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Effect of water-assisted radio frequency heat treatment on the quality of 'Fuyu' persimmons

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Water-assisted radio frequency (RF) heating was studied as a potential alternative to chemical fumigation for providing quarantine security against Mexican fruit fly (*Anastrepha ludens*) in 'Fuyu' persimmons. Three holding times were chosen for each of the three treatment temperatures (46, 48 and 50 °C), one time at, one above and another below 100% insect mortality. Heat-treatment protocols included preheating the fruit in 40 °C water, followed by RF heating in a 12 kW, 27.12 MHz RF system, holding at the target temperature for the required time and then hydrocooling at 4 °C for 30 min. The preheating time at 40 °C was determined based on the final RF heating uniformity over the fruit cross-section. Quality parameters, including weight loss, firmness, soluble solids, titratable acidity, peel and pulp colour and calyx browning of persimmons, were evaluated after 7 days at room temperature (22 °C) or in cold storage (4 °C). All treatments except for one condition (48 °C+8 min holding) had no significantly adverse effects on quality attributes. Slight calyx browning was observed in the treated samples and the degree of browning increased with the treatment time for each treatment temperature. The results suggested that water-assisted RF heat treatments provided the potential for disinfestation of persimmons with acceptable product quality.

1. Introduction

China, Japan and Korea are traditionally major producers of persimmon (*Diospyros Kaki*) fruit, contributing 95% of the world production (Soriano et al., 2006). In the United States, the Human Nutrition Information Service (HNIS) in the Department of Agriculture has placed it in the category of specialty fruit of increasing popularity among the US consumers (Homnava et al., 1991). California is a major producer of 'Fuyu' persimmons in the US (Forbus et al., 1991; Clark and MacFall, 2003). The Mexican fruit fly, *Anastrepha ludens* (Loew), although originated in Mexico, is found in tropical fruit such as persimmons in California (Monzon et al., 2007), posing a major threat for international and inter-state persimmon fruit trade, which requires quarantine security before exporting.

Currently, methyl bromide fumigation is used for pest control in fresh fruits (Aegerter and Folwell, 2000; Hansen et al., 2000) but its use in future is uncertain as it has been recognised as an ozone-depleting substance under the Montreal Protocol (USEPA, 1998). Increased international pressure to limit methyl bromide use due to environmental issues, a continual increase in price and reduced production have resulted in an urgent need for developing non-chemical alternative quarantine treatments.

Hot air and hot water treatments have been studied as alternatives to disinfest codling moth in cherries (Feng et al., 2004), Caribbean fruit fly in oranges (Sharp and McGuire,

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1996), Mexican and West Indian fruit fly in mangoes (Sharp et al., 1989) and other insects in apples (Smith and Lay-Yee, 2000) and persimmons (Dentener et al., 1996, 1997; Lay-Yee et al., 1997). These conventional heating methods require lengthy treatment times (in hours) for 100% disinfestations of fruit flies as heat transfers slowly from the surface to the core of the fruit. Exposure to heat for a prolonged time results in adverse effects on the overall quality of fruits, such as weight and firmness loss, skin browning and other quality losses.

Radio frequency (RF) heating has been investigated as a quarantine treatment in dry products such as walnuts (Wang et al., 2001, 2002) and in fresh fruits such as apples (Wang et al., 2006), cherries (Monzon et al., 2006), oranges (Birla et al., 2005) and more recently in persimmons (Monzon et al., 2007). The main advantages of RF heating over other conventional heating methods are its rapid heating, potential differential heating between pest and commodity (Wang et al., 2003) and ability to penetrate deep into the target material (Tang et al., 2000; Hansen and Johnson, 2007).

Monzon et al. (2007) evaluated potential for RF heating as a quarantine heat treatment in persimmon fruit using the saline water immersion technique. In that study, fruit samples were immersed in salt water to reduce non-uniform heating during RF treatments. The dielectric properties of water were adjusted to match that of persimmon by adding an appropriate amount of salt. RF non-uniform heating was still found in the treated persimmons, resulting in loss of firmness and calyx browning in some treatments. Similar studies on RF treatments of apples and oranges showed that even matching the dielectric properties of fruit with the surrounding water did not provide adequate heating uniformity among the fruit (Birla et al., 2004, 2005). By combining RF core heating with water surface pretreatment, RF treatments have been successfully explored for disinfesting apples (Wang et al., 2006) with acceptable product quality. It is desirable to develop water-assisted RF treatments for controlling the insect pests in persimmons without quality damage.

The objectives of this study were to: (1) determine the preheating times at each target temperature based on the required RF heating uniformity, (2) develop a treatment protocol of water-assisted RF heating for 'Fuyu' persimmon control of Mexican fruit fly and (3) evaluate the product quality of RF-treated persimmons under ambient and cold storage conditions.

2. Material and methods

2.1. Sample preparations and thermal treatment designs

'Fuyu' persimmons (average weight of 137±9.6 g and diameter of 6.9±0.4 cm) were purchased from a commercial orchard in Visalia, CA, and shipped overnight to Washington State University, Pullman, WA, USA. Persimmons were maintained in cold storage (4 °C) until used for the next day treatments. The samples were left at ambient temperature (~22 °C) for at least 12 h to achieve uniform fruit temperature before RF treatments and avoid the enhanced thermal tolerance of insects (Wang et al., 2005). Fruits had initial average firmness 40.3±5.3 N, total soluble solids 11.3±0.5% and peel colour 60.8±3.0, 31.3±3.8 and 53.9±5.6 in the L, a^*, b^* scale.

Thermal death kinetic studies of third instars (most heat tolerant stage) of Mexican fruit fly indicated that 100% mortality can be achieved by exposing to 46 °C for 25 min, or 48 °C for 6 min or 50 °C for 2 min (Hallman et al., 2005). In this study, three target temperatures of 46, 48 and 50 °C and three holding times corresponding to a level at, above and below 100% mortality were selected for RF heat treatment and quality analysis (Table 1).

2.2. Treatment parameter determinations

We selected 40 °C as the preheating temperature for all thermal treatments. Liu (1978) reported that heat exposure to 40 °C for 4 days had no adverse effects on the quality of '*Golden Delicious*' apples. In preliminary tests, we also observed no quality change in persimmons after treating in 40 °C water for 60 min. Prior to RF treatments, eight fruits were placed in a circulating water bath (Model ZD, Grant, Cambridge, UK) at 40 °C for 30 min. Two thermocouples (Type-T, THQSS-020U-6, Omega Engineering Inc., Stamford, CT) were inserted into one fruit to measure the fruit surface and core temperatures; the data were recorded every 5 s using a data logger (DL2e, Delta-T Devices Ltd., Cambridge, UK). After heating 5, 10, 15, 20, 25 and 30 min, one randomly selected fruit was removed from the water bath and cut into halves along the surface perpendicular to the calyx. One half fruit facing upward was immediately placed into a water-filled container with 90% fruit immersed in water. Water temperature was maintained equal to the fruit surface temperature to reduce heat loss from the exposed fruit surface. A thermal image of the exposed fruit surface was taken immediately using an infra-red imaging camera with accuracy ±2 °C (ThermaCAM™ Researcher 2001, FL-IR Systems, Portland, OR). The subsurface and core temperatures of the preheated fruit were measured at 2 mm below the peel and the fruit centre, respectively, by a thermocouple, which were compared with those measured by thermal imaging

Table 1 – Experimental design of radio frequency heat treatment

Treatments	Treatment description
46 °C+20 min 46 °C+25 min 46 °C+30 min	Preheating at 40 °C and RF heating to raise the temperature up to 46 °C and holding at 46 °C for 20, 25 and 30 min
48 °C+4 min 48 °C+6 min 48 °C+8 min	Preheating at 40 °C and RF heating to raise the temperature up to 48 °C and holding at 48 °C for 4, 6 and 8 min
50 °C+1 min 50 °C+2 min 50 °C+4 min	Preheating at 40 °C and RF heating to raise the temperature up to 50 °C and holding at 50 °C for 1, 2 and 4 min
Control	No heat treatment

methods for the mentioned specific times. The fruit surface and core temperatures after RF treatments with a target temperature of 48 °C were also recorded during 30 min of cooling.

To determine the best preheating time for each target temperature, a preliminary experiment was conducted to compare the heating uniformity of the fruit samples after RF treatments for different preheating times at 40 °C. After preheating for the given times, eight fruits as a group were immediately transferred to a fruit mover filled with 40 °C water. Water inside the fruit mover was circulated using a 0.745 kW, single-phase centrifugal pump (TEEL Model # 2PC27, Dayton Electrical Mfg. Co., Niles, IL). The description and operation procedures of the fruit mover can be found in Birla et al. (2004). The fruit mover was placed between the two parallel electrodes of a 12 kW, 27 MHz batch-type RF heating system (E-200, Strayfield International Limited, Workingham, UK). RF heating was conducted using an 8 kW power with an electrode gap of 210 mm. Circulating water temperature was monitored by thermocouples, placed in the circulation pipe outside the RF system. RF power was switched off once the circulating water temperature reached the target temperature. Two fruit samples were immediately taken out from the fruit mover and cut into halves to map the temperature distribution by the infra-red imaging camera. The mean temperature and standard deviation of RF-treated samples were calculated from thermal images. The best heating uniformity around the target temperature was used to determine the preheating time for the final RF treatments.

2.3. *Treatment procedures*

Based on those preliminary tests, three preheating times of 25, 30 and 35 min; 15, 20 and 25 min; and 5, 10 and 15 min were chosen for the target fruit temperatures of 46, 48 and 50 °C, respectively. Longer preheating times at 40 °C and shorter RF heating were used to achieve the desired heating uniformity for a lower final target temperature.

In the experiment for quality studies, eight persimmons were heated in a water bath at 40 °C with the optimised preheating time for each final temperature. Preheated fruits were transferred to the fruit mover filled with 40 °C water inside the RF system. RF power (8 kW) was applied till the circulating water reached the target temperatures (46 or 48 or 50 °C). Fruit samples were immediately removed from the fruit mover and kept in the water bath maintained at the selected target temperature for different holding times (Table 1). Fruits were then hydro-cooled in 4 °C water for 30 min and stored in open space at room (22 °C and 35% relative humidity) and cold storage (4 °C and 80% relative humidity) for 7 days. Controls were dipped in water at room temperature for 30 min before keeping them with treated fruits in both storage conditions. Each treatment was replicated three times.

2.4. *Quality evaluation*

Quality parameters including weight loss, firmness, soluble solids, peel and pulp colour, and titratable acidity were measured after 7 days at room and cold storage. Weight loss was expressed as percentage of fruit weight reduction from initial weight. Firmness was measured in Newton (N) by a Texture Analyzer (Model TA-XT2, Stable Micro Systems, YL, UK) using a cylindrical (7.9 mm diameter) hemispherical tip probe. The speed of the probe was set at 400 mm/min; the measurements were made at three equally spaced positions (120° apart) along the equatorial fruit surface. Prior to firmness measurement, fruits skins were peeled off at all three positions. Peel colour was measured at three marked spots on each fruit by a colorimeter (Model CM-2002, Minolta Corp., Ramsey, NJ) and expressed in the L, a^* and b^* scale. Pulp colour was measured at two spots on each exposed fruit surface after cutting it into two halves. Hand-squeezed juice from six persimmons was used to measure sample titratable acidity (TA) after each treatment. Five-ml juice sample was titrated against 0.1 N NaOH till the final pH reached 8.2. The TA value was expressed in terms of equivalent anhydrous malic acid in g/100 ml of juice. Total soluble solids (°Brix) were measured using a hand-held refractometer (Model N-1α, ATAGO Co. Ltd., Tokyo, Japan) and expressed as percentage soluble solids in juice. Visual observations for skin and calyx browning were also made after 7 days of room and cold storages.

The measurement of individual quality attribute was subjected to an analysis of variance (ANOVA) and means were separated using Tukey's method (SAS Institute, 2002, Cary, NC) at a significance level of 0.05.

3. Results and discussions

3.1. *Comparison of thermal imaging and thermocouple methods*

Table 2 shows the core and surface temperatures of persimmon fruit measured by thermal imaging and thermocouple methods. Temperature data were compared after 5, 10, 15, 20, 25 and 30 min of preheating at 40 °C and hydro-cooling at 4 °C for 30 min. A good agreement was obtained between these two methods both for surface and for core temperatures. The temperature difference between thermal imaging and thermocouple methods was below 1.4 °C (Table 2).

3.2. *Preheating time determination*

The average temperatures (mean ± S.D.) of persimmon fruit cut surface measured by thermal imaging after initial RF treatments with different preheating times are shown in Table 3. In general, in order to obtain relatively uniform treatments, longer preheating times and shorter RF heating were needed for lower target temperatures. For example, preheating at 40 °C for 20 min yielded an average fruit temperature of 47.7 ± 0.6 °C, aimed to achieve 48 °C, while 15 and 25 min preheating yielded average fruit temperatures of 44.8 ± 0.5 and 50.8 ± 0.8 °C, respectively, after RF heating, which were not suitable for the 48 °C treatment (Table 3). Similarly, preheating times of 30 and 10 min at 40 °C were found appropriate for 46 and 50 °C final treatment temperatures, providing uniform average fruit temperatures of 46.1 ± 0.3 and 49.9 ± 0.4 °C after RF heating. Therefore, based

Table 2 – Comparisons of measured surface and core temperatures of ‘Fuyu’ persimmon between thermal imaging (TI) and thermocouple (TC) methods during preheating and hydro-cooling

Treatments	Time, min	Surface temperature, °C		Core temperature, °C	
		TI	TC	TI	TC
Preheating in 40 °C water	5	38.5	39.5	25.4	25.9
	10	38.5	39.9	28.8	29.8
	15	38.6	40.0	32.5	33.1
	20	38.8	40.0	34.7	35.4
	25	39.2	40.0	36.6	37.0
	30	39.6	40.0	37.4	38.0
Hydrocooling in 4 °C water	30	5.6	5.4	12.8	13.4

Table 3 – Preheating time determinations at 40 °C water baths based on heating uniformity after RF treatment of ‘Fuyu’ persimmon at three different target temperatures

Target temperature after RF treatment	Preheating time in a 40 °C water bath, min	Average and standard deviation temperatures after RF treatment, °C
46 °C	25	43.9 ± 0.3
	30	**46.1 ± 0.4**
	35	48.2 ± 0.7
48 °C	15	44.8 ± 0.5
	20	**47.7 ± 0.6**
	25	50.8 ± 0.8
50 °C	5	44.8 ± 0.9
	10	**49.9 ± 0.4**
	15	51.0 ± 0.3

on the achieved target temperature and heating uniformity, preheating times of 30, 20 and 10 min at 40 °C were chosen for final treatment temperatures of 46, 48 and 50 °C, respectively. The selected preheating times in 40 °C water bath and subsequent RF heating times required for the fruit to reach three different final temperatures (namely 46, 48 and 50 °C) as measured at the core and subsurface are summarised in Fig. 1. It took about 70, 120 and 140 s of RF heating for the fruit core to reach 46, 48 and 50 °C, respectively, after the preheating described above (Fig. 1).

3.3. *Temperature–time profile of persimmon*

Fig. 2 shows the temperature–time history of persimmon fruit at different stages: preheating in 40 °C water for 20 min, RF heating to raise the fruit temperature up to 48 °C, holding at 48 °C for 6 min and cooling at 4 °C for 30 min in a 48 °C+6 min heat treatment. The core and surface temperatures of persimmon fruit were 35.4 and 40 °C, respectively, after 20 min of preheating (Fig. 3a). Slow heat transfer from the surface to the core of the fruit resulted in a relatively lower core temperature. The core temperature of fruit during RF heating rose from 35.4 to 48.4 °C whereas the surface temperature rose from 40 to 47.8 °C (Fig. 3b), showing preferential core heating by RF treatments. It is obvious that pretreatment surface heating prior to RF treatment compensated core RF heating of fruit and assured uniform fruit temperature (mean ± S.D., 47.7 ± 0.6 °C). Holding fruit in 48 °C water for 6 min further improved the heating uniformity. The average temperature (mean ± S.D.) after holding was 47.9 ± 0.2 °C (Fig. 3c). Cooling for 30 min reduced fruit surface and core temperatures to 5.4 and 13.4 °C, respectively (Fig. 3d). Cooling time can be further reduced based on the required fruit core temperature to reduce the operational cost in industrial applications of this technology.

3.4. *Quality*

3.4.1. *Weight loss*

RF heat treatment itself had no significant effect on weight loss of treated fruits after 7 days at room temperature and in cold storage ($P > 0.05$) (Tables 4 and 5). In another study also, no significant difference in weight loss was observed between RF-treated and control persimmons after 12 days at 20 °C storage (Monzon et al., 2007). Table 6 shows the results of factorial ANOVA analysis performed on individual quality attributes. Regardless of the RF treatment, storage conditions significantly affected the weight loss ($P < 0.05$). Fruits stored in cold storage had lower weight loss (~1.4–1.5%) compared to those stored at room temperature (6.9–8.4%) (Tables 4 and 5). The sharp reduction in weight loss for samples in cold storage might be attributed to the lower level of dehydration and reduced physiological changes in fruit such as respiration, transpiration and ripening.

3.4.2. *Firmness*

No significant difference was detected in firmness between control and the treated samples after a 7-day storage at room temperature, except for fruits that went through the 48 °C+8 min holding treatment ($P < 0.05$) (Table 4). The reduced firmness for this particular treatment might have been caused by prolonged heating, resulting in an increased rate of ripening in the treated fruit. Monzon et al. (2007) also reported a reduction in the firmness of

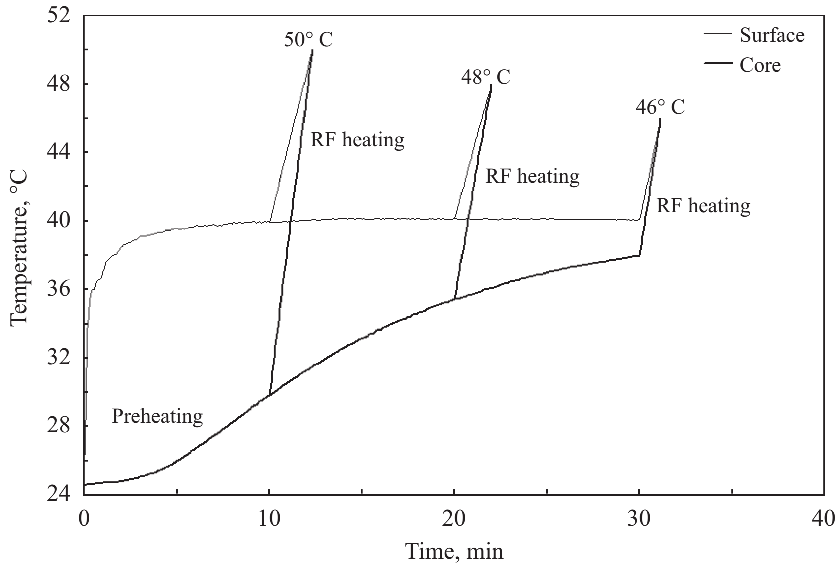

Fig. 1 – Experimentally determined preheating and radio frequency (RF) heating times for the surface and core temperatures of 'Fuyu' persimmon to each of the three selected target temperatures.

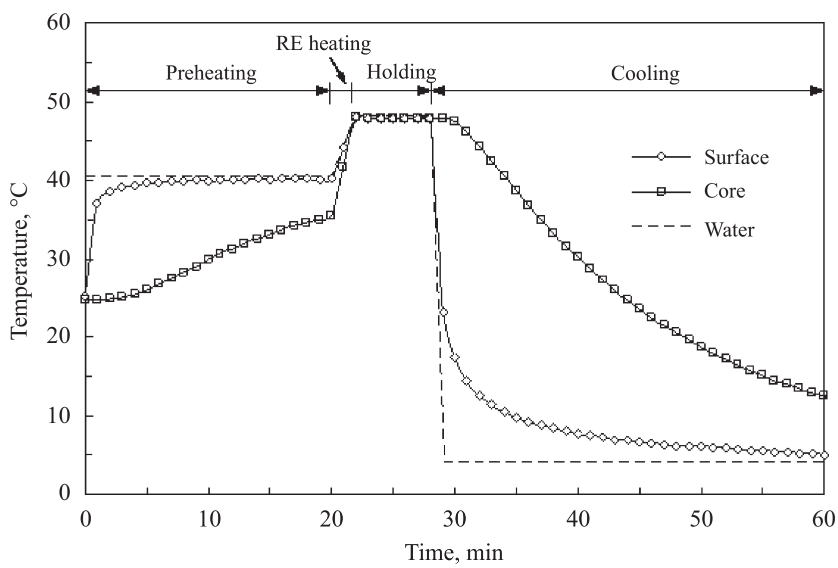

Fig. 2 – Heating and cooling profiles for surface and core of 'Fuyu' persimmon (diameter of 7 cm), subjected to preheating in hot water at 40 °C, followed by RF heating to raise the temperature up to 48 °C, holding at 48 °C for 6 min and hydro-cooling for 30 min at 4 °C water.

persimmons, after a 48 °C RF treatment with holing times of 12 and 18 min. All treated persimmons in cold storage were significantly firmer than the untreated control (Table 5). The reason for the increased firmness of persimmons could be the inhibition of ethylene synthesis due to heat treatment, which subsequently delays the ripening (Lurie and Mitcham, 2007). Such an increase in the firmness of treated persimmons was not observed in the room condition, but it was definitely evident in cold storage. Studies on apples (Lurie and Klein, 1992a; Lurie and Nussinovitch, 1996) and tomato (Lurie and Klein, 1992b) showed that heat treatment, followed by reduced temperature storage either significantly increased the firmness or delayed the ripening of commodity. Kim et al. (1994) reported that heat treatment at 45 °C for 1.75 h, followed by 2 °C storage for a week significantly increased firmness of '*Golden Delicious*' apples than those stored at 10, 18 and 25 °C. This observable fact might be helpful in extending the storage life of persimmons.

3.4.3. *Peel and pulp colour*

There was no significant difference in peel colour between the control and all treated fruits after a 7-day storage at room temperature, except for the 48 °C+8 min holding treatment. Peel colour (hue) was significantly lower in the 48 °C+8 min holding treatment ($P < 0.05$) (Table 4), which was evident by

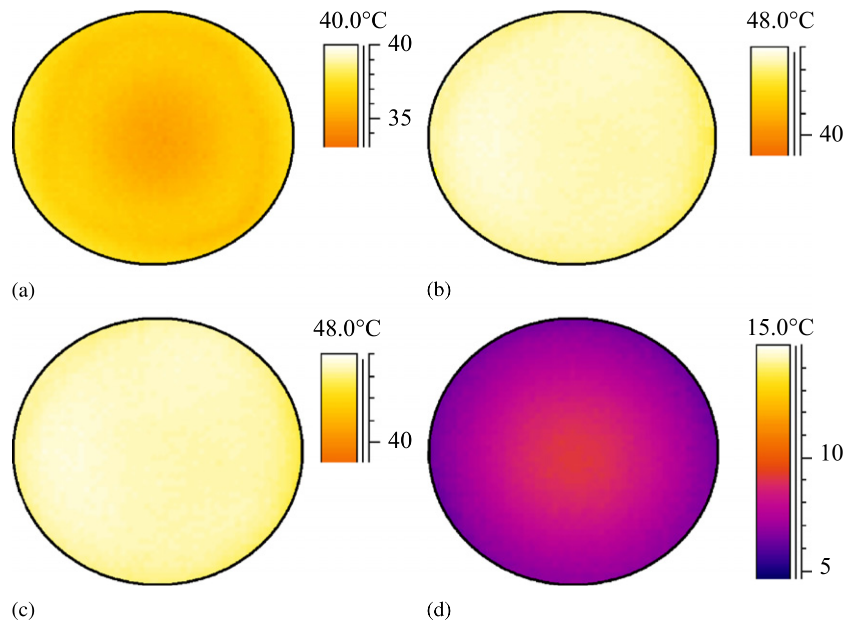

Fig. 3 – Temperature distributions of persimmons obtained by thermal imaging after: (a) water preheating at 40 °C for 20 min, (b) RF heating from 40 to 48 °C, (c) holding in hot water at 48 °C for 6 min and (d) cooling in cold water at 4 °C for 30 min.

Table 4 – Quality parameters of control and RF-treated 'Fuyu' persimmons after 7 days of storage at room temperature (22 °C, 35% RH)

Treatment	Weight loss, %	Firmness, N	Total soluble solids, %	Acidity, g/100 ml	Peel colour, Hue	Pulp colour, Hue
Control	6.9a*	16.75a	14.6a	0.15a	56.4a	53.2a
46 °C+20 min	6.4a	16.43a	14.0a	0.14a	54.7a,b	52.9a,b
46 °C+25 min	8.4a	18.61a	13.2a	0.13a	55.6a	54.6a
46 °C+30 min	6.1a	16.04a	14.1a	0.13a	54.4a,b	52.6a,b
48 °C+4 min	6.0a	16.59a	14.5a	0.12a	56.1a	54.2a
48 °C+6 min	8.1a	18.40a	14.0a	0.15a	55.8a	53.8a
48 °C+8 min	7.6a	11.94b	13.9a	0.14a	53.2b	50.5b
50 °C+1 min	7.3a	17.14a	14.5a	0.12a	55.3a,b	52.5a,b
50 °C+2 min	8.3a	19.96a	14.6a	0.14a	56.2a	52.7a,b
50 °C+4 min	8.1a	16.20a	14.6a	0.12a	54.8a,b	53.7a

*Different letters within a column indicate that means are significantly different ($P<0.05$).

the dark shade on the surface of the treated fruits. Heat exposure for a relatively longer time, followed by room storage could have enhanced the rate of ripening, resulting in a dark colour for this particular treatment. However, no significant difference was observed in peel colour between treated and control fruits in cold storage ($P>0.05$) (Table 5).

Treatments at 48 °C for 8 min holding also showed significant effects on the pulp colour of RF-treated persimmons after storage at room temperature ($P<0.05$) (Table 4). Decreases in hue (dark shade) indicated overripening of fruits. Firmness loss and peel colour change supported the findings for this particular treatment. No significant difference in pulp colour was detected between treated and control fruits after 7 days of cold storage ($P>0.05$) (Table 5).

3.4.4. *Total soluble solids and titratable acidity*

RF treatment had no significant effect on soluble solids and titratable acidity of persimmons ($P>0.05$). Studies on RF-treated apples (Wang et al., 2006) and oranges (Birla et al., 2005) also showed similar results. Storage conditions significantly affected TA and TSS of fruits ($P<0.05$) (Table 6). A slight decrease in TA and TSS was observed in cold-stored fruits compared to those stored at room temperature (Tables 4 and 5). This could be attributed to the lower metabolic activities of fruits in cold storage (Prasanna et al., 2000), resulting in a slow rate of maturity. The quantity of malic acid in immature persimmons was found to be less than that in mature ones (Senter et al., 1991). The lower TSS in cold storage could be due to the reduced conversion rate of starch into sugars.

Table 5 – Quality parameters of control and RF-treated ‘Fuyu’ persimmons after 7 days in cold storage (4 °C, 80% RH)

Treatment	Weight loss, %	Firmness, N	Total soluble solids, %	Acidity, g/100 ml	Peel colour, Hue	Pulp colour, Hue
Control	1.4a*	18.0a	12a	0.09a	56.3a	52.3a
46 °C+20 min	1.5a	35.3b	12a	0.12a	56.9a	53.1a
46 °C+25 min	1.5a	28.5c	13a	0.12a	56.1a	53.9a
46 °C+30 min	1.5a	25.0c,d	11a	0.09a	56.1a	52.9a
48 °C+4 min	1.5a	25.9c,d	12a	0.08a	56.2a	52.7a
48 °C+6 min	1.5a	29.4b,d	12a	0.10a	55.9a	52.4a
48 °C+8 min	1.4a	21.5a,d	12a	0.09a	55.9a	53.3a
50 °C+1 min	1.4a	21.1a,d	11a	0.10a	55.5a	52.9a
50 °C+2 min	1.5a	23.7c,d	11a	0.10a	55.9a	53.3a
50 °C+4 min	1.4a	24.9c,d	12a	0.11a	55.5a	52.1a

*Different letters within a column indicate that means are significantly different ($P<0.05$).

Table 6 – ANOVA P-values ($\alpha = 0.05$) for the effect of treatment, storage and treatment × storage interaction on persimmon quality parameters

	Weight loss	Firmness	Soluble solids	Acidity	Peel colour	Pulp colour
Treatment (T)	0.0729	<0.0001	0.7965	0.0628	<0.0001	0.0021
Storage (S)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.4480
T × S	0.0263	<0.0001	0.0959	0.0158	<0.0001	0.0002

*$P<0.05$ indicates a significant effect at the 5% level from the influence of treatment, storage and treatment × storage on quality parameters.

3.4.5. *Visual observations*

In all RF treatments, the calyx was slightly browner than controls and the browning was more severe in the longest holding time in each of three target temperatures. No shrivel or skin browning was observed in treated fruits.

4. Conclusions

Water-assisted RF heating was investigated as a quarantine treatment for Mexican fruit fly in ‘Fuyu’ persimmons at 46, 48 and 50 °C. Quality parameters, including weight loss, firmness, soluble solids and titratable acidity, peel and pulp colour, were evaluated after 7 days of room and cold storage. All RF treatments except for 48 °C+8 min holding either significantly improved or had no effect on the overall quality of persimmons. Increased firmness in cold-stored treated fruits may be useful for extending the storage life of persimmons. Based on the results, RF treatments for 46 °C+25 min holding, or 48 °C+6 min holding, or 50 °C+2 min holding have the potential to provide 100% mortality of Mexican fruit fly with acceptable fruit quality. Water-assisted RF heating can overcome the heating non-uniformity problem associated with RF treatments in fresh fruits. Large-scale tests are needed to establish a quarantine protocol for persimmons using the water-assisted RF heating technique.

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