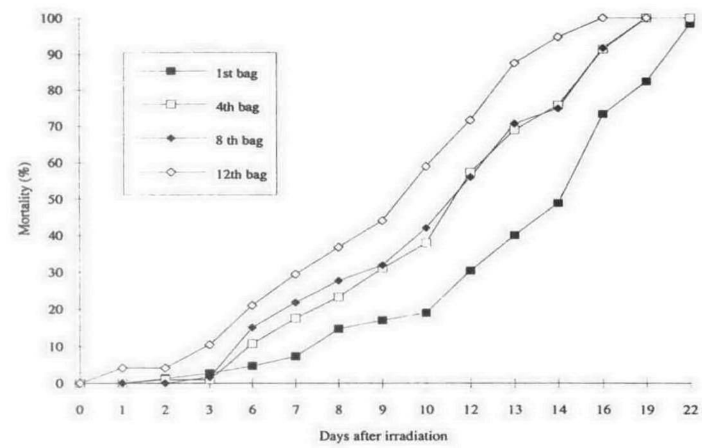

Fig. 5. Mortality of the grain weevil adults isolated from the 1st, 4th, 8th and 12th bag of a group of 13 jute bags, which were disinfested with electron beams at a dose of 1.06 kGy.

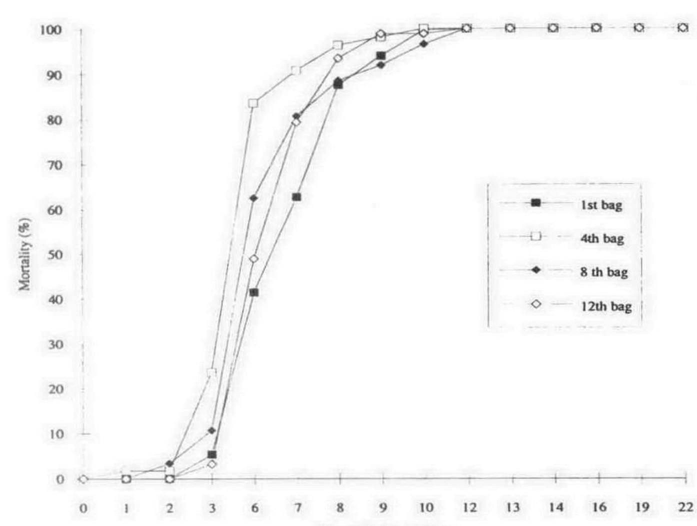

Fig. 6. Mortality of the rice weevil adults isolated from the 1st, 4th, 8th and 12th bag of a group of 13 jute bags, which were disinfested with electron beams at a dose of 1.06 kGy.

End-product specification

In terms of this description of trials of radiation disinfestation of used packages, the end-product specification is that, in the irradiated packages, no live mites and insects will be found within a few days after the treatment, or only moribund or dying pests will be isolated from the treated packages immediately after the treatment.

Acknowledgment

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Table 4. Efficacy of radiation disinfestation of plastic bags with electron beams. Mortality (%) of the grain weevil (*S. granarius* L.) and the rice weevil (*S. oryzae* L.) isolated from the upper or lower layer of a batch of 50 bags.

Species	Post treatment day	Dose 2.8 kGy		Dose 2.3 kGy	
		Upper layer (2.84 kGy)[a]	Lower layer (2.80 kGy)	Upper layer (2.31 kGy)	Lower layer (2.2 kGy)
S. granarius	1	0.0 (205)[b]	91.2(204)[b]	0.0 (202)[b]	0.0 (201)[b]
	3	98.5	91.2	53.5	2.5
	6	100.0	98.5	96.5	7.0
	8	100.0	100.0	98.5	13.9
	10	100.0	100.0	100.0	22.4
S. oryzae	1	100.0 (207)[b]	100.0 (185)[b]	58.3 (200)[b]	0.5 (199)[b]
	3	100.0	100.0	89.4	37.0
S. oryzae	6	100.0	100.0	96.4	51.5
	8	100.0	100.0	97.0	72.0
	10	100.0	100.0	99.0	82.0

[a] a size of the actual dose of fast electrons as determined by an alanine dosimeter.
[b] a number of observed insects is given in the parenthesis.

Table 5. Efficacy of radiation disinfestation of jute bags with electron beams. Mortality (%) of the grain weevil (*S. granarius L.*) and the rice weevil (*S. oryzae L.*) isolated from the upper or lower layer of a batch of 50 bags.

Species	Post treatment day	Dose 2.8 kGy		Dose 2.3 kGy	
		Upper layer (2.84 kGy)[a]	Lower layer (1.65 kGy)	Upper layer (2.31 kGy)	Lower layer (1.5 kGy)
S. granarius	1	0.0 (200)[b]	0.0 (199)[b]	0.0 (177)[b]	0.0 (198)[b]
	3	99.5	4.5	53.3	2.0
	6	99.5	8.5	100.0	6.6
	8	99.5	19.1	100.0	19.7
	10	99.5	32.2	100.0	24.7
S. oryzae	1	0.5 (199)[b]	0.0 (194)[b]	0.0 (104)[b]	0.0 (208)[b]
	3	100.0	13.9	100.0	12.0
	6	100.0	74.2	100.0	30.3
	8	100.0	95.9	100.0	63.3
	10	100.0	98.5	100.0	82.7

[a] a size of the actual dose of fast electrons as determined by an alanine dosimeter.
[b] a number of observed insects is µgiven in the parenthesis.

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