Influence of Gamma and Ultraviolet Irradiation on Pest Control

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Abstract: Irradiation as a commercial insect control technique was applied for the first time in 1929 to cigars to control lasioderma serricorne although the X-ray machine used turned out to be unsuitable for continuous processing. Sterile insect technique (SIT) is a promising environment-friendly method for control or eradication of a number of insect pests. It is rapidly becoming a major component of integrated pest management for fruit fly control. Gamma irradiation is currently the most common method used to sterilize mass reared males for SIT and effectiveness of SIT depends greatly on the production of good quality sterile males that are released into target wild populations. To ensure that released males are effective at inducing reproductive failure in their mates, it is important that irradiation procedures achieve an adequate level of sterility. The Ultraviolet (UV) portion of the spectrum has been widely used as a germicide and as an attractant for insects in embryological physiological studies for the surface disinfection of insect eggs from pathogens and for the suppression of insects and different stages of the life cycle.

Keywords: insect, history, Sterile insect technique

Introduction

Historical application and reviews of irradiation for stored product pest control

Soon after ionizing radiation was discovered in the late 19th century it was found that organisms could be reproductively sterilized with relatively low doses that showed no other gross effects to the organisms [14, 27, 31]. Irradiation as a commercial insect control technique was applied for the first time in 1929 to cigars to control Lasioderma serricorne although the X-ray machine used turned out to be unsuitable for continuous processing [3]. Research reviewed the literature on stored product pest irradiation and concluded that the technology was an important, effective, safe technique for maintaining shelf life of stored products [17]. A dose of 0.5 kGy would be necessary to stop reproduction of all stored product pests although many species (especially Coleoptera) could be controlled with lower doses, arrived at similar conclusions: a dose of 0.5 kGy would control virtually all stored product pests by preventing their reproduction instead of providing acute mortality, which would require much higher doses. He further concluded that even though insects would be alive for some time after irradiation at 0.5 kGy their feeding was greatly reduced, thus, further damage would be minimal. Lepidoptera were harder to control than Coleoptera, with bruchids requiring the lowest doses for stored product pests [2, 33, 54]. Research reasoned that irradiation of bulk grain was not economical because of the high cost of facility construction and the logistics of passing grains through an irradiation system. At the time (1960’s) industry had a serious problem with
infestation of wheat flour and it was thought that irradiation could be a solution, but an integrated system of controlling pests in flour consisting of more pest-resistant facilities, improved pesticides, better sanitation and other types of physical controls alleviated that problem by the early 1970’s removing the urgency for irradiation of flour. The largest and longest use of irradiation to control insects was the annual treatment of 400,000 tons of grain imported by the Soviet Union at the Ukrainian port of Odessa which began in 1980 and continued until 2007. The system could treat 400 tons of grain per hour with 0.2e0.4 kGy. During the latter years of operation the amount of grain irradiated at Odessa dropped to 70,000 tons/yr because grain was being imported at other ports in the region after the dissolution of the Soviet Union [30, 37, 48, 51]. Brower and Tilton (1985) noted that although most stored product pests are cosmopolitan, some, e.g., Trogoderma granarium Everts, Prostephanus truncatus (Horn), Corcyra cephalonica (Stainton), and some bruchids and ptinids, are not cosmopolitan and they recommended the use of irradiation as a phytosanitary treatment against these pests. This article is review and the aim of influence of gamma and ultraviolet irradiation on pest control.

**Sterile insect technique (SIT)**

Sterile insect technique (SIT) is a promising environment-friendly method for control or eradication of a number of insect pests. It is rapidly becoming a major component of integrated pest management for fruit fly control [12, 19, 39]. The aim of SIT is to reduce the growth rate of target population by saturating wild females with released mass reared sterilized males [1].

**Gamma irradiation**

Gamma irradiation is currently the most common method used to sterilize mass reared males for SIT [42] and effectiveness of SIT depends greatly on the production of good quality sterile males that are released into target wild populations. To ensure that released males are effective at inducing reproductive failure in their mates, it is important that irradiation procedures achieve an adequate level of sterility. For instance, 99.5% sterility from crosses between sterile males and fertile females is usually required in Ceratitis capitata (Wiedemann) (FAO/IAEA/USDA 2003). Quality of sterile males is assured through a system of bioassays of quality parameters that primarily reflect the male’s ability to survive, interact with its environment, locate, mate, and fertilize females of target wild populations [7, 9, 23, 42]. Recently, the effect of gamma radiation on development, morphology and anatomy of the peach fruit fly gonads was studied [2, 35, 44, 50] in addition, the influence of radiation dose on selected biological aspects of the peach fruit fly was evaluated [9].

### Table 1. Percentage (means2S.E.) of wheat grains damaged by *Sitophilus granarius* following gamma irradiation at doses from 10±500 Gy

<table>
<thead>
<tr>
<th>Stages irradiated</th>
<th>Doses (Gy)</th>
<th>Egg</th>
<th>Larva</th>
<th>Pupa</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>19.3±2.6 a</td>
<td>19.3±2.7 a</td>
<td>19.0±0.9 a</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>4.3±1.5 b</td>
<td>10.8±1.4 b</td>
<td>14.0±1.2 b</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>0.0 c</td>
<td>0.0 c</td>
<td>10.0±0.9 c</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>0.0 c</td>
<td>0.0 c</td>
<td>7.3±0.5 d</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>0.0 c</td>
<td>0.0 c</td>
<td>4.0±0.4 e</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>0.0 c</td>
<td>0.0 c</td>
<td>2.3±0.8 e</td>
</tr>
<tr>
<td></td>
<td>300-500</td>
<td>0.0 c</td>
<td>0.0 c</td>
<td>0.0 f</td>
</tr>
</tbody>
</table>

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Means with the same letters in same column were not significantly (Aldryhim and Adam, 1999)

The Ultraviolet (UV) portion of the spectrum

The Ultraviolet (UV) portion of the spectrum has been widely used as a germicide and as an attractant for insects [6] in embryological physiological studies for the surface disinfection of insect eggs from pathogens [17, 38, 44] and for the suppression of insects and different stages of the life cycle (Beard, 1972; Baden et al., 1996). Among these, UV-B/C radiation is very important in influencing biological systems [11, 39]. Egg parasitoids in the genus Trichogramma are one of the most important biological control agents of pest insects in different crops. Augmentative releases of the Trichogramma species require mass rearing. The eggs of Ephesia kuehniella Zell. (Lepidoptera: Pyralidae) are used as an alternative host for rearing Trichogramma. E. kuehniella larvae that hatch from unparasitized eggs and can attack parasitized ones. To prevent host larvae hatch, ultraviolet light (UV) can be used to kill host eggs. Gamma radiation is an ionizing radiation type and has a very high penetrating ability [16, 52]. Nevertheless, host eggs exposed to gamma irradiation can be used as a food for Trichogramma rearing [4, 16]. In Turkey, some studies have been conducted on the effect of gamma rays on Trichogramma [6, 10, 25]. Unfortunately, no research has been conducted on the effect of ultraviolet radiation on the Trichogramma. Keeping in mind the importance and feasibility of the use of UV-rays, the present investigation was undertaken to evaluate the effect of gamma and UV-irradiation on the commercially relevant aspects of Trichogramma rearing. It is, however, difficult to make direct comparisons between gamma and UV radiation studies as the level of gamma and UV dose achieved is not always stated, and radiation intensities vary with sources. The ability of UV to penetrate surfaces is very limited, and thus its effect is limited to surfaces, whereas gamma rays can penetrate deep into tissues. In principle, ultraviolet C (UVC) radiation may provide an effective means of combating pest infestations associated with the structure of a building and may serve as a potential new hygiene measure. Although the use of gamma radiation as a method of pest control has been extensively investigated [7, 18, 27, 44, 50] the use of UV-C radiation has not been widely studied due to the lack of penetration through substrates [33].

Mode of action of radiation in insects

In general, the mode of action of ionizing radiations in living cells consists basically in a chain of oxidative reactions along the radiation path and the formation of free damaging peroxy-radicals, which alter irreversibly the organic molecules. At the cytological level, sterilization is the result of the germ cell chromosome fragmentation (dominant lethal mutations, translocations, and other chromosomal aberrations), leading to the production of imbalanced gametes and, subsequently, inhibition of mitosis and the death of fertilized eggs. Beside the reproductive sterility induced by direct lesion of the genetic material by radiation, researcher reported that there are other causes of reproductive sterility that might have a cytological or physiological basis. According to the law of Bergonie and Tribondeau, cells are most sensitive to radiation when they are dividing. The most radiosensitive cells are, therefore, those with a high mitotic rate, with a long mitotic future and that are of the stem or germ cell type [16]. Apparently, neither DNA content, chromosome number, nor chromosome arm number can be responsible for the differences in radiosensitivity of cells [5, 39]. Even though, there is a relationship between the interphase nuclear volume and cell sensitivity to radiation, that is used in vertebrate animals and plants to predict their sensitivity to
chronic irradiation, which express that the larger the nuclear volume, the greater the sensitivity [21, 36]. The radiosensitivity of the mitotically active reproductive cells has different sterilization and killing susceptibility regarding the developmental stage and the division phase. Spermatocytes and spermatogonia are more radiosensitive than the spermatids and spermatozoa. we found that the chromosomes of the bug Physopelta schlanbuschi were more sensitive to X rays at the spermatogonial metaphase and anaphase [4, 14, 23]. The sensitivity of the mitotically active reproductive cells in female insects can be increased by the presence of nurse cells, which possesses polytene chromosomes with huge nucleus of unraveled chromatin when undergoing endomitosis [17, 35]. Thus, female insects are, in general, more radiosensitive than males [33]. Somatic cells are less sensitive to radiation than stem or gonial cells, as they are generally differentiated cells that have lost their ability to divide at the adult stage, what explains why lethal doses are usually higher than the sterilizing doses for insects [23]. The effect of radiation on somatic cells can be expressed by the development of abnormalities, reduction of adult lifespan, flight ability, mating propensity, nutrition, and, ultimately, death of the insect [41, 49].

Radiation as quarantine treatment against insect pests

The advantages of radiation include the no resistance development by pest insects, the absence of residual radioactivity and few significant changes in the physicochemical properties or the nutritive value of the treated products [17]. A major disadvantage is that it is the only commercially applied quarantine treatment that does not result in significant acute mortality. This issue is very important because when inspectors find live quarantine pests from the major phytosanitary treatments, which are based on heat, cold or methyl bromide fumigation, the entire consignment is rejected or retreated regardless of certification of treatment. In this case, the inspectors assume that the treatment was not properly done, the shipment was contaminated with infested commodity or that the cargo was reinfested after treatment. In addition, live adults found in survey traps could trigger restrictive and costly regulatory responses in importing countries [48].

Nevertheless, stated that the objective of irradiation is not acute mortality but prevention of development or reproduction, as most commodities do not tolerate the usual dose ranges required to reach it (usually ≥ 1 kGy). Therefore, the inhibition of further development must be considered as a measure of efficacy of phytosanitary irradiation [18, 29]. The US Animal and Plant Health Inspection Service (APHIS) has not objected to live adults because of a comprehensive process of validation and certification of irradiation treatment facilities with monitoring of dosimetry and dose application during preclearance programs [14]. The APHIS and the International Plant Protection Convention (IPPC) have approved phytosanitary irradiation treatments for more than 20 insect pest species [13, 37]. Tephritid fruit flies are one of the most invasive quarantine pests, attacking 21 of the 24 fresh commodities exported to the United States and to sterilize or disrupt normal development of early stages, doses ranging from 70 to 100 Gy are sufficient for Anastrepha species, whilst Bactrocera spp. and other species may require doses in the range of 100 to 150 Gy [1]. After fruit flies, tortricid moths are the most important pests of quarantine concern for fruit and vegetables. Several studies have shown that a dose of 200 Gy could be sufficient to control codling moth (Cydia pomonella L.), Ectylophora aurantiana Lima and oriental fruit moth (Grapholita molesta Busck) [40, 42, 51]. Curculionid weevils are another important group of pests and available studies suggest that a dose

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≤ 150 Gy may be sufficient to control cowpea weevil (Callosobruchus chinensis L.), Euscepes postfasciatus Fairmaire and boll weevil (Anthonomus grandis Boheman) [17, 42]. Hallman et al. (2010) analyzed several factors that could affect phytosanitary irradiation efficacy, such as hypoxia, insect life stage, host, dose rate, temperature, diapause and genotypes. After dose itself, hypoxia can be considered the most important factor that abates the effects of radiation on living organisms because lesser radioinduced radicals are produced [22]. Cryptically-feeding Tephritidae and Curculionidae that occur as immature inside host plants (practically hypoxic conditions) may present increased radiotolerance [40].

Fig 1. Mean (±SD) parasitization and adult emergence from gamma and UV irradiated eggs of T. euproctidis (TUNCBILEK et al., 2012)

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