FINAL REPORT
WTFRC Project # PH-01-128

Project title: Determination of quality parameters in apple cultivars after radio frequency treatments of apples against codling moth

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Objectives:
The principle objectives are to determine the appropriate parameters that provide for an effective, practical RF treatment to disinfest codling moth from apples without fruit injury. Because RF involves heat, we need to develop techniques to reduce thermal injury and to identify other factors that may influence fruit quality, such as initial fruit temperatures before treatment, heat resistance cultivars, maturity at harvest, and duration of cold storage. Because fruits are treated in water, additives, such as calcium chloride, can be examined to minimize osmotic stress. We also need to determine the effect of fruit size on post-treatment quality.

Significant findings:
1. Direct RF exposure was unsuitable for developing a postharvest treatment because of the unacceptable irregular heating among and within fruits.

2. Submerging and rotating fruits with a water tank during RF exposure did not reduce heating irregularity

3. Holding fruits until all fruit positions reached efficacious temperatures to kill codling moth larvbae resulted in unacceptable damage fruits.

4. RF exposures could be used as a pretreatment for hot water dips as a means to increase internal fruit temperature and reduce total exposure time.

5. The best treatment for codling moth control was 2.75 min RF exposure followed by a 40 min hot water dip at 51 C.

6. ‘Fuji’ apples tolerateed heat tratments better than ‘Delicious’ and ‘Gala’ cultivars.

Methods:
1. Tests were conducted using the pilot-scale RF unit at 27.16 MHz at YARL. Infested apples were put in receptacles that will be heated to 50 to 53°C (122 to 127°F), then held 2 to 5 minutes before immersed in a ~ 3°C (37°F) water bath. Control fruits were not be treated. ‘Fuji’ was the standard cultivar.

2. Parameters examined were:
   a. popular cultivars, including the ‘Delicious’ and ‘Fuji’ as standards;
   b. initial fruit temperatures ranging from near-freezing to room temperature;

c. popular fruit sizes from Size 125 to Size 88;
d. different concentrations of the osmodicum, calcium chloride;
. degree of ripeness at harvest;
f. exposure to controlled atmospheres and regular air cold storage.

3. After storage (RA and CA) fruit were treated and transported to the TFRL Wenatchee, WA for evaluation and further storage. Upon arrival at the TFRL fruit quality was assessed after treatment and after 7 days at ambient temperature storage, and after 60 days of RA storage followed by 7 days at ambient temperature. The additional 60 days of storage simulated shipping and handling time. Evaluation at both 0 and 60 days after treatment provided complete information on the quality of the treated fruit in the market. Fruit quality was evaluated based on firmness, external and internal color, chemical and subjective sensory analysis.

Results and discussion:
Preliminary tests showed that energy was not equally distributed throughout the electrode surfaces. This was demonstrated by placing 1 qt-glass jars filled with water on the lower electrode and exposing for 5 min while reaching 2.0 amps (maximum unit efficiency). The warmer temperatures were at the farthest right while the middle had the coolest temperatures (Table 1).

To compensate for this irregular heating, fruits were RF treated while rotating in a water tank. Temperature measurements at 1 and 2 cm depths indicated much variability in heating both in location of fruit and among fruits (Fig. 1). This irregular heating precluded the development of a precise treatment based on time of exposure because temperatures were not equal and could not be reliably predicted with confidence among fruits or locations on each fruit.

However, within fruit temperature variation lessen with time because heat dispersion, which allowed for efficacy to be determined. Efficacy of the treatment increased with final fruit temperature at 2 cm and with holding time (Fig. 2). Total mortality of the treated larval population was obtained at 50°C for 20 min, 57°C for 10 min, and 67°C for 5 min, but survivors were observed after 20 min at 54°C. No distinct dose-response pattern was observed for either temperature or holding time. Regardless, fruit quality was unacceptable under these conditions.

Because RF energy can penetrate deep inside the fruit with minimal change in surface temperature, it could be used as a preliminary treatment for hot water dips. The best exposure time was 2.75 min on fruits submersed, but not rotated, in a water tank, then resubmersed in a hot water tank at set temperatures. To determine maximum efficacy, larval mortality was measured at different times (Table 2).

Using the combination RF-hot water treatment, fruit quality was evaluated among ‘Fuji,’ ‘Gala,’ and ‘Delicious’ cultivars for the shortest time period for each of the temperatures that resulted in no codling moth survivors. Within 14 days, most of the treatments resulted in unacceptable damage (Table 3). External damage was more prevalent than internal damage, which indicates that the radio frequency exposures were less severe than the hot water exposures. The 50°C treatment for 40 min tended to have less overall damage than the other two temperature treatments. The least sensitive cultivar was ‘Fuji’ apples where no significant differences were found between those treated for 40 min at 50°C and their controls. ‘Gala,’ perhaps because of its lighter color, showed external and internal damage. No water core was observed for any of the treatments and no internal browning was found at the two higher temperatures.

After 60 days of RA storage, all fruits regardless of cultivar were damaged beyond retail consideration and no measurements were taken. Enhanced fruit respiration as a result of heating may have caused fruit degradation and the rapid decline in fruit quality after RF treatment. This combination treatment would not be suitable for fruits in long term cold storage.

In summary, this study demonstrated a quick method for screening potential combination treatments using radio frequency and hot water dips. Increasing the radio frequency exposure should lower the duration for hot water dips, which would decrease external damage. These treatments were more likely to be used with 'Fuji,' 'Delicious,' and other dark cultivars rather than the pale-skinned cultivars. Emphasis should be given to the high temperature (50°C) short duration treatments because of their high efficiency (> 99.39% mortality) while maintaining good fruit quality. More larvae will need to be treated in order to demonstrate quarantine security. However, the final treatment will take less than an hour, which is more efficient than any current or anticipated postharvest treatment for apples.

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PI: J. D. Hansen
Proposed project duration: 2001-2002.
Project total (1 year): $9,600

Item	Cost ($)
Labor (Wenatchee)	6,100
Labor (Wapato)	1,082
Benefits 10% (USDA-ARS)	718
Transportation[1]	500
Apples and supplies	1,200
Total	9,600

[1] Between Wapato and Wenatchee

Other support: USDA-CSRS-NRI Grant
Purchase of RF unit: $48,506
Yearly maintenance on RF unit: $1,600
Fiber-optic temperature sensor: $4,000

Table 1 . The mean ± SD of water temperatures (°C)[1] measured horizontally from 20 950-ml glass jars exposed for 5 min in a 27.12 MHz radio frequency unit at 2.0 amps; *n* = 5. Row 1 at the front and Row 4 at the back of the unit; Column A on the far left and Column E on the far right.

	Back				
Column	A	B	C	D	E
Row 4	50.7±1.2	50.7±2.4	53.2±3.7	55.0±2.1	57.9±3.1
3	52.0±1.7	53.0±1.2	47.9±2.4	53.9±0.7	56.1±3.4
2	50.0±2.1	50.7±3.1	49.6±3.9	54.1±3.0	56.2±3.9
1	50.5±1.9	51.8±3.6	52.2±2.4	53.7±2.3	56.8±3.8
	Front				

[1] °F = 1.8 °C + 32°

Table 2. Total number of live and dead larvae recovered inside fruit per treatment*. Time is for hot water dip duration. Initial infestation rate for the treatment control and each of three treatment replicates was 96 larvae per 24 apples.

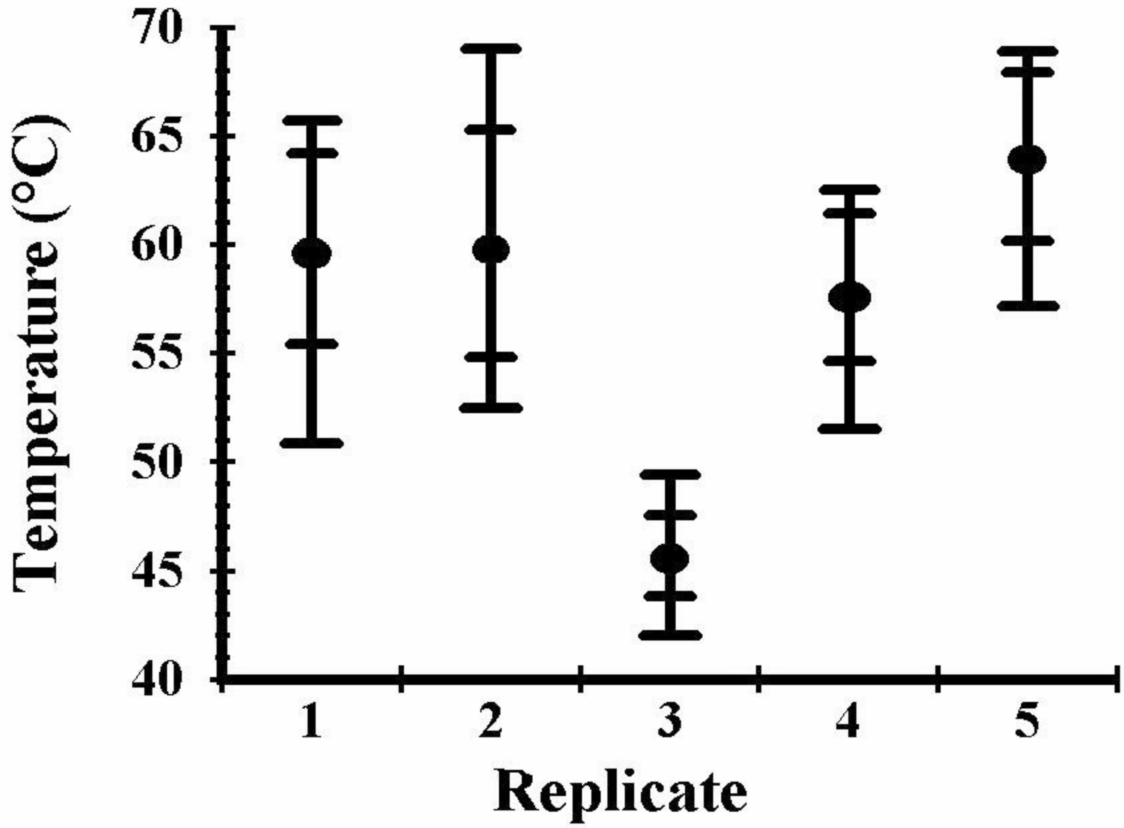
Temperature (°C)	Time	No. Live	No. Dead
48	Control	75	6
	1.5 h	1	202
	2.0 h	0	195
	2.5 h	0	175
49	Control	78	7
	50 min	0	203
	70 min	0	214
	90 min	0	193
50	Control	84	3
	30 min	18	161
	40 min	0	187
	50 min	0	165

* Combination treatment of radio frequency (27.12 MHz) exposure at 12 kW for 205 sec, followed a hot water dip.

Table 3. Significant differences based on of fruit quality parameters within 14 days after radio frequency-hot water submersion treatment Wilcoxon rank sum test for two samples and the Kruskal-Wallis k-sample test for more than two samples. Parameters: “E = exterior; “I”= interior; “a,” “b,” “L,” = Hunter values; “Firm” = fruit firmness; “SSC” = soluble solids; “TA” = titratable acidity, “WC” = water core; “IB” = internal browning .

Cultivar	EL	Ea	Eb	IL	Ia	Ib	Firm	SSC	TA	IB
Among all treatments										
Gala	ns	**	**	**	ns	*	*	ns	ns	ns
Red	ns	*	*	*	ns	ns	ns	ns	**	*
Fuji	ns	ns	**	ns	**	ns	ns	ns	**	**
Between Control and 48°C, 2 hr exposure time?										
Gala	ns	*	*	ns	*	*	*	ns	ns	ns
Red	ns	*	*	*	ns	ns	ns	ns	*	*
Fuji	ns	ns	*	*	*	ns	ns	ns	*	*
Between Control and 49°C, 70 min exposure time?										
Gala	ns	*	*	*	ns	ns	*	*	ns	ns
Red	ns	*	*	*	ns	ns	ns	ns	*	ns
Fuji	ns	ns	*	ns	ns	ns	ns	*	*	ns
Between Control and 50°C, 40 min exposure time?										
Gala	ns	*	ns	*	ns	*	ns	ns	ns	ns
Red	ns	*	*	ns	ns	ns	ns	ns	*	ns
Fuji	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns=not significant; * < 0.05; ** < 0.01


Temperature (°C)
70
65
60
55
50
45
40
1
2
3
4
5
Replicate

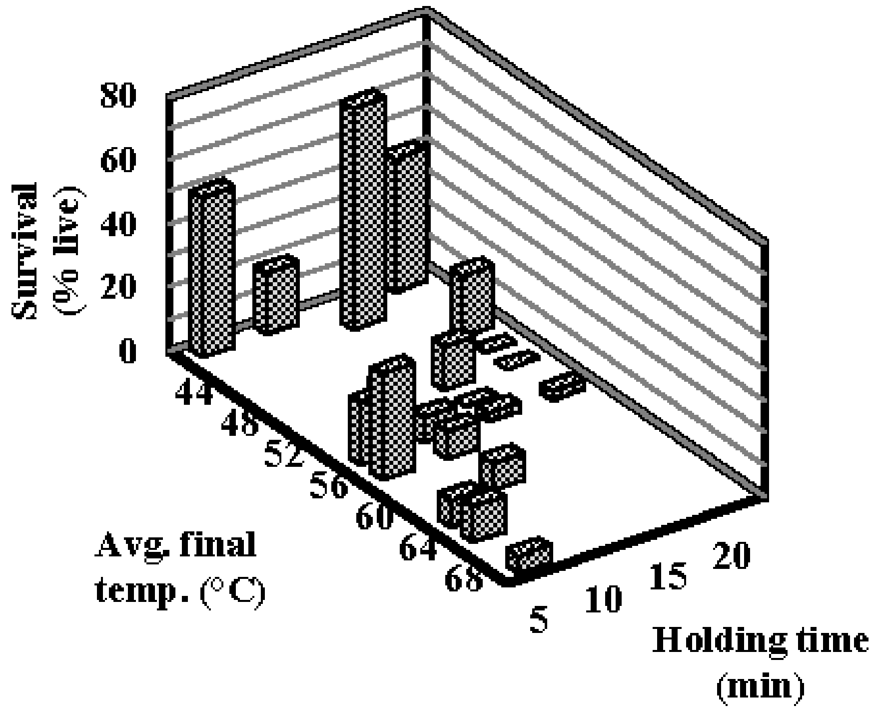


Fig. 2. Percent survival of codling moth larvae infesting nine apples (initial infestation rate of 4 larvae/fruit) after reaching a mean pulp temperature at 2 cm (0.8 in) depth and held for the specified times.