Generic phytosanitary irradiation dose for phytophagous mites (Sarcoptiformes: Acaridae; Trombidiformes: Eriophyidae, Tarsonemidae, Tenuipalpidae, Tetranychidae)

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Abstract

Phytophagous mites are often quarantine pests of traded horticultural commodities, requiring phytosanitary treatments before the commodities can be exported to geographical areas that have quarantines against them. Phytosanitary irradiation (PI) is a treatment that is increasing in use worldwide. However, there are currently few accepted PI doses for mite quarantines, and the objective of this study was to critically examine the literature for reports that can be used to support PI doses and to recommend research toward widely applicable generic doses. Prevention of F_1 egg hatch is the most viable measurement of efficacy that could be used for PI against mites because there are data supporting efficacious doses, and it is a measurement of efficacy that is acceptable to a number of plant protection organizations. A total of 22 studies on 14 species of mites provided data on doses required to prevent F_1 egg hatch. Multiple studies were found pertaining to the phytophagous families Acaridae, Eriophyidae, Tenuipalpidae and Tetranychidae. Studies with the other important phytophagous family, Tarsonemidae, were lacking. Twelve of the 22 studies were of Tetranychidae, and half of the latter were of *Tetranychus urticae* Koch. Doses as low as 350 Gy might suffice for mites generally, but large-scale testing is lacking to confirm the adequacy doses needed to provide quarantine security. On the other hand it would be feasible to seek a different criterion or measurement of efficacy as an alternative to the prevention of F_1 egg hatch in order to achieve a lower target dose with an acceptable level of low risk. Thus several approved PI treatments use prevention of significant development beyond the first instar in the F_1 generation as the criterion (measurement) of efficacy. Thus, large-scale testing of mites could focus on prevention of the 1st nymphal stage, for example.

Key Words: ionizing radiation; quarantine treatment; Trombidiformes; *Tetranychus urticae*; twospotted spider mite; Tarsonemidae

Resumen

Los ácaros fitófagos a menudo son plagas cuarentenarias de productos hortícolas comercializados, que requieren tratamientos fitosanitarios antes de que los productos puedan ser exportados a zonas geográficas que tienen cuarentenas contra ellos. La irradiación fitosanitaria (IF) es un tratamiento que su uso está aumentando en todo el mundo. Sin embargo, en la actualidad hay pocas dosis IF que son aceptadas para ácaros de importancia cuarentenaria, y el objetivo de este estudio fue examinar críticamente la literatura para los informes que se pueden utilizar para apoyar una dosis IF y recomendar investigación hacia una dosis genérica ampliamente aplicable. La prevención de la eclosión de los huevos de la F_1 es la medida más viable de eficacia que se podría utilizar para IF contra los ácaros porque hay datos que apoyan estas dosis eficaces, y es una medida de la eficacia que es aceptable para un número de organizaciones fitosanitarias. Un total de 22 estudios sobre 14 especies de ácaros proveyeron datos sobre las dosis necesarias para evitar la eclosión de huevos de la F_1. Se encontraron varios estudios relacionados con otros ácaros fitófagos de las familias Acaridae, Eriophyidae, Tenuipalpidae y Tetranychidae. Faltaron los estudios con otros ácaros importantes de la familia Tarsonemidae. Doce de los 22 estudios fueron de Tetranychidae, y la mitad de estos últimos fueron a cerca de *Tetranychus urticae* Koch. Una dosis tan baja como 350 Gy puede ser suficiente para los ácaros en general, pero hace falta pruebas a gran escala para confirmar la dosis adecuada necesaria para proveer una seguridad cuarentenaria. Por otra parte, sería factible para buscar un diferente criterio o la medición de la eficacia como una alternativa a la prevención de la eclosión de los huevos de la F_1 a fin de lograr una dosis objetivo menor con un nivel aceptable de bajo riesgo. Por lo tanto varios tratamientos aprobados de IF utilizan la prevención del desarrollo significativo más allá del primer estadio en la generación F_1 como el criterio (medición) de la eficacia. Por lo tanto, las pruebas a gran escala de los ácaros podría centrarse en la prevención de la 1ª estadio de ninfa, por ejemplo.

Palabras Clave: radiación ionizante; tratamiento de cuarentena; Trombidiformes; *Tetranychus urticae*; araña de dos manchas; Tarsonemidae

Mites of the families Eriophyidae, Tarsonemidae, Tenuipalpidae, and Tetranychidae (Trombidiformes) are plant pests found in pest risk analyses of many fresh commodities proposed for trade. Mites of the family Acaridae (Sarcoptiformes) are pests of plant bulbs and stored products. Phytosanitary measures to deal with these quarantine pest taxa involve washing and subsequent inspection both of the plants and the filtrate to observe the presence of mites or their symptoms. However, these methods are not 100% effective at discovering the presence of mites because of their small size and lack of symptoms at low population densities. Thus, phytosanitary treatments would be use-

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ful as an alternative to inspection, especially when the commodities must also be treated for other quarantine pests. The United States of America has approved several phytosanitary treatments against mites based on methyl bromide fumigation, cold plus methyl bromide fumigation, hot water immersion, washing and waxing, and irradiation (APHIS 2015). However, these treatments are limited to several species and a limited number of commodities, except for the 300 Gy-dose irradiation treatment against *Brevipalpis chilensis* Baker (Trombidiformes: Tenuipalpidae), which is applicable to all of its hosts.

Irradiation has been studied as a phytosanitary treatment against phytophagous mites. Australia and New Zealand presently accept generic treatments of 400 Gy for Tetranychidae and 500 Gy for all other mites (DABPD 2014). Hallman (2012) suggested that a generic dose for mites might be as low as 350 Gy.

This objectives of this study are to 1) evaluate the literature of phytosanitary irradiation (PI) for mites regarding the possibility of recommending generic doses that might be acceptable to the International Plant Protection Convention and 2) suggest research needed to support generic doses for them.

Materials and Methods

The literature of mite irradiation was evaluated for data relevant to PI. A minimum set of conditions in each study should support any data used for PI purposes. Thus each study was examined to assure that it clearly indicated that:

1. Sufficient information on dosimetry was provided.
2. The most tolerant stage was irradiated. That would normally be the adult, which is considered the most tolerant stage when all stages could be present, such as with mites (Hallman et al. 2010).
3. The measure (criterion) of efficacy was the prevention of reproduction, which can be variously defined as prevention of: oviposition, F_1 egg hatch, or significant development of successive immature stages in the F_1 generation.
4. The growth, development and reproduction of non-irradiated controls were within normally expected limits.
5. Irradiated mites were evaluated for reproduction until all had died.

Results

The most common measures of efficacy found in the literature were prevention of oviposition and prevention of F_1 egg hatch. Prevention of the occurrence of any F_1 adults was recorded in a few studies; for example, while Boczek et al. (1985) found that 400 Gy to adult *Aleuroglyphus ovatus* Troupeau (Sarcoptiformes: Acaridae) prevented F_1 egg hatch, the next lowest dose studied (200 Gy) prevented F_1 adult development. However, prevention of F_1 adult development, although theoretically efficacious in preventing mite establishment, allows for excessive development that is not usually accepted by plant protection organizations because it does not provide a sufficiently wide margin of error. Furthermore, there are few data on doses to prevent F_1 mite development beyond egg hatch.

Prevention of oviposition was seldom achieved by the doses studied (up to 1 or more kGy). Therefore, prevention of F_1 egg hatch is the most viable measurement of efficacy that could be used for PI against mites because there are data supporting efficacious doses and it would most likely be accepted as a measurement of efficacy by plant protection organizations.

A total of 22 studies with 14 species of mites provided data on doses required to prevent F_1 egg hatch (Table 1). Multiple studies were found representing the 5 phytophagous families of concern except the Tarsonemidae. Twelve of the 22 studies were of Tetranychidae, and half of the latter dealt with 1 species, *Tetranychus urticae* Koch (Trombidiformes: Tetranychidae).

Egg hatch often was found to increase (to an upper limit) as irradiated adults aged. For example, Dohino & Tanabe (1993) found that hatch of eggs laid by adult *T. urticae* irradiated with 200 Gy increased from near 0% from 0–6 d post irradiation to 35–45% at 7–14 d and 0 % at 15–17 d. Oviposition stopped after 17 d although 17% of irradiated females were still alive. Goodwin & Wellham (1990) found similar results with the same species.

Zhou et al. (2002) found that eggs laid by 2–3 d-old adult *Phyllocoptruta oleivora* (Ashmead) (Trombidiformes: Eriophyidae) required a larger dose—i.e., 400 Gy—to completely prevent hatching than did eggs laid by younger (1 d-old) adults, i.e.,—350 Gy.

Discussion

Some of the studies did not satisfy the criteria suggested in the methodology above. For example, observations on the mite with the largest sample size (8,042 adult *Brevipalpus chilensis* Baker irradiated at 300 Gy) were terminated after 2 wk when 57% of irradiated mites were still alive instead of waiting until all had died—in case some recovery of F_1 egg hatch would have occurred later. Also, the non-irradiated control did not perform as expected; control mites laid a mean of only 1.0 egg per female and only 33.2% hatched.

The 6 studies of *T. urticae* generally agreed in that a dose to completely prevent F_1 egg hatch for this species would be > 300 Gy (Table 1). The 1 study cited indicating that 400 Gy might be required did not examine the use of doses between 200–400 Gy (Dohino & Tanabe 1993). In any case, the number of mites studied (2–160 mites/study) is too small to support a specific phytosanitary treatment, and often the large-scale testing required to confirm a phytosanitary treatment resulted in the dose being increased above the dose first indicated by small-scale—because dose-response data usually follow the normal distribution, i.e., as sample size increases the probability of finding an egg hatching at the same dose increases.

The generic doses of 400 Gy for Tetranychidae and 500 Gy for all other mites accepted by Australia and New Zealand (DABPD 2014), although not supported by large-scale confirmatory testing, are probably high enough to be phytosanitarily safe. The fact that there are more studies done with Tetranychidae than the rest of the families combined justifies the lower dose for Tetranychidae. Without large-scale confirmatory testing there is no justification for lowering those doses further.

Because large-scale testing with mites has not been done, it would be feasible to seek a measurement of efficacy that is an alternative to the prevention of egg hatch in order to achieve a lower dose, while still achieving an acceptably low level of risk. Several accepted PI treatments use prevention of significant development beyond the F_1 first instar as the measurement of efficacy. Large-scale testing of mites could focus on prevention of the 1st nymphal stage, for example.

Typically for insects the dose required to achieve a fixed level of phytosanitary security decreases as the targeted developmental threshold stage increases (Hallman et al. 2010); i.e., a lower dose is usually required to prevent development of F_1 2nd instars than to prevent F_1 egg hatch when parent adults are irradiated. However, Sulaiman et al. (2004) found that the developmental success of *Tetranychus piercei* McGregor F_1 eggs laid by adults irradiated with 200 Gy did not diminish appreciably in the successive instars following egg hatch through to

Table. 1. Lowest dose of irradiation applied to adult mites of those attempted in each study that prevented F_1 egg hatch.

Family, species	Dose (Gy) to achieve efficacy	Number treated	Next lowest dose attempted; egg hatch	Reference
Acaridae				
Aleuroglyphus ovatus Troupeau	400	40	200 Gy; 19 %	Boczek et al. 1985
Rhizoglyphus echinopus (Fumouze & Robin)	400	40	200 Gy; 6 %	Boczek et al. 1985
R. echinopus	300	66	250 Gy; 0.2 %	Ignatowicz & Wróblicka-Sysiak 1996
Tyrophagus putrescentiae (Schrank)	260	80	90 Gy; 73.8 %	Ignatowicz & Brzostek 1990
Eriophyidae				
Aceria litchi (Keifer)	400	40	300 Gy; 1.4 %	Arthur & Machi 2016
Aculus schlechtendali (Nalepa)	300	20	280 Gy; 2.5 %	Ignatowicz 2005
Eriophyes pyri Pagenstecher	300	20	280 Gy; 5.7%	Ignatowicz 2005
Phyllocoptruta oleivora (Ashmead)	400	500	350 Gy; "low"	Zhou et al. 2002
Tenuipalpidae				
Brevipalpus chilensis Baker	300	8042	250 Gy; 5.6 %	Castro et al. 2004
Brevipalpus phoenicis (Geijskes)	300	210	200 Gy; 9.7 %	Machi & Arthur 2016
Tetranychidae				
Oligonychus biharensis Hirst	300	?	200 Gy; 10 %	Bhuiya et al. 1999
Panonychus citri McGregor	320	30	240 Gy; 21.0 %	Beavers et al. 1971
P. citri	400	150	200 Gy; 2.41 %	Zhu et al. 2012
Tetranychus cinnabarinus (Boisduval)	320	?	310 Gy; 6.5 %	Ignatowicz & Banasik-Solgala 1999
T. cinnabarinus	250	150	95 Gy; 3.99%	Wu et al. 2013
Tetranychus piercei McGregor	240	155?	200 Gy; 0.6 %	Sulaiman et al. 2004
Tetranychus urticae Koch	320	96 or 144	240 Gy; 1.7 %	Henneberry 1964
T. urticae	200	2	100 Gy; 47.4 %	Nelson & Stafford 1972
T. urticae	300	160	150 Gy; 1-13 %	Goodwin & Wellham 1990
T. urticae	400	25	200 Gy; ~20 %	Dohino & Tanabe 1993
T. urticae	320	?	310 Gy; 2.5 %	Ignatowicz & Banasik-Solgala 1999
T. urticae	300	150	250 Gy; 3.5%	Osouli et al. 2013

the F_1 adult stage, meaning that almost every egg that hatched at 200 Gy (0.6 %) successfully developed into an adult. Therefore, if this trend holds for mites, generally, then the lowering of the PI dose might not be possible by choosing the prevention of development beyond a more advanced developmental stage as the one targeted for the measurement of efficacy. It should be noted that Sulaiman et al. (2004) found that when *T. piercei* adults were irradiated with 100 Gy, 13% of eggs hatched and 74% of these larvae eggs developed to the adult stage.?

In any case, large-scale testing (at least 10,000 adults) of species from different mite families should be required to confirm generic PI doses.

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