Radio Frequency Heating of Walnuts and Sweet Cherries to Control Insects after Harvest

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Abstract

Radio frequency (RF) heating has been explored as a potential non-chemical method to control insects in harvested walnuts and as a quarantine treatment for 'Bing' sweet cherries. Walnuts were heated to 50 to 90°C. Heating walnuts to 55°C or higher resulted in 100% mortality of fifth instar navel orangeworm, and heating to 80°C had no effect on walnut quality. Moisture content had a significant influence on the heating rate of the walnut kernels. For industrial applications, walnuts could move on a conveyor through one or more RF systems with mixing of nuts between systems. 'Bing' sweet cherries were heated in a polyethylene container holding 10 liters of circulating distilled water with 2.3 g of NaCl. Fresh fruit must be treated in a saline solution to prevent burning at fruit contact points, and circulation improves heating uniformity within the RF field. Cherries were equilibrated in 38°C water for 6 minutes, then heated with RF energy to target temperatures between 50 and 54.5°C and held for 0.5 to 6 min before hydrocooling. Fruit were stored for 1 day at 5°C or 14 days at 0°C to simulate air or sea shipment, respectively. Shorter treatments at higher temperatures were better tolerated than longer treatments at lower temperatures. Cherry fruit infested with codling moth larvae were subjected to the same treatments. Mortality was 100% in all treatments except those at 50°C. However, fruit quality was unacceptable following sea shipment and marginal following air shipment. Treatment times would be significantly longer to provide for Probit 9 security (99.9968% mortality) required for export to Japan and therefore RF treatments do not appear promising for sweet cherry fruit.

INTRODUCTION

Methyl bromide (MeBr) fumigation is the current treatment applied to most in-shell walnuts to meet quarantine and phytosanitary requirements before shipment to domestic and international markets. The three most economically significant pests in walnuts are codling moth (*Cydia pomonella* [L.]), navel orangeworm (*Amyelois transitella* [Walker]), and Indianmeal moth (*Plodia interpunctella* [Hübner]). Methyl bromide fumigation is currently required for export of California sweet cherry fruit to Japan to control potential codling moth infestations. Under the Montreal Protocol of the United Nations, MeBr will be banned from use for purposes other than pre-shipment and quarantine by 2005 (Anonymous, 2001). In addition, increased MeBr restrictions have increased the cost of the fumigant three-fold, and may reduce its availability in the future. For these reasons there is interest to develop alternative methods.

Industrial radio frequency (RF) heating has been successfully used in the food processing and textile industries. Direct interactions between dielectric materials, such as fruits and nuts, with electromagnetic waves generate heat throughout the product avoiding

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limitations experienced with conventional surface heating with air or water due to airspaces or product bulkiness. Because of their dielectric properties, RF may also heat insects faster than some fresh fruit and especially nuts (Wang et al., 2003). RF is classified as "non-ionizing" radiation because these frequencies produce insufficient energy to ionize water molecules.

In developing a postharvest treatment, tests must be done on the most tolerant life stage and species of the target insects. To determine the most tolerant species and life stage, insect mortality data must be developed over a range of temperatures. Washington State University has developed a thermal block heating system to heat insects at various rates comparable to those achieved with RF heating and to a range of different temperatures (Wang et al., 2002). The experiments done by Wang et al. led to a "thermal death curve" for the different life stages of codling moth, navel orangeworm, and Indianmeal moth. These data were used to establish the optimal temperatures and exposure times for insect control with RF.

Hot water heating has been tested as a potential quarantine treatment for sweet cherries. Fruit heated to 122°F in approximately 5 minutes. However, there was only a narrow window where fruit tolerance and codling moth mortality were both acceptable (Feng et al., 2004). Radiofrequency (RF) heating allows cherry fruit to be heated to insecticidal temperatures in as little as 2 minutes as compared with 5 minutes or longer by hot water heating (Ikediala et al., 2002). Radio frequency treatments are shorter, the heating rate is stable and faster, and fruit heat fairly evenly from inside to outside resulting in a lower total heat exposure on the fruit surface where most damage occurs.

Quarantine treatments against insects commonly require Probit 9 mortality (99.9986%). Treatments to control pests in storage or pre-shipment require a high level of mortality, but not Probit 9 efficacy. It is important to examine the effects on product quality of treatments (times and temperatures) that control the target pests.

MATERIALS AND METHODS

Walnuts

Walnuts (*Juglans regia* L. 'Hartley') were obtained from a local processing plant and stored at 0°C in 23 kg raffia bags until use. About 2.5 kg of nuts (ca. 500 nuts) were heated in a cylindrical polyethylene sample container with a diameter of 33.5 cm and a height of 20 cm until the coldest of 8 walnuts of which the kernel temperature was monitored reached target temperatures of 47 to 55°C. In every experiment, the target temperature was the minimum temperature. The container was filled completely in all experiments. A 27 MHz, 12 kW batch RF machine (Strayfield Inter. Ltd., Workingham UK) was used for these experiments. The standard settings of the RF unit were: a minimum gap of 20.5 cm between the upper and the lower electrode and a voltage of 12 kW. The $A_{initial}$ is the heating power (amps) just after beginning RF heating.

During RF heating, the kernel temperatures of eight nuts were monitored using fiber-optic probes (Fiso Technologies Inc., Quebec, Canada). Four probes were randomly placed in walnuts located in the lower part of the container; the remaining probes were placed in walnuts in the top layer.

The moisture content of in-shell walnuts was adjusted by immersing them in tap water for approximately 8 hours. After immersion, the nuts were dried in a room at 25°C or 35°C. Nuts were heated in the RF unit on day 1, 2, 4, 7 and 16 during drying and moisture content was determined.

To determine the upper limit of walnut tolerance to heating, walnuts were heated with RF to 50, 60, 70, 80 or 90°C. Accelerated storage life tests were conducted in which walnuts were stored for 20 days at 35°C to simulate storage at 4°C for 2 years (Taoukis et al., 1997), or samples were analyzed directly after RF treatment without storage. Samples were stored at 0°C until oil analyses. Oil was pressed from the walnuts at room temperature using a Carver Laboratory Press; model K (Fred S. Carver Inc., Summit, NJ, USA), and milliequivalents of peroxide (PV; AOCS, 1998a) and percent free fatty acid values (FA; based on oleic acid; AOCS, 1998b) of the oil were determined.

Walnuts were infested with fifth instar navel orangeworm larvae at the USDA-ARS laboratory in Parlier, California. The larva was placed in a walnut through a pre-drilled hole in the shell which was then sealed with adhesive clay to prevent insects from escaping. The infested nuts (891) were mixed randomly with about 1,100 uninfested nuts from the same batch and with the same moisture content. The infested and uninfested nuts were divided into four lots, and treated with RF until the lowest temperature of 8 monitored nuts reached 47, 50, 53, or 55°C. Walnuts were held in the treatment container for 5 minutes before being spread for cooling at ambient temperatures. The infested walnuts were held at room temperature for 4 days before cracking the shells to determine mortality.

Sweet Cherry

Cherries were treated on the day of harvest. For each treatment, 50 cherries were placed into the RF treatment tank (175 mm high x 270 mm diameter) which held a volume of 10 L of water and 2.3 g NaCl. Treatments were based on cherry fruit temperatures which were measured by inserting a fiber optic probe near the stem then into the middle part of the cherry cheek halfway between the pit and the outer skin of three cherry fruit per treatment. One additional probe was used in the tank to measure water temperature.

Each treatment consisted of a pretreatment in hot water (38°C) then RF heating to one of four temperatures and holding for different lengths of time, and finally cooling for 8 minutes in a 0°C water bath (Fig. 1). After cooling, half of the fruit were stored to simulate air shipment (1 day at 5°C) and the other half simulated sea shipment (14 days at 0°C). After cold storage, the fruit were held at 20°C for 15 hours then evaluated for external quality.

Immediately after the 38°C pretreatment, RF treatments were initiated. There were a total of 10 treatments consisting of four temperatures at different holding periods: 50°C for 4, 5, and 6 min; 52°C for 2, 3, and 4 min; 53.5°C for 1 and 1.5 min; 54.5°C for 0.5 and 1 min. Treatments were compared to two controls: cherries circulating in the RF treatment tank in water at 25°C for 6 min, and cherries circulating in water at 38°C for 6 min. The same treatments were used for cherry fruit infested with third instar codling moth larvae. Larval mortality was evaluated 24h after treatment.

RESULTS AND DISCUSSION

Walnuts

The relationship between the moisture content and the heating rate of the walnut kernel was linear, and the variation in moisture content was higher at higher average moisture contents (data not shown). Some walnuts took up more water than others when immersed, however, the differences in moisture content decreased during drying. The initial, large variability in moisture content on day 1 and 2 influenced the variation in heating rate of the walnuts: where there was a larger variability in moisture content the variability in heating rate was larger as well.

The results demonstrate the importance of controlling the moisture content of in-shell walnuts to ensure uniform RF heating. The effects of commercial washing of in-shell walnuts in bleach or peroxide solution on RF heating require further testing. In some operations, it may be preferable to apply the RF treatment after washing and bleaching and before drying of the in-shell walnuts. RF could then be employed to accomplish most of the re-drying, which could save considerable time and result in product with a more even moisture content.

Wang et al. (2001) found the total moisture content to be 10.0 ± 0.8% after 2 minutes of simulated washing under laboratory conditions. After washing, walnuts must be re-dried to reduce the moisture content to at least 7% to avoid mould development in storage. Wang et al. (2001) found that the moisture content of walnuts was reduced from

10.0% to an acceptable 5.6% for storage when they were subjected to a procedure in which walnuts were RF-heated to 55°C together with forced hot air at 53 to 55°C.

Radio frequency heating of walnuts to 55ºC resulted in 100% mortality of fifth instar codling moth larvae (Table 1). To effectively kill all insect pests, each walnut must reach the lethal temperature. However, heating variability causes some nuts to get much hotter than the target temperature. Therefore, we determined how much heat can be applied to the walnuts without loss of quality. Treated walnut kernels had slightly higher free fatty acid values following 2 years simulated storage (Table 2). Peroxide values were similar between control and treated kernels immediately after RF heating except for kernels heated at 90°C which had higher peroxide values. After 2 years simulated storage, peroxide values were similar to untreated kernels when walnuts were heated to 50, 60 or 90°C (Table 2). Peroxide values were slightly lower in kernels heated to 70 or 80°C compared with the control. Walnuts are considered significantly rancid by commercial laboratories when PV values exceed 1 meq kg^{-1} or FA values exceed 0.6%, therefore all kernels were of acceptable quality before and after storage.

Cherries

There were significant differences in cherry quality between air and sea shipments, where sea shipment resulted in higher levels of damage for each quality factor. For air shipment, there was no difference in pitting damage between the control fruit and fruit heated to 52°C and held for 2 or 3 min., the two treatments that produced the least pitting (Fig. 2). However, when fruits were stored for sea shipment, there was more pitting in all treated fruit as compared with the controls, and there were no differences among the heat treatments, except for fruits that were heated to 52°C and held for 2 min. Among the treatments, the longer fruit were held at a particular temperature, the more pitting. Stem browning was a major source of fruit damage resulting from radio frequency treatments. The longer holding times at each temperature produced more stem browning especially in simulated sea storage (Fig. 3). There was a minor amount of berry browning, and the longest exposures at each temperature caused more berry browning (data not shown).

Fruits were significantly more firm after air shipment, showing no differences among the treatments, while results from sea shipment showed that control fruit (25 and 38°C) were firmer than the treated fruit (Fig. 4). There were no significant effects on decay or shrivel, the values for each being very low (data not shown).

Codling moth mortality was 100% for all treatments except those at 50°C (data not shown).

CONCLUSIONS

For walnut, nut tolerance was very good and insect control was successful. RF treatment could be accomplished with an on-line system because of the fast heating rates. In fact, on-line RF equipment is currently commercially available for food processing and would require little modification for treatment of walnuts.

A radio frequency treatment system for sweet cherry or other fresh fruit could be envisioned as a continuous conveyor system or tube with cherries in a slightly saline solution. The saline solution allows the water and the cherries to heat at a similar rate. The cherries and solution would pass between two electrodes where the heating would occur. The saline solution could be re-circulated and slightly cooled during this process, to be reused. However, our results with sweet cherry were not promising for Probit 9 control because of the limits of fruit tolerance. Stem browning and pitting increased with time in cold storage reducing the marketability of RF treated fruit. Fruit quality was acceptable after air shipment, but treatment times would need to be longer to achieve Probit 9 mortality likely making this treatment infeasible.

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Tables

Table 1. Mortality of fifth instar codling moth following artificial infestation and radio frequency heating.

Treatment (ºC)	# Insects	Mortality (%)
Control	224	0
47	173	33
50	192	77
53	193	99
55	333	100

Table 2. Quality of walnut oil following radio frequency heating to various temperatures and following simulated storage.

	Free fatty acids (%)		Peroxide Value (meq)	
	0 day	20 day*	0 day	20 day*
Control	0.10	0.16	0.80	0.86
50	0.15	0.20	0.63	0.86
60	0.15	0.22	0.74	0.83
70	0.16	0.19	0.89	0.73
80	0.15	0.18	0.76	0.74
90	0.15	0.17	1.46	0.83

*35ºC for 20 days simulates two years storage at 4ºC

Figures

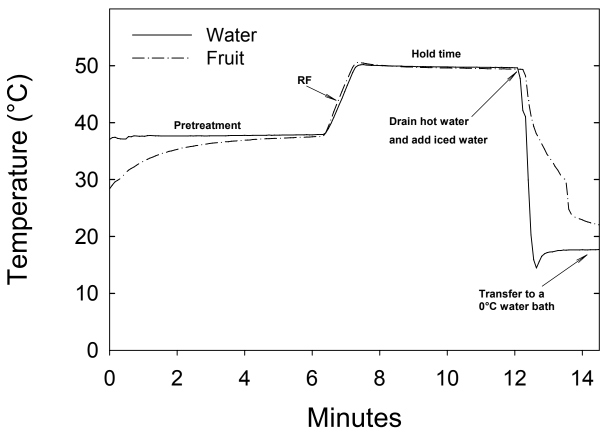

Fig. 1. Heating rate of water and fruit during the pretreatment and RF treatment (50°C for 5 minutes), fruit were then placed in iced water (0°C) for hydrocooling.

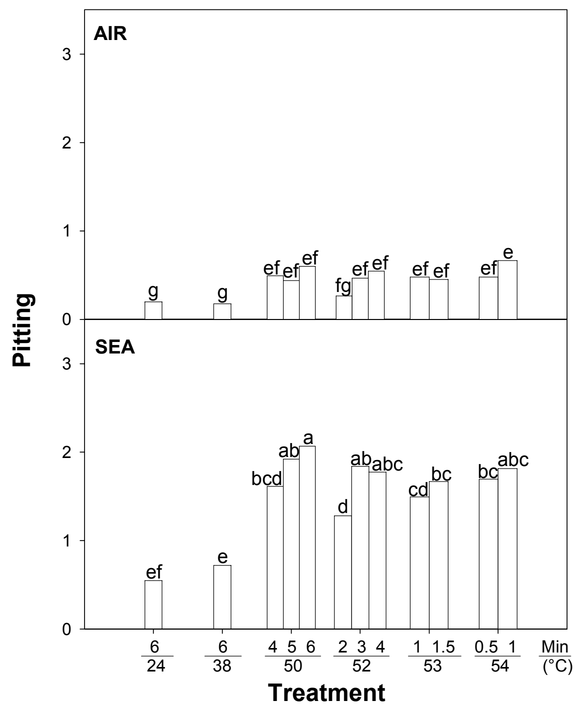

Fig. 2. Mean values between shipment/treatment interaction for cherry pitting. Mean separation was performed using Tukey-Kramer adjustment among treatments and shipments. Different letters are significantly different across shipment type and treatments ($\alpha = 0.05$). Values are from 3 harvests with 25 fruit per replicate. Fruit were evaluated under a scale of 0 = none; 1 = slight; 2 = moderate; 3 = severe.

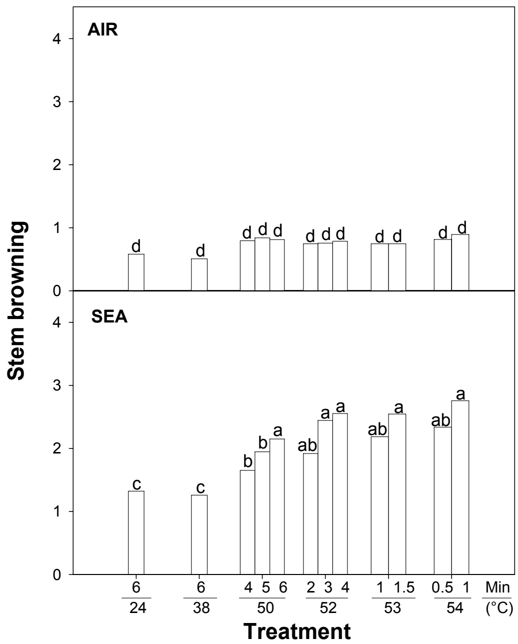

Fig. 3. Mean values between shipment/treatment interaction for cherry stem browning. Mean separation was performed using Tukey-Kramer adjustment among treatments and shipments. Different letters are significantly different across shipment type and treatments ($\alpha = 0.05$). Values are from 3 harvests with 25 fruit per replicate. Fruit were evaluated with a scale of 0 = none; 1 = 1-25%; 2 = 26-50%; 3 = 51-75%; and 4 = 76-100%.

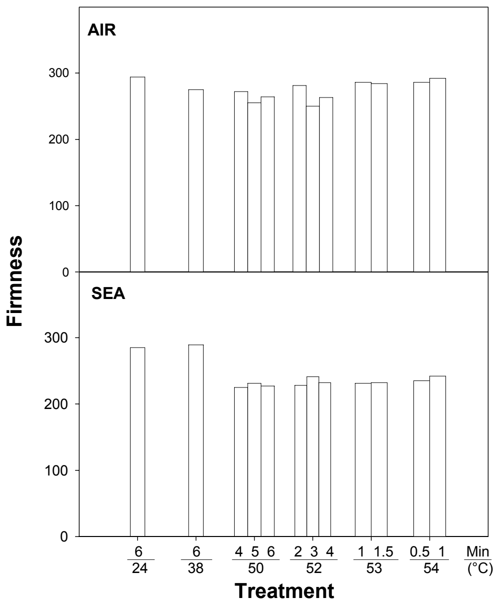

Fig. 4. Firmness (grams) of sweet cherry fruit following radio frequency heating and simulated air or sea shipment.