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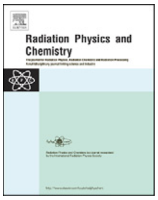

Review

Generic phytosanitary irradiation treatments

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ABSTRACT

The history of the development of generic phytosanitary irradiation (PI) treatments is discussed beginning with its initial proposal in 1986. Generic PI treatments in use today are 150 Gy for all hosts of Tephritidae, 250 Gy for all arthropods on mango and papaya shipped from Australia to New Zealand, 300 Gy for all arthropods on mango shipped from Australia to Malaysia, 350 Gy for all arthropods on lychee shipped from Australia to New Zealand and 400 Gy for all hosts of insects other than pupae and adult Lepidoptera shipped to the United States. Efforts to develop additional generic PI treatments and reduce the dose for the 400 Gy treatment are ongoing with a broad based 5-year, 12-nation cooperative research project coordinated by the joint Food and Agricultural Organization/International Atomic Energy Agency Program on Nuclear Techniques in Food and Agriculture. Key groups identified for further development of generic PI treatments are Lepidoptera (eggs and larvae), mealybugs and scale insects. A dose of 250 Gy may suffice for these three groups plus others, such as thrips, weevils and whiteflies.

1. Introduction

The development, approval and commercial adoption of generic phytosanitary irradiation treatments has been a significant accomplishment over the past 20 years by a number of organizations and people. The objective of this paper is to create a record of this accomplishment and provide guidance for further development of generic phytosanitary irradiation treatments.

2. Phytosanitary treatments

A phytosanitary treatment is an "official procedure for the killing, inactivation or removal of pests, or for rendering pests infertile or for devitalization" (IPPC, 2009). "Official" indicates that the treatment is established by legislation designed to protect agriculture from invasive species, thus they are directed against quarantine pests. However, the noun "phytosanitation" and its adjective "phytosanitary" are sometimes broadly used for plant health; thus, any pest control actions could have been called phytosanitation. In keeping with international agreements, these terms should be reserved for legislation and actions against regulated or quarantine pests.

Most phytosanitary treatments in use today involve subjecting traded commodities to heat (~46 °C), cold (~1 °C) or chemical fumigants to acutely kill essentially 100% of regulated pests. Treatments involving pesticide sprays or dips, high pressure, cleaning, and waxing have been used in specific cases to disinfest commodities of quarantine pests (Hallman, 2007). Ionizing radiation does not cause considerable acute mortality, but renders pests incapable of completing development and/or reproducing. Although prevention of reproduction is sufficient to prevent the establishment of quarantine pests, it means that phytosanitary irradiation (PI) does not have an independent measure of efficacy, such as dead pests upon inspection, as is the case with every other commercial phytosanitary treatment. Therefore, it is arguably more crucial with PI that the research be dependable than with other treatments where there is an independent verification of efficacy after treatment (dead pests). No phytosanitary treatment should harm the quality of the commodity to a degree that prevents its sale, and the treatment should be commercially feasible and cost-effective.

2.1. Generic treatments

The generic phytosanitary treatment concept is that one specific treatment is used for a group of quarantine pests and or commodities although not all were tested for efficacy (Hallman et al., 2010). Since the beginning of modern phytosanitary treatments almost 90 years ago they were often applied generically. For example, the International Plant Quarantine Treatment Manual (FAO, 1984) lists 16 fruits followed by "etc." for cold treatment schedules against Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann), although efficacy studies were only done with a few fruits. A number of ethylene dibromide treatment schedules

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are given for all *Anastrepha* spp. in Central and North America, although only a couple of species may have been tested for any given schedule. There are many other examples of generic treatments for pest and commodity groups (FAO, 1984; APHIS, 2012), but irradiation has greatly expanded on the concept. There is no apparent record as to why some treatments were made somewhat generic in earlier years. It seems to coincide with a need for solutions to certain plant quarantines that cover a certain spectrum of quarantine pests and or commodities.

3. History of the generic treatment concept for irradiation

The International Consultative Group on Food Irradiation (ICGFI) was established in 1984 under the aegis of the United Nations Food and Agricultural Organization, International Atomic Energy Agency (IAEA) and World Health Organization to provide member countries with information and advice on food irradiation. At a meeting on phytosanitary irradiation in Chiang Ma, Thailand in 1986 ICGFI first proposed generic treatments of 150 Gy for tephritid fruit flies and 300 Gy for all other insects regardless of plant host (ICGFI, 1986). No supporting data were published in the brief document, although data may have been presented at the meeting. The concept of broad treatment application was natural for those participants at this meeting from a food irradiation background because broad application was proposed internationally as the norm for food irradiation. At a 1991 meeting results of studies from the literature that supported these doses were published (Table 1). Three of the 11 tephritid species listed had upper effective dose ranges of 150, and the upper dose for another was 154 Gy. A generic dose should be higher than the highest dose required for any species included in that dose to cover untested species that might require a higher dose. In that regard a generic dose of 150 Gy for a group for which four of the 11 insects studied report upper control limits of 150 Gy is inadequate. Only six insects were listed in support of the generic dose for insects of 300 Gy; two of these had an effective dose of 300 Gy, which was not the upper range, but the sole dose reported in both cases.

Table 1
Summary of data presented at 1991 International Consultative Group on Food Irradiation meeting supporting generic doses of 150 Gy for tephritid fruit flies and 300 Gy for insects (ICGFI, 1991)).

Order, Family, *Genus species*	Range of effective doses reported
Diptera Tephritidae	
Anastrepha ludens	50–100
A. obliqua	100
A. serpentina	100
A. suspensa	25–154
Bactrocera cucurbitae	100–150
B. dorsalis	75–150
B. jarvisi	75–101
B. tryoni	50–101
B. zonata	50–55
Ceratitis capitata	25–150
Rhagoletis indifferens	97
Liriomyzidae	
Liriomyza trifolii	80
Coleoptera	
Asynonchus servinus	150
Sternochaetus mangiferae	300
Hemiptera	
Brachycorynella asparagi	100
Quadraspidiotus perniciosus	300
Thysanoptera	
Frankliniella pallida	100
Acarina[a]	
Brevipalpus destructor	300
Tetranychus urticae	300

[a] Although the proposed 300 Gy treatment did not include mites, data for two mites were included in the original table.

The Joint FAO/IAEA Program on Nuclear Techniques in Food and Agriculture (NTFA), understanding that the data presented so far were insufficient to substantiate these generic doses, coordinated and financially supported worldwide research to determine PI doses for a variety of quarantine pest groups and produced numerous published proceedings of PI research, which may be accessed at their website (IAEA, 2012). The effort continues with a new 12-country cooperative research project to develop additional generic PI treatments (IAEA, 2009).

At a workshop on phytosanitary irradiation 3 years after the 1991 ICGFI meeting Hallman (1994) noted that some literature indicated that doses to prevent adult emergence of *C. capitata* and the oriental fruit fly, *Bactrocera dorsalis* (Hendel), were >150 Gy and that several lepidopterans and the depressed flour beetle, *Palorus subdepressus* (Wollaston), required doses >300 Gy to prevent reproduction. A question and answer session following Hallman (1994) is appended to that publication. One commenter said that emerged adults obtained at 150 Gy in one of the *C. capitata* studies were due to “some unexplained deviation” and that when the study was re-done in 1993 no adults were found at that dose. Another commenter said that apparent post-irradiation infestation explains why previous studies done in Hawaii with *C. capitata* and *B. dorsalis* resulted in some adults emerging at doses >150 Gy. The studies cited (Balock et al., 1966; Seo et al., 1973) indicated that at least 210–250 Gy was necessary for *C. capitata* and *B. dorsalis* and possibly melon fly, *Bactrocera cucurbitae* (Coquillett), as well.

Five years later Hallman (1999) further analyzed the irradiation literature on Tephritidae and suggested a generic dose of 250 Gy for this taxonomic group until further studies with *C. capitata* and *B. dorsalis* could support lowering the dose. Two years later Hallman (2001) concluded that 150 Gy would suffice for Tephritidae, and in 2002 after a detailed analysis of the literature on radiation phytosanitary treatments Hallman and Loaharanu (2002) recommended that the 150 Gy generic dose for tephritids be adopted. They argued that studies showing 150 Gy to be insufficient most likely suffered from contamination, which they noted is not rare in phytosanitary treatment research. They also noted that all of the studies that report survivors at doses >150 Gy were done before ICGFI and IAEA became involved in phytosanitary irradiation consulting and training in the mid 1980s.

In 2004 Follett and Armstrong (2004) reported that 144, 124, and 100 Gy, respectively, were effective against *B. cucurbitae*, *B. dorsalis* and *C. capitata* infesting papayas in Hawaii. To infest papayas, diet-reared 3rd instars were inserted into the central cavity through holes bored into the fruit. Some of the research with *B. cucurbitae* at one dose (150 Gy) was done via oviposition into papayas, but not the other two species for which more concern about the effect of infestation techniques was raised relevant to previous research.

Several researchers used insertion without testing its effect on efficacy (Hallman and Thomas, 2010). Tephritids are reared to the late 3rd instar on diet and a number of them are inserted into a hole bored into the fruit. The hole is then sealed with the same plug bored from the fruit or another means. Advantages to this technique are that stage and number of insects and condition of the infested fruit are carefully controlled. However, there are reasons and precedents to hypothesize that larvae inserted into fruit might be controlled with lower doses than those developing in fruit via oviposition. Infestation via oviposition is usually done by putting fruit into a cage with adults.

Females drill a small hole into the peel with their ovipositor and lay eggs just below the fruit surface. The oviposition hole usually heals, isolating the eggs from the outside environment. It has been known for some time that adult emergence of tephritids can be achieved at lower doses in vitro than in fruit (Balock et al., 1956), and Mansour and Franz (1996) prevented adult emergence of $>100{,}000$ *C. capitata* at the surprisingly low dose of 40 Gy when diet-reared 3rd instars were inserted into peach and orange.

Seo et al., (1973) found that a total of 24 of >0.5 million *C. capitata* and *B. dorsalis* emerged as adults when larvae in papaya in cartons holding 12–16 fruit were irradiated with minimum doses of 218–244 Gy (maximum or mean doses not reported). Larvae were infested via oviposition into fruit some days before irradiation and insertion of larvae into fruit immediately before irradiation; however, results of the two infestation techniques were not given separately. One hypothesis, given what is reported about greater radiosusceptibility of tephritids in vitro compared with in fruit, is that the survivors could have been from larvae infesting fruit via oviposition, although they would have been young larvae when irradiated, and insects increase in radiotolerance as they mature (Hallman et al., 2010). (Of course, other reasons for the recovery of adult *C. capitata* and *B. dorsalis* after irradiation in this case can be hypothesized, such as inadequate dosimetry and reinfestation.) Hallman and Worley (1999) suggested that natural infestation in fruit without access to the outside leads to a low oxygen environment inside the fruit that reduces the production of oxidative radicals, thus reducing secondary damage to tephritid immatures therein. Therefore, by 2000 it was a reasonable hypothesis that larvae reared on diet and inserted into fruit could be easier to control than those naturally reared in fruit.

Hallman and Thomas (2010) tested insertion vs. infestation via oviposition for *Anastrepha ludens* (Loew) in grapefruit and found them to be statistically indistinguishable. However, they cautioned against extrapolating this result with one tephritid in one fruit to all tephritids and fruits without testing other species because their review of studies with *C. capitata* indicated that this tephritid might be more radiotolerant under natural infestation compared with insertion of diet-reared larvae. Furthermore, the fact that there is no independent confirmation of efficacy for PI (e.g., acute mortality identified by post-treatment inspection) means that factors that reduce efficacy might not be identified, resulting in undocumented treatment failure.

Insertion of diet-reared late instars into fruit for development of postharvest phytosanitary treatments is such a drastic alteration of the natural state of tephritid infestation that its effect on efficacy should be tested before it is used to develop phytosanitary treatments. For example, Heather and Hallman (2008) noted that 3rd instar tephritids raised on diet and inserted into holes bored to the seed surface of mangoes and then sealed were easier to kill when the mangoes were immersed in hot water than those naturally reared to the 3rd instar via oviposition into mangoes.

The International Plant Protection Convention (IPPC) approved the generic dose of 150 Gy for Tephritidae (IPPC, 2009)) citing 11 studies (Bustos et al., 2004; Follett and Armstrong, 2004; Gould and von Windeguth, 1991; Hallman 2004; Hallman and Martínez (2001); Hallman and Thomas 1999; Hallman and Worley 1999; Heather et al. 1991; Jessup et al., (1992); von Windeguth, 1986; von Windeguth and Ismail, 1987). The IPPC did not approve some treatments that were based entirely on data generated using diet-reared insects when no comparison with natural infestation was done (Hallman et al., 2010).

In the discussion proposing the 400 Gy generic dose for all insects except pupae and adults of Lepidoptera APHIS, 2005 gives three citable sources of information: Hallman (2000, 2001) and the IAEA on-line International Database on Insect Disinfestation and Sterilization (latest version IDIDAS, 2011). Hallman (2000, 2001) are critical views of the PI literature, and IDIDAS is an on-line collection of PI and sterile insect technique references that does not critically analyze the literature but lists doses as reported. Another paper that should be mentioned regarding the 400 Gy dose is Hallman (1998) upon which some of the salient observations in Hallman (2000, 2001) are based. The dose was set at 400 Gy in large part because of a study with *P. subdepressus* (Brower, 1973) that Hallman (1998) interpreted as requiring 400 Gy to prevent reproduction of female adults. Lepidoptera adults were not included in the 400 Gy dose because Hallman (1998) reported that data of Cogburn et al. (1966) show that adult females of two species, *Sitotroga cerealella* (Olivier) and *Plodia interpunctella* (Hübner), require at least 1 kGy to prevent reproduction. Hallman and Phillips (2008) subsequently found that adult *S. cerealella* and *P. interpunctella* could be controlled with ~0.5 and ~0.39 kGy, respectively. Pupae of Lepidoptera were not included because that dose would not prevent adult emergence of late pupae, thus, the pupal stage should be treated as if it were an adult barring data showing its reproductive potential to be lower than the adult when irradiated (Hallman, 1998). Mites were not included because Hallman (1998) noted that Ignatowicz (1992) found that 500 Gy was necessary to prevent reproduction of female adult *Rhizoglyphus echinopus* (Fumouze & Robin). The generic dose of 400 Gy was proposed to the IPPC but was not accepted because it was considered excessive extrapolation given the data accumulated (Hallman et al., 2010).

4. Use of currently approved generic irradiation treatments

Most commodities treated with PI today use generic treatments (Hallman, 2011). The generic dose of 150 Gy for Tephritidae is used for citrus fruit, manzano pepper, and mango exported from Mexico to the US. The 400 Gy generic dose is used for several fruits and curry leaf from Hawaii, several fruits from Thailand, mango from India and Pakistan, guava from Mexico and dragon fruit from Vietnam, all exported to the US.

Australia uses three PI treatments generic for all regulated arthropod pests for mango and papaya exported to New Zealand (250 Gy), mango to Malaysia (300 Gy) and lychee shipped from Australia to New Zealand (350 Gy). These were developed after reviews of the literature pertaining to regulated pests in Australia for commodities shipped to specific countries. The dose for mangoes exported to Malaysia is greater than that for New Zealand because the former country regulates for mango seed weevil and 300 Gy is the dose currently required for that insect. The dose for lychee is 350 Gy because of the presence of mites on lychee that do not occur in New Zealand.

5. Current efforts on generic irradiation treatments

Generic PI treatments have proven viable in commercial practice. Efforts are being made to provide generic treatments for more groups of quarantine pests and reduce the dose of 400 Gy accepted by APHIS for all insects except pupae and adults of Lepidoptera. The NTFA is sponsoring a five year, 12 nation cooperative research project to develop generic PI treatments (2009). Regulatory agencies, such as the IPPC and APHIS, participate as observers. The project is working with a number of arthropods representing key quarantine pest groups, such as Lepidoptera, Pseudococcidae, Agromyzidae, Thysanoptera, and phytophagous Acari. At the end of the 5-year term (2014) new generic PI treatments will be proposed. The project is also researching factors that might affect the efficacy of PI, such as low-oxygen storage, dose rate, and host. It has generally been assumed that radiation dose is the only factor of concern in PI, although data exist that question that assumption (Hallman et al., 2010). Because PI has no viable independent verification of efficacy it is of paramount importance that any factor that negatively affects efficacy be identified.

6. Research directions

Fourteen years ago Hallman (1998) summarized doses that could be used for generic irradiation based on the literature available at the time. At that time maximum doses required for tephritid fruit flies and the most radiotolerant known insects (stored product moths) were considered to be 0.25 and 1 kGy, respectively. The doses have been periodically updated (Table 2). Some doses have increased while others decreased in accordance with new research or reinterpretation of existing research. The largest change was a 40% decline in the proposed generic dose for Tephritidae in 2001 due to the hypothesis that earlier research done in Hawaii that pointed toward a required dose of 250 Gy was subject to post-irradiation reinfestation (discussed in Hallman and Loaharanu (2002)). Doses that remained unchanged may have done so because new research did not suggest changes were needed, or simply no new research with the group has been done (such as Scarabaeidae, which has been dropped from recent lists for lack of new data as well as lack of interest from the regulatory community).

6.1. Generic dose for weevils

The fact that the proposed dose for Curculionidae has decreased from 200 to 150 Gy by 2008 (Table 2) seems contradictory in light of the 300 Gy dose set by APHIS for mango seed weevil, *Sternochetus mangiferae* (F.), in 2002; hence, this development should be analyzed in detail. Two years earlier APHIS, 2000 proposed a dose of 100 Gy for *S. mangiferae* "because research by ARS (Follett, 1999) has demonstrated that the weevils are effectively killed or sterilized at this dose." No citation for "Follett (1999)" is given, and it is probably a personal communication with the scientist who was working on irradiation of *S. mangiferae* at the time. In the final rule it was concluded that the dose should be raised to 300 Gy based on comments received and a reexamination of the research on curculionids that "found that a dose in the 300 Gy range was necessary to effectively control the weevil" (APHIS, 2002). Studies cited for supporting a dose of 300 Gy for *S. mangiferae* were Heather and Corcoran (1992), Jessup et al. (1992) and a personal communication with P. Follett dated 1999.

Table 2
Generic doses proposed over time since 1998.

Pest group (comment or common name)	Dose proposed at publication date (Gy)[a]				
	1998	2000	2001	2008	2011
Bruchidae (seed weevils)	100	100	100	100	100
Sternorrhyncha (of families tested)	100	100	100	100	100
Scarabaeidae	150	150	150	–	–
Curculionidae (weevils)	200	200	165	150	150
Tephritidae (fruit flies)	250	250	150	150	150
Thysanoptera (thrips)	–	250	250	250	250
Coccoidea (of families tested)	–	–	–	250	250
Lepidoptera (non-stored product larvae)	300	280	280	250	250
Lepidoptera (non-stored product pupae)	300	300	350	350	350
Prostigmata (mites)	300	320	350	350	350
Coleoptera (stored product)	400	400	400	–	–
Lepidoptera (stored product)	1000	1000	1000	–	–
Nematoda	4000	4000	4000	4000	–

[a] References in chronological order are Hallman (1998; 2000; 2001), Heather and Hallman (2008), Hallman (2011).

Heather and Corcoran (1992) irradiated mangoes (298–339 Gy) infested with an estimated 161 newly formed adults of *S. mangiferae* and found that no adults emerged from the fruit. Larger numbers of pupae and larvae (possibly more susceptible to radiation than adults) were irradiated with no adult emergence. Jessup et al., (1992), listed as "Jessup and Rigney (1990)" in APHIS, 2002, did not study *S. mangiferae*.

Follett (2001) irradiated $\sim$80 *S. mangiferae* adults naturally occurring in mangoes at $\sim$50, 60–105 and 180–315 Gy. At $\sim$50 Gy 57 eggs were laid and 26.3% hatched. At the higher dose ranges no eggs were laid. However, oviposition (2.4 eggs/female) and eclosion (37%) in the control were low, indicating that the test insects were not responding adequately; e.g., Seo et al. (1974) obtained 69.1 eggs/control female with 54.4% hatching.

Recently the IPPC, 2011) established a dose of 165 Gy for the sweetpotato weevil, *Cylas formicarius elegantulus* (Summers) although the initial proposal was for 150 Gy. Research being done with mango pulp weevil, *Sternochetus frigidus* (Fabricius), also points to a dose near 165 Gy. Therefore, the suggested generic dose for Curculionidae (Table 2) should be raised to $>$165 Gy.

6.2. Pest groups that warrant generic doses

Hallman (2011) suggests that future research on generic doses concentrate on quarantine pests from currently used or approved PI protocols. This would ensure that doses derived would be directly applicable. Additionally, specific doses developed for individual pest species would have a greater possibility of being used if they are already being commercially irradiated at the generic dose of 400 Gy.

PI is currently used in Australia, India, Malaysia, Mexico, Pakistan, Thailand, the United States, and Vietnam. Ghana is permitted to ship irradiated eggplant (*Solanum melongena*), okra (*Abelmoschus esculentus*) and peppers (*Capsicum annuum* and *C. frutescens*) into the US since 2007 (APHIS, 2007) but has not done so. South Africa gained permission to irradiate and ship persimmon to the US in 2011 (APHIS, 2011). These treatments require generic doses of 400 Gy except for fruit irradiated in Australia for export and citrus fruit, mango and manzano pepper from Mexico. The 400 Gy dose is probably excessive for almost all of the pests for which it is used and a reduction in the dose should reduce the risk of damage to fresh commodities as well as reduce cost and time of treatment. To lower this dose requires research across many pest groups with a large number ($\sim$30,000) of individuals from representatives of the pest groups tested to confirm that lower doses are efficacious even when infestation levels may be high. Because there is no independent measure of efficacy for PI as there is for all other commercially applied treatments (all pests dead soon after treatment) and these doses will be applied across broad pest and commodity groups, these doses should only be established after rigorous, comprehensive research.

Table 3 lists numbers of regulated pests in taxonomic groups for commodities approved or being considered for approval for irradiation at 400 Gy. The 400 Gy dose is also used for internal quarantines in Australia and the United States. Three pest groups: scale insects, Lepidoptera (larvae), and mealybugs, respectively, stand out by occurring on 54, 67, and 71% of all country/commodity combinations. The next highest group in occurrence is weevils in 25% of the combinations. Having generic doses of 250 Gy (Table 2) for scale insects, Lepidoptera, and mealybugs would allow for 250 Gy to be used in 62.5% of the cases listed in Table 3 instead of the currently required 400 Gy. At least one representative from at least one of these three groups

Table 3
Numbers of species within each quarantine pest group for which a generic dose of 400 Gy is required. All commodities are for export to the United States except for United States peach, which is for export to Mexico.

Country or region, commodity	Pest group[a]						
	Lepidoptera[b]	Mealybug	Scale	Thrips	True bug	Weevil	Whitefly
Central America, Pitahaya	0	2	0	0	0	0	0
Ghana, Eggplant	8	2	0	1	0	0	0
Okra	6	2	0	1	2	0	0
Pepper	6	1	1	2	1	0	0
India, Mango	0	0	5	0	0	2	0
Pomegranate	4	3	2	0	0	0	0
Malaysia, Carambola	2	5	0	0	0	0	0
Papaya	2	0	0	0	0	0	0
Mexico, Guava	1	6	1	0	0	2	4
Pakistan, Mango	0	0	6	0	0	0	0
South Africa, Grape	1	0	0	0	0	1	0
Lychee	2	1	3	0	0	0	0
Pear	2	0	0	0	0	0	0
Persimmon	2	2	3	0	0	0	0
Prunus	2	0	0	0	1	1	0
Thailand, Dragon fruit	0	5	0	0	0	0	0
Longan	3	4	2	0	0	0	0
Lychee	3	3	2	0	0	0	0
Mango	0	6	4	0	0	3	0
Mangosteen	0	6	2	0	0	0	0
Pineapple	0	2	1	1	0	0	0
Rambutan	1	6	1	0	0	0	0
United States, Peach	5[c]	0	0	0	0	1[c]	0
Vietnam, Dragon fruit	0	3	0	0	0	0	0

[a] Scientific names for pest groups are mealybug family Pseudococcidae, scale families Coccidae and Diaspididae, thrips order Thysanoptera, weevil families Curculionidae and Brentidae and whitefly family Aleyrodidae.

[b] Lepidoptera includes only eggs or larvae, not pupae or adults.

[c] Two pests (the Lepidoptera *Grapholita molesta* and the weevil *Conotrachelus nenuphar*) do not require 400 Gy because individual lower doses (232 and 92 Gy, respectively) have been established (IPPC, 2010a, 2010b). They are included as representatives of groups for which generic doses may be needed.

(scale insects, Lepidoptera, and mealybugs) is a quarantine pest in all of the cases (Table 3). Therefore, these three pest groups should be primary objectives for the development of generic doses. Follett (2009) lists quarantine pests for 23 Hawaiian fruits and vegetables for proposed export to the mainland United States which also show predominance of scale insects and mealybugs. Lepidoptera seem not as important, but only one family (Tortricidae) is considered; the Lepidoptera in Table 3 are from several families.

6.3. Generic vs. specific doses

Phytosanitary treatments are mainly used for internal pests that are difficult to find via inspection, namely fruit flies, weevils and internally feeding Lepidoptera. Weevils are generally host specific, so although they are important quarantine pests for specific commodities, their narrow host ranges result in their not being risk factors for the majority of commodities. Although a generic dose for weevils would be valuable, research resources in that group may wish to concentrate on obtaining doses for the specific weevil pests of concern for the regulated commodities. For mangoes they are *Sternochetus frigidus*, *S. mangiferae*, and *S. olivieri* (Faust). A country infested with all three species, such as Thailand, could do comparative research to determine the most tolerant species and would need to do confirmative research only on that species. If doses existed for those weevils and generic doses were available for two of the key groups identified above (mealybugs and scales), mangoes from most countries could probably be shipped with a dose near 250 Gy. Having doses for the two weevils in guavas from Mexico would not result in a lower than 400 Gy dose for that commodity even if generic doses existed for Lepidoptera larvae, mealybugs and scales because four species of whitefly would still need to be researched.

In cases where only a couple of non-fruit fly pests are of concern (e.g., grape and pear from South Africa and papaya from Malaysia) researchers in those countries should develop treatment doses specific for those pests, which would also contribute to the international effort to develop generic doses for the entire groups.

6.4. Generic dose for mites

Mites are quarantine pests in several of these commodities and they are dealt with by inspection because the 400 Gy generic dose does not cover mites. The inspection for damage caused by mites (e.g. "bronzing") is relatively easy, however only high populations of mites may cause these symptoms and not for all hosts. For the presence of the mites themselves, a wash with soapy water or alcohol is required for inspection with subsequent examination of the washed liquid filtrate under low-powered microscope. This inspection method is not well suited to busy commercial ports and high volumes that commercial shipments generate. Hence, there is a need for a generic dose for mites and it may not be much lower than the current 400 Gy dose for insects (Table 2).

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