Possibilities for irradiation to control insects and mites in cutflowers after harvest.

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Abstract.
In experiments 200 Gy of gamma radiation could be used to control 5 representatives of important insect groups occurring in cutflowers. This dose was tolerated by 65.2% of 72 cutflower species investigated.
Application of irradiation for post harvest control of insects in cutflowers will be determined largely by the acceptation of this technique as a quarantine treatment.

1. Introduction.

Gamma radiation can be an alternative to fumigants as ethylene dibromide and methylbromide (Anon. 1985). Especially in fruits this technique shows potentials for the disinfestation from subtropical fruit flies (Balock et al. 1963, 1966). The possibilities of post harvest control of insects and mites in cutflowers by using gamma radiation were studied. Important groups of insects and mites which may occur in cutflowers are thrips, aphids, two-spotted spider mite, and the eggs and larvae of Lepidoptera and leafminers (Diptera: Liriomyzidae). The sensitivity to irradiation of both cutflowers and a number of insect and mite species occurring on them was determined.
Effects of gamma radiation on insects and mites include inactivation (= disruption of development) and sterilization (= loss of ability to reproduce). In earlier experiments Wit and van de Vrie (1985) found 100 Gy to be sufficient for sterilizing apterous green peach aphid (*Myzus persicae* Sulzer) and inactivating full-grown larvae of the thrips *Frankliniella pallida* Uzel.
To sterilize both sexes of the two-spotted spider mite (*Tetranychus urticae* (Koch)) 320 Gy of gamma radiation was needed (Henneberry, 1964). Nelson and Stafford (1972) inactivated the eggs of this species by levels of 30 to 32 Gy. A complete inhibition of adult formation was found in Clepsis spectrana Tr. (Lepidoptera: Tortricidae) after treatment of the larvae with 200 Gy (Wit and van de Vrie, 1985). Doses reported in literature to inactivate the eggs and larvae of other leafrollers (Lepidoptera: Tortricidae, Olethreutidae) are identical. In *Cydia pomonella* (L.) and *Epiphyas postvittana* (Walk.) 200 Gy of irradiation inactivated the eggs and larval stages (Batchelor et al., 1982; 1984). Kollner (1977) found 1.5% of adult development after exposure of eggs of various ages of

Epichoristodes acerbella Walk. to 110 Gy; treatment of larvae of this species with 150 Gy resulted in 18% of adult development.
Few data are available on the doses needed to inactivate eggs and larvae of Noctuid moths. One and three-day-old eggs of Spodoptera exigua Hb. did not hatch after being exposed to 35 and 170 Gy, respectively. Exposure of first instar larvae of this species to 40 Gy resulted in adults laying non-viable eggs; for full-grown larvae 150 Gy was needed to inhibit adult hatching (El-Badry et al. 1969; Zaki et al. 1970). In Heliothis virescens (F.) El-Sayed and Graves (1969) found 100% inhibition of development to the pupal stage after irradiating 2 to 3-day-old eggs with 140 Gy; exposure of 15-day-old larvae of this species to 100 Gy resulted in 4.5% adult emergence. For the spotted bollworms Earias fabia and E. insulana Ahmed (1975) found 255 Gy to be necessary to inactivate three-day-old eggs. Eggs of this age of Trichoplusia ni (Hubner) were inactivated by 100-150 Gy (Toba and Kishaba, 1974).

2. Materials and methods.

Insects, mites and cutflowers were radiated at the Pilot Plant for Food Irradiation at Wageningen. For treatments a Cobalt-60 source was used at a dose-rate of 51-72 Gy per minute.
For the experiments representatives of the most important insects and mites in cutflowers were used. Two-spotted spider mite (Tetranychus urticae (Koch)) was reared on bean leaves on wet cotton wool, larvae of Clepsis spectrana Tr. (Lepidoptera: Tortricidae) and Spodoptera exigua Hb. (Lepidoptera: Noctuidae) on artificial diet in plastic boxes, thrips (Frankliniella pallida Uzel, Taeniothrips simplex Bournier) in Munger cells on bean leaves, and larvae of the leafminer Liriomyza trifolii Burgess on bean. After irradiation the insects and mi- tes were kept at 25° C. and L:D = 18:6. After treatment inac- tivation and sterilisation were regularly determined. The inhibition of develop- ment before the adult stage was chosen as a criterion for inactivation.

The reactions of cutflowers to irradiation were studied in 72 species. After treatment the flowers were stored in boxes at 5° C for 24h. Following this transport simulation flowers were put on vases in a conditioned room at 20° C, L:D = 12:12 and RH = 60%. Except for Amaryllus, Amaranthus and Celosia, 12 g/l of cutflower nutrient (chrysal) was added to the vasewater.

Vaselife and damage symptoms were studied during 12-13 days. For evaluation of the effects the quality of the untreated was taken as a reference. Effects of irradiation could be divided into 3 groups: (1) no damage (no difference in quality between the treated and untreated (a), or treated flowers had a longer vaselife (b)), (2) commercially acceptable damage (slight damage symptoms, which will be acceptable to the consumer), and (3) unacceptable damage (severe damage).

3. Results.

3.1. Effects on insects and mites.

3.1.1. Tetranychus urticae (Koch)

Eggs younger than 48h were inactivated by a dose of 50 Gy. Older eggs were more tolerant: irradiating eggs 48-72hrs old with 300 Gy resulted in 4.6% of egg hatch (table 1a).
Treatment of female larvae of various ages caused a partial mortality of the larvae and a reduced fertility in the adults. A dose of 350 Gy effected in adults laying very few eggs which were non-viable (table 1b).
The level of irradiation necessary to sterilize the female adult was determined by crossing treated virgin females with non-radiated males. For total sterilization 350 Gy of gamma radiation was needed (Table 1c), although a dramatic effect was observed after treatment with 150 Gy.

Table 1a. Effects of irradiation on eggs of two-spotted spider mite (T. urticae (Koch)).

Eggs 0-24h Dose (Gy)	0	30	50	250	300	350	
number of eggs studied	856	966	871	67	62	48	
egg hatch (%)	96.6	2.8	0.6	0	0	0	
larval mortality (%)	67.5	95.0	100.0	-	-	-	
adult hatch *)	60.4	0.1	0	0	0	0	
Eggs 24-48h Dose (Gy)	0	30	50	100	250	300	350
number of eggs studied	953	832	780	689	140	119	113
egg hatch (%)	92.4	9.1	5.3	0	0	0	0
larval mortality (%)	67.5	96.9	100.0	-	-	-	-
adult hatch *)	57.8	0.3	0	0	0	0	0
Eggs 48-72h Dose (Gy)	0	100	200	300			
number of eggs studied	430	890	525	405			
egg hatch (%)	90.6	19.3	6.6	4.6			

*) given as percentage of the number of eggs studied

Table 1b. Effects of gamma radiation on female larvae of two-spotted spider mite (T. urticae (Koch)).

Dose (Gy)	0	100	250	350
number of larvae studied	49	45	50	51
larval mortality (%)	16.3	22.2	32.0	27.5
number of eggs/adult	15.5	9.9	1.4	0.3
egg hatch F1-generation (%)	80.2	40.8	4.3	0

Table 1c. Effects of gamma radiation on the female adult of two-spotted spider mite (T. urticae (Koch)).

Dose (Gy)	0	150	200	300	350
number of crossings	22	14	16	18	22
number of eggs/female	19.5	10.8	7.7	6.3	9.5
egg hatch (%)	92.1	7.3	1.6	0.8	0

3.1.2. Frankliniella pallida Uzel and Taeniothrips simplex Bournier

The level of irradiation necessary to inactivate full-grown (L2) larvae of T. simplex Bournier was comparable to that reported for F. pallida Uzel (Wit and van de Vrie, 1985). Development to the (pre) pupa was almost completely inhibited after treatment with 100 Gy of gamma radiation. No adults hatched after this treatment (table 2a).

Table 2a. Effects of gamma radiation on full-grown larvae of Taeniothrips simplex Bournier

Dose (Gy)	0	50	100	200	300
number of larvae studied	157	103	107	45	98
larval mortality (%)	17.8	23.3	95.3	86.7	90.8
adult hatch *)	58.6	44.7	0	0	0

*) percentage of the number of larvae studied

Irradiating a mixture of prepupae and pupae of various ages sometimes resulted in a partial mortality of these stages (table 2b).

Table 2b. Effects of gamma radiation on prepupae and pupae of 2 thrips species.

Frankliniella pallida Uzel, experiment I Dose (Gy)	0	150	200	250
number of (pre)pupae studied	42	47	22	30
adult hatch	88.1	91.5	63.6	40.0

Frankliniella pallida Uzel, experiment II Dose (Gy)	0	100	200	300
number of (pre)pupae studied	18	24	23	24
adult hatch	66.7	62.5	56.5	62.5

Taeniothrips simplex Bournier Dose (Gy)	0	10	20	30
number of (pre)pupae studied	43	40	40	40
adult hatch	81.4	42.5	22.5	7.5

Sterilisation of the adults was only studied in <u>F. pallida</u> Uzel. Reproduction in this species is sexual and parthenogenetic. In the experiments female thrips adults were kept for 5 days in the Munger cells for oviposition. A level of 200 Gy was needed to sterilize sexual reproducing females; when reproduction was parthenogenetic a lower dose of irradiation could be used (table 2c).

Table 2c. Effects of gamma radiation on female adults of Frankliniella pallida Uzel

Parthenogenetic reproduction Dose (Gy)	0	100	200
number of females	38	18	15
number of larvae/female	27.1	0.2	0

Sexual reproduction Dose	0	100	150	200
number of crossings	12	13	12	6
number of larvae/female	7.0	1.9	0.1	0

3.1.3. Liriomyza trifolii Burgess

The eggs and larvae of this leafminer are very sensitive to gamma radiation. To determine the dose needed to inactivate eggs, bean plants were placed in a greenhouse containing adult flies for oviposition. After 5 days the plants were supposed to contain enough eggs to be treated. A dose of 80 Gy inhibited further development to the adult stage in both eggs and full-grown larvae (table 3).

Table 3. Effects of gamma radiation on eggs and full-grown larvae of Liriomyza trifolii Burgess

Eggs Dose (Gy)	0	30	50	80
number of pupae	161	85	62	49
number of hatched flies	35	1	1	0

Full-grown larvae Dose (Gy)	0	30	50	80	100
number of larvae studied	277	52	153	159	191
larval mortality (%)	8.3	9.6	11.8	14.5	12.6
adult hatch *)	52.3	40.4	22.2	0	0

*) percentage of the number of larvae studied

3.1.4 Clepsis spectrana Tr. and Spodoptera exigua Hb.

The effects of gamma radiation on the eggs and first instar larvae were studied in the noctuid S. exigua Hb. A dose of 50 Gy resulted in a partial hatch of eggs younger than 48h; 3.3% of these eggs developed into deformed adults after this dose. In older eggs a partial hatch was found after doses as high as 300 Gy; although 100 Gy of irradiation inhibited development to the adult stage. First instar larvae could be inactivated by a treatment with 150 Gy (table 4a). Irradiation experiments on medium-sized (L3) and full-grown (L5) larvae were performed in both C. spectrana (Tortricidae) and S. exigua (Noctuidae). In third instar larvae of C. spectrana development to normal adults was inhibited after a dose of 100 Gy; female larvae of this species seemed more sensitive than male larvae. In S. exigua the L3-stage could be inactivated by 80 Gy (table 4b).

Table 4a. Effects of gamma radiation on eggs and first instar larvae of Spodoptera exigua Hb.

Eggs 0-48h Dose (Gy)	0	30	50
number of eggs studied	77	107	120
egg hatch (%)	55.8	18.7	8.3
larval mortality *)	23.4	4.7	5.0
adult hatch *)	28.6	9.3	3.3

Eggs older than 48h Dose (Gy)	0	100	200	300
number of eggs studied	69	126	108	95
egg hatch (%)	78.3	13.5	7.4	8.4
larval mortality *)	4.3	9.5	7.4	8.4
adult hatch *)	72.5	0	0	0

First instar larvae Dose (Gy)	0	50	100	150
number of larvae studied	137	109	159	119
larval mortality (%)	10.2	32.1	86.2	100.0
adult hatch *)	69.3	36.7	1.3	0

*) percentage of the total number of eggs or larvae studied

Table 4b. Effects of gamma radiation on third instar larvae of 2 lepidopteran species.

Clepsis spectrana Tr. Dose (Gy)	0	50	80	100
number of larvae studied	153	74	78	149
larval mortality (%)	5.2	9.5	23.1	54.0
adult hatch *)	80.4	73.0	42.3	4.7

Spodoptera exigua Hb. Dose (Gy)	0	50	80	100	150
number of larvae studied	340	214	98	179	72
larval mortality (%)	11.8	9.3	57.1	49.7	75.0
adult hatch *)	76.2	58.4	0	0	0

*) percentage of the number of larvae studied

Full-grown larvae of C. spectrana were inactivated by a dose of 200 Gy; females of this stage seemed to be more sensitive than males larvae. In S. exigua 150 Gy of gamma radiation was sufficient to inactivate the L5-larva (table 4c). To determine the dose inducing sterility after treatment of L5-stages of C. spectrana crossings were made between treated and non-treated adults. Females treated as a larva with 50 Gy produced non-viable eggs. In the males the induction of sterility was achieved by a dose of 80 Gy (table 4d).

Table 4c. Effects of gamma radiation on fifth instar larvae of 2 lepidopteran species.

Clepsis spectrana Hb.								
1985 data #	230	230	80	230	80	150	80	80
Dose (Gy)	0	50	80	100	120	150	200	250
% normal adults	75.5	56	39	3	5	0	0	0
number of larvae studied	274	276	134	207	81	148	73	
larval mortality (%)	13.1	21.7	11.2	51.7	64.2	74.3	89.0	
adult hatch *)	76.6	57.2	29.9	18.8	11.1	2.0	0	

Spodoptera exigua Hb.						
Dose (Gy)	0	50	100	130	150	200
number of larvae studied	321	84	186	122	177	101
larval mortality (%)	5.3	3.6	48.4	39.3	36.7	34.7
adult hatch *)	78.8	36.9	1.1	4.1	0	0

*) percentage of number of larvae studied

Table 4d. Crossings with adults of C. spectrana Tr. irradiated during L5-stage.

male x female	number of crossings	number of eggs/ female	number of sterile crossings	number of larvae/ female	number of crossings with non-viable eggs
0k x 0k	14	153.2	1	34.3	6
5k x 0k	12	150.3	0	1.3	10
0k x 5k	17	9.8	7	0	10
8k x 0k	4	107.0	1	0	3
0k x 8k	8	14.4	6	0	2
10k x 0k	3	119.7	0	0	3

3.2. Effects on cutflowers.

3.2.1. General effects.

Effects of irradiation varied per flower species and cultivar. In many cases the vaselife and quality of treated flowers were comparable to the untreated, whereas in other cases they were negatively influenced (table 5). In some flowers a longer vaselife occurred after treatment with gamma radiation (Freesia 'Wintergold', Rosa 'Sonia' and Dianthus 'White Sim').

In a number of cases the effects were partly influenced by the physiological state. Indications were found in 3 reactions: (1) after a transport simulation at 17° C damage was more severe in Alstroemeria 'Appleblossom', Physostegia, Rudbeckia and Rosa 'Motrea' than after 24h at 5° C., (2) damage in Phlox maculata, Solidago, Physostegia and Liatris was more severe when no cutflower nutrient was added to the vasewater, and (3) in Liatris, Iris, Gypsophila and Brodiaea effects of irradiation were dependent on the season: during May up to July/August inclusive these species tolerated 500 Gy, but during winter levels higher than 200 Gy induced damage.

Striking differences in sensitivity occurred between the cultivars of Chrysanthemum, Freesia and Rosa. Chrysanthemum 'Accent', 'Byoux', 'Yellow Cappa' and 'Pink Pompon' tolerated levels as high as 500 Gy. Leafscorching occurred in the Chry- santhemums 'Yellow Cassa', 'White Cassa', 'Regoltime' and 'Statesman' at doses as low as 50-100 Gy. Leaves of Chrysanthemum 'Cottonball' turned yellow after being irradiated at 500 Gy. Freesia 'Wintergold' tolerated 500 Gy, but in the cv 'Ballerina' and 'Miranda' vaselife was shortened by treatment with 200-300 Gy. Rosa cv 'Mercedes' and 'Motrea' were very sensitive to irradiation; in these cultivars flowers did not open after treatment with 100 Gy. Flowers of Rosa 'Sonia' changed colour after treatment with 100-200 Gy. Rosa 'Carol' tolerated 200 Gy, but flowers opened partly (only) after treatment with 300 Gy.

3.2.2. Damage symptoms.

In general damage symptoms were visible 5-6 days after treatment. Various types of damage were found. In a number of cases the effects which naturally occurred were increased or accelerated after irradiation. Sometimes a combination of more symptoms was found.

Irradiation resulted in a shorter vaselife in Achillea millefolium, Amaryllus, Asclepias tuberosa, Bouvardia, Celosia argentea, Delphinium, Freesia ('Ballerina', 'Miranda'), Gypsophila, Liatris and Matthiola.

Flowers did not open after irradiation in Anthirrhinum majus, Aster Novi-Belgii, Calendula officinalis, Iris, Limonium sinuatum, Rosa ('Mercedes', 'Motrea', 'Carol'), and Phlox. Flowers opened less in Ixia, Nerine, Nigella damascena, and Physostegia virginiana.

Scorching of leaves and/or flowers occurred in Anthurium, Callistephus chinensis, Chrysanthemum ('Yellow Cassa', 'White Cassa', 'Regoltime', 'Statesman'), Dahlia, Erigeron, Lysimachia clethroides, Matricaria parthenium, Rudbeckia nitida, Solidago hybr. and Tanacetum vulgare. In Alstroemeria ('Appleblossom', 'Carmen', 'Cyprus', 'Flamingo', 'Jacqueline', 'Jubilee', 'Red Sunset', 'Rosario', 'Rosita'), Anethum graveolens, Chrysanthemum 'Cottonball', Lilium ('Enchantment', 'Harvest', 'Sunray'), Moluccella laevis, Rosa 'Sonia' and Tulipa 'Christmas Marvel' leaves and/or flowers changed colour.

Wilting occurred after treatment of Brodiaea, Gerbera ('Clementine', 'Kaukasus', 'Pascal' and 'Terra Mor'), Gomphrena globosa, and Syringa.

Table 5. Reactions of cutflowers to gamma radiation.

cutflower	number of tests at .. Gy					maximum dose inducing no or commercially acceptable damage (Gy)
	50	100	200	300	500	
Achillea filipendulina	3	4	2	4	4	>500
Achillea millefolium	3	3	1	3	2	200
Aconitum napellus	2	2	2	2	2	>500
Alchemilla mollis	5	5	2	5	5	>500
Allium aflatunense	1	2	0	2	2	>500
Allium schoenoprasum	2	2	0	2	2	>500
Alstroemeria	8	11	2	11	7	100
Amaranthus sangiuneus	1	1	1	1	1	>500
Amaryllus	1	2	1	2	1	300
Anemone	3	4	2	4	3	>500
Anethum graveolens	5	5	3	5	4	200
Anthirrhinum majus	1	3	2	3	2	50
Anthurium	0	1	1	1	0	<100
Asclepias tuberosa	2	3	1	3	2	< 50
Aster x Novi-Belgii	1	1	0	1	1	50
Aster ericoides	0	1	0	1	1	>500
Astilbe flanum	2	3	2	3	3	>500
Astrantia major	2	2	1	2	2	>500
Brodiaea	4	6	2	6	6	200
Bouvardia	3	5	1	5	5	300
Calendula officinalis	1	2	1	2	2	100
Callistephus chinensis	3	4	2	4	4	50
Campanula glomerata	2	2	0	2	2	>500
Campanula persicifolia	2	3	1	3	3	>500
Carthamus tinctorius	4	5	3	5	5	>500
Celosia argentea	1	1	0	1	1	100

Table 5. Reactions of cutflowers to gamma radiation (continued).

cutflower	number of tests at .. Gy 50	100	200	300	500	maximum dose inducing no or commercially acceptable damage (Gy)
Centaurea cyanus	2	2	0	2	2	>500
Centaurea macrocephalon	1	1	0	1	1	>500
Chelone obliqua	1	2	1	2	2	>500
Chrysanthemum	14	20	6	19	15	*
Chrysanthemum leucanthemum	1	1	0	1	1	>500
Dahlia	1	1	0	1	1	300
Delphinium	7	7	2	7	6	300
Dianthus barbatus	4	5	2	5	4	>500
Dianthus	8	10	4	8	6	>500
Doronicum orientale	1	1	0	1	1	>500
Erigeron hybr.	1	1	0	1	1	< 50
Eryngium planum	1	1	0	1	1	>500
Eustoma russelianum	1	1	0	1	1	>500
Freesia	6	6	1	5	4	*
Gerbera	4	5	1	5	4	100
Gladiolus	3	4	3	4	4	>500
Gomphrena globosa	2	2	1	2	2	200
Gypsophila	7	11	6	11	8	**
Hesperis matronalis	1	1	0	1	1	>500
Iris	8	11	2	12	7	**
Ixia	2	3	1	3	2	100
Liatris	9	13	6	13	10	**
Lilium	5	8	2	8	6	50
Limonium sinuatum	3	5	2	5	4	< 50
Lysimachia clethroides	2	3	2	3	3	100
Matricaria parthenium	3	5	3	5	5	100
Matthiola	2	4	2	4	2	< 50
Moluccella laevis	1	2	1	2	2	200
Montbretia	2	3	2	3	3	>500
Nerine	1	1	1	1	0	< 50
Nigella damascena	1	1	0	1	1	< 50
Ornithogalum thyrsoides	9	10	4	10	8	>500
Paeonia officinalis	1	1	1	1	1	>500
Phlox	2	2	1	2	2	< 50
Physostegia virginiana	2	2	2	2	2	100
Rosa	4	13	9	13	8	*
Rudbeckia nitida	2	3	1	3	3	< 50
Saponaria hispanica	4	5	2	5	5	>500
Scabiosa caucasica	2	2	1	2	2	>500
Sedum telephium	1	2	1	2	2	>500
Solidago hybr.	4	6	3	6	6	300
Spiraea	1	1	0	1	1	>500
Syringa	1	1	0	1	0	< 50
Tanacetum vulgare	2	2	0	2	2	< 50
Trachelium caeruleum	5	5	2	5	5	>500
Tulipa	2	2	1	2	1	100

*) dependent on the cultivar; **) dependent on the season

4. Discussion.

Differences in sensitivity occurred between the various species and stages of insects and mites. In general immature stages were foundto be more sensitive than the adults. In C. spectrana Tr. a difference was found in the sensitivity of both sexes.

Insect species could be controlled with lower doses than the mite T. urticae (Koch). Inactivation of the eggs and sterilization of the female larvae and adults of T. urticae (Koch) was achieved by 350 Gy of irradiation. The dipteran L. trifolii Burgess was the most sensitive of the insects investigated. Eggs and larvae of this species could be inactivated before the adult stage by 80 Gy. To sterilize apterous aphids of M. persicae Sulzer 100 Gy of gamma radiation was needed (Wit and van de Vrie, 1985). A dose of 200 Gy was sufficient for inactivating the larvae and sterilizing the female adults of the thrips F. pallida Uzel. The eggs and larvae of the lepidopteran species C. spectrana Tr. (Tortricidae) and S. exigua Hb. (Noctuidae) were inactivated before the adult stage by 200 and 150 Gy, respectively.

Effects of irradiation on cutflowers were dependent on the species and cultivar. In a number of flowers the effects of irradiation were partly influenced by the physiological state. Negative effects of gamma radiation occurred in a number of cutflowers. For the 5 doses studied the percentages of flowers showing no or acceptabel damage were as follows: 50 Gy (84.5%), 100 Gy (75.0%), 200 Gy (65.2%), 300 Gy (51.4%), and 500 Gy (45.1%).

As T. urticae is relatively unimportant as a quarantine species, and taking the sensitivity of cutflowers into account, a post harvest treatment in cutflowers should be aimed at the insects.

Mainly gamma radiation to control insects in cutflowers depends on the acceptation of irradiation as a quarantine treatment. As gamma radiation does not kill the insects other criteria than insect mortality have to be established to describe treatment efficacy. In case the criterion will be 'sterilization' lower doses of irradiation can be used than in case efficacy must be described by 'inactivation'.

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