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Influence of hot water treatments on postharvest physicochemical characteristics of Hayward and Jintao kiwifruit slices

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Abstract

The effect of precutting hot water treatments on the quality of minimally processed kiwifruits was studies. Whole fruits were subjected to hot water dipping (HWD) at 45 °C for 25 or 75 min, minimally processed, packed and stored at 0 °C for 8 days. Weight loss, respiration rate, gas composition, texture, color, titratable acidity, pH, soluble solids content, sensory analysis, vitamin C, total polyphenols, antioxidant capacity, and microbial analysis were investigated. An overall beneficial effect of HWD 45 °C/75 min on the postharvest quality was observed. The fruits subjected to this treatment showed lower respiration rate, maintained the initial color and presented a better visual quality compared to the control. Moreover, both in Hayward and Jintao, heat treatments inhibited the microbial growth during storage. The study selected HWD 45 °C/75 min as the optimal combination to retain postharvest quality of fresh-cut kiwifruit for the cold storage period and throughout the supply chain.

Practical applications

Extending the shelf-life and improving the food safety without chemical treatments will have a positive impact on industry and consumers. The aim of this work was to evaluate the effect of precut hot water treatment on quality characteristics, microbial growth, and visual aspects of fresh-cut kiwifruit slices. In general, hot water treatments significantly controlled weight losses, color parameters, and microbiological quality of minimally processed kiwifruits. The results indicated that postharvest hot water dipping of whole kiwifruits could be used as an emergent, clean, and environmental friendly process to improve the shelf-life.

1 | INTRODUCTION

With a production exceeding 450.000 tons in 2014, kiwifruit is a very important crop with high economic importance in Italy (Food and Agriculture Organization, 2016). Although kiwifruits have been known to have great possibility for industrial utilization (fresh-cut, fruit puree, juices), limited processed kiwifruit commodity are present in the retail stores. Ready-to-eat fruits maintains high nutritional value and fresh quality over their shelf-life, but it is recognized that fresh-cut processing accelerates senescence, loss of quality and microbial growth resulting in loss of nutritional, sensorial quality, and commercial value (Gil, Aguayo, & Kader, 2006; Watada, Ko, & Minott, 1996). Thus, there is the necessity to find postharvest techniques to maintain fruits quality and extend the shelf-life of fresh-cut products.

Recently, fresh-cut companies have directed to decrease the use of chemicals to prolong postharvest life of fruit and vegetables. Therefore, the application of innovative and unusual physical techniques has become more important. Among these alternatives practices, UV-C, gamma irradiation, heat treatment, hypobaric treatment, and modified atmosphere have been applied to many fresh products (Fallik, 2004; Golding et al., 2014; Hashmi, East, Palmer, & Heyes, 2014; Karabulut & Baykal, 2004). Mild heat-treatments reduce ethylene production and respiration rate, delay softening, limit moisture loss, and control browning during storage of a wide range of fruits like bananas, apples, strawberries, and peaches (Ghasemnezhad, Marsh, Shilton, Babalar, & Woolf, 2008; Jemric et al., 2011; Martinez & Civello, 2008; Shao et al., 2007). Moreover, different studies indicate that heat-treatments improve quality and reduce undesirable flavors (D'Aquino, Chessa, & Schirra,

2014). Precutting heat treatment could be used to extend the shelf-life of melons and mangoes fresh-cut (Charles, Morgado, Mattiuz, & Sallanon, 2015; Lamikanra, Bett-Garber, Ingram, & Watson, 2005). Koukounaras, Diamantidis, and Sfakiotakis (2008) reported that heating fresh-cut peach at 50 °C before cutting significantly limited flesh browning and controlled firmness loss during shelf-life. In fresh-cut Braeburn apple slices the use of hot water treatments and calcium ascorbate dipping increased the antioxidant activity (Aguayo, Jackman, Stanley, & Woolf, 2015). In fresh-cut kiwifruits, Beirão-da-Costa, Steiner, Correia, Empis, and Moldao-Martins (2006) showed that moderate heat treatments changed the physiology and biochemistry of the fruits and preserved fruit quality during storage. Moreover, heat precutting treatments below 45 °C increased flesh firmness and preserved soluble solids content of fresh-cut kiwifruits (Beirão-da-Costa, Cardoso, Martins, Empis, & Moldão-Martins, 2008).

The objective of the present work is to evaluate the effect of mild heat pretreatments on minimally processed kiwifruit quality, physicochemical characteristics, microbiological, and visual aspects, both immediately after the treatment and during the whole storage period.

2 | MATERIAL AND METHODS

2.1 | Plant material

Samples of *Actinidia deliciosa* cv Hayward and *Actinidia chinensis* cv Jintao (which are marketed as Jingold™ from the Italian Kiwigold® consortium) were used. Kiwifruits samples were harvested from a commercial orchard located in the north–west of Italy (Scarnafigi -CN-). Only fruits with uniform size, shape, maturity stage, and no external defects were used.

2.2 | Hot water dipping and storage

Whole kiwifruits were dipped in a thermostatically controlled water bath set at 45 °C for 25 or 75 min. Control kiwifruits were dipped in water at ambient temperature. The treated and control kiwifruits were then stored for 24 hr at 0 °C before fresh-cut processing. Later fruits were hand peeled and cut into 8 mm slices with a commercial slicing machine and packed in PLA trays (8 slices per tray) 14 cm × 7 cm × 9 cm in size (Compac, Italy). The trays were machine-enveloped with a 40 μm film (Compac, Italy, O_2 transmission rates of 480 mL m^{-2} day^{-1} atm^{-1} and a water vapor transmission rate (WVTR) of 15.3 g m^{-2} day^{-1} at 39 °C and 90% RH) and stored at 0 °C for 8 days.

2.3 | Headspace gas composition

The CO_2 and O_2 values (kPa) inside the packaging were evaluated with a Checkmate gas analyzer (PBI Dansensor, Italy). The gases concentrations were determined with a paramagnetic sensor for O_2 and an infrared sensor for CO_2 concentration. Three measurements were taken for each treatment at Days 1, 2, 3, 6, 7, and 8 of cold storage.

2.4 | Respiration rate

Respiration rate was determined using the method of Zhou, Ye, Zhang, Su, and Du (2013). Three trays for each treatment were placed at room temperature for 24 hr and the headspace gas samples were analyzed using a Check-Point gas analyzer (PBI Dansensor, Italy). Respiration rate was calculated as follows: $RR = \Delta CO_2\ V/\Delta t\ m$. Where ΔCO_2 was obtained as differences in CO_2 concentration in 24 hr, V is the volume of the sample tray, Δt is the time period (24 hr), and m is the fruits mass. The results were expressed as mL CO_2/kg/hr.

2.5 | Weight loss

Weight loss was calculated in each sample tray during cold storage. The results (%) were expressed as the weight loss with respect to the initial weight.

2.6 | Quality evaluation

2.6.1 | Flesh color evaluation

Flesh color measurements were determined on kiwi slices cut surface with a Minolta Chroma Meter CR-400 (Konica Minolta, Japan). Ten measurements (10 slices) per treatment were performed at Day 0 and after 1, 3, 6, and 8 days of storage. The results was expressed as CIE-LAB (L^*, a^*, b^*) color space. The color was also expressed as h^* (hue angle) and C^* (chroma or saturation).

2.6.2 | Total soluble solids content, titratable acidity, pH, and dry matter

Physicochemical quality of kiwifruit samples was evaluated at the beginning of the trial (time 0) and at the end (8 days). Total soluble solids content (TSSC) (°Brix) was measured in the undiluted filtered juice extracted from 10 slices from each treatment using a handheld refractometer (ATAGO-1; Atago Co. Ltd., Tokyo, Japan). Titratable acidity (TA; meq/l) and pH were determined by adding 50 mL distilled water into 10 mL of filtered juice and titrated with 0.1 N NaOH to pH 8.2 with an automatic titrator (Compact 44–00, Crison Instruments SA, Barcelona, Spain). To evaluate the dry matter, kiwifruit slices were dried in oven set at 60–65 °C until constant weight (approximately 72 hr). Dry matter was calculated by percentage weight difference. Three replicates were made at Day 0 and at the end of storage period (8 days) for each treatment.

2.6.3 | Texture evaluation

Sample slices were air-conditioned at 20 °C for 3 hr before the texture evaluation with a Texture Analyzer TA-XT2i (Stable Micro Systems Ltd., Godalming, UK) with a 25-kg load cell.

2.6.4 | Firmness

For firmness evaluation, a cylindrical 4-mm-diameter stainless plunger (P/4) was used. The experimental conditions were: pretest speed 5 mm/s; test speed 1 mm/s; post-test speed 10 mm/s; penetrating distance of 4 mm into the slice; and data acquisition rate of 200 pulses per second. Force–distance curves were obtained from the puncture

tests and firmness values were taken as the peak forces values and expressed in N. Firmness means values were calculated from the results of 30 slices for each treatment at Day 0 and after 1, 3, 6, and 8 days of cold storage.

2.6.5 | Texture profile analysis

Texture profile analysis (TPA) was made with a 75 mm diameter cylinder (P/75) probe. The test conditions used for the measurement were: pretest speed 5.0 mm/s, test speed 1.0 mm/s, post-test speed 10.0 mm/s, penetration distance 3 mm, rest period of 5 s between the two cycles and data acquisition rate of 200 pulses per second. Values for hardness, springiness, chewiness and resilience were calculated on 30 slices for each treatment at Day 0 and after 1, 3, 6, and 8 days of cold storage.

2.7 | Visual evaluation

The visual quality evaluation of fresh-cut kiwifruit samples was performed on Day 6 of storage using a 5-point evaluation scales for appearance (fresh-like appearance), water stress level (surface moisture), flavor (fresh-like aroma), and overall acceptability (Beaulieu & Lea, 2003). The higher value corresponded to superior quality. The visual evaluations were made by the same panel of eight people that was qualified to identify and score the visual characteristics of fresh fruits. Each sample was characterized by a three-digit number to cover the treatment identity to minimize subjectivity and guarantee the precision. All samples were evaluated individually.

2.8 | Total phenolic content and total antioxidant capacity evaluation

To determine the total phenolic content and the total antioxidant capacity, extracts were set on 10 g of fresh fruits adding 25 mL of methanol and homogenizing for 1 min under reduced light conditions. Extracts were then centrifuged (3,000 rpm for 15 min) and the clear supernatant collected and stored at −26 °C. Three replicates were performed at Day 0 and at the end of storage period (8 days) for each treatment. Total phenolic content was determined with the method of Folin–Ciocalteu (Singleton, Orthofer, & Lamuela-Raventos, 1999) where 0.5 g of the extract was mixed with 2.5 mL of Folin–Ciocalteu reagent and 10 mL of sodium carbonate. Absorbance was measured at 765 nm using a U-5100 Spectrophotometer (Hitachi, Japan) and the results were expressed as mg gallic acid equivalents (GAE) per 100 g of fresh fruits. Three replicates for each treatment were performed at day 0 and at the end of storage period (8 days).

Total antioxidant capacity was evaluated using the ferric reducing antioxidant power test (FRAP), with some modifications of the Pellegrini et al. (2003) method. Results were expressed as mmol Fe^{2+}/kg of fresh kiwifruits. The reported values are the mean ± *SE* of three replicates for each treatment, measured at Day 0 and at the end of storage period (8 days). All reagents and standards were of analytical purity "pro-analysis" and were purchased from SIGMA (Sigma Italiana SRL, Ozzano Emilia, Italy).

2.9 | Extraction and evaluation of vitamin C

Vitamin C content was determined by the method of Gonzales-Molina, Moreno, & Viguera, 2008) and the results were expressed as mg/100 g of fresh kiwifruits. Reported values are the mean ± *SE* of three replicates for each treatment at Day 0 and at the end of storage period (8 days). All standards and reagents were of analytical purity "pro-analysis" and were purchased from SIGMA (Sigma Italiana SRL, Ozzano Emilia, Italy).

2.10 | Microbiological evaluation

Yeasts and molds content was evaluated at Day 0 and at the end of cold storage (8 days), as described by the Compendium of Methods for the Microbiological Examination of Foods (Vanderzant & Splettstoesser, 1992). A sample of 30 g of fresh kiwifruits was blended (Stomacher®400 Circulator, Seward, Worthing, UK) with 270 mL of peptone buffered water (Sigma Italiana SRL, Ozzano Emilia, Italy) for 1 min in a Stomacher® bag. Appropriate dilutions were equipped. Rose Bengal agar (Sigma Italiana SRL, Ozzano Emilia, Italy) was used for the yeasts and molds evaluation. All the plates were incubated at 30 °C for 5 days. Microbial counts were expressed as colony forming units (CFU) g^{-1}.

3 | STATISTICAL ANALYSIS

Where possible, results were expressed as mean ± *SE*. Data were subjected to analyses of variance (ANOVA) and the means were compared by Tukey's HSP test (honest significant differences). Source of variations were the heat treatment and the storage time. Differences between mean values were considered significant when $p \leq .05$. STATISTICA software was used for all data analyses (version 6.0, StatSoft Inc., Tulsa, USA).

4 | RESULTS AND DISCUSSION

In Hayward, the quality attributes values before the hot water dipping were: hardness, 28.53 N; L^*, 56.54; h^*, 114.91; C^*, 33.85; pH, 3.25; TA, 304.98 meq/L; TSSC, 7.9°Brix; and dry matter, 17.52%. In Jintao: hardness, 19.22 N; L^*, 59.31; h^*, 103.65; C^*, 28.04; pH, 3.36; TA, 219.42 meq/L; TSSC, 12.80°Brix and dry matter, 20.45%.

4.1 | Headspace gas composition

During storage, gas composition (O_2 and CO_2) within packages was monitored to determine if the different HWT affected the quality of kiwifruit slices (Figures 1 and 2). In Hayward slices CO_2 partial pressure increased in all the samples without reaching an equilibrium within the package and at a faster percentage during the last 3 days of storage, in particular in control samples. The HWT samples showed a lower CO_2 concentration compared to control. This result indicates a decreased respiration rate in treated kiwifruits compared to the control. In this case, HWT significantly affected the CO_2 production by fresh-cut kiwifruit after 6, 7, and 8 days of storage. Inversely, O_2 partial pressure inside the trays decreased during storage reaching a final partial

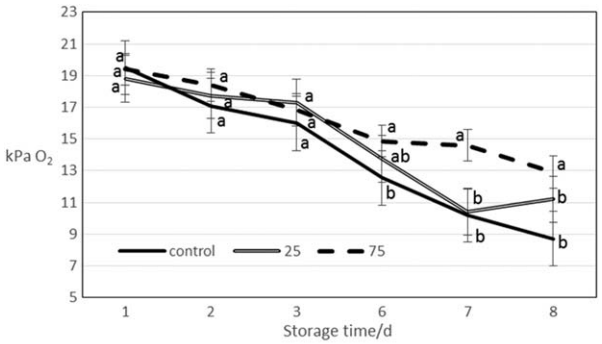

FIGURE 1 O_2 partial pressure (kPa) of fresh-cut Hayward kiwifruit slices heat-treated. 25 min of heat treatment at 45 °C (25), 75 min of heat treatment at 45 °C (75), and control (control), storage at 0 °C for 8 days. Means sharing the same letters among treatments are not significantly different from each other (Tukey's HSD test, $p \leq .05$). Data is average of three replicates ± *SE*

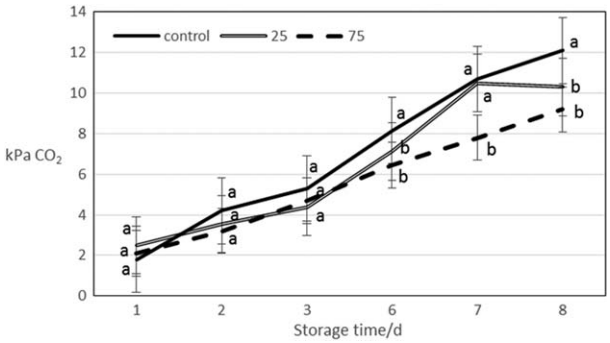

FIGURE 2 CO_2 partial pressure (kPa) of fresh-cut Hayward kiwifruit slices heat-treated. 25 min of heat treatment at 45 °C (25), 75 min of heat treatment at 45 °C (75), and control (control), storage at 0 °C for 8 days. Means sharing the same letters among treatments are not significantly different from each other (Tukey's HSD test, $p \leq .05$). Data is average of three replicates ± *SE*

pressures between 9 and 13 kPa after 8 days of storage. Significantly lower CO_2 values were obtained in HWT samples from the sixth day of storage and forwards. Reduced respiration rates as a result of HWT have been observed in previous works on fresh-cut kiwifruits (Beirão-da-Costa, Steiner, et al., 2008) and fresh-cut peaches (Koukounaras et al., 2008).

In Jintao, CO_2 partial pressure increased in all samples in a similar way. HWT slices showed slight lower values compared to control, denoting a reduced metabolic activity but without significant differences between samples (data not shown). CO_2 partial pressure reached final values of about 8.8, 8.3, and 8 kPa CO_2 in control, HWT for 25 and HT for 75 min, respectively.

4.2 | Respiration rate

In Hayward HWT samples a lower respiration rate was observed compared to control (0.59 mL CO_2 hr^{-1} g^{-1} FW, 0.54 mL CO_2 hr^{-1} g^{-1} FW, and 0.62 mL CO_2 hr^{-1} g^{-1} FW for 25 min HWT, 75 min HWT and control, respectively). Jintao control fruits and HWT (25 min) samples showed the same respiration rate values (0.7 mL CO_2 hr^{-1} g^{-1} FW). By contrast, the application of HWT for 75 min reduced the respiration rate of about 10% (0.62 mL CO_2 hr^{-1} g^{-1} FW).

The lower respiration rates may be due to a slower ripening process due to HWT and a minor microbial growth in accordance with Aguayo, Escalona, and Artés (2007). The same result was found also in fresh-cut HWT melon (Silveira, Aguayo, Chisari, & Artés, 2011).

4.3 | Weight loss

Hayward HWT samples showed, on average, lower weight losses than control with significant differences ($p \leq .05$) after 2, 3, 7, and 8 days of cold storage. In Jintao samples no significant effect of HWT on weight losses was found (data not shown). This result is in agreement with prior works, in which HWT determined no significant changes in weight losses (Fallik, 2004; González-Aguilar et al., 2000).

4.4 | Quality evaluation

4.4.1 | Flesh color evaluation

Table 1 shows the effect of HWT on lightness values of minimally processed Hayward and Jintao during cold storage (0 °C) for 8 days.

TABLE 1 Changes in color parameter (L*) of fresh-cut kiwifruit slices heat-treated

		Storage time/d				
	Treatment	0	1	3	6	8
Hayward						
*L**(C)	control	$57.00 \pm 3.05^{A,a}$	$54.33 \pm 6.04^{AB,a}$	$53.91 \pm 3.66^{AB,a}$	$49.27 \pm 3.25^{B,\ b}$	$51.28 \pm 4.05^{B,a}$
	25	$57.01 \pm 2.36^{A,a}$	$55.37 \pm 3.98^{AB,a}$	$54.07 \pm 3.47^{AB,a}$	$54.33 \pm 3.20^{AB,a}$	$52.59 \pm 2.81^{B,a}$
	75	$56.50 \pm 2.76^{A,a}$	$55.10 \pm 4.20^{A,a}$	$55.05 \pm 3.53^{A,a}$	$56.36 \pm 2.21^{A,a}$	$53.36 \pm 4.85^{B,a}$
Jintao						
*L**(C)	control	$55.99 \pm 2.78^{A,a}$	$52.86 \pm 2.91^{AB,a}$	$50.73 \pm 3.83^{AB,\ b}$	$50.36 \pm 5.48^{BC,a}$	$45.76 \pm 4.79^{C,a}$
	25	$56.46 \pm 3.69^{A,a}$	$51.90 \pm 3.62^{AB,a}$	$55.25 \pm 3.26^{A,\ ab}$	$54.29 \pm 3.01^{A,a}$	$48.59 \pm 5.46^{B,a}$
	75	$54.68 \pm 3.51^{A,a}$	$55.48 \pm 4.96^{A,a}$	$57.07 \pm 4.26^{A,a}$	$54.34 \pm 3.22^{A,a}$	$51.54 \pm 5.58^{A,a}$

Note. 25 min of heat treatment at 45°C (25), 75 min of heat treatment at 45°C (75) and control (control), storage at 0°C for 8 days.
Means sharing the same letters in rows (A, B, C) and in column (a, b, c) are not significantly different from each other (Tukey's HSD test, $p \leq 0.05$).
Data is average of ten replicates ± SE.

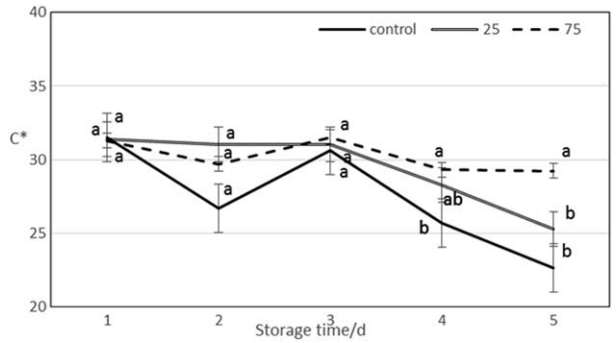

FIGURE 3 Changes in color parameter (C^*) of Hayward fresh-cut kiwifruit slices heat-treated. 25 min of heat treatment at 45 °C (25), 75 min of heat treatment at 45 °C (75), and control (control), storage at 0 °C for 8 days. Means sharing the same letters in the same storage time are not significantly different from each other (Tukey's HSD test, $p \leq .05$). Data is average of ten replicates ± *SE*

Storage time affected significantly ($p \leq .05$) the color parameters in all samples, excepted for Jintao HWT samples for 75 min that exhibited a general decrease during the storage period.

After 6 days of storage, Hayward HWT samples showed significant higher L^* values than control and at the end of storage period HWT samples (75 min) lost 6.3% of their initial L^* value, whereas HWT (25 min) and control samples showed higher losses of about 7.7% and 10.05%, respectively. This result validates previous scientific works about the positive effect of HWT on controlling tissue browning (Abreu, Beirao-da-Costa, Goncalves, Beirao-da-Costa, & Moldao-Martins, 2003).

Hue angle values during storage ranged from 103.84 to 102.34, from 104.15 to 103.57, and from 103.35 to 104.15, in control and in 25 min HWT and 75 min HWT, respectively, without significant changes with storage time or treatments (data not shown).

The 75 min HWT samples did not show any color changes in term of C^* values during storage and remained quite stable up to the end of storage (Figure 3). By contrast, control samples exhibited a significant reduction in C^* parameter during storage and reached their minimum values (22.6) after 8 days of storage, indicating a loss of greenness and a darkening during storage.

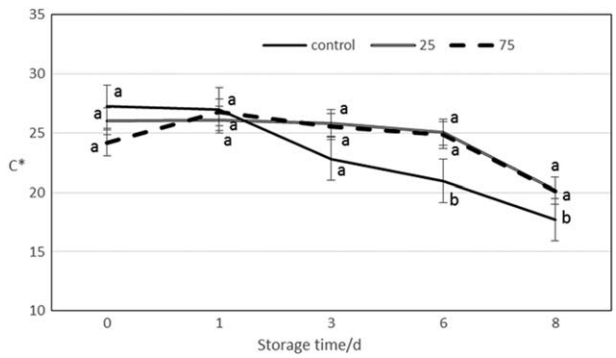

FIGURE 4 Changes in color parameter (C^*) of Jintao fresh-cut kiwifruit slices heat-treated. Twenty five minutes of heat treatment at 45 °C (25), 75 min of heat treatment at 45 °C (75), and control (control), storage at 0 °C for 8 days. Means sharing the same letters in the same storage time are not significantly different from each other (Tukey's HSD test, $p \leq .05$). Data is average of ten replicates ± *SE*

In Jintao samples, the higher L^* values of HWT slices confirmed that it is an effective treatment to control flesh browning of minimally processed fruits during storage (Table 1), in particular after 8 days of storage. In kiwifruit slices, the increasing of browning during storage is due to the development of translucent symptoms and not to the enzymatic browning because kiwifruits have low tannin and polyphenoloxidase content (Munira, Rosnah, Zaulia, & Russly, 2013; Okuse & Ryugo, 1981). In this study, HWT limited the color reduction in agreement with Koukounaras et al. (2008) in peaches. Hue angle values during storage ranged from 114.76 to 116.11, from 114.57 to 115.69, and from 114.82 to 113.61, in control and in 25 and 75 min HWT respectively, without significant differences between samples. Considering C^* values, HWT samples showed no significative changes in C^* values during storage, conversely, control samples showed a significant decline in C^* parameter from the third day of storage and lost about 35% of the original color after 8 days of storage (Figure 4). In this case HWT significantly reduced the C^* color changes and consequently little variations were found in slices appearance. Reduced color changes as a result of HWT have also been observed in other studies (Beirão-da-Costa, Cardoso, et al., 2008).

4.4.2 | TSSC, TA, pH, and dry matter

A stable or increasing TSSC after HWT has been previously described by Beirão-da-Costa, Steiner, et al. (2008) in minimally processed kiwifruits. In this work, TSSC decreased or remained quite stable during storage in all samples (Table 3). In Hayward, 75 min HWT samples showed significant lower TSSC and TA than control slices. Moreover, after 8 days of storage, all samples showed slight increases in pH (Table 2), coincident with TA decreases.

In Jintao, significant effect of HWT and storage time on TA was observed.

4.4.3 | Firmness evaluation

In general, in Hayward a significant loss of firmness was observed throughout refrigerated storage but without differences between treatments. No beneficial effects of HWT during storage was found (Table 3). The same result was obtained in Jintao samples, where no significant differences ($p \leq .05$) were detected between treated and control samples. During storage, softening significantly increased in all treatments (Table 3). Nonuniform flesh characteristics of kiwifruits lead to a large variability between kiwifruit samples slices mechanical characteristics. Published works reported similar results (Agar, Massantini, Hess-Pierce, & Kader, 1999; Beirão-da-Costa, Steiner, et al., 2008).

4.4.4 | TPA profile analysis

The instrumental TPA values are presented in Tables 4 and 5. Hardness, springiness, and chewiness decreased during storage in all treatments corresponding to fruit softening as a consequence of tissue senescence (Yang et al., 2007). In Hayward, hardness and chewiness were significantly lower ($p \leq .05$) after 8 days of storage, while

springiness remained stable in all samples. Previous research found that springiness was significantly affected by storage temperature more than by the treatments (Chen & Opara, 2013). In this work, HWT significantly influenced hardness, after 1 and 8 days of storage (Table 4).

In Jintao, hardness decreased during storage and the HWT for 75 min exhibited the highest values compared to the other samples (Table 4). At the end of the storage, this treatment lost about 21.4% of their initial hardness compared to 36.2% of HWT (25 min) and 54.9% of control.

Springiness values remained stable during storage, or, in some cases, increased but without significant differences between treatments and storage time.

Chewiness values reflected the resistance of fruit to chewing and results showed a significant decrease during storage in control and HWT (25 min) but without significant differences between them. The same results were obtained in strawberry during storage period (Caner, Aday, & Demir, 2008). This parameter is strictly associated to the fresh structure and to the composition of fruit cell wall (Yang et al., 2007).

4.5 | Visual evaluation

In general, HWT showed a beneficial effect on visual quality of kiwifruit slices. In particular, after 6 days of storage the Hayward samples showed an overall acceptability score of 2.5 for control, 3 for 25 min HWT, and 3.75 for 75 min HWT samples. Also in the evaluation of appearance parameter HWT samples highlighted higher scores of about 3.62 for 25 min HWT and 3.87 for 75 min HWT compared to 2.65 of control samples. Lower scores of this parameter was principally caused by the increase of translucency in some of the control slices. Moreover, in 75 min HWT samples no dehydration (water stress level) and off-odor were detected. Published works (Koukounaras et al., 2008) reported the same result in precutting peaches HWT at 50 °C for 10 min.

4.6 | Total phenolic content and total antioxidant capacity

Hayward samples showed just after HWT significant differences ($p \leq .05$) in total phenolic content between control and heat treatments samples (Table 5). The total phenolic content of control sample was 104.49 mg GAE 100 g^{-1} FW, significantly higher compared to HWT samples (86.48 and 86.39 mg GAE 100 g^{-1} FW in HT kiwifruit HT for 25 and 75 min, respectively). A significant loss in phenolic content after HWT was previously reported (Siddiq, Roidoung, Sogi, & Dolan, 2013). During cold storage, total phenolic content decreased without significant differences between treatments. HWT significantly also decreased the level of antioxidant capacity just after the treatment but not during storage (Table 5).

In Jintao samples control slices showed the same trend observed for Hayward with significantly higher values (169.13 mg per 100 g FW) than HWT samples (145.88 and158.61 mg per 100 g FW in 25 and 75

TABLE 2 Changes in quality parameter of fresh-cut kiwifruit slices heat-treated

		TSSC (°Brix)		TA (meq/L)		pH		Dry Matter (%)	
		Storage time/d		Storage time/d		Storage time/d		Storage time/d	
	Treatment	0	8	0	8	0	8	0	8
Hayward	control	$10.1 \pm 0.52^{A,a}$	$10.27 \pm 1.23^{A,a}$	$278.49 \pm 5.25^{A,a}$	$255.86 \pm 5.78^{B,a}$	$3.28 \pm 0.5^{A,a}$	$3.43 \pm 0.19^{A,a}$	$19.78 \pm 0.85^{A,a}$	$19.51 \pm 1.17^{A,a}$
	25	$9.9 \pm 0.26^{A,a}$	$9.9 \pm 0.32^{A,ab}$	$269.34 \pm 8.15^{A,b}$	$214.05 \pm 6.79^{B,b}$	$3.31 \pm 0.33^{A,a}$	$3.52 \pm 0.18^{A,a}$	$19.88 \pm 0.65^{A,a}$	$19.62 \pm 0.97^{A,a}$
	75	$9.4 \pm 1.2^{A,b}$	$9.5 \pm 0.32^{A,b}$	$256.67 \pm 6.35^{A,c}$	$245.27 \pm 8.15^{A,ab}$	$3.37 \pm 0.11^{A,a}$	$3.46 \pm 0.23^{A,a}$	$20.28 \pm 0.12^{A,a}$	$19.32 \pm 0.88^{A,a}$
Jintao	control	$12.9 \pm 1.32^{A,a}$	$13.15 \pm 1.05^{A,a}$	$200.17 \pm 3.22^{A,a}$	$153.87 \pm 5.25^{B,b}$	$3.47 \pm 0.12^{A,a}$	$3.66 \pm 0.18^{A,a}$	$22.17 \pm 1.35^{A,a}$	$22.18 \pm 0.74^{A,a}$
	25	$12.9 \pm 0.88^{A,a}$	$12.77 \pm 1.22^{A,a}$	$193.8 \pm 4.12^{A,b}$	$172.61 \pm 7.23^{B,a}$	$3.61 \pm 0.15^{A,a}$	$3.66 \pm 0.18^{A,a}$	$21.89 \pm 1.42^{A,a}$	$21.04 \pm 1.14^{A,a}$
	75	$12.6 \pm 1.5^{A,a}$	$12.77 \pm 0.85^{A,a}$	$203.47 \pm 5.68^{A,ab}$	$173.11 \pm 6.32^{B,a}$	$3.53 \pm 0.21^{A,a}$	$3.72 \pm 0.20^{A,a}$	$20.73 \pm 1.41^{A,a}$	$20.61 \pm 2.12^{A,a}$

Note. Total Soluble Solid Content (TSSC), Titratable Acidity (TA), pH and Dry Matter. 25 min of heat treatment at 45°C (25), 75 min of heat treatment at 45°C (75) and control (control), storage at 0°C for 8 days.
Means sharing the same letters in rows (A, B, C) and in column (a, b, c) are not significantly different from each other (Tukey's HSD test, $p \leq 0.05$). Data is average of three replicates ± SE.

TABLE 3 Changes in texture parameter of Hayward fresh-cut kiwifruit slices heat-treated

	Storage time/d				
	0	1	3	6	8
Firmness (N)					
Control	$7.94 \pm 1.21^{A,a}$	$6.12 \pm 1.33^{AB,a}$	$5.32 \pm 2.01^{AB,a}$	$5.29 \pm 1.15^{B,a}$	$4.84 \pm 0.51^{B,a}$
25	$8.62 \pm 0.98^{A,a}$	$6.32 \pm 1.21^{B,a}$	$5.81 \pm 0.92^{B,a}$	$5.84 \pm 0.84^{B,a}$	$5.65 \pm 0.45^{B,a}$
75	$7.48 \pm 1.01^{A,a}$	$6 \pm 1.11^{AB,a}$	$5.41 \pm 0.82^{B,a}$	$5.26 \pm 0.65^{B,a}$	$5.26 \pm 0.52^{B,a}$
Hardness (N)					
Control	$19.90 \pm 1.00^{A,a}$	$19.01 \pm 0.96^{A,a}$	$16.20 \pm 1.05^{AB,a}$	$13.76 \pm 0.99^{AB,a}$	$12.12 \pm 0.87^{B,a}$
25	$21.19 \pm 1.15^{A,a}$	$20.07 \pm 1.14^{A,\ ab}$	$17.80 \pm 1.12^{AB,a}$	$14.05 \pm 1.02^{BC,a}$	$10.86 \pm 0.78^{C,\ b}$
75	$19.48 \pm 1.11^{A,a}$	$17.59 \pm 1.13^{B,\ ab}$	$15.92 \pm 0.96^{AB,a}$	$14.06 \pm 1.02^{AB,a}$	$12.24 \pm 1.02^{B,a}$
Springiness					
Control	$0.62 \pm 0.08^{A,a}$	$0.70 \pm 0.08^{A,a}$	$0.61 \pm 0.05^{A,a}$	$0.64 \pm 0.06^{A,a}$	$0.58 \pm 0.03^{A,a}$
25	$0.67 \pm 0.06^{A,a}$	$0.73 \pm 0.07^{A,a}$	$0.69 \pm 0.04^{A,a}$	$0.58 \pm 0.05^{A,a}$	$0.67 \pm 0.04^{A,a}$
75	$0.64 \pm 0.06^{A,a}$	$0.59 \pm 0.05^{A,a}$	$0.61 \pm 0.05^{A,a}$	$0.55 \pm 0.03^{A,a}$	$0.61 \pm 0.04^{A,a}$
Chewiness (N)					
Control	$10.13 \pm 0.02^{A,a}$	$10.40 \pm 0.06^{A,a}$	$7.68 \pm 0.08^{AB,a}$	$6.70 \pm 0.09^{AB,a}$	$4.87 \pm 0.03^{B,a}$
25	$11.79 \pm 0.03^{A,a}$	$11.63 \pm 0.06^{A,a}$	$9.69 \pm 0.09^{AB,a}$	$7.01 \pm 1.01^{B,a}$	$5.53 \pm 0.04^{B,a}$
75	$10.61 \pm 0.05^{A,a}$	$8.29 \pm 0.04^{A,\ b}$	$8.25 \pm 0.09^{A,a}$	$6.1 \pm 0.07^{A,a}$	$5.78 \pm 0.04^{A,a}$

Note. 25 min of heat treatment at 45°C (25), 75 min of heat treatment at 45°C (75) and control (control), storage at 0°C for 8 days.
Means sharing the same letters in rows (A, B, C) and in column (a, b, c) are not significantly different from each other (Tukey's HSD test, $p \leq 0.05$).
Data is average of ten replicates ± SE.

min HT kiwifruits) just after processing. During storage at 0°C no significant changes were observed (Table 5) according to Gil et al. (2006) that showed the same result on whole and minimally processed kiwifruits during 9 days of storage.

HWT showed an insignificant effect on total antioxidants both at time 0 and at the end of storage, in agreement with previous work in fresh-cut peach slices (Koukounaras et al., 2008).

4.7 | Vitamin C

Vitamin C contents decreased during storage without significant differences between treatments or storage time (Table 5). The same result was also obtained by Beirão-da-Costa, Cardoso, et al. (2008) and Yang et al. (2007) in kiwifruit slices, and may be in part justified by the pH of the fruit. For this reason, Ferguson and Macrae (1991) described that the vitamin C content in kiwifruits showed slight or no decrease during storage period.

TABLE 4 Changes in texture parameter of Jintao fresh-cut kiwifruit slices heat-treated

	Storage time/d				
	0	1	3	6	8
Firmness (N)					
Control	$4.05^{A,a}$	$3.07^{AB,a}$	$2.06^{BC,a}$	$2.33^{C,a}$	$1.73^{C,a}$
25	$5.08^{A,a}$	$5.49^{A,a}$	$4.9^{B,a}$	$2.14^{B,a}$	$1.93^{B,a}$
75	4.9	$5.51^{A,a}$	$4.34^{AB,a}$	$2.09^{BC,a}$	$1.89^{C,a}$
Hardness (N)					
Control	$17.26^{A,a}$	$14.95^{AB,a}$	$12.63^{AB,a}$	$11.52^{B,a}$	$11.01^{B,a}$
25	$20.21^{A,a}$	$15.15^{B,a}$	$13.22^{BC,a}$	$11.60^{BC,a}$	$9.10^{C,a}$
75	$17.09^{A,a}$	$15.22^{A,a}$	$13.47^{A,a}$	$11.64^{A,a}$	$13.42^{A,a}$
Springiness					
Control	$0.64 \pm 0.07^{A,a}$	$0.66 \pm 0.04^{A,a}$	$0.71 \pm 0.02^{A,a}$	$0.67 \pm 0.03^{A,a}$	$0.66 \pm 0.02^{A,a}$
25	$0.71 \pm 0.06^{A,a}$	$0.67 \pm 0.07^{A,a}$	$0.66 \pm 0.02^{A,a}$	$0.65 \pm 0.03^{A,a}$	$0.62 \pm 0.03^{A,a}$
75	$0.68 \pm 0.05^{A,a}$	$0.71 \pm 0.06^{A,a}$	$0.71 \pm 0.05^{A,a}$	$0.63 \pm 0.05^{A,a}$	$0.72 \pm 0.03^{A,a}$
Chewiness (N)					
Control	$9.87 \pm 0.12^{A,a}$	$7.95 \pm 0.21^{AB,a}$	$6.29 \pm 0.08^{B,a}$	$5.26 \pm 0.08^{B,a}$	$4.93 \pm 0.07^{B,a}$
25	$11.90 \pm 0.11^{A,a}$	$8.21 \pm 0.14^{A,a}$	$6.12 \pm 0.09^{BC,a}$	$5.50 \pm 0.08^{BC,a}$	$4.36 \pm 0.07^{C,a}$
75	$9.31 \pm 0.08^{A,a}$	$10.89 \pm 0.07^{A,a}$	$7.46 \pm 0.09^{A,a}$	$7.34 \pm 0.09^{A,a}$	$7.06 \pm 0.12^{A,a}$

Note. 25 min of heat treatment at 45°C (25), 75 min of heat treatment at 45°C (75) and control (control), storage at 0°C for 8 days.
Means sharing the same letters in rows (A, B, C) and in column (a, b, c) are not significantly different from each other (Tukey's HSD test, $p \leq 0.05$).
Data is average of ten replicates ± SE.

TABLE 5 Total phenolic content, vitamin C (mg g −1 FW) contents, antioxidant activity (mmol Fe^{2+} kg^{-1} FW) and total phenolic content (mg 100 g^{-1} FW) of fresh-cut kiwifruits slices heat-treated

		Vitamin c (mg g^{-1} FW)		Antioxidant capacity (mmol Fe2+ kg^{-1} FW)		Total phenolic content (mg 100 g-1 FW)	
		Storage time/d		Storage time/d		Storage time/d	
	Treatment	0	8	0	8	0	8
Hayward	Control	$23.72 \pm 4.98^{A,a}$	$18.95 \pm 1.97^{A,a}$	$20.99 \pm 1.22^{A,a}$	$14.40 \pm 1.25^{B,a}$	$104.49 \pm 18.23^{A,a}$	$76.98 \pm 7.58^{B,a}$
	25	$22.99 \pm 3.06^{A,a}$	$21.85 \pm 2.73^{A,a}$	$16.60 \pm 1.02^{A,b}$	$15.16 \pm 0.15^{A,a}$	$86.48 \pm 13.57^{A,b}$	$69.45 \pm 4.21^{B,a}$
	75	$19.75 \pm 4.11^{A,a}$	$16.47 \pm 2.00^{A,a}$	$16.93 \pm 1.26^{A,b}$	$15.03 \pm 1.13^{A,a}$	$86.39 \pm 1.83^{A,b}$	$77.79 \pm 5.16^{B,a}$
Jintao	Control	$66.00 \pm 4.45^{A,a}$	$64.12 \pm 6.71^{A,a}$	$29.99 \pm 0.20^{A,a}$	$29.65 \pm 1.25^{A,a}$	$169.13 \pm 22.23^{A,a}$	$152.51 \pm 21.61^{A,a}$
	25	$60.08 \pm 2.08^{A,a}$	$59.09 \pm 1.87^{A,a}$	$27.91 \pm 1.87^{A,a}$	$31.45 \pm 1.37^{A,a}$	$145.88 \pm 19.57^{A,b}$	$167.03 \pm 17.45^{A,a}$
	75	$56.92 \pm 5.70^{A,a}$	$59.15 \pm 6.05^{A,a}$	$30.47 \pm 1.29^{A,a}$	$31.29 \pm 2.18^{A,a}$	$158.61 \pm 15.32^{A,b}$	$162.99 \pm 16.20^{A,a}$

Note. 25 min of heat treatment at 45°C (25), 75 min of heat treatment at 45°C (75) and control (control), storage at 0°C for 8 days.
Means sharing the same letters in rows (A, B, C) and in column (a, b, c) are not significantly different from each other (Tukey's HSD test, $p \leq 0.05$).
Data is average of three replicates ± SE.

4.8 | Microbiological evaluation

Microbial counts increased during storage (Table 6). HWT significantly reduced the molds and yeasts proliferation compared to control samples that showed higher level of molds and yeasts populations both in Hayward and Jintao. This result was probably due to an immediate reduction of bacterial populations occurred after HWT. The same result was also obtained at the end of storage. In general, the growth of natural microbiota was inhibited by precutting HWT just after the processing and after the storage period.

5 | CONCLUSION

The treatments evaluated in this work showed some beneficial effects on the quality of ready-to-eat kiwifruits. Results indicated that hot water treatments are more effective in Hayward kiwifruits than in Jingold. In general, HWT at 45 °C for 75 min significantly controlled weight losses, color parameters, and microbiological quality of kiwifruits slices. During postharvest storage CO_2 production, respiration rate, visual quality, TSSC, and TA were significantly affected by HWT.

TABLE 6 Changes in molds and yeasts count of fresh-cut kiwifruit slices heat-treated

	Molds (log CFU/g)		Yeasts (log CFU/g)	
	Storage time/day		Storage time/day	
	0	8	0	8
Hayward				
Control	2.45^{a}	4.20^{a}	3.11^{a}	2.62^{a}
25	$<1.60^{b}$	2.31^{b}	2.11^{b}	$<1.60^{b}$
75	2.00^{b}	2.64^{b}	2.41^{b}	$<1.60^{b}$
Jintao				
Control	2.39^{a}	3.68^{a}	2.62^{a}	2.79^{a}
25	$<1.60^{b}$	1.90^{b}	1.60^{b}	1.77^{b}
75	$<1.60^{b}$	1.77^{b}	$<1.60^{b}$	$<1.60^{b}$

Note. 25 min of heat treatment at 45°C (25), 75 min of heat treatment at 45°C (75) and control (control) storage at 0°C for 8 days.
Means sharing the same letters in column are not significantly different from each other (Tukey's HSD test, $p \leq 0.05$).

In conclusion, this study show that hot water treatments (45 °C, 75 min) may be a simple and interesting nonchemical method in addition to the benefits of low temperature postharvest management, to improve the postharvest quality of ready-to-eat kiwifruits.

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