Generic phytosanitary irradiation dose of 300 Gy proposed for the Insecta excluding pupal and adult Lepidoptera

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Abstract

The commercial use of phytosanitary irradiation (PI) is growing steadily. Most of the doses in use are generic for groups of organisms, most often a 400 Gy dose for all insect taxa except lepidopteran pupae and adults. When applied on a commercial scale, a minimum required dose of 400 Gy may result in a maximum dose applied to pallet loads of fresh produce that approaches 1 kGy, which may cause some commodity damage. A lower dose that still achieves an acceptable level of risk could reduce the cost of treatment and the potential for commodity injury. Examination of the literature on insect irradiation for information relevant to a lower generic dose for the Insecta except pupae and adults of lepidopteran species revealed that in all cases, except possibly one, 300 Gy would suffice with a comfortable margin of error. The one possible exception is the depressed flour beetle, *Palorus subdepressus* (Wollaston) (Coleoptera: Tenebrionidae), and this is based on 1 study in which 300 Gy reduced the production of adults by 94% when either male or female parents were irradiated, but the study did not investigate production of F_1 stages when both parents were irradiated. Generic doses of 250 and 200 Gy, respectively, might also suffice for species of diaspidid scale insects (Hemiptera: Coccoidea) and agromyzid leaf miners (Diptera: Opomyzoidea: Agromyzoinea).

Key Words: phytosanitation; quarantine treatment; phytosanitary treatment; scale insects

Resumen

El uso comercial de la irradiación fitosanitaria está creciendo constantemente. La mayoría de las dosis son genéricas para grupos de organismos, más a menudo una dosis de Gy 400 para todos los insectos menos para las pupas y adultos de Lepidoptera. Cuando se aplica en una escala comercial, una dosis mínima requerida de 400 Gy puede resultar en una dosis máxima aplicada a cargas de productos frescos en plataformas que se aproxima a 1 kGy, lo que puede dar lugar a un cierto daño de los productos. Una dosis más baja que todavía alcanza un nivel aceptable de riesgo podría reducir el costo del tratamiento y la posibilidad de daño de los productos. Se examinó la literatura de irradiación de insectos para obtener información pertinente a una dosis genérico menor para la clase Insecta excepto para las pupas y adultos de Lepidoptera, y se encontró que en todos los casos, menos en uno, 300 Gy sería suficiente con un cómodo margen de error. La única excepción es el escarabajo de la harina, *Palorus subdepressus* (Wollaston) (Coleoptera: Tenebrionidae), y esto se basa en un estudio realizado hace > 40 años que parece proveer una dosis excesiva para lograr la seguridad de cuarentena. Los dosis genéricas de 250 y 200 Gy, respectivamente, también podrían ser suficientes para los insectos escama diaspididos (Hemiptera: Coccoidea) y minadores de hojas agromyzidos (Diptera: Opomyzoidea).

Palabras Clave: fitosanidad; tratamiento de cuarentena; tratamiento fitosanitario**;** cochinillas

The use of phytosanitary irradiation (PI) is growing modestly but steadily. Most of the doses used commercially are generic for groups of organisms, most often being 400 Gy for all insect species except for the pupae and adults of lepidopteran species—as is accepted by the United States of America (USA). Because there is confusion and inaccurate understanding of the origin, structure, and use of generic PI doses in the literature, it is useful for the reader to refer to Hallman (2012) where the history, use, and acknowledgment of generic PI treatments are carefully documented and cited.

The studies done by participants of the Coordinated Research Project reported in this special issue together with other studies done during the past several years justify revisiting the generic doses and the examination of data pertaining to new doses that might be considered by plant protection organizations that accept fresh commodities irradiated for phytosanitary purposes. Articles elsewhere in this special issue support generic doses for mealybugs (Pseudococcidae) and "true weevils" (Curculionidae). This study examined the PI literature with the objective of suggesting a dose that could be used against all insects—except pupae and adults of lepidopteran species—that is lower than the currently used 400 Gy.

CURRENT BROADLY APPLICABLE GENERIC IRRADIATION DOSES

The generic dose of 400 Gy accepted by the USA excludes lepidopteran pupae and adults and mites because 3 literature reviews (Bakri et al. 2005, Hallman 2000, 2001) cited by APHIS (2005) indicate that these groups might not be fully controlled by that dose. The generic dose was set at 400 Gy mainly because the most tolerant insect species—other than the lepidopteran pupae and adults discussed in those reviews—was the tenebrionid stored product beetle *Palorus*

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subdepressus (Wollaston), which was reported to require a dose of > 300 Gy to prevent the production of adult progeny when either the male or the female adult parent was irradiated and crossed with a non-irradiated parent (Brower 1973). Thus when either the male or the female parents were irradiated with 300 Gy the production of F_1 adults was reduced by 94.4%, while at the next highest dose, 400 Gy, no F_1 adults developed. Also the longevity of adults irradiated at 300 Gy was reduced by > 92% compared with non-irradiated adults. However it should be noted that Brower (1973) did not determine the dose required to induce complete sterility when both males and females were irradiated, as would be the case with phytosanitary treatments. Nevertheless, even though *P. subdepressus* is not a quarantine pest the fact that ~400 Gy was required to prevent its reproduction implies that other insect species that may be quarantine pests and that have not been tested for radiosensitivity might also require ~400 Gy.

Nevertheless, if not for this 1 study with *P. subdepressus,* it is likely that the generic dose would have been set at 300 Gy because the 3 reviews above reported that all other insect species required < 300 Gy for quarantine security (APHIS 2005). Moreover, it seems possible that < 400 Gy would prevent reproduction of *P. subdepressus*, and the literature reports doses that seem doubtfully high for controlling certain other insect species. For example, Cogburn et al. (1966) found that > 1 kGy was required to prevent reproduction of adult *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae), while Hallman & Phillips (2008) found that < 400 Gy sufficed. There are a number of factors including inadequate dosimetry, cross contamination, and post-irradiation re-infestation that can result in the reporting of doses for efficacy that are higher than are actually necessary (Hallman & Loaharanu 2002; Hallman & Phillips 2008; Hallman et al. 2013a, b).

New Zealand has approved a generic dose of 400 Gy for all insect taxa—except lepidopteran adults and pupae and various species that vector diseases of man and other vertebrates—but only on mango (*Mangifera indica* L.; Sapindales: Anacardiaceae), lychee (*Litchi sinensis* Sonn.; Sapindales: Sapindaceae), tomato *Solanum lycopersicum* L.; Solanales: Solanaceae), and capsicum (*Capsicum* spp.; Solanales: Solanaceae). Unlike the generic 400 Gy dose approved in the USA for all insect taxa except the Lepidoptera, the New Zealand generic dose also includes mites of the family Tetranychidae, and a generic dose of 500 Gy is approved in New Zealand for all other mite taxa.

A generic dose of 250 Gy is established for actionable regulated quarantine pests of lychee and mango including a wide variety of insect species from the Orders Coleoptera, Diptera, Hemiptera, Lepidoptera, and Thysanoptera. Specific phytosanitary irradiation research has been conducted on representative species, but not on the great majority of species belonging to these orders, which supports the contention that the generic dose of 400 Gy for insects—other than lepidopteran pupae and adults—may be excessive. A generic dose of 300 Gy for Australian mangoes exported to Malaysia covers many of the same regulated pests for New Zealand including the mango seed weevil, *Sternochetus mangiferae* (F.) (Coleoptera: Curculionidae). The reason that the dose is 300 Gy—which is the dose for this weevil set by APHIS (2002)—for Malaysia instead of 250 Gy is primarily because *S. mangiferae* has the potential to become established as a major pest of commercial mango orchards in Malaysia, while New Zealand is not commercial mango territory. Hallman (2012) discusses why the dose to disinfest mangoes of *S. mangiferae* was set at 300 Gy and not a lower dose that would probably suffice. Essentially, the research done with *S. mangiferae* did not identify the lowest possible dose to prevent reproduction or suffered from uncertainties due to poor performance in the non-irradiated controls.

RATIONALE FOR LOWERING THE CURRENT 400 GY GENERIC DOSE

Hallman (2012) indicated that for arthropod pest groups of quarantine significance—except for mites and lepidopteran pupae and adults—a dose of 250 Gy would probably suffice. However, because of lack of information, especially lack of large-scale confirmatory data, it might be risky to support a dose of 250 Gy for these groups until appropriate data have become available. A dose of 300 Gy for all insect species— other than lepidopteran pupae and adults—might be more acceptable and would be a significant improvement over the 400 Gy dose, resulting in less potential risk of damage to fresh commodities, possible savings in time and cost of treatment, and the reduced possibility of exceeding current regulatory limits on the dose that may be applied to certain products. This proposal is justified in the following paragraphs.

Besides the reviews mentioned above (Bakri et al. 2005; Hallman 2000, 2001; Hallman et al. 2013a) that support a dose of 300 Gy for insect species—other than lepidopteran pupae and adults—other reports support this dose, including all articles in this special issue. Hallman (1998) cited literature reports on 24 insect species belonging to the Coleoptera and Hemiptera that are prevented from reproducing when irradiated with < 300 Gy—except the aforementioned *P. subdepressus,* a coleopteran species.

The present review concentrates on the literature since Bakri et al. (2005) and APHIS (2005) that is not covered in other reviews. All citable information indicating a dose that completely prevented reproduction of an insect is included.

Bakri et al. (2005) do not report specific studies but summarized results as mean ± 95% confidence level by family in 55 families of 7 insect orders. Hallman (2000, 2001), and Hallman et al. (2013a) included only studies that satisfy certain criteria directly relevant to PI efficacy. A basic criterion of an acceptable PI treatment for most insect species is that the results of trials must adequately support a dose that completely prevents reproduction—which may be variously defined—when adults are irradiated; while for the irradiation of late larvae of species belonging either to the Tephritidae or to the Lepidoptera it must prevent adult emergence.

Hallman (2013a) reviewed the literature of radiation doses required to prevent reproduction of stored product pest species, which are almost exclusively not quarantine pests but are included as examples for their groups. According to this body of literature, the only insect species—besides lepidopteran species, which are excluded because the PI dose must prevent reproduction—that may not be controlled by 300 Gy is the aforementioned *P. subdepressus*. However the definitive research on this matter has not been conducted with the latter species.

RECENT LITERATURE RELEVANT TO A 300 GY GENERIC DOSE FOR INSECTA

Table 1 lists additional insect species that have not been summarized in previous reviews of PI doses. Measurements of efficacy in Table 1 as well as in previous reviews of PI treatment doses are variously defined. It is important to have a clearly defined measurement of efficacy for phytosanitary treatments so that regulatory organizations know the location of the threshold between treatment success and failure. For example, the measure of efficacy for PI of tephritids is prevention of adult emergence. Therefore, puparia found upon inspection are acceptable, but if an emerged adult tephritid is found in an irradiated load it should not be accepted. Although it is not possible to prevent some development of the F_1 generation when adults or late pupae are irradiated, significant development within the F_1 generation should not occur. For example, some treatments allow for F_1 adult development (Follett 2006b), which may risk the possible establishment of an in-

Table 1. Radiation doses that might provide phytosanitary security for the most radiotolerant stages of insect and springtail species that would be present in shipped commodities. This is a summary of reports not included in the reviews by Bakri et al. (2005), Duvenhage & Johnson (2014), Hallman (1998, 2000, 2016a), Hallman et al. (2013a) and Hofmeyr et al. (2016).

ORDER Family	Genus and species	Measure (criterion) of efficacy; prevention of[1]	Lowest dose that resulted in 100% control (Gy)	Total number irradiated	Reference
COLLEMBOLA					
Isotomidae	*Folsomia candida*	hatch of F_1 eggs	60[2]	50	Nakamori et al. 2008
DIPTERA					
Agromyzidae	*Liriomyza huidobrensis*	leaf mining by F_1 of parents irradiated as late puparia	175	10,419	Ozyardimci et al. 2016
	Liriomyza sativa	leaf mining by F_1 of parents irradiated as late puparia	174	10,583	Ozyardimci et al. 2016
	Liriomyza trifolii	leaf mining by F_1 of parents irradiated as late puparia	214	3,271	Hallman et al. 2011
	L. trifolii	leaf mining by F_1 of parents irradiated as late puparia	166	10,280	Ozyardimci et al. 2016
Drosophilidae	*Drosophila suzukii*	development to adulthood by F_1 of parents irradiated as late puparia	78	33,086	Follett et al. 2014
HEMIPTERA					
Aphididae	*Myzus persicae*	hatch of F_1 eggs	70	30-40	Moon et al. 2010
Aleyrodidae	*Bemisia tabaci*	hatch of F_1 eggs	70	30-40	Moon et al. 2010
	Trialeurodes vaporariorum	hatch of F_1 eggs when late pupae were irradiated	108	33,625	Van Nieuwenhove et al. 2016a
Diaspididae	*Aonidiella aurantii*	F_1 1st instars	222	32,101	Khan et al. 2016b
	Aspidiotus destructor	F_1 2nd instars	200	274	Follett 2006a
	A. destructor	F_1 1st instars	224	51,101	Khan et al. 2016a
	Hemiberlesia lataniae	F_1 1st instars	209	31,877	Van Nieuwenhove et al. 2016b
	Pseudaulacaspis pentagona	Gravid F_1 adults	150	35,424	Follett 2006b
Liviidae	*Diaphorina citri*	hatch of F_1 eggs	150	1,200	Hallman & Chapa 2016
HYMENOPTERA					
Formicidae	*Linepithema humile*	F_1 larvae	90	12	Coulin et al. 2013
Formicidae	*Pheidole megacephala*	F_1 larvae	90	9	Follett & Taniguchi 2007
Formicidae	*Wasmannia auropunctata*	F_1 pupae	70	15	Calcaterra et al. 2012

[1]Actively reproducing adults irradiated except where noted.

[2]Most irradiated insects had not died when observations on efficacy were terminated. It is theoretically possible for recovery of fertility or fecundity to occur—as has been reported in snails (Hallman 2016b); therefore, irradiated organisms should be observed until all have died.

vasive species. A reasonably safe, conservative criterion of efficacy is prevention of the F_1 second instar; this criterion allows the hatching of F_1 eggs, but it does not allow any further F_1 development.

The pseudococcid (Hofmeyr et al. 2016) and curculionid (Hallman 2016a) articles in this special issue support a 300 Gy generic dose for the Insecta—except pupae and adults of lepidopteran species—because the recommended doses for each are 250 and 150 Gy, respectively. Further support for a 300 Gy generic dose is provided by Hallman et al (2013a) who recommended a generic dose of 250 Gy for eggs and larvae of lepidopteran species.

In summary, there is now a considerable body of literature supporting a generic PI dose of 300 Gy for the Insecta—except pupae and adults of lepidopteran species—which still leaves a margin of security because in all cases observed (except possibly of *P. subdepressus*) ≤ 250 Gy suffices. A dose of 300 Gy was suggested as long ago as 1986, although that initial recommendation also included pupae and adults of lepidopteran species (Hallman 2012). Several studies indicate that > 300 Gy is required for pupae and adults of some lepidopteran species (Hallman et al. 2013b).

OTHER POSSIBLE GENERIC DOSES EVIDENT FROM THIS STUDY

The armored scale insects of the family Diaspididae (Hemiptera) include a number of species of quarantine importance. Four large-scale tests have been done with 4 species (Table 1), all of which point to a generic dose of ~250 Gy for that important family. Adoption of this generic dose would be useful because there are multiple examples of commodities that require treatments against tephritid fruit flies, mealybugs, and scale insects (Hallman 2011), and a generic dose of 150 Gy already exists for tephritids and 250 Gy is proposed for mealybugs (Hofmeyr et al. 2016). If a dose of 250 Gy were accepted for scale insects and mealybugs many commodities could be irradiated with a minimum absorbed dose of 250 Gy instead of the 400 Gy currently used.

A dose as low as 200 Gy might suffice for agromyzid leaf miners (Table 1); agromyzids may be found in cut flowers and leafy vegetables. However, other quarantine pests such as thrips and mites are often also found in these commodities, meaning that commodities so infested would need to be treated with the highest dose required of the most radiotolerant quarantine pest species present. Nevertheless, a generic dose for any group supported by adequate research would be worthwhile. In any case, researchers are advised to focus on the development of generic doses that stand a good chance of being commercially applied.

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