Irradiation Quarantine Treatments for Deciduous Tree Fruits

A REVIEW OF RESEARCH IN THE PACIFIC NORTHWEST

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The Players

- **Art Burdett:** Research Entomologist
- **Hal Moffitt:** Research Entomologist
- **Harold Toba:** Research Entomologist
- **Stephen Drake:** Research Postharvest Physiologist
- **Lisa Neven:** Research Entomologist

The Commodities

- Apples
- Sweet Cherries
- Pears
- Peaches
- Nectarines

The Pests

- **Codling moth**

- **Western Cherry fruit fly**

Burditt

- Burditt, A.K.; Moffitt, H.R. Radiation disinfestation of food and agricultural products : proceedings of an international conference, Honolulu, Hawaii, November 14-18, 1983 / edited by James H. Moy, 1985, 87-97
- Burditt, A.K. Food irradiation as a quarantine treatment of fruits. Food technology, 1982, 36 (11), 51-54, 58-60, 62
- Burditt, A.K.; Moffitt, H.R.; Hungate, F.P. Effects of gamma irradiation as a quarantine treatment on the development of codling moth larvae. Food irradiation processing : Proceedings of an International Symposium on Food Irradiation Processing and held in Washington, D.C., 4-8 march 1985 / jointly organized by IAEA and FAO, 1985, 3-8.
- BURDITT, JR., A. K.; HUNGATE, F. P.. 1988. Gamma Irradiation as a Quarantine Treatment for Cherries Infested by Western Cherry Fruit Fly (Diptera: Tephritidae). J. Econ. Entomol. 81: 859-862.
- BURDITT, JR., A. K.; HUNGATE, F. P. 1989. Gamma Irradiation as a Quarantine Treatment for Apples Infested by Codling Moth (Lepidoptera: Tortricidae). J. Econ. Entomol. 82: 1386-1390.
- Burditt, J.A.; Toba, H.H. 1992. Gamma irradiation of codling moth (Lepidoptera: Tortricidae) eggs as a quarantine treatment. J Econ Entomol 85 (2); 464-467.
- Burditt Jr., A.K.; Toba, H.H.; Hungate, F.P. 1989. Gamma irradiation: Effect of dose and dose rate on development of mature codling moth larvae and adult eclosion. International journal of radiation applications and instrumentation. part; 34 (6); 979-984.

Moffitt

- Toba, H.H.; Moffitt, H.R. Posttreatment development and fertility of nondiapausing codling moth (Lepidoptera: Tortricidae) larvae and their progeny following gamma irradiation. Journal of Economic Entomology; 1996; 89 (1); 56-62
- Drake, S.R.; Moffitt, H.R.; Eakin, D.E. Low dose irradiation of 'Rainer' sweet cherries as a quarantine treatment. Journal of food processing and preservation; 1994; 18 (6); 473-481
- Burditt, A.K.; Moffitt, H.R. Irradiation as a quarantine treatment for fruit subject to infestation by codling moth larvae. In Radiation disinfestation of food and agricultural products : proceedings of an international conference, Honolulu, Hawaii, november 14-18, 1983 / edited by James H. Moy; 1985: 87-97
- Burditt, A.K.; Moffitt, H.R.; Hungate, F.P. Effects of gamma irradiation as a quarantine treatment on the development of codling moth larvae. In Food irradiation processing : proceedings of an international symposium on food irradiation processing and held in Washington, D.C., 4-8 march 1985 / jointly organized by IAEA and FAO; 1985; 3-8

Toba

- Toba, H.H.; Moffitt, H.R. Posttreatment development and fertility of nondiapausing codling moth (Lepidoptera: Tortricidae) larvae and their progeny following gamma irradiation. Journal of Economic Entomology; 1996; 89 (1); 56-62
- Burditt, J.A.; Toba, H.H. Gamma irradiation of codling moth (Lepidoptera: Tortricidae) eggs as a quarantine treatment. Journal of economic entomology; 1992; 85 (2); 464
- Burditt Jr., A.K.; Toba, H.H.; Hungate, F.P. Gamma irradiation: Effect of dose and dose rate on development of mature codling moth larvae and adult eclosion. International Journal of Radiation Applications and Instrumentation. part; 1989; 34 (6); 979-984

Drake

- Drake, S.R.; Neven, L.G.; Sanderson, P.G. Carbohydrate concentrations of apples and pears as influenced by irradiation as a quarantine treatment. Journal of food processing and preservation; 2003; 27 (3); 165-172
- Drake, S.R.; Neven, L.G. Quality response of 'Bing' and 'Rainier' sweet cherries to low dose electron beam irradiation. Journal of food processing and preservation; 1997; 21 (4); 345-351
- Drake, S.R.; Sanderson, P.G.; Neven, L.G. Response of apple and winter pear fruit quality to irradiation as a quarantine treatment. Journal of food processing and preservation; 1999; 23 (3); 203-216
- Drake, S.R.; Moffitt, H.R.; Eakin, D.E. Low dose irradiation of 'Rainer' sweet cherries as a quarantine treatment. Journal of food processing and preservation; 1994; 18 (6); 473-481
- Drake, S.R.; Neven, L.G. Influence of electron beam irradiation on sweet cherry quality. 1995 annual international research conference on methyl bromide alternatives and emissions reductions /; 1995; (); 701-702
- Olsen, K.L.; Hungate, F.P.; Drake, S.R.; Eakin, D.E. 'Red Delicious' apple response to low dose radiation. Journal of food quality; 1989; 12 (2); 107-114
- Neven, L.G.; Drake, S.R. Comparison of alternative postharvest quarantine treatments for sweet cherries. Postharvest biology and technology; 2000; 20 (2); 107-114
- Drake, S.R.; Neven, L.G. Irradiation as an alternative to methyl bromide for quarantine treatment of stone fruits. Journal of food quality; 1998; 21 (6); 529-538

Neven

- Neven, L.G. Physiological effects of physical postharvest treatments on insects. Horttechnology; 2003; 13 (2); 272-275
- Drake, S.R.; Neven, L.G.; Sanderson, P.G. Carbohydrate concentrations of apples and pears as influenced by irradiation as a quarantine treatment. Journal of food processing and preservation; 2003; 27 (3); 165-172
- Drake, S.R.; Sanderson, P.G.; Neven, L.G. Response of apple and winter pear fruit quality to irradiation as a quarantine treatment. Journal of food processing and preservation; 1999; 23 (3); 203-216
- Drake, S.R.; Neven, L.G. Influence of electron beam irradiation on sweet cherry quality. 1995 annual international research conference on methyl bromide alternatives and emissions reductions /; 1995; (); 701-702
- Neven, L.G.; Morford, M. Effects of Irradiation on Phenoloxidase Levels in Codling Moth (Lepidoptera: Tortricidae) Larvae. Journal of economic entomology; 1998; 91 (2); 534-538
- Neven, L.G. Postharvest management of insects in horticultural products by conventional and organic means, primarily for quarantine purposes. Stewart postharvest review; 2010; 6 (1); 1-11
- Follett, P.A.; Neven, L.G. Current trends in quarantine entomology. Annual review of entomology; 2006; 51 : 359-385
- Drake, S.R.; Neven, L.G. Quality response of 'Bing' and 'Rainier' sweet cherries to low dose electron beam irradiation. Journal of food processing and preservation; 1997; 21 (4); 345-351
- Neven, L.G.; Drake, S.R. Comparison of alternative postharvest quarantine treatments for sweet cherries. Postharvest biology and technology; 2000; 20 (2); 107-114
- Drake, S.R.; Neven, L.G. Irradiation as an alternative to methyl bromide for quarantine treatment of stone fruits. Journal of food quality; 1998; 21 (6); 529-538

Results: Insect Control

- Codling Moth: *Burditt 1989*.
- Eggs most sensitive. 100 Gy prevent hatch.
  - **Source: $Cobalt_{60}$
  - No pupation at 200 Gy.
  - Diapausing CM required 230 Gy.
  - Dose rate affected efficacy.
  - Dose of 187 Gy prevented adult emergence.
    - Treated 79,540 immature larvae
      - 15,501 formed cocoons
      - 256 pupated
      - Zero adult emergence.

Results: Insect Control (continued)

- Western Cherry Fruit fly: Burdett & Hungate 1988.
  - >124,000 naturally infested cherries @ 97 Gy
    - Zero normal adults out of est. 84,369 treated .
      - **Source: $Cobalt_{60}$
- WCFF: (Neven, unpublished)
  - Determined 3rd instar most tolerant.
  - Dose response resulted in 1 pupae, no adults, at 200 Gy.
    - **Source: $Cobalt_{60}$

Status of Doses for Insect Control

- Codling Moth – 200 Gy *(ISPM 28 PT 6)*
- Western Cherry Fruit Fly – 150 Gy *(ISPM 28 PT 7)*
- Apple Maggot – 150 Gy *(ISPM 28 PT 7)*
- Oriental Fruit Moth – 232 Gy *(ISPM 28 PT 10)*
- Spotted Winged *Drosophila* – 80 Gy *(Follett 2014, in press)*

Results: Bio-Markers for Irradiation

- Phenoloxidase
  - Nation et al. 1995, PO was indicator for irradiated Caribbean fruit fly.
  - Neven & Morford, 1998:
    - 5th instar CM did not show consistent delay of melanization, decrease in PO protein concentration, or enzyme activity.

- DNA Repair Enzymes: *(Neven, unpublished)*
  - Study on the dose and time after treatment indicated changes in the DNA repair enzymes pattern of expression.
  - Further confirmation of results on other species pending.

Phenyloxidase in Irradiated Codling Moth

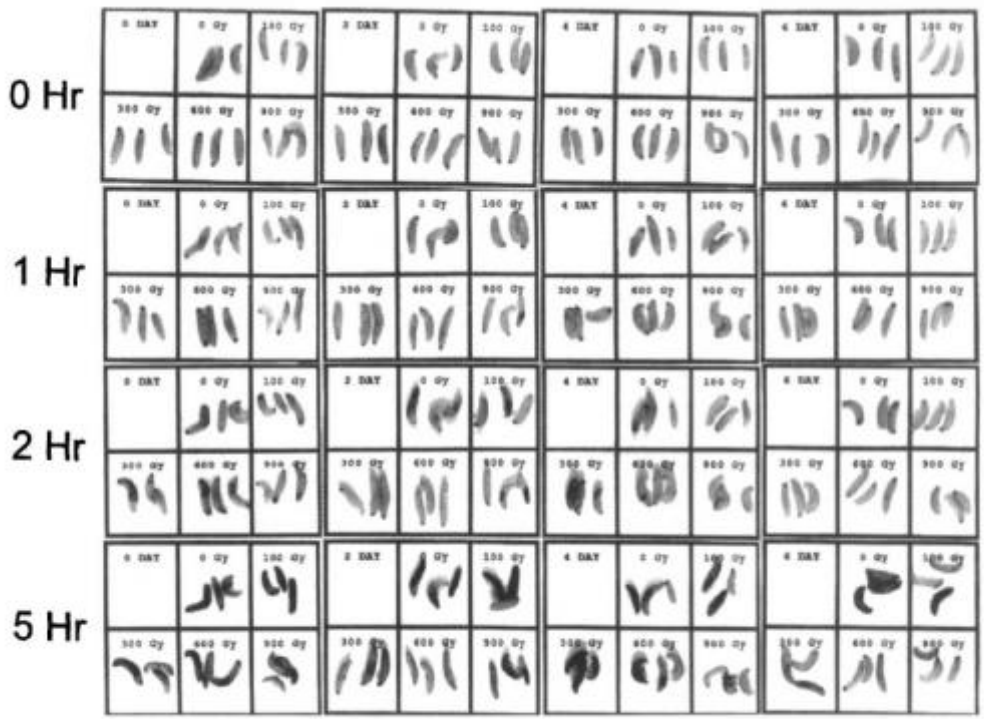

Fig. 1. Melanization of 5th-instar codling moth at 0, 1, 4, and 8 h following removal from −80°C (melanization method).

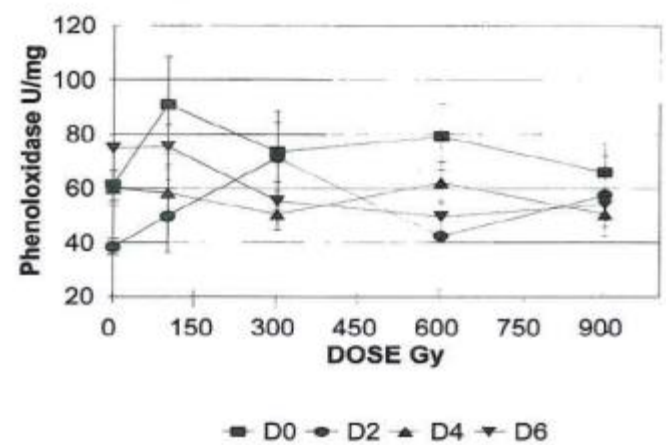

Fig. 3. Effects of irradiation on phenoloxidase activity in the hemolymph of 5th instar codling moth. Values are mean (n = 40) units of phenoloxidase/mg protein ± SE. ■, day 0; ●, day 2; ▲, day 4; ▼, day 6. Results were similar for all instars tested.

Results: Apple Quality

- Fuji & Granny Smith. *Drake et al. 2003*.
  - Carbohydrate levels were not significantly changed at doses up to 900 Gy.
- Fuji, Gala, Granny Smith. *Drake et al 1999*.
  - Firmness decreased as dose increased from150 to 600 Gy.
  - Firmness did not drop below WA standards (54 N) at 900 Gy.
  - No significant loss TA with Granny Smith or Fuji.
  - Gala did lose TA at doses ≥ 600 Gy.
  - Irradiation had no effect on external color in all 3 cultivars.

Results: Pear Quality

- d'Anjou & Bosc. *Drake et al. 1999.*
  - Bosc lost firmness in a dose dependent manner.
  - Scald increased in d'Anjou in a dose dependent manner.
  - Both cultivars ripened normally after irradiation.
  - Some reduction in decay was noted.
- d'Anjou & Bosc. *Drake et al. 2003.*
  - *Doses up to 900 Gy not affect carbohydrate levels.*

Results: Sweet Cherry Quality

Cobalt 60 Source

- **Bing**. *Drake & Neven 1995. MBAO*.
  - No quality change up to 300 Gy.
  - At ≥ 600 Gy was 14% loss firmness
  - At ≥ 600 Gy increased Hunter L values
  - No other changes in hue or visual fruit color
  - No change in stem color.
- **Rainier**. *Drake & Neven 1995. MBAO*.
  - Loss in firmness ≥ 300 Gy.
  - At ≥ 600 Gy increase hue values.
  - Stem color improved with increasing dose
  - Loss in TA ≥ 900 Gy
- Overall, little loss of market quality at doses used for disinfestation.

Results: Sweet Cherry Quality

Electron Beam Source

- **Bing**. *Drake & Neven 1997*.
  - No changes in defects related to dose.
  - No change in SS, TA or flavor
  - More red color with increasing dose
  - No change in stem color related to dose
  - Slight decrease in firmness at doses ≥ 600 Gy
- **Rainier**. *Drake & Neven 1997*.
  - Increase in defects at doses ≥ 600 Gy
  - No change in SS, TA or flavor
  - Reduction in red color at doses ≥ 600 Gy
  - Stem color improved at doses ≥ 600 Gy
  - Slight decrease in firmness at doses ≥ 600 Gy

TABLE 1.
QUALITY ATTRIBUTES OF 'BING' AND 'RAINIER' CHERRIES AFTER QUARANTINE TREATMENT WITH METHYL BROMIDE OR IRRADIATION

Quarantine Treatment	Firmness (N)	Soluble solids (%)	Titratable acidity (% malic)	SS/TA ratio	Condition[z] Fruit	Condition[z] Stem	Bruising[y]	Pitting[y]
				'Bing'				
Control	8.2a[x]	22.8a	0.85b	27.0a	1.3a	1.3a	1.2a	1.2a
MeBr	7.9ab	22.7a	0.91a	25.0a	1.3a	1.3a	1.3a	1.2a
300 gy	7.2c	22.2a	0.85b	26.1a	1.3a	1.3a	1.2a	1.2a
600 gy	7.5bc	22.5a	0.85b	26.4a	1.3a	1.3a	1.3a	1.2a
				'Rainier'				
Control	6.2ab	23.4a	0.63ab	37.1b	1.2b	1.1c	1.3b	1.1b
MeBr	6.3a	23.8a	0.67a	35.5c	1.3ab	1.3bc	1.3b	1.2a
300 gy	6.0b	23.0a	0.61b	37.7b	1.4a	1.5a	1.5a	1.2a
600 gy	5.7c	23.3a	0.59b	39.5a	1.4a	1.4ab	1.5a	1.1b

[z]Condition of fruit and stem graded on a scale of 1 to 3 (1=good, 2=fair, 3=poor).
[y]Bruising and pitting graded on a scale of 1 to 3 (1=none, 2=slight, 3=severe).
[x]Means in a column, within cultivars, not followed by a common are significantly different (P=0.05).

FRUIT AND STEM COLOR OF 'BING' AND 'RAINIER' CHERRIES AFTER QUARANTINE TREATMENT WITH METHYL BROMIDE OR IRRADIATION

Quarantine Treatment	Fruit		Stem	
	Hunter L	hue	Hunter L	hue
		'Bing'		
Control	34.9a[z]	10.9bc	27.9a	89.4b
MeBr	28.7c	12.9a	28.2a	91.3a
300 gy	32.2b	9.4c	28.3a	90.3b
600 gy	34.0a	11.0b	29.0a	90.0b
		'Rainier'		
Control	61.1ab	64.9a	34.3b	97.1b
MeBr	58.6b	56.8b	38.1a	103.5a
300 gy	58.1b	62.0a	35.1b	94.7b
600 gy	62.3a	64.6a	34.4b	95.4b

[z]Means in a column, within cultivars, not followed by a common letter are significantly different (P=0.05).

Results: Stone Fruit Quality

Drake & Neven 1998.

- ‘Bing’ sweet cherries:
  - Slight loss in firmness @300 Gy, but not at 600 Gy.
  - No change in SS or TA
  - No significant changes in visual fruit or stem scores
- ‘Rainier’ sweet cherries:
  - Slight loss of firmness
  - No change in SS or TA
  - No significant changes in visual fruit or stem scores

Results: Stone Fruit Quality

Drake & Neven 1998.

- ‘Perfection’ apricots:
  - No negative effects on exterior color, SS or TA
  - Decrease in firmness & increase internal breakdown ≥ 600 Gy
- ‘Rival’ apricots:
  - No negative effects on exterior color, SS or TA.
  - Decrease in firmness & increase internal breakdown > 300 Gy
- ‘Regina’ peaches:
  - No negative effects on exterior color, SS or TA.
  - Loss of firmness at 600 & 900 Gy.
  - Exterior finish affected at 900 Gy.
  - Exterior finish OK at 300 & 600 Gy.

QUALITY ATTRIBUTES OF 'PERFECTION' AND 'RIVAL' APRICOTS AS INFLUENCED BY THE INTERACTION OF IRRADIATION AND STORAGE TIME

Storage (days)	Irradiation (gy)	Firmness (N)		Internal Breakdown (%)		Interior Color Hunter L	Interior Color hue
		'Perf.'	'Rival'	'Perf.'	'Rival'	'Perf.'	'Rival'
30	0	6.2ab[z]	9.4bc	32bc	6e	55.5ab	63.4abc
	150	6.1b	11.3ab	15d	6e	56.1a	63.4abc
	300	7.4a	12.3a	20cd	12de	55.5ab	64.3ab
	600	4.5c	9.4bc	22cd	22cd	54.4bc	64.7a
	900	3.4cd	7.8cde	48a	30bc	52.5d	64.1ab
45	0	3.7cd	7.0def	33abc	22cd	56.5a	64.3ab
	150	4.5cd	7.8cde	28bcd	15cde	54.4bc	63.4abc
	300	4.5cd	8.1cd	43ab	28bc	55.5ab	62.3c
	600	3.5cd	6.1ef	48a	42ab	51.9d	64.1ab
	900	3.3d	5.3f	43ab	53a	53.4cd	63.1bc

[z]Means in a column not followed by a common letter are significantly different (P=0.05).

TABLE 4.
QUALITY ATTRIBUTES OF 'PERFECTION' AND 'RIVAL' APRICOTS AS INFLUENCED BY THE INTERACTION OF IRRADIATION AND RIPENING TIME

Ripe (days)	Irradiation (gy)	Firmness (N)		Internal Breakdown (%)	Interior Color	
					Hunter L	hue
		'Perf.'	'Rival'	'Rival'	'Rival'	'Rival'
0	0	7.1a[z]	11.8b	5de	56.1ab	63.4abc
	150	7.1a	14.0a	2e	56.4a	63.4abc
	300	8.3a	15.0a	2e	56.6a	64.3ab
	600	4.8b	11.6b	8cde	54.8bcd	64.7a
	900	4.0bc	8.8c	23bc	54.4cd	64.1ab
2	0	2.8cd	4.7d	23bc	55.9abc	64.3ab
	150	3.5cd	5.0d	20cd	54.1d	63.4abc
	300	3.6bcd	5.4d	38b	54.5cd	62.3c
	600	3.3cd	3.9d	55a	51.5e	64.1ab
	900	2.6c	4.3d	60a	51.5e	63.1bc

[z]Means in a column not followed by a common letter are significantly different (P=0.05).

TABLE 5.
QUALITY OF ATTRIBUTES OF 'REGINA' PEACHES AS INFLUENCED BY LOW DOSE IRRADIATION AS A QUARANTINE TREATMENT

Irradiation (gy)	Firmness (N)	Souble solids (%)	Titratable acidity (% malic)	Exterior Hunter Color		Interior Hunter Color		Fruit Finish[z]
				L	hue	L	hue	
0	23.3a[y]	13.3a	0.84a	46.3a	43.3a	70.1a	88.7a	1.5c
150	24.2a	13.1a	0.85a	46.3a	44.4a	69.8a	88.9a	1.5c
300	21.9a	13.1a	0.80a	47.2a	46.3a	70.1a	88.4a	2.0b
600	17.4b	13.4a	0.80a	46.8a	46.9a	69.1a	87.7a	2.0b
900	16.5b	13.4a	0.78a	46.0a	44.1a	69.8a	87.7a	2.3a

[z]Fruit finish graded on a scale of 1 to 3 (1=good, 3=poor).
[y]Means in a column not followed by a commmon letter are significantly different (P=0.05).

Overall Consensus of Irradiation as a Quarantine Treatment

- Industry is not interested in irradiation until it is accepted by key trading partners for which they are currently fumigating fruit.
  - Australia, Japan, Indonesia, South Korea, New Zealand
- Irradiation will not replace cold treatments.
- Dosages already worked out for key pests and fruits.
- Want to talk about delivery of the technology.

What's Fumigated?

- Sweet cherries to Australia
- Sweet cherries to Indonesia
- Apples to Japan
- Sweet Cherries to Japan
- Nectarines to Japan
- Sweet Cherries to South Korea
- Sweet Cherries to New Zealand

2013 Top Export Markets Sweet Cherry

Country	Volume (20 lb. Cases)
Canada	1,573,592
China	567,333
Korea	**491,890**
Hong Kong	446,984
Taiwan	367,591
Japan	**251,453**
Australia	**161,133**
United Kingdom	73,422

National Agricultural Statistics Service 2007 Census of Agriculture.
All other data provided by the Northwest Cherry Growers, 2013 Foreign Market

Dollar Value of Sweet Cherry Crop

Year	Total	Export
2013	$670,914,353	$211,904,418
2012	$759,505,935	$283,254,304
2011	$783,013,504	$257,098,218
2010	$572,624,738	$178,367,963
2009	$541,494,490	$159,458,538
2008	$436,388,970	$127,847,518

2012 Fumigated Sweet Cherries

Country	# 20# boxes	Value (est)
Korea	682,325	$ 13,646,500.00
Japan	217,386	$ 4,347,720.00
Australia	465,118	$ 9,302,360.00
New Zealand	8,326	$ 166,520.00
Total	**907,431**	**$ 27,463,100.00**

Bottom Line

- Doses worked out for key pests & commodities.
- Need importing countries to accept irradiation.
- Technology needs to be accessible.
- Technology needs to be affordable.
- Technology has to handle short season & lot loads.