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INSECT PESTS OF STORED GRAIN PRODUCTS: A REVIEW

LES INSECTES NUISIBLES DES GRAINS: UN EXAMEN

Noemi Chuaqui-Offermanns

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Etablissement de recherches nucléaires de Whiteshell

Pinawa, Manitoba R0E 1L0

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RÉSUMÉ

La présence d'insectes dans les produits stockés est un problème universel reconnu. Dans le présent rapport, on examine des techniques chimiques et physiques pour limiter l'infestation des produits stockés par les insectes. On accorde une attention particulière à l'emploi du rayonnement ionisant pour limiter les insectes nuisibles dans les grains stockés. On présente et examine la radiosensibilité des insectes nuisibles les plus communs à leurs différents stades de développement. On rassemble les conclusions de l'examen dans un résumé abrégé.

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ABSTRACT

The presence of insects in stored products is a worldwide recognized problem. In this report chemical and physical methods to control insect infestations in stored products are discussed. Special attention is given to the use of ionizing radiation to control insect pests in stored grains. The radiosensitivity of the most common insect pests at their different developmental stages is presented and discussed. The conclusions of this review are compiled in an executive summary.

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1. SUMMARY

The objective in preparing this report was to review and summarize the studies done on radiosensitivity of the most common insect pests found worldwide in infested stored grains. Since the presence of these pests varies according to the climate of the storage geographical region, a list of the insect pests of stored grains by country is presented (Tables I to VII). The countries were selected considering factors such as (i) climatic zones, (ii) volume of grain produced and exported and (iii) volume of grain produced and consumed. The presence of these pests also varies with the type of stored grain, therefore a list of pests found in major crops (Table VIII) as well as a list of pests in specific cereals (Table IX) are presented.

From these Tables (I to IX) a list of the worldwide most common insect pests of stored grain was prepared. The radiosensitivity of each of these pests was renewed and summarized in Table X.

The following conclusions are supported by the information presented in this review:

(1) The presence of insects in stored food products is recognized to be a worldwide problem.

(2) The climate has a large effect on the species and population of insects found in stored foods.

(3) Worldwide product losses due to insect infestation are in the order of 5 to 10%. Losses in countries with warm climate can be as high as 50%.

(4) Ionizing radiation is one of the physical methods that has been extensively studied to control insects in stored products.

(5) The effectiveness of the process has been fully demonstrated.

(6) Many studies on the susceptibility to radiation of the most common species of insect pests have shown that:

  (a) Resistance to radiation increases as the insect development progresses from egg to adult.

  (b) Doses between 3 and 5 kGy produce complete and immediate kill after treatment. A dose of 1 kGy produces complete kill a few days after irradiation.

  (c) Doses between 0.2 and 0.5 kGy control most of the insect pests. With these doses, complete sterilization results immediately, with death ensuing a few weeks after treatment.

(d) There is no significant difference between the doses required to control insect infestations with either accelerated electrons or ^{60}Co gamma rays.

(7) The sterile male technique has proven to be impractical, due to factors such as: species specificity of the method; the large number of insects that have to be released, etc.

(8) From the point of view of the economics of the radiation process, it is recommended that a dose of 0.2 kGy be used. This dose will inhibit reproduction and cause eventual death (a few weeks after treatment) in most of the insects found in infested grains.

2. INTRODUCTION

Cereal grains [1] are a primary source of food for humans. Fifty percent of the food consumed by humans comes from wheat, rice, corn, millet, sorghum, rye and barley. If potato, sweet potato, coconut, banana, common bean, soybean and peanut are added to this list, we can account for 90% of all food for humans [2,3]. (Appendix I). Food losses to pests are high. Post-harvest losses are estimated to range from 9% to 50%, with the prime pests being microorganisms, insects and rodents. In the durable commodities such as cereal grains, legumes, pulses and oilseeds, losses are primarily due to insects, mites, fungi and rodents. In fruits, meats and vegetables, the losses are mainly due to microbial spoilage.

Food losses occur at all levels in the post-harvest system, in the field, farm storage, central storage, in transit, marketing and at the point of consumption. Between 80 and 95% of cereals [4] are retained in the country where they are grown. Most are stored locally on the farm and consumed in the region of production. Only in countries like Argentina, U.S.A., Canada, Australia and France, where a central storage system has been developed, are the grains handled in bulk for the local and international market. Losses at this point (storage) of the post-harvest process have been estimated at more than 20% [1,4] of the total production. These losses are acute in tropical countries, where insects proliferate very rapidly. In these countries the problem often is aggravated by the lack of proper facilities so that in many local areas the losses are higher than the average figure and are difficult to estimate.

A number of approaches are being taken to control grain infestation:

(a) preventative methods,
(b) physical methods, and
(c) chemical methods.

Preventative controls are the most logical in countries where the weather is cold and therefore the insect population is low. These methods involve aeration, good cleaning of the granaries by washing them with insecticide, refrigeration, and routine examination of the stocks to check for possible infestation.

In the area of physical control [5], there is a wide range of technologies, some of them in use, while some others are at an experimental stage: for example, carbon dioxide atmosphere, microwave radiation, ionizing radiation, and heat disinfestation used together with fluidized bed systems or conveyor systems. Chemical control is the method most widely used and involves the use of fumigants and insecticides. The advantages and disadvantages of using each method have been extensively reviewed in the literature [6,7,8,9]. Consequently they will be only briefly discussed:

Advantages and disadvantages of several methods used to control grain infestations.

Physical Methods

Temperature: Insects, as any other biological system, have optimum temperature ranges to grow and multiply. Temperatures below or above these thresholds will alter their life cycles, resulting in changes leading to death. Heat has been used to disinfect buildings and machinery in flour mills. Temperatures of 54 to 60°C, maintained for 12 hours, are recommended. The major disadvantages of heat treatment of buildings are: (a) damage to equipment, (b) loss of heat if the building is not well insulated, and (c) the method can be used only in summer months, because of economical considerations.

Heat has also been used to treat grain at 65°C. This is done: (a) with a fluidized bed system that uses hot air. The grain has to be cooled after treatment. The major disadvantages of this method are its high cost and its possible unknown effects on the quality of the grain. (b) Microwave irradiation on conveyor belt. The disadvantages are the same as in (a) above.

Low temperatures have also been used to control insect infestation, particularly in countries with cold winters such as Canada. In the Prairie Provinces "freeze-outs" are used to control insects in flour mills. The "freeze-outs" are obtained when the temperature remains at -30°C or lower for at least three days. When using low temperature to control insect infestations in grain stored in bulk, a uniform cooling should be obtained, otherwise the method is not effective. Uniformity could be obtained by a combination of cooling with a proper aeration system.

Electromagnetic radiation, infrared radiation and radiofrequency are among the nonionizing radiations used in controlling insect pests. However, so far they have been proven to be uneconomical.

The use of modified atmospheres, such as combinations of oxygen, nitrogen and carbon dioxide, has been shown to be effective in controlling insect infestations in stored grains. The method has to be used in air-tight bins in order to maintain the proper levels of gases. This requirement constitutes the main drawback of the method, because of the high cost involved in the construction of the air-tight bins.

Chemical Control: The use of contact insecticides and fumigants has been the method of choice to control pest populations in grain elevators, flour mills, feed mills, etc. However, due to factors such as toxicity to humans and other animals, and development of resistant insect strains, the use of alternative methods is becoming mandatory.

This review focuses mainly on the use of ionizing radiation to control infestation in stored grain products, consequently, a general overview is given in section 3.

3. INSECT CONTROL IN CEREAL FOOD BY MEANS OF IONIZING RADIATION

3.1 ADVANTAGES AND DISADVANTAGES

Ionizing radiation has been recommended to control insects in stored products [4,5,7,10,11,12,13]. Two types of radiation have been proposed: accelerated electrons produced by machines or gamma rays from radioactive isotopes such as ^{60}Co or ^{137}Cs. The control of the insect population can be done by direct treatment of the product or by genetic control of the insect by the so-called male sterility technique.

Direct treatment of the infested product leaves a product that is residue free, which is a very good advantage over the chemical treatments (insecticides and fumigants). The genetic control involves the release of radiation sterilized males in the normal population, which compete with the fertile males, so the females lay sterile eggs. The main drawback of this technique is that a large number of sterile insects must be released periodically. The method is specific for each species, therefore it has to be used in combination with insecticides to control other pests.

The effectiveness of the radiation process has been extensively studied and many reviews on the subject have been published [4,5,7,10,11,12,13]. One disadvantage of the direct irradiation of the infested product is when irradiated at the doses approved and considered economically acceptable [14], (U.S.A. 0.2 to 0.5 kGy, Canada up to 0.75 kGy, Brazil up to 1.0 kGy), the insects take several days to die. In order to achieve mortality within 24 hours of treatment, doses of 2.5 to 5.0 kGy are needed. Combinations of treatments such as heat and irradiation, which increase the effectiveness of the process, are being considered as a means of achieving a more rapid die-off.

3.2 RADIOSENSITIVITY

3.2.1 What is Radiosensitivity and Parameters Affecting It? Different Ways to Measure Radiosensitivity.

Radiosensitivity can have different meanings depending on the parameter measured. The most common parameters used to determine radiosensitivity are cell death, mitotic inhibition and inhibition or loss of biochemical and physiological functions. Radiosensitivity of cells depends on many factors with the most radiosensitive cells being those with highest metabolic rate, lowest state of differentiation and highest proliferation capacity. In addition to these main factors, there are others such as phase in the mitotic cycle, age, metabolic state, species or strain, etc.

Ionizing radiation produces two biological effects on insects [7] (a) lethality, and (b) sterility. Lethal effect results in death in a period of time, which depends on the radiation dose. Sterility results in loss of the reproductive capacity, although the insect may remain alive for several weeks.

Lethal doses vary individually with species and developmental stage. For example, a dose of 0.2 kGy [7,15] is needed to kill 100% of a population of <u>Sitophilus zeamais</u> (M) present in infested maize, while a dose of 0.8 kGy is necessary to achieve the same effects on Rhizopertha dominica (F) and Tribolium castaneum (H). As regards developmental stage, the radiosensitivity varies from egg to adult. For example, the radiation dose required to kill 99.9% of the eggs of Tribolium confusum [16,17] is 0.044 kGy, for its larvae is 0.052 kGy, for its pupae is 0.145 kGy and for its adult is 0.120 kGy. The above examples clearly demonstrate the dependency of the lethal dose on the species, as well as on the stage of development.

It has also been observed that the dose required to kill, reduce or sterilize a given species varies according to other factors: (Table X). These variations may be due to different strains within the species or differences in experimental conditions. An example of differences in susceptibility within strains of the same species is in the work reported by Cornwell [18], where the radiosensitivity of five laboratory strains and thirty wild strains of Sitophilus granarius from various parts of the world were compared. The time required to kill 50% of the population of a standard laboratory strain after a dose of 0.060 kGy was twelve days, compared with a time of 16 days for an Argentinian strain. The author concludes that strains of S. granarius differ considerably in their rate of response to killing by irradiation - in the post-irradiation period for 50% kill and in their content of individuals dying within 12 days of irradiation. There is a smaller variation in LD50, if viability is measured at 28 days after irradiation instead of 12 days.

3.2.2 Different Ways to Measure Radiosensitivity

Radiosensitivity can be measured in several ways. Survival after irradiation is usually chosen as the end-point and is most commonly expressed as LD50/time, which means that the dose in question kills 50% of a given population within a given period of time. In addition, some other expressions are found in the literature such as:

LT50/Dose = Time in days required to kill 50% of a given population at a given dose.
LT95/Dose = Time required to kill 95% of the population at a given dose.
LT100/Dose = Time in days required to kill 100% of the population at a given dose.

4. THE AUSTRALIAN SCENE

4.1 GRAIN HANDLING PROCEDURES [9,19,20,21]

4.1.1 Introduction

In 1981/82, Australia produced 22 million tonnes of cereal grains, of which 16 million tonnes were wheat, 3.5 million tonnes were barley, 1.2 million tonnes were sorghum and 1.1 million tonnes were oats. Seventy percent of the wheat production is exported, contributing about 11 to 12% of the total volume of international trade of wheat.

The Australian Wheat Board, a federal institution, buys the majority of the wheat as soon as it is harvested, and is in charge of all sales. The storage of the grain is in the hands of the State Bulk Handling Authorities, created expressly for this purpose in each of the five states. By operating in this manner the local farm storage has been eliminated. Three of the Grain Handling Authorities are state-controlled while the other two, in South and Western Australia, are owned by farmer cooperatives.

Ninety percent of the grain produced in Australia is handled by the Grain Handling Authorities. The wheat is transported from the farm to the country depot in bulk bins on road vehicles and from the country stores to the shipping terminals in bulk on rail wagons.

Several types of storage structures are found in the five Australian states. The most common ones are: vertical concrete silos, horizontal sheds and welded steel bin construction. The type of the storage facility used depends on the region. In New South Wales, the state with the largest wheat crop, combinations of vertical silos and horizontal sheds are found.

The capacity of the storage facilities varies from 600 tonnes in country areas to 300 000 tonnes at the shipping terminals. The newest storage structures are vertical welded steel air-tight type constructions, which lend themselves well to aeration, fumigation or treatment with CO_2.

4.2 GRAIN INSECT PESTS [8,9,19]

4.2.1 Infestation Patterns

The insects most commonly found in Australian wheat are Rhyzopertha dominica (F), Sitophilus oryzae (L), Sitophilus granarius (L), Tribolium castaneum (Herbst), Oryzaephilus surinamensis, Cryptolestes ferrugineus and Ephestia cautella. The order of importance of these five species depends on the climatic zone. In the wheat growing parts of Western Australia with a Mediterranean climate, Rhizopertha dominica is the most important pest in stored wheat, followed by Sitophilus oryzae, Tribolium castaneum and Oryzaephilus surinamensis in descending order of importance. Sitophilus granarius is not a major pest. In South Australia, with humid Mediterranean weather, the order of importance is S. granarius, T. Castaneum, O. surinamensis, Cryptolestes spp, R. dominica and S. oryzae. In the Queensland region (Northwest Australia), S. granarius is not important, with S. oryzae and R. dominica being the predominant pest species.

4.2.2 Chemical Control of Insects Infesting Stored Grain in Australia [9,19]

Once the grain reaches the storage place it is immediately treated with contact insecticides. One of the first insecticides introduced in Australia was malathion (1960-61). By 1965 all wheat received by the Grain Handling Authorities from growers was being treated with malathion before storage. The treatment with malathion was a great success, with the number of exported cargoes found infested during 1965-66 being quite small compared with earlier periods. However, despite the big success, it was expected that sooner or later strains of insects would develop resistance to the pesticide. As expected, in 1973-74 and 1976-77 an increase in infestation was detected. As before, R. dominica, T. castaneum and S. oryzae were the most common insects. In view of the resistances observed towards malathion, alternative chemical protectants were investigated, and by 1976-1977 a new stock was available.

In 1976-77, bioresmethrin was used to treat all wheat from Queensland, New South Wales and Victoria. Pyrethrum was used when bioresmethrin was not available. Although these two protectants were very effective in controlling R. dominica, much higher doses were needed for controlling other species. Therefore, combinations of bioresmethrin with other insecticides were used. In the eastern states (1977-78) the wheat was treated with a mixture of fenitrothion and bioresmethrin resulting in a significant reduction of infestation. In 1984, an increased resistance to fenitrothion was observed, specifically in Orzyaephilis surinamensis populations. Also, some strains of R. dominica showed resistance to bioresmethrin.

Phosphine is an excellent fumigant, much cheaper than many other insecticides. Very little resistance to phosphine has been detected and the Australian Grain Authorities are taking measures to avoid the development of resistance. In general, the use of insecticides is haunted by the problem of resistance development. A period of ten years is considered the useful life for any insecticide [20]. In order to palliate this problem, Australia has an ongoing resistance testing program, where a national committee is continually evaluating new insecticides in order to have a list of alternate chemicals in case resistance develops to those currently in use.

4.2.3 Prevention, Detection and Control Methods

Australia has a very strong research program on problems of insects in stored products. Areas of research, such as the use of pesticides, storage under controlled atmospheres, aeration, refrigeration, heat disinfestation, irradiation, storage structure design, grain handling, and resistance to insecticides, are extensively supported.

Besides the well known good practices of cleaning and treatment of the farm equipment and storage places (silos, bins, etc.), and aeration, new prevention methods at the experimental stage are in use. For instance, refrigeration, and solar grain cooling (sun removes moisture from forced air in moist, hot grain) are used. In detection, very sensitive equipment is being developed to detect and monitor moisture, temperature and moisture-temperature in farm granaries, terminals and bunkers. Several methods to detect the presence of insects are at an experimental stage, such as the use of pheromones; trapping by using plastic of different colors that attract insects; and sampling by using inclined screens, etc.

In control, new physical and chemical methods are under development.

Physical

(a) Use of CO_2, produced as a by-product of neighboring industries, recirculated through the stored grain. Also, a mobile CO_2 generator has been developed that is able to treat storage bins on the farm.

(b) Microwave irradiation on a conveyor belt.

(c) Irradiation using accelerated electrons (under consideration).

(d) Heat disinfestation with fluidized bed systems using hot air.

(e) Heat disinfestation on a conveyor system.

Chemical

Fumigation

(a) Use of phosphine in continuous flow at low concentrations. Use in combination with sealed structures.

(b) Sorption of fumigants into materials.

(c) Combination of methyl bromide and CO_2. The CO_2 reduces the normal dose of methyl bromide as required.

Contact Insecticides

(a) As resistance develops, deltamethrin will eventually replace bioresmethrin.

(b) Chlorpyrifos-methyl will replace fenitrothion.

Another method of control at the experimental stage is based on a system analysis that involves computer modelling as a means of predicting pest population behaviour. These models incorporate different parameters affecting insect infestation of stored grains, such as insect numbers, temperature, heat transfer, moisture, aeration, economic factors, etc. These models are applied in management of stored grains.

5. INSECT PESTS OF STORED GRAIN BY COUNTRY

5.1 INTRODUCTION

In this section, an attempt has been made to list the pests of stored grains by country. In the selection of the countries, several factors were considered, such as (a) climatic zones, (b) volume of grain produced and exported, and (c) volume of grain produced and consumed.

(a) Climate Affects Stored Food Products and their Insect Pests [8]

Storage geographical areas can be classified from a climatic point of view, into five major areas:

Semi-arid zones. The climate varies depending on the latitude, from hot summers and winters to cool and cold winters with little rainfall. Some countries with this climate are: Egypt, Nigeria and Pakistan.

Low-latitude wet-and-dry lands. All seasons are warm or hot. A wet season is followed by a dry season. Countries such as India, Brazil, Ghana, and Indonesia possess this type of climate.

Mediterranean lands. All seasons are fairly warm or hot, with dry summers, and mild, humid winters. Typical countries include: Italy, Israel and Portugal.

Humid tropical lands. All seasons are hot and humid. Typical countries with this weather are Indonesia, Venezuela, Congo and Burma.

Middle-latitude humid lands. Typical countries include Canada, Japan, some parts of the U.S.A., east coast of Australia, Argentina and Western Europe. In this climatic zone, four sub-zones can be distinguished:

(1) humid continental with short, hot, humid summers, and cool to cold winters;
(2) humid continental with long summers, mild winters;
(3) humid subtropical with high humidity most of the year; and
(4) West-Coast Marine.

(b) Production and Exports

Cereals are produced in all six continents, wheat being the grain produced in the largest volume. The world has been divided into seven areas according to its production [2]:

(1) The U.S.S.R. Region

(2) The European Region
  (a) The Plain of Hungary
  (b) The Danube Basin
  (c) Western Europe
  (d) The Mediterranean Area

(3) Northern Pakistan - India Region

(4) The North-Central China Region

(5) The Southeastern Australia Region

(6) The South American Region
  (a) The Pampas of Argentina
  (b) Southern Chile

(7) The North American Region
  (a) The Southern Great Plains of the U.S.A.
  (b) The Northern Great Plains of Canada and the U.S.A.
  (c) The Columbia Plateau Area

The four countries that have dominated the export wheat markets for decades are: U.S.A., Canada, Australia and Argentina. To this, exports from U.S.S.R., the European Economic Community (EEC), Mexico, Romania, Bulgaria, Spain, Greece and Sweden have to be added.

(c) Exports and Imports

Crop productions, consumption per capita, tariffs, trade agreements, credit terms, and diplomatic relations are the factors determining if a country exports or imports wheat. The largest market for wheat is in Asia, although it is the continent with the largest wheat production. The second largest market is Central and South America, followed by Europe, Africa and Oceania.

Rice, ranking third among the cereals produced worldwide is second on the list of cereals consumed worldwide per capita [2]. The main continent that produces rice is Asia.

5.2 EXPLANATION OF TABLES I TO VII

Tables I to VII contain lists of insect pests found in stored grain products, by country. The insects are listed in column I by their common name (when available), and in column II by their latin (scientific) names in alphabetical order. In column III, the most commonly found insects are indicated. In some cases, when information is available, the place and/or the commodity where these insects are found is also given.

The scientific name is composed of two parts: the genus and the species, e.g. Tribolium castaneum, genus Tribolium, species castaneum. It is common practice to write the scientific name of the genus and the species in italic type. The first letter of the genus only is written with a capital letter. The name of the person who described the species is written next to the scientific name. If the name of this person is in parentheses, it means that the species was originally described in association with another genus.

TABLE I

INSECT PESTS OF STORED GRAINS IN AUSTRALIA [22]

Common Name	Latin Name	Most Commonly Found
Foreign grain beetle	*Ahasverus advena* (Waltl)	
Lesser meal worm	*Alphitobius diaperinus* (Panzer)	
Corn sap beetle	*Carpophilus* spp.	
Fungus beetle	*Corticaria* spp.	
Flat grain beetle	*Cryptolestes* spp.	+
Tropical warehouse moth	*Ephestia cautella* (Walker)	+
Mediterranean flour moth	*Ephestia kuehniella* (Zeller)	
Broad-horned flour beetle	*Gnathocerus cornutus* (Fabricius)	
Long-haired flour beetle	*Latheticus oryzae* Waterhouse	
Psocids	*Liposcilis* spp.	NSW cold areas
Saw-toothed grain beetle	*Oryzaephilus surinamensis* (Linnaeus)	+
	Palorus spp.	
Indian meal moth	*Plodia interpunctella* (Hübner)	
Meal snout moth	*Pyralis farinalis* (Linnaeus)	
Lesser grain borer	*Rhyzopertha dominica* (Fabricius)	+
Angoumois grain moth	*Sitotroga cerealella* (Olivier)	
Granary weevil	*Sitophilus granarius* (Linnaeus)	+
Rice weevil	*Sitophilus oryzae* (Linnaeus)	+
Maize weevil	*Sitophilus zeamais* Moteschulsky	+
Cadelle	*Tenebrio mauritanicus* (Linnaeus)	
Meal worms	*Tenebrio molitor* Linnaeus	
	Tenebrio obscurus	
Rust-red flour beetle	*Tribolium castaneum* (Herbst)	+
Confused flour beetle	*Tribolium confusum* (Jacquelin du Val)	+
Hairy fungus beetle	*Typhaea stercorea* (Linnaeus)	

TABLE II

INSECT PESTS OF STORED GRAINS IN CANADA

(Grain elevators, flour mills, feed mills [8])

Common Name	Latin Name	Most Common In Flm[a]	Elv[b]	Fdm[c]
Mites	Acarina		+	
Foreign grain beetle	Ahasverus advena (Waltl)			
A rove beetle	Aleochara bimaculata (Grvh.)			
Lesser meal worm	Alphitobius diaperinus (Panzer)			
Narrow-necked grain beetle	Anthicus floralis (Linnaeus)			
Carpet beetle	Anthrenus scrophulariae (Linnaeus)			
Varied carpet beetle	Anthrenus verbasci (Linnaeus)			
Stored nut moth	Aphomis gularis (Zeller)			
A beetle	Attagenus pellio (Linnaeus)			
Black carpet beetle	Attagenus unicolor (Brahm)			
Carpet beetles	Attagenus spp.	+	+	+
A carpet beetle	Carcinops quatuordecimstriata (Stephens)			
A fungus beetle	Cartodere filiformis (Gyllenhal)			
Squarenecked grain beetle	Cathartus quadricollis (Guérin-Méneville)			
Rusty grain beetle	Cryptolestes ferrugineus (Stephens)	+	+	+
Flat grain beetle	Cryptolestes pusillus (Schönherr)	+	+	
Flour mill beetle	Cryptolestes turcicus (Grouvelle)			
Flat grain beetles	Cryptolestes spp.			
A fungus beetle	Cryptophagus cellaris (Scopoli)			
Fungus beetles	Cryptophagus spp.			
Larger black flour beetle	Cynaeus angustus (LeConte)			
Larder beetle	Dermestes lardarius (Linnaeus)			
Dermestid beetles	Dermestidae			
Flies and maggots	Diptera			
White-shouldered house moth	Endrosis sarcitrella (Linnaeus)			
Almond moth	Ephestia cautella (Walker)			
Tobacco moth	Ephestia elutella (Hübner)			

a Flm = flour mills
b Elv = elevators
c Fdm = feed mills

continued ...

TABLE II (continued)

Common Name	Latin Name	Most Common In Flm	Elv	Fdm
Mediterranean flour moth	Ephestia kuehniella (Zeller)			
Ants	Formicidae			
Shiny spider beetle	Gibbium psylloides (Czenpinski)	+		
Four-spotted sap beetle	Glischrochilus quadrisignatus (Say)			
Broadhorned flour beetle	Gnatocerus cornutus (Fabricius)			
A clothes moth	Haplotinea ditella			
A snout beetle	Hexarthrum (Rhyncalus) ulkei (Horn)			
Brown house moth	Hofmannophila pseudospretella (Stainton)			
Sowbugs	Isopoda			
A pseudoscorpion	Larca granulata (Banks)			
Cigarette beetle	Lasioderma serricorne (Fabricius)			
Longheaded flour beetle	Latheticus oryzae (Waterhouse)			
Squarenosed fungus beetle	Lathridius minutus Linnaeus (=Enicmus minutus (L.))			
Fungus beetles	Lathridius spp.			
Moth and caterpillars	Lepidoptera spp.			
A silverfish	Lepisma saccharina Linnaeus			
Boxelder bug	Leptocoris trivittatus (Say)			
American spider beetle	Mezium americanum (Laporte)			
A fungus beetle	Microgramme filum (Aube)			
Fungus beetles	Microgramme spp.			
European grain moth	Nemapogon granella (Linnaeus)		+	+
Golden spider beetle	Niptus hololeucus (Faldermann)			
A spider beetle	Niptus unicolor (Piller & Mitterpacher)			
	Obisium ischonoceles			
Grasshoppers	Orthoptera			
Merchant grain beetle	Oryzaephilus mercator (Fauvel)			
Saw-toothed grain beetle	Oryzaephilus surinamensis (Linnaeus)			+

continued ...

TABLE II (continued)

Common Name	Latin Name	Most Common In: Flm	Elv	Fdm
Smalleyed flour beetle	*Palorus ratzeburgi* (Wissmann)			
Indian meal moth	*Plodia interpunctella* (Hübner)			+
A sowbug	*Porcellio laevis* Latreille			+
A pseudoscorpion	*Pselaphochernes* sp.			
A pseudoscorpion	*Pselaphochernes parvus* Hoff.			
Book lice	Psocoptera			
Brown spider beetle	*Ptinus clavipes* (Panzer)			
Whitemarked spider beetle	*Ptinus fur* (Linnaeus)			
Brown spider beetle	*Ptinus hirtellus* (Sturm) (=P. clavipes Panzer)			
Australian spider beetle	*Ptinus ocellus* (Brown)			
Canadian spider beetle (eastern)	*Ptinus raptor* (Sturm)			
A spider beetle	*Ptinus tectus* (Boieldieu)			
Hairy spider beetle	*Ptinus villiger* (Reitter)			
Spider beetles	*Ptinus* spp.			
Meal moth	*Pyralis farinalis* (Linnaeus)		+	
Lesser grain borer	*Rhyzopertha dominica* (Fabricius)			
Window fly	*Scenopinus fenestralis* (Linnaeus)			
Granary weevil	*Sitophilus granarius* (Linnaeus)	+	+	
Rice weevil	*Sitophilus oryzae* (Linnaeus)		+	
Grain weevils	*Sitophilus* spp.			
Angoumois grain moth	*Sitotroga cerealella* (Olivier)			
Rove beetles	Staphylinidae spp.			
Drugstore beetle	*Stegobium paniceum* (Linnaeus)			
Yellow mealworm	*Tenebrio molitor* (Linnaeus)	+	+	+
Dark mealworm	*Tenebrio obscurus* (Fabricius)			
Cadelle	*Tenebroides mauritanicus* (Linnaeus)	+	+	+
A fungus beetle	*Thes bergrothi* (Reitter)			
Large pale clothes moth	*Tinea pallescentella* (Stainton)			

continued ...

TABLE II (concluded)

Common Name	Latin Name	Most Common In Flm	Elv	Fdm
Casemaking clothes moth	Tinea pellionella (Linnaeus)			
Webbing clothes moth	Tineola bisselliella (Hummel)			
Black flour beetle	Tribolium audax (Halstead)			
Red flour beetle	Tribolium castaneum (Herbst)	+		+
Confused flour beetle	Tribolium confusum Jacquelin du Val	+		+
A black flour beetle	Tribolium destructor Uyttenboogaart			
Flour beetles	Tribolium spp.	+		+
Caddis flies	Trichoptera			
Large pale trogiid	Trogium pulsatorium (Linnaeus)			
Larger cabinet beetle	Trogoderma inclusum (Lec.)			
A carpet beetle	Trogoderma variabile (Ballion)			
Dermestids	Trogoderma spp.			
Hairy fungus beetle	Typhaea stercorea (Linnaeus)			

TABLE III

INSECT PESTS OF STORED GRAINS IN MALAYSIA [24]

Insect pests of padi and rice

PADI*

Common Name	Latin Name
Grey rice moth	Corcyra cephalonica (Staint.)
Angoumois grain moth	Sitotroga cerealella (Ol.)
Lesser meal worm	Alphitobius diaperinus (Panz.)
	Alphitobius laevigatus (F.)
Flat grain beetle	Cryptolestes pusillus (Schon.)
Bamboo borer	Dinoderus minutus F.
Siamese grain beetle	Lophocateres pusillus (Klug.)
Saw-toothed grain beetle	Oryzaephilus surinamensis (L.)

* PADI = Threshed unmilled rice

continued ...

TABLE III (concluded)

Common Name	Latin Name
Lesser grain beetle	*Rhizopertha dominica* (F.)
Rice weevil	*Sitophilus oryzae* (L.)
Larger black Cadelle	*Tenebroides mauritanicus* (L.)
	Thorictodes heydeni (Reitt.)
Rust-red flour beetle	*Tribolium castaneum* (Hbst)
	Typhaea stercorea (L.)

RICE

Common Name	Latin Name
Grey rice moth	*Corcyra cephalonica* (Staint.)
	Doloessa viridis Zell.
Grey rice moth	*Ephestia cautella* (Wlk.)
Indian meal moth	*Plodia interpunctella* (Hbn.)
	Setomorpha rutella Zell.
Angoumois grain moth	*Sitotroga cerealella* (Ol.)
Foreign grain beetle	*Ahasverus advena* Waltl.
Lesser meal worm	*Alphitobius diaperinus* (Panz.)
	A. laevigatus (F.)
Corn sap beetle	*Carpophilus dimidiatus* (F.)
Flat grain beetle	*Cryptolestes pusillus* (Schon.)
	Dinoderus minutus F.
	Latheticus oryzae Waterh.
Siamese grain beetle	*Lophocateres pusillus* (Klug.)
	Murmidius segregatus Waterh.
Saw-toothed grain beetle	*Oryzaephilus surinamensis* (L.)
	Palorus subdepresseus Woll.
	Palorus sp.
Rice weevil	*Sitophilus oryzae* (L.)
Larger black cadelle	*Tenebroides mauritanicus* (L.)
	Thorictodes heydeni (Reitt.)
Rust-red flour beetle	*Tribolium castaneum* (Hbst)
Khapra beetle	*Trogoderma granarium* Everts
	Proctes entomophilus Endl.

TABLE IV

INSECT PESTS OF STORED GRAINS IN NIGERIA

List of major pests infesting cereal crops [8,25]

RICE

Common Name	Latin Name	Degree of Importance
Foreign grain beetle	*Ahasverus advena* (Waltl)	2**
Coffee bean weevil	*Araecerus fasciculatus* (deG)	2
Square-necked grain beetle	*Cathartus quadricollis* (Guer)	2
Rice moth	*Corcyra cephalonica* (Staint.)	2
Rusty grain	*Cryptolestes ferrugineus* (Stph)	2
Cigarette beetle	*Lasioderma serricorne* (F)	2
Siamese grain beetle	*Lophocateres pusillus* (Klug)	2
	Mussidia nigrivenella (Rag.)	2
Merchant grain beetle	*Oryzaephilus mercator* (Fauv)	2
Saw-toothed grain beetle	*Oryzaephilus surinamensis* (L)	2
Smalleyed flour beetle	*Palorus ratzeburgi* (Wissm)	2
	Ptinus tectus (Boield)	2
Lesser grain borer	*Rhizopertha dominica* (F.)	1*
Rice weevil	*Sitophilus oryzae* (L)	1
Maize weevil	*Sitophilus zeamais* (Mots)	2
Angumois grain moth	*Sitotroga cerealella* (Oliv.)	2
Cadelle beetle	*Tenebroides mauritanicus* (L)	2
Red flour beetle	*Tribolium castaneum* (Herbst)	2

* Major pest

** Pest occasionally important

continued ...

TABLE IV (concluded)

MILLET

Common Name	Latin Name	Degree of Importance
Rice moth	*Corcyra cephalonica* (Staint)	2
Fig moth	*Ephestia cautella* (Wlk)	2
Cigarette beetle	*Lasioderma serricorne* (F.)	1
Merchant grain beetle	*Oryzaephilus mercator* (Fauv)	1
Lesser grain borer	*Rhizopertha dominica* (F.)	1
Rice weevil	*Sitophilus oryzae* (L)	2
Angumois grain moth	*Sitotroga cerealella* (Oliv.)	1
Red flour beetle	*Tribolium castaneum* (Herbst)	2

MAIZE

Common Name	Latin Name	Degree of Importance
	Aglossa ocellela (Lederer)	2
Coffee bean weevil	*Araecerus fasciculatus* (deG)	
	Brachypeplus pilosellus (Murray)	2
	Carpophilus fumatus Boh	2
Square-necked grain beetle	*Cathartus quadricollis* (Guer)	2
Rusty grain beetle	*Cryptolestes ferrugineus* (Steph)	2
Fig moth	*Ephestia cautella* (Wlk)	2
Slender-horned flour beetle	*Gnathocerus maxillosus* (F.)	1
Merchant grain beetle	*Oryzaephilus mercator* (Fauv.)	1
Smalleyed flour beetle	*Palorus ratzeburgi* (Wissm)	2
Depressed flour beetle	*Palorus subdepressus* (Woll.)	2
Lesser grain borer	*Rhizopertha dominica* (F.)	1
Rice weevil	*Sitophilus oryzae* (L)	2
Maize weevil	*Sitophilus zeamais* (Mots.)	1
Red flour beetle	*Tribolium castaneum* (Herbst)	2

TABLE V

INSECT PESTS OF STORED GRAINS IN SOUTHEAST ASIA [26]

Main crop rice. Production 30.7 million ton/year.

Post-harvest losses 10 to 37%.

Common Name	Latin Name	Philippines	Indonesia	Thailand	Malaysia
Foreign grain beetle	*Ahasverus advena* (Waltl)	+	+	+	+
Lesser meal worm	*Alphitobius diaperinus* (Panzer)	+	+	+	+
Black fungus beetle	*Alphitobius laevigatus* (Fabricius)	+	+	+	+
Mediterranean flour moth	*Anagasta kukniella* (Tell.)	+			
Coffee bean weevil	*Araecerus fasciculatus* (De Geer)	+	+	+	+
Carpet beetle	*Attagenus megatoma* (Fabricius)	+			
	Attagenus gloriosae (Fabricius)			+	
Corn sap beetle	*Carpophilus dimidiatus* (Fabricius)	+	+	+	+
Dried fruit beetle	*Carpophilus pilosellus* (Linnaeus)	+	+		
	Carpophilus flavipes (M.)		+		
	Carpophilus hemipterus (Linnaeus)				
	Carpophilus humeralis (Fabricius)		+		
Square-necked grain beetle	*Cathartus quadricollis* (Guérin-Meneville)	+		+	
Black beetle	*Coelopalorus foveicolus* (B)	+			

continued ...

TABLE V (continued)

Common Name	Latin Name	Philippines	Indonesia	Thailand	Malaysia
Rice moth	*Corcyra cephalonica* (Stainton)	+	+	+	+
Rusty grain beetle	*Cryptolestes ferrugineus* (Stephens)	+	+		
Flat grain beetle	*Cryptolestes pusillus* (Schönherr)	+	+	+	+
	Cryptolestes turcicus (Grouvelle)			+	
Black larder beetle	*Dermestes ater* De Geer			+	
Bamboo borer	*Dinoderus minutus* (Fabricius)			+	+
Green rice moth	*Doloessa viridiz* (Lell)	+	+		+
Fig moth	*Ephestia cautella* (Walker)	+	+	+	+
Tobacco moth	*Ephestia elutella* (Hübner)	+	+		
Slender-horned flour beetle	*Gnatocerus maxillosus* (Fabricius)	+			
Flour beetle	*Gonocephalum* sp.	+			
Cigarette beetle	*Lasioderma serricorne* (Fabricius)	+	+	+	
Long head beetle	*Latheticus oryzae* Waterhouse	+			+
	Liposcelis enthomophilus (Edl)				+
Siamese grain beetle	*Lophocateres pusillus* (Klug)	+	+	+	+
	Murmdius segregatus (Wat)				+
	Nausibius Clavicornis (Klug)	+			

continued ...

TABLE V (continued)

Common Name	Latin Name	Philippines	Indonesia	Thailand	Malaysia
Red-legged ham beetle	*Necrobia rufipes* (De Geer)	+	+		
Merchant grain beetle	*Oryzaephilus mercator* (Fauvel)		+	+	+
Saw-toothed grain beetle	*Oryzaephilus surinamensis* (Linnaeus)	+	+	+	+
	Palembos dermetoides				+
Smalleyed flour beetle	*Palorus ratzeburgi* (Wissmann)	+		+	
Depressed flour beetle	*Palorus subdepressus* (Wollaston)	+		+	+
Mexican grain beetle	*Pharaxonotha kirschi* (Reitter)	+			
Indian meal moth	*Plodia interpunctella* (Hübner)	+	+		+
	Proctes entomophilus (Edl)		+		
Meal snout moth	*Pyralis farinalis* (Linnaeus)	+			
Lesser grain borer	*Rhizopertha dominica* (F.)	+	+		
Rice weevil	*Sitophilus oryzae* (Linnaeus)	+	+	+	+
Maize weevil	*Sitophilus zeamais* Motschulsky	+	+	+	+
Angoumois grain moth	*Sitotroga cerealella* (Olivier)	+	+	+	+
Drugstore beetle	*Stegobium paniceum* (Linnaeus)	+	+	+	
Cadelle beetle	*Tenebroides mauritanicus* (Linnaeus)	+	+	+	+
Red flour beetle	*Tribolium castaneum* (Herbst)	+	+	+	+

continued ...

TABLE V (concluded)

Common Name	Latin Name	Philip-pines	Indo-nesia	Thai-land	Mal-aysia
Confused flour beetle	*Tribolium confusum* (Jacquelin du Val)	+	+	+	
Larger carpet beetle	*Trogoderma anthrenoides* (Sharp)	+			
Khapra beetle	*Trogoderma granarium* Everts	+	+		+
Hairy fungus beetle	*Typhaea stercorea* (Linnaeus)	+	+	+	

TABLE VI

INSECT PESTS OF STORED GRAINS IN U.S.A. [27]

Stored Grains and Milled Cereal Products. (The most common ones.)

Common Name	Latin Name	U.S.A. Region
Lesser meal worm	*Alphitobius diaperinus* (Panzer)	
Black fungus beetle	*Alphitobius laevigatus* (Fabricius)	
Two-banded fungus beetle	*Alphitophagus bifasciatus* (Say)	
Coffee bean weevil	*Araecerus fasciculatus* (De Geer)	Southern states
Black carpet beetle	*Attagenus piceus*	
Corn sap beetle	*Carpophilus dimidiatus* (Fabricius)	Southern states
Square-necked grain beetle	*Cathartus quadricollis* (Guérin-Méneville)	Southern states
Broad-nosed grain weevil	*Caulophilus latinasus* (Say)	Southern states
Rice moth	*Corcyra cephalonica* (Stainton)	Southern states

continued ...

TABLE VI (continued)

Common Name	Latin Name	U.S.A. Region
Rust red grain beetle	Cryptolestes ferrugineus (Stephens)	Northern states
Flat grain beetle	Cryptolestes pusillus (Schönherr)	Northern states
	Cryptolestes turcicus (Grouvelle)	
Flour beetle	Cynaeus angustus (LeConte)	Kansas, Missouri, Iowa, Washington
	Ephestia cautella (Walker)	Southern and central states
	Ephestia elutella (Hübner)	Southern and central states
	Ephestia figulilella Gregson	Southern and central states
Mediterranean flour moth	Ephestia kuehniella Zeller	
Broad-horned flour beetle	Gnatocerus cornutus (Fabricius)	Widely distributed
Slender-horned flour beetle	Gnatocerus maxillosus (Fabricius)	Southern states
Cigarette beetle	Lasioderma serricorne (Fabricius)	Well distributed
Long-headed flour beetle	Latheticus oryzae (Waterhouse)	Southern and middle western states
Siamese grain beetle	Lophocateres pusillus (Klug)	Southern states
Wolf moth	Nemapogon granella (Linnaeus)	Widespread
	Oryzaephilus mercator (Fauvel)	Widespread
Saw-toothed grain beetle	Oryzaephilus surinamensis (Linnaeus)	Widespread

continued ...

TABLE VI (continued)

Common Name	Latin Name	U.S.A. Region
Smalleyed flour beetle	*Palorus ratzeburgi* (Wissmann)	Widely distributed
	Palorus subdepressus (Wollaston)	Great plains region
Mexican grain beetle	*Pharaxonotha kirschi* Reitter	Texas
Indian meal moth	*Plodia interpunctella* (Hübner)	Widespread
Larger grain borer	*Prostephanus truncatus* (Horn)	Texas, California, dist. of Columbia
White-marked spider beetle	*Ptinus fur* (Linnaeus)	Extreme northern states
Spider beetle	*Ptinus villiger* (Reitter)	Northern states
Meal snout moth	*Pyralis farinalis* (Linnaeus)	
Pink corn worm	*Pyroderces rileyi* (Walsingham)	Southern states
Lesser grain borer	*Rhyzopertha dominica* (Fabricius)	Gulf states, Oklahoma, Kansas
Granary weevil	*Sitophilus granarius* (Linnaeus)	Northern states
Rice weevil	*Sitophilus oryzae* (Linnaeus)	Widespread
Angumois grain moth	*Sitotroga cerealella* (Olivier)	South, east and central states
Drugstore beetle	*Stegoblum paniceum* (Linnaeus)	
Yellow meal worm	*Tenebrio molitor* Linnaeus	Widespread
American meal worm or European meal worm	*Tenebrio obscurus* (Fabricius)	Widespread
Cadelle	*Tenebroides mauritanicus* (Linnaeus)	Widespread
Red flour beetle	*Tribolium castaneum* (Herbst)	Widespread

continued ...

TABLE VI (concluded)

Common Name	Latin Name	U.S.A. Region
Confused flour beetle	Tribolium confusum (Jacquelin du Val)	Widespread
Khapra beetle	Trogoderma granarium (Everts)	California, Arizona, New Mexico
Hairy fungus beetle	Typhaea stercorea (Linnaeus)	Widespread

TABLE VII

INSECT PESTS OF STORED GRAINS IN U.S.S.R.* [8]

Common Name	Latin Name	Region
Rusty grain beetle	Cryptolestes ferrugineus (Stephens)	North
Mediterranean flour moth	Ephestia kuehniella (Zeller)	South
Saw-toothed grain beetle	Oryzaephilus surinamensis	South
Lesser grain borer	Rhyzopertha dominica (Fabricius)	South
Granary weevil	Sitophilus granarius (Linnaeus)	North
Rice weevil	Sitophilus oryzae (Linnaeus)	Central and South
Maize weevil	Sitophilus zeamais (Motschulsky)	South
Angoumois grain moth	Sitotroga cerealella (Olivier)	South
Red flour beetle	Tribolium castaneum (Herbst)	South

* Information available is very limited, therefore this table contains the nine most common species of insect pests found in the U.S.S.R. stored grain products. By no means should this be considered a complete table.

6. INSECT PEST BY STORED PRODUCT

6.1 EXPLANATION OF TABLES VIII AND IX

Table VIII contains a list of insect pests found in starchy grain crops such as wheat, corn, barley, rice, oats, sorghum, millet etc. The insects are listed in column I by their common name (where available), and in column II by their Latin name (scientific) in alphabetical order. In column III, the insects with primary pest status categories are indicated (8).

Table IX contains a list of insect pests found in specific cereals, although any of these species can be associated with another kind of crop. The commodities are listed in column I; column II and III contain the common and scientific name respectively, of the insect species found in each commodity.

TABLE VIII

INSECT PESTS IN STORED CEREALS (WHEAT, RICE, CORN, BARLEY, OATS, SORGHUM, MILLET, RICE [8,23,24,28]

Common Name	Latin Name	Incidence
Foreign grain beetle	Ahasverus advena (Waltl)	
Lesser meal worm	Alphitobius diaperinus (Panzer)	
Black fungus beetle	Alphitobius laevigatus (Fabricius)	
Varied carpet beetle	Anthrenus verbasci (Linnaeus)	
Stored nut moth	Aphomia gularis (Zeller)	
Coffee bean weevil	Araecerus fasciculatus (De Geer)	H
A beetle	Attagenus pellio (Linnaeus)	
Black carpet beetle	Attagenus unicolor (Brahm)	
Corn sap beetle	Carpophilus dimidiatus (Fabricius)	
	Carpophilus freemani (Dobson)	
	Carpophilus hemipterus (Linnaeus)	
	Carpophilus lugubris (Murray)	
	Carpophilus maculatus (Murray)	
	Carpophilus obsoletus (Erichson)	
	Carpophilus pallipennis (Say)	H
Square-necked grain beetle	Cathartus quadricollis (Guérin-Meneville)	
	Caulophilus oryzae (Gyllenhal)	
Rice moth	Corcyra cephalonica (Stainton)	H
	Cryptolestes capensis (Waltl)	
Rusty grain beetle	Cryptolestes ferrugineus (Stephens)	H
	Cryptolestes pusilloides (Steel & Howe)	
Flat grain beetle	Cryptolestes pusillus (Schönherr)	H
Flour meal beetle	Cryptolestes turcicus (Grouvelle)	H
	Cryptolestes ugandae (Steel & Howe)	

continued...

TABLE VIII (continued)

Common Name	Latin Name	Incidence*
Larger black flour beetle	Cynaeus angustus (LeConte)	
Black larder beetle	Dermestes ater (De Geer)	
White-shouldered house moth	Endrosis sarcitrella (Linnaeus)	
Almond moth	Ephestia cautella (Walker)	H
	Ephestia figulilella (Gregson)	
Mediterranean flour moth	Ephestia kuehniella (Zeller)	H
Broad-horned flour beetle	Gnatocerus cornutus (Fabricius)	H
Slender-horned flour beetle	Gnatocerus maxillosus (Fabricius)	
Cigarette beetle	Lasioderma serricorne (Fabricius)	
Long-headed flour beetle	Latheticus oryzae (Waterhouse)	
	Liposcelis bostrychophilus (Badonnel)	
Siamese grain beetle	Lophocateres pusillus (Klug)	
	Mycetaea hirta (Marsham)	
European grain moth	Nemapogon granella (Linnaeus)	H
Golden spider beetle	Niptus hololeucus (Faldermann)	
Merchant grain beetle	Oryzaephilus mercator (Fauveli)	H
Saw-toothed grain beetle	Oryzaephilus surinamensis (Linnaeus)	H
Smalleyed flour beetle	Palorus ratzeburgi (Wissmann)	
Depressed flour beetle	Palorus subdepressus (Wollaston)	
Mexican grain beetle	Pharaxonotha kirschi (Reitter)	H
	Platydema ruficorne (Sturm)	
Indian meal moth	Plodia interpunctella (Hübner)	H
Larger grain borer	Prostephanus truncatus (Horn)	H
Whitemarked spider beetle	Ptinus fur (Linnaeus)	
Hairy spider beetle	Ptinus villiger (Reitter)	
Meal moth	Pyralis farinalis (Linnaeus)	
	Pyroderces rileyi (Walsingham)	H
Lesser grain borer	Rhyzopertha dominica (Fabricius)	H
Granary weevil	Sitophilus granarius (Linnaeus)	H
Rice weevil	Sitophilus oryzae (Linnaeus)	H

continued...

TABLE VIII (concluded)

Common Name	Latin Name	Incidence*
Maize weevil	*Sitophilus zeamais* (Motschulsky)	H
Angoumois grain moth	*Sitotroga cerealella* (Olivier)	H
Drugstore beetle	*Stegobium paniceum* (Linnaeus)	
Yellow meal worm	*Tenebrio molitor* (Linnaeus)	
Dark meal worm	*Tenebrio obscurus* (Fabricius)	
Cadelle	*Tenebroides mauritanicus* (Linnaeus)	H
	Tipnus unicolor (Piller & Mitterpacher)	
American black flour beetle	*Tribolium audax* (Halstead)	
Red flour beetle	*Tribolium castaneum* (Herbst)	H
Confused flour beetle	*Tribolium confusum* (Jacquelin du Val)	H
Large flour beetle	*Tribolium destructor* (Uyttenboogaart)	H
European black flour beetle	*Tribolium madens* (Charpentier)	
	Trigonogenius globulus (Solier)	
	Trogoderma glabrum (Herbst)	H
Khapra beetle	*Trogoderma granarium* (Everts)	
	Trogoderma variabile (Ballion)	
Hairy fungus beetle	*Typhaea stercorea* (Linnaeus)	
	Urophorus humeralis (Fabricius)	

* Indicates primary status incidence high.

TABLE IX

INSECT PESTS IN SPECIFIC CEREALS

Commodity	Common Name	Scientific Name
(1) Rice [23,24]		
(a) Paddy		
	Grey rice moth	Corcyra cephalonica (Staint.)
	Angoumois grain moth	Sitotroga cerealella (Ol.)
	Lesser meal worm	Alphitobius diaparenus (Panz.)
		Alphitobius laevigatus (F.)
	Flat grain beetle	Cryptolestes pusillus (Schon.)
	Bamboo borer	Dinoderus minutus
	Siamese grain beetle	Lophocateres pusilus (Klug.)
	Saw-toothed grain beetle	Oryzaephilus surinamensis (L.)
	Lesser grain borer	Rhizopertha dominica (F.)
	Rice weevil	Sitophilus oryzae (L.)
	Larger black cadelle	Tenebroides mauritanicus (L.)
	Rust red flour beetle	Tribolium castaneum (Hbst)
		Typhaea stercorea (L.)
(b) Milled Rice [23,24]		
	Rice moth	Corcyra cephalonica (Staint.)
		Doloessa viridis (Tell.)
	Gray rice moth	Ephestia cautella (Wlk)
	Indian meal moth	Plodia interpunctella (Hbr)
		Setomorpha rutella Zell.
	Angoumois grain moth	Sitotroga cerealella (Ol)
	Foreign grain beetle	Ahasverus advena Waltl.
	Lesser meal worm	Alphitobius diaperinus (Panz.)
		A. Laevigatus (F.)
	Corn sap beetle	Carpophilus dimidiatus (F.)
	Flat grain beetle	Cryptolestes pusillus (Schon)
		Dinoderus minutus (F.)

continued...

TABLE IX (concluded)

Commodity	Common Name	Scientific Name
	Longheaded flour beetle	Latheticus oryzae (Waterh.)
	Siamese grain beetle	Lophocateres pusillus (Klug)
		Murmidius segregatus (Waterh.)
	Saw-toothed grain beetle	Oryzaephilus surinamensis (L.)
		Palorus subdepresseus Woll.
	Rice weevil	Sitophilus oryzae (L.)
	Larger black cadelle	Tenebroides mauritanicus (L.)
		Thorictodes heydeni (Reitt)
	Rust-red flour beetle	Tribolium castaneum (Hbst)
	Khapra beetle	Trogoderma granarium everts
(2) Maize [23,29,30]		
	Angoumois grain moth	Sitotroga cerealella (Ol.)
	Caruncho das tulhas	Araecerus fasciculatus (Geer)
	Larger grain borer	Prostephanus truncatus (Horn)
	Rice weevil	Sitophilus oryzae (L.)
	Maize weevil	Sitophilus zeamais (Mots.)

7. WORLDWIDE MOST COMMON INSECT PESTS OF STORED GRAINS AND THEIR SENSITIVITY TO RADIATION

7.1 EXPLANATION TO TABLE X

Table X contains a list of the most common insect pests found worldwide in stored grains. The radiosensitivity at the different developmental stages of each species is indicated in a separate listing, where each species is characterized further by providing information as follows:

(a) common name,
(b) scientific name,
(c) commodities most frequently infested,
(d) countries most commonly found,
(e) references.

TABLE X

WORLDWIDE MOST COMMON INSECT PESTS OF STORED GRAINS AND THEIR SENSITIVITY TO RADIATION

Common Name	Latin Name
Square-necked grain beetle	Cathartus quadricollis (Guérin-Meneville)
Gray rice moth	Corcyra cephalonica (Stainton)
Rusty grain beetle	Cryptolestes ferrugineus (Stephens)
Flat grain beetle	Cryptolestes pusillus (Schönherr)
Almond moth	Ephestia cautella (Walker)
Cigarette or tobacco beetle	Lasioderma serricorne (F.)
Merchant grain beetle	Oryzaephilus mercator (Fauvel)
Saw-toothed grain beetle	Oryzaephilus surinamensis (Linnaeus)
Depressed grain beetle	Palorus subdepressus (Wollaston)
Lesser grain borer	Rhyzopertha dominica (Fabricius)
Granary weevil	Sitophilus granarius (Linnaeus)
Rice weevil	Sitophilus oryzae (Linnaeus)
Maize weevil	Sitophilus zeamais (Motschulsky)
Angumois grain moth	Sitotroga cerealella (Oliv.)
Cadelle	Tenebroides mauritanicus (Linnaeus)
Rust flour beetle	Tribolium castaneum (Herbst)
Confused flour beetle	Tribolium confusum (Jacquelin du Val)
Khapra beetle	Trogoderma granarium (Everts)

TABLE X

COMMON NAME: Square-necked grain beetle
SCIENTIFIC NAME: *Cathartus quadricollis*
COMMODITIES: Cereals (wheat, rice)
COUNTRIES: Ghana, Nigeria, Toga

COMMENTS	STAGE	RADIOSENSITIVITY (Gy)					REFERENCES
		LD:50 days	LD:100 days	LT:50 dose	LT:95 dose	LT:100 dose	
Sterilizing dose: for males 300 Gy and for females 200 Gy [13] Emergence: [31] Eggs: A dose of 5 Gy prevented the development of irradiated eggs to adult. Larvae: A dose of 5 Gy prevented the development of larvae to adults. Pupae: A dose of 1000 Gy produced 100% reduction in emergence. Mortality: A dose of 200 Gy killed 99.9% of the irradiated adults after exposure.	Adults		200_{21}				31

continued ...

TABLE X (continued)

COMMON NAME: Grey rice moth
SCIENTIFIC NAME: *Corcyra cephalonica*
COMMODITIES: Rice, wheat, maize, barley, sorghum
COUNTRIES: South Africa, Kenya, Nigeria, Burma, Malaysia, India, Brazil

COMMENTS	STAGE	RADIOSENSITIVITY (Gy)					REFERENCES
		LD:50 days	LD:100 days	LT:50 dose	LT:95 dose	LT:100 dose	
This is an important pest in	eggs						
stored rice in low-latitude	1 day old		25				32
and wet and dry lands,	2 days old		75				32
e.g. Burma, India, and Pakistan.	3 days old		250				32
	4 days old		250				
A dose of 1700 Gy [33] produces							
100% mortality in insects							
irradiated in the adult stage.	larvae						
Irradiation of the different	1st stage		100				32
stages of development [32]	Full grown		200				32
results in:							
Eggs: Freshly laid eggs are							
more susceptible than 1 to 4 day	adults		1700				33
old eggs. Emergence is not							
observed in freshly laid eggs							
when irradiated at 10 Gy.							
However, for 3 and 4 day old							
eggs 250 Gy was required to							
prevent emergence.							

continued ...

COMMON NAME: Grey rice moth (continued)
SCIENTIFIC NAME:
COMMODITIES:
COUNTRIES:

COMMENTS	STAGE	RADIOSENSITIVITY Gy) LD:50 days	LD:100 days	LT:50 dose	LT:95 dose	LT:100 dose	REFERENCES
<u>Larvae</u>: Doses lower than 75 Gy do not produce any ill effect, while 100 Gy inhibit the development to the pupae stage. <u>Full-grown larvae</u>: Doses between 150 to 200 Gy produce necrosis and cause death. <u>Fertility</u>: Females, when irradiated at pupae stage with 50 Gy, lay eggs that do not reach adult stage. Males irradiated at pupae stage with a dose of 200 Gy, are completely sterile. Adult females are more sensitive to radiation sterilization than adult males. The adult emergence from eggs laid, by adult females irradiated at 100 Gy is 0%. Adult males require 150 Gy for complete sterilization.							

continued ...

TABLE X (continued)

COMMON NAME: Grey rice moth (concluded)
SCIENTIFIC NAME:
COMMODITIES:
COUNTRIES:

COMMENTS	STAGE	RADIOSENSITIVITY (Gy)					REFERENCES
		LD:50 days	LD:100 days	LT:50 dose	LT:95 dose	LT:100 dose	
Conclusion: A dose of 250 Gy is recommended to fully check (control) infestation of grains by C. cephalonica. A dose of 400 Gy causes complete sterility in both sexes.							

continued ...

TABLE X (continued)

COMMON NAME: Rusty grain beetle
SCIENTIFIC NAME: Cryptolestes ferrugineus
COMMODITIES: Grains: rye, wheat, millet [6,8]
COUNTRIES: Farms and central storages in Queensland (Australia) [14], primary silos Southern Canada, Northern U.S.A., Argentina, Brazil, Kenya, Nigeria, India, U.S.S.R. and Burma.

COMMENTS	STAGE	RADIOSENSITIVITY (Gy) LD:50 days	LD:100 days	LT:50 dose	LT:95 dose	LT:100 dose	REFERENCES
C. ferrugineus is the most common of the Cryptolestes spp. found in farms and central storages in Queensland (Australia) [35].	adult			15_{465}*	21_{465}*		10
				7_{125}	14_{125}	21_{125}	34
				$21_{62.5}$	$217_{62.5}$	$259_{62.5}$	34
A dose of 184 Gy inhibits the growth of young larvae. At this dose emergence from late larvae and pupae is observed. However, the survivors are sterile [10].							
A dose of 465 Gy inhibits the emergence of adults from most of the irradiated immature stages.							
The differences in the results reported by different groups can be attributed to factors such as: variations in strains as well as in experimental conditions.							
* Reported as 500 rep.							

continued ...

TABLE X (continued)

COMMON NAME: Flat grain beetle
SCIENTIFIC NAME: *Crytolestes pusillus*
COMMODITIES: Damaged grain and legumes, maize, barley, rice, sorghum, beans, coffee
COUNTRIES: Ghana, Mexico, Southeast Queensland (Australia)

COMMENTS	STAGE	RADIOSENSITIVITY (Gy)					REFERENCES
		LD:50 days	LD:100 days	LT:50 dose	LT:95 dose	LT:100 dose	
When adults are irradiated at doses of 200 Gy or greater, the insect population does not grow [15]. Thus, 200 Gy is the recommended dose to control growth of C. pusillus.							15

continued ...

TABLE X (continued)

COMMON NAME: Almond moth
SCIENTIFIC NAME: *Ephestia cautella*, cadra cautella
COMMODITIES: Corn, barley, oats
COUNTRIES: Mediterranean lands, Italy, Greece, Turkey, Israel, Portugal

COMMENTS	STAGE	RADIOSENSITIVITY (Gy)					REFERENCES
		LD:50 days	LD:100 days	LT:50 dose	LT:95 dose	LT:100 dose	
There is significant difference between the sexes in susceptibility to radiation [36]. A dose of 116 Gy reduced by 50% the number of emerged females from irradiated eggs, while a dose of 284 Gy is required to produce the same effect on male emergence. Fertility: 50% reduction in progenity is obtained with 27 Gy and 99% reduction with 237 Gy. Sterilizing doses of 400 Gy have been reported for complete control of E. cautella populations [37].							36 37

continued ...

TABLE X (continued)

COMMON NAME: Cigarette or tobacco beetle
SCIENTIFIC NAME: *Lasioderma serricorne*
COMMODITIES: Crushed oats, flour
COUNTRIES: Queensland (Australia), Philippines, Indonesia, Thailand, Malaysia, Nigeria

COMMENTS	STAGE	RADIOSENSITIVITY (Gy)					REFERENCES
		LD:50 days	LD:100 days	LT:50 dose	LT:95 dose	LT:100 dose	
At irradiation doses ranging from 130 to 1000 Gy the following was observed [38].	larvae	132_{26} 450_{21} 1000_{14}	132_{49} 450_{35} 1000_{7}	26_{132} 21_{450} 14_{1000}			7,36,38
Irradiated eggs: Some of them hatched but none of the larvae progressed to the pupae stage.	pupae	132_{21} 450_{14} 1000_{6}		21_{132} 14_{450} 6_{1000}			
Larvae: Significant number of irradiated larvae transformed to pupae, but they never became adults.	adult	132_{25} 450_{20} 1000_{20}		25_{132} 20_{450}	38_{132}		
Pupae: Large number of irradiated pupae transformed into adults in inverse ratio to the dosage level.							

continued ...

TABLE X (continued)

COMMON NAME: Cigarette or tobacco beetle (concluded)
SCIENTIFIC NAME:
COMMODITIES:
COUNTRIES:

COMMENTS	STAGE	RADIOSENSITIVITY Gy)					REFERENCES
		LD:50 days	LD:100 days	LT:50 dose	LT:95 dose	LT:100 dose	
Adults: Sterilization dose 160 Gy The table shows the days required to kill either 50 or 100% of the population of adults emerging from the corresponding stage of development, when irradiated at the stipulated dose; e.g. $LD:50=132_{26}$ indicates that after 26 days the number of adults that have emerged from eggs irradiated at 132 Gy, were reduced by 50% of the original number.							

continued ...

TABLE X (continued)

COMMON NAME: Merchant grain beetle
SCIENTIFIC NAME: Oryzaephilus mercator
COMMODITIES: Rice, wheat, pulse, oilseed and derivatives
COUNTRIES: Nigeria, Burma

COMMENTS	STAGE	RADIOSENSITIVITY Gy)					REFERENCES
		LD:50 days	LD:100 days	LT:50 dose	LT:95 dose	LT:100 dose	
Eggs and larvae treated with 100 Gy do not develop to adults. Pupae treated with 100 Gy develop to adult but they do not reproduce [39]. Adults. A 99% mortality is obtained in 3 weeks in adults treated at 100 Gy and 100% at all dosages above that. Doses of 200 Gy or above produce complete sterility.	Adult	100_{49}					39
		200_{14}					39
		300_{14}					39

continued ...

COMMON NAME: Saw-toothed grain beetle
SCIENTIFIC NAME: Oryzaephilus surinamensis
COMMODITIES: Cereal and cereal products, rice [23], oats, wheat, barley, rye, sorghum, flour, nuts
COUNTRIES: U.S.A., Britain, Canada (Cold, hardy, adaptable species)

COMMENTS	STAGE	RADIOSENSITIVITY (Gy) LD:50 days	LD:100 days	LT:50 dose	LT:95 dose	LT:100 dose	REFERENCES
Effect of gamma radiation at different stages of development.	Eggs						40
	1 day old		30				40
	4 days old		36				40
Eggs: Resistance to radiation increases with age. 5-day old eggs are more tolerant than 1 and 4 day old eggs.	5 days old		50				41
			96_{21}				41
	larvae		86_{21}				41
	pupae						
	early		144_{21}				41
SURVIVAL	late		308_{21}				41
Eggs: A dose of 96 Gy is required to kill 99.9% of emerged population in 21 days.	adults		206_{21}				41
			500_{14}				7
Larvae: 86 Gy kill 99.9% of the emerged population in 3 weeks.							
Pupae: Doses ranging from 144 to 308 Gy kill 99.9% of the emerged population in three weeks.							
Adults: A dose of 206 Gy kills 99.9% of the adults in three weeks, while 500 Gy has the same effect in 2 weeks.							

continued ...

TABLE X (continued)

COMMON NAME: Saw-toothed grain beetle (concluded)
SCIENTIFIC NAME:
COMMODITIES:
COUNTRIES:

COMMENTS	STAGE	RADIOSENSITIVITY (Gy)					REFERENCES
		LD:50 days	LD:100 days	LT:50 dose	LT:95 dose	LT:100 dose	
FERTILITY The production of progeny is reduced by 99.9% when eggs, larvae, early pupae, mature pupae and adults are irradiated at 80, 65, 77, 120 and 153 Gy, respectively. Sterilization by ionizing radiation is effective only in females; males recover their fertility by the second week after treatment.							

continued ...

COMMON NAME: Depressed grain beetle
SCIENTIFIC NAME: *Palorus subdepressus*
COMMODITIES: Cereals, common pest of rice
COUNTRIES: Toga, Malaysia

COMMENTS	STAGE	RADIOSENSITIVITY (Gy)					REFERENCES
		LD:50 days	LD:100 days	LT:50 dose	LT:95 dose	LT:100 dose	
It is one of the most radio resistant species of the coleoptera order [42]. Females and males irradiated at 300 Gy are not 100% sterilized, but their fecundity and longevity are significantly reduced.	Larvae		200_{21}				43
	Pupae		1000				
	Adult		50_{238} 100_{217} 200_{21}				
Eggs and larvae irradiated at 100 Gy do not develop to the adult stage. Pupae treated with 50, 100, 200, 300 or 500 Gy develop to adults, but their life span is greatly reduced [43]. All adults from pupae treated at 200 Gy or above are dead within 3 weeks.							
A dose of 300 Gy or above is recommended to control infestations by *Palorus* spp.							

continued ...

TABLE X (continued)

COMMON NAME: Lesser grain borer
SCIENTIFIC NAME: *Rhyzopertha dominica*
COMMODITIES: Rice paddy [22], wheat
COUNTRIES: Cosmopolitan, tropical and sub-tropical climates (Central India, South Africa, New South Wales, Australia)

COMMENTS	STAGE	RADIOSENSITIVITY (Gy)					REFERENCES
		LD:50 days	LD:100 days	LT:50 dose	LT:95 dose	LT:100 dose	
Doses of 175 [13] and 160 Gy [36]	Adults	95_{35}, 80_{63},	248.8_{63}				36
are recommended as sterilizing	from ir-	136_{28},					
doses. Doses of 30 and 40 Gy have	radiated	74.4_{63}					
been reported as threshold doses	pupae						
for mortality of pupae and adults							
respectively [36].	Adults	95_{48}, 136_{32}	256.5_{63}				36
	irradi-	69.6_{63}					36
The number of adults that emerge	ated	125_{63}	125_{105}				34
from irradiated pupae are not	directly	132_{35}	132_{75}				44
reduced by doses up to		175_{27}	175_{47}				44
200 Gy [36].		250_{28}	250_{56}				34
		500_{14-21}	500_{21}				34
<u>Reduction in progenity</u>			399_{28}				45,46
Adults directly irradiated at			450_{26}				34
doses of 22.4 Gy or emerging from							
pupae irradiated at 21.4 Gy							
experience 50% progeny reduction							
within three weeks. When the							
doses used are changed to 112.4							
and 107.5 Gy, respectively, 100%							
progeny reduction is obtained.							

continued ...

TABLE X (continued)

COMMON NAME: Lesser grain borer (concluded)
SCIENTIFIC NAME:
COMMODITIES:
COUNTRIES:

COMMENTS	STAGE	RADIOSENSITIVITY (Gy)					REFERENCES
		LD:50 days	LD:100 days	LT:50 dose	LT:95 dose	LT:100 dose	
Conclusion R. dominica is more resistant to killing by irradiation than most other pests of stored products. 99.9% kill is obtained nine weeks after irradiation at dose of 250 Gy. Pupae and adults are equally susceptible to radiation sterilization. 160 Gy is an effective sterilizing dose. The discrepancies between the LD:50 and LD:100 by different authors can be attributed to variations in strain, experimental conditions and/or maturity.							

continued ...

TABLE X (continued)

COMMON NAME: Granary weevil
SCIENTIFIC NAME: *Sitophilus granarius*
COMMODITIES: Maize and wheat
COUNTRIES: Farms in Southern Ontario (Canada), Queensland and New South Wales (Australia), Mexico

COMMENTS	STAGE	RADIOSENSITIVITY (Gy)					REFERENCES
		LD:50 days	LD:100 days	LT:50 dose	LT:95 dose	LT:100 dose	
Resistance to radiation increases	eggs	11_{60}	41_{60}, 27_{28}				16
with the developmental stage.							47
Doses of 27, 38 and 107 Gy reduce	larvae	30_{60}	42_{60}, 38_{28}				16,47
by 100% the survival of adults							47
emerging from irradiated eggs,	pupae	47_{60}	85_{60}, 107_{28}				16,47
larvae and pupae, respectively.							
Doses of 41, 42, 85 and 90 Gy	adults	52_{28},81_{28}**	90_{60}	16_{60}	21_{60}	28_{60},28_{80}**	16,47,48
produce 99.9% kill of eggs,		72_{60}		$<7_{62.5}$	$21_{62.5}$		16,34
larvae, pupae and adults,				$<7_{125}$	14_{125}		34
respectively. Grain weevils				12_{64}			47
treated with 141 and 171 Gy [47]		68_{21}, 75_{21}	140_{21}				49
show a reduction in progenity				13_{120}	18_{120}		47
of 99 and 99.9%, respectively.				12_{465}		20_{465}	10
SD:50 (dose that sterilizes 50% of							
the population) of 9.7 to 17.6 Gy,							
as well as a SD99.9 (dose that							
sterilizes 100%) of 90 Gy have							
been reported [49].							
** susceptibility studies of							
pupae and mature adults to							
radiation from ^{60}Co and accele-							
rated electrons (2.5 MeV linear							

continued ...

TABLE X (continued)

COMMON NAME: Granary weevil (continued)
SCIENTIFIC NAME:
COMMODITIES:
COUNTRIES:

COMMENTS	STAGE	RADIOSENSITIVITY (Gy)					REFERENCES
		LD:50 days	LD:100 days	LT:50 dose	LT:95 dose	LT:100 dose	
accelerator dose rate 8.64 x 10^4 Gy/h) show that both types of radiation are equally effective in preventing emergence from pupae. Accelerated electrons were less effective in inducing sterility in adults emerging from irradiated pupae. Mature adults were more susceptible to the killing effects of irradiation with ^{60}Co. The LD:50 was 30 Gy higher with accelerated electrons than with ^{60}Co gammas. The SD50 is 60 Gy higher for e−. The difference in dose for 99.9% mortality and sterility with the two sources is 50 Gy. Comparative radiosensitivity studies between Manitoba and Australian [50] strains of _S. granarius_ show that the Manitoba strains are more sensitive to radiation							

continued ...

TABLE X (continued)

COMMON NAME: Granary weevil (concluded)
SCIENTIFIC NAME:
COMMODITIES:
COUNTRIES:

COMMENTS	STAGE	RADIOSENSITIVITY (Gy) LD:50 days	LD:100 days	LT:50 dose	LT:95 dose	LT:100 dose	REFERENCES
($LD:50_{21}$=52 Gy; $LD:100_{21}$=80 Gy) than Australian strains ($LD:50_{21}$= 68-75, $LD:100_{21}$=140). A dose of 160 Gy is recommended for use in commercial radiation disinfestation of grain infested with S. granarius (Australian or any other origin [49]. ** Accelerated electrons.							

continued ...

TABLE X (continued)

COMMON NAME: Rice weevil
SCIENTIFIC NAME: *Sitophilus oryzae*
COMMODITIES: Maize, wheat, rice
COUNTRIES: Mexico, Australia, Egypt. One of the most important pest species infesting stored grains in Queensland [27] and in Japan.

COMMENTS	STAGE	RADIOSENSITIVITY (Gy) LD:50 days	LD:100 days	LT:50 dose	LT:95 dose	LT:100 dose	REFERENCES
Resistance to radiation increases	eggs		26_{21}				47
with the stage of development [47].			50				50
Doses of 26, 40 and 52 Gy reduce							
by 100%, after 21 days, the sur-	larvae		40_{21}				47
vival of adult emerging from ir-			75				51
radiated eggs, larvae and pupae,	pupae		52_{21}, 750				47,51
respectively. No adults emerge	adults		74_{21}				47
[50] from egg, larvae and pupae				7_{660}, 12_{250}	11_{660}	14_{660}, 21_{250}	38
when irradiated at 50, 75 and				11_{60}	17_{60}		7
750 Gy, respectively. 160 Gy is				11_{132}	21_{132}		38
the recommended dose for control-				10_{250}	17_{250}		38
ling rice weevils in industrial				3_{1000}	6_{1000}		38
applications of grain disinfes-				7.5_{465}		14_{465}	10
tation by ionizing radiation. This			500_{30}				52
is a sterilization dose, not a			200_{21}				50
killing dose. A total kill at this			$200\text{-}300_{21}$				53
dose is obtained after 6 months			100_{30}				54
[52].			160_{180}				52
			80_{21}, 210_{21}				55
250 Gy has also been reported as a control dose [56] for irradiation of infested wheat, rice, maize and 500 Gy for complete disinfestation.							

continued ...

TABLE X (continued)

COMMON NAME: Maize weevil
SCIENTIFIC NAME: *Sitophilus zeamais*
COMMODITIES: Maize, wheat
COUNTRIES: Cosmopolitan, warm tropical and subtropical areas, Kenya, South Africa, Zambia, Nigeria, Mexico, U.S.A.

COMMENTS	STAGE	RADIOSENSITIVITY (Gy)					REFERENCES
		LD:50 days	LD:100 days	LT:50 dose	LT:95 dose	LT:100 dose	
Resistance to radiation increases	eggs						
with the stage of development.	0-3 days old		28				47
	3-5 days old		40				47
Eggs: When eggs of 0 to 3 days							
old are irradiated at 28 Gy no	larvae						
emergence is observed. 3% emer-	5-7 days old		40				47
gence is observed when more mature	9-13 days old		40				47
eggs are irradiated at the same	16-20 days old		56				47
dose as above.							
	adults		54_{21}				47
Larvae: Irradiation of larvae			52_{21}				45
stages at 28 Gy resulted in 3%			150_{14}				45
emergence reduction.			100_{35}				57
			200_{28}				57
Pupae: A 7% emergence was			300_{21}				57
observed at doses up to 500 Gy			500_{21}				57
[57], although other observations			1000_{6}				57
[47] indicate a 66% emergence at a							
similar dose (515 Gy). However,							
very small survival after 3 to 4							
weeks was detected in the adults							
emerged from the irradiated pupae.							

continued ...

TABLE X (continued)

COMMON NAME: Maize weevil (concluded)
SCIENTIFIC NAME:
COMMODITIES:
COUNTRIES:

COMMENTS	STAGE	RADIOSENSITIVITY (Gy)					REFERENCES
		LD:50 days	LD:100 days	LT:50 dose	LT:95 dose	LT:100 dose	
The radiation susceptibility of adults varies with age. Young are more susceptible than old adults. A sterilizing dose of 160 Gy is recommended as optimum dose to control maize weevils for industrial applications.							

continued ...

TABLE X (continued)

COMMON NAME: Angoumois grain moth
SCIENTIFIC NAME: Sitotroga cerealella [25,31]
COMMODITIES: Paddy (bulk stored), wheat, maize
COUNTRIES: Humid tropical lands. Congo, Ceylon, Colombia, Brazil, Burma

COMMENTS	STAGE	RADIOSENSITIVITY (Gy)					REFERENCES
		LD:50 days	LD:100 days	LT:50 dose	LT:95 dose	LT:100 dose	
Irradiation of eggs and larvae by 100 Gy results in a significant decrease in the number of emerged adults.	Emergence from irradiated eggs		200				45
1000 Gy has been reported as the highest dose permitting reproduction for male and females.	larvae		100				45
A sterilizing dose of over 1000 Gy has been reported [13]							

continued ...

TABLE X (continued)

COMMON NAME: Cadelle
SCIENTIFIC NAME: *Tenebroides mauritanicus*
COMMODITIES: Cereal grain and its products, oilseeds, cacao, spices
COUNTRIES: Europe, North and South America, Africa, Indonesia, Hawaii, Australia, Brazil, India, Egypt [8]

COMMENTS	STAGE	RADIOSENSITIVITY (Gy)					REFERENCES
		LD:50 days	LD:100 days	LT:50 dose	LT:95 dose	LT:100 dose	
A dose of 50 Gy prevents the emergence of adults from irradiated eggs and larvae. Pupae treated with doses of 50 to 1000 Gy develop to adult but longevity is reduced. Adults irradiated at 100 Gy die within 42 days [58].	adults		100_{42}				58
			$50_{\geq 365}$				58

continued ...

TABLE X (continued)

COMMON NAME: Rust red flour beetle
SCIENTIFIC NAME: *Tribolium castaneum*
COMMODITIES: Grain, cereal products, oilseeds, nuts
COUNTRIES: Canada, Australia, Pakistan, Turkey, Mexico. Major pest in the Tropics.

COMMENTS	STAGE	RADIOSENSITIVITY (Gy)					REFERENCES
		LD:50 days	LD:100 days	LT:50 dose	LT:95 dose	LT:100 dose	
It is also known as the pest of the rice bran [8].	egg		108_{35}				16
Fertility: no progeny is obtained from adults irradiated at 125 Gy or higher. At the very low dose of 62.5 Gy adults produce progeny intermittently. Thus, this dose is close to the threshold for sterility.	larvae	150	70				59
			104_{35}				16
A SD99.9 (99.9% sterilizing dose) of 92 to 98 Gy has also been reported [49].	pupae		257_{35}				
* The range reported for LD:50 and LD:100 is due to the fact that the studies were conducted with wild and laboratory strains. Wild strains are more resistant than the laboratory ones.	adults	$^{*}110_{24}$ to 150_{24}	$^{*}212_{24}$ to 345_{24}	$14\text{-}21_{1875}$	$21_{187.5}$	$28_{187.5}$	34,49
				$14\text{-}21_{500}$		21_{500}	34
			215_{21}	$14\text{-}21_{750}$		21_{750}	34,16
						21_{250}	34
				7_{1500}	14_{1500}	14_{1500}	34
				$21_{131.9}$			16
				14.5_{250}			

continued ...

TABLE X (continued)

COMMON NAME: Rust red flour beetle (concluded)
SCIENTIFIC NAME:
COMMODITIES:
COUNTRIES:

COMMENTS	STAGE	RADIOSENSITIVITY (Gy)					REFERENCES
		LD:50 days	LD:100 days	LT:50 dose	LT:95 dose	LT:100 dose	
A dose of 225 Gy kills all stages of red flour beetles present in stored grains within one year [59] after irradiation. Higher doses have also been reported: (a) 400 Gy [47,59] as a practical control level for irradiation of infested wheat, rice, maize (b) 500 Gy [56] for complete disinfestation.							

continued ...

TABLE X (continued)

COMMON NAME: Confused flour beetle
SCIENTIFIC NAME: *Tribolium confusium*
COMMODITIES: Flour, grain
COUNTRIES: Cosmopolitan, spp. of low importance, Australia, Hungary

COMMENTS	STAGE	RADIOSENSITIVITY (Gy)					REFERENCES
		LD:50 days	LD:100 days	LT:50 dose	LT:95 dose	LT:100 dose	
The susceptibility to radiation decreases from eggs to adults. The doses required for 99.9% kill of eggs, larvae, pupae and adults are 44, 52, 145 and 128 Gy, respectively. Production of progenity is reduced by 99.9% at 34, 64, 47 and 71 Gy, respectively. It also can be noted that there are differences in the results reported by different groups. The variation can be attributed to different strains within species and/or different experimental conditions.	eggs	12_{28}	44_{28}				16,17
	larvae	33_{28}	52_{28}				16
	pupae	75_{28}	145_{28}				16
	adults	94_{28}	128_{28}	$7\text{-}14_{63}$	21_{63}	182_{63}	16,34
				24_{85}			60
				$28_{93.7}$			16
				20.5_{120}	26_{120}		17
				$7\text{-}14_{125}$	14_{125}	21_{125}	34
				17_{132}	26_{132}		38
				21_{175}	28_{175}		44
				9_{175}	16_{175}		38

continued ...

TABLE X (continued)

COMMON NAME: Confused flour beetle (concluded)
SCIENTIFIC NAME:
COMMODITIES:
COUNTRIES:

COMMENTS	STAGE	RADIOSENSITIVITY (Gy)					REFERENCES
		LD:50 days	LD:100 days	LT:50 dose	LT:95 dose	LT:100 dose	
A commercial dose of 160 Gy is				11_{250}	19_{250}		38
recommended to control T. confusum.				19.4_{250}	25_{250}	21_{250}	17,34
Survival time after treatment de-				9_{450}	14_{450}		38
pends on the dose, insects survive				1	28_{128}		16
for periods of two to three weeks				13_{465}*	17_{465}	21_{465}	10
at doses ranging from 125 to 750 Gy				16_{500}	20_{500}		17
[34]. The lifespan of the insect				$<7_{500}$	$<14_{500}$	14_{500}	34
is considerably shortened by				$<7_{750}$	$<7_{750}$	14_{750}	34
irradiation.				2_{2008}*		4_{2008}*	61
100% mortality: dose 0 = 30 weeks							
100% mortality: dose 250 = 3 weeks							
* reported in reps.							

continued ...

TABLE X (concluded)

COMMON NAME: Khapra beetle
SCIENTIFIC NAME: *Trogoderma granarium*
COMMODITIES: Stored grains
COUNTRIES: India, Europe, Southwestern U.S.A. [27]

COMMENTS	STAGE	RADIOSENSITIVITY (Gy)					REFERENCES
		LD:50 days	LD:100 days	LT:50 dose	LT:95 dose	LT:100 dose	
Eggs of different maturities (12, 24, 36, 48, 60 and 72 h of age) do not hatch after being irradiated at 50 Gy [62].	eggs		50				7
Freshly hatched larvae irradiated at a dose of 100 Gy, show 50% mortality 9 days after treament, while 100% mortality is observed after 15 days [7].	larvae	100_{9}	100_{15}				7
Adults: When irradiated at 60 Gy, mortalities of 50 and 100% are reached in 15 and 47 days, respectively.	adults	60_{15}	60_{47}				7

8. CONCLUSIONS

The review reaches the following conclusions:

(1) The presence of insects in stored food products is recognized to be a worldwide problem.

(2) The effectiveness of the radiation process to control insect infestations has been fully demonstrated.

(3) Doses of 0.2 to 0.5 kGy can control most insect pests. These doses are sufficient for immediate complete sterilization of most insects. Exceptions are: *Setotroga cerealella* and *Corcyra cephalonica*. Death follows a few weeks after treatment.

(4) There is no significant difference between the doses required to control insect infestation with either accelerated electrons or ^{60}Co gamma rays.

(5) From the point of view of the economics of the radiation process, it is recommended that a dose of 0.2 kGy be used. This dose will inhibit reproduction and cause eventual death within a few weeks after treatment, of most insects found in infested grains.

(6) The radiosensitivity of the most economically important species of insect has been determined. Therefore, further experimental work in this area is not required at this time.

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APPENDIX I

WORLD PRODUCTION OF CEREALS, POTATOES AND SUGAR [2,3]

COMMODITY	PRODUCTION (metric tonnes)
Wheat	305 100 000
Corn	233 910 000
Rice	181 000 000
Barley	110 770 000
Oats	50 860 000
Rye	32 400 000
Potatoes	279 300 000
Sugar (cane and beet)	76 414 000

APPENDIX II

INSECT PESTS IN PULSE OR BEAN CROPS

Common Name	Latin Name	Incidence*
Foreign grain beetle	Acanthoscelides obtectus (Say)	H
	Ahasverus advena (Waltl)	
Coffee bean weevil	Araecerus fasciculatus (De Geer)	H
	Bruchus pisorum (Linnaeus)	
	Bruchus rufimanus (Boheman)	H
	Callosobruchus analis (Fabricius)	H
	Callosobruchus chinensis (Linnaeus)	H
	Callosobruchus maculatus (Fabricius)	H
	Callosobruchus rhodesianus (Pic)	H
	Carpophilus hemipterus (Linnaeus)	
	Caprophilus obsoletus (Erichson)	
	Caryedon serratus (Olivier)	H
	Cryptolestes capensis (Waltl)	
Flat grain beetle	Cryptolestes pusillus (Schönherr)	H
	Cryptolestes ugandae (Steel & Howe)	
White-shouldered house moth	Endrosis sarcitrella (Linnaeus)	
	Ephestia calidella (Guenee)	H
Mediterranean flour moth	Ephestia kuehniella (Zeller)	
Brown house moth	Hofmannophila pseudospretella (Stainton)	
Cigarette beetle	Lasioderma serricorne (Fabricius)	
Siamese grain beetle	Lophocateres pusillus (Klug)	
Merchant grain beetle	Oryzaephilus mercator (Fauvel)	H
Saw-toothed grain beetle	Oryzaephilus surinamensis (Linnaeus)	H
Smalleyed flour beetle	Palorus ratzeburgi (Wissmann)	
Australian spider beetle	Ptinus ocellus (Brown)	
Meal moth	Pyralis farinalis (Linnaeus)	
Lesser grain borer	Rhyzopertha dominica (Fabricius)	H
Rice weevil	Sitophilus oryzae (Linnaeus)	H
	Trogoderma glabrum (Herbst)	
Carpet beetle	Trogoderma variabile (Ballion)	
Hairy fungus beetle	Typhaea stercorea (Linnaeus)	
	Zabrotes subfasciatus (Boheman)	H

* Indicates primary status incidence high.

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