The Heating and Cooling of 'Idared' Apple with Respect to the Duration of the Hot Water Dip Heat Treatment

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Summary

A research was conducted on the effect of heat treatments on the heating and cooling of the 'Idared' apple fruit. The heat treatment was performed as hot water dip (HWD), where fruit were dipped into water at 50 °C, for two, four and six minutes (HWD 50⁰C 2', HWD 50⁰C 4' and HWD 50⁰C 6', respectively). The aim of the study was to determine the effect of heat treatments on the warming and cooling on the fruit which was observed by thermographic images recorded every minute for the duration of 12 minutes in total. The fruit treated with HWD 50°C 6' achieved the highest temperature (50.6 ⁰C), followed by HWD 50⁰C 4' (48.2 ⁰C) and HWD 50⁰C 2' (44.3 ⁰C). The damage to fruit caused by high temperatures (heat damage) was visible only on the fruit treated with HWD 50°C 6'. The differences in maximal temperature of fruit surface were statistically different among all three exposures for the whole duration of recording, meaning that the duration of the hot water dip treatment significantly affects the intensity of fruit cooling after heat treatment.

Key words

infrathermal camera, apple, heat treatment, heating, cooling

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Introduction

Thermography is a contactless method of temperature measuring and its allocation on the surface of objects. Infrared thermography is a measurement method used to measure the irradiation of object surfaces in specific areas of the infrared spectrum (Andrassy et al., 2008). The application of this method in agriculture has been reviewed in works by Vadivambal and Jayas (2011), as well by Gomes and Leta (2012).

'Idared' is an old apple cultivar, which was created in USA in 1935 through the hybridization of 'Jonathan' and 'Wagener' cultivars. It was released in 1942. It is a highly productive cultivar and, without doubt, the most popular apple cultivar in Croatia today. Due to its large and pleasant-looking fruit and the unusually long storage period, it is highly regarded and represents over half of all apples produced in Croatia (Čmelik et al., 2010).

Heat treatments are one of the methods used to reduce the postharvest loss of fruit caused by pathogens or physical damage of the fruit (Jemric et al., 2006, 2011). Since postharvest use of pesticides is not allowed in many countries, including Croatia, and due to increased consumer demand for organic fruit, heat treatments are used more often as an alternative for chemical treatments due to its low negative environmental impact (Maxin and Weber, 2011). Apples that undergo heat treatment synthesize a specific group of heat shock proteins (Lindquist and Craig, 1998). The function of these proteins is the protection of ATP synthase and stimulation of its activity, as well as the stabilization of proteins and prevention of denaturation. This contributes to the maintenance of the structure and functions of cells in conditions of heat stress (Lerner, 1999). Heat treatments close tears in the cuticle by melting surface waxes, and thus help prevent the entrance of pathogens to the fruit (Montero et al., 2010).

Research indicates that heat treatments combined with sodium sorbate and sodium bicarbonate are effective against pathogens (Fadda et al., 2015), like *Neofabrea* spp. (Maxin and Weber, 2011). Heat treatments on temperatures ranging between 47 and 52 °C for the duration of three minutes control pathogens such as *Phacidiopycnis washingtonensis* (Maxin and Weber, 2011). In addition to these positive effects of heat treatments, it must be noted that they can also reduce effects of storage disorders of the fruit, such as superficial scald of apple (Jemric et al., 2006). Heat treatments are also used in organic production of fruit for reduction of apple disease occurrences (Maxin et al., 2005).

However, the use of heat treatments is connected with a risk of damaging the fruit through exposure to high temperatures. Temperatures of 65 °C can lead to cell damage (Li et al., 2015). Even temperatures above 45 °C can lead to damage if combined with excessive light exposure (Hengari et al., 2014). Long exposure to the same temperature (10 minutes and longer) can lead to fruit damage even without exposure to the light (Moscetti et al., 2013). High temperature damage is more likely to occur if heat treatments are combined with usage of sodium bicarbonate (Venditti et al., 2010).

It is thus important to find the best combination of temperature and the exposure to increase the efficiency of heat treatments. Higher temperatures and longer exposures increase efficiency, but also increase the risk of heat damage. Therefore, it is necessary to find an optimal treatment temperature which will be effective even with shorter periods of exposure, in order to reduce the risk of heat damage and to enable easier incorporation of heat treatments into post-harvest procedures.

Materials and methods

This research was conducted in the laboratory of the Department of Pomology, Faculty of Agriculture of the University of Zagreb.

Fruit used in research

The heat treatments conducted during the research were done on 'Idared' apple fruit harvested in the optimal harvest period by AGRA Čakovec. The fruit was harvested on September 20, 2015. Within 2 hours after the harvest, the fruit was transported to the Department of Pomology, Faculty of Agriculture of the University of Zagreb. Total of 30 kilograms of fruit was harvested from all parts of the tree canopy. Among these fruit, samples of 20 perfectly healthy fruit of relatively equal weight and size were randomly selected for each treatment. For thermographic recording, three heat-treated fruits were randomly selected.

Heat treatment

Three hot water dips at 50 ± 0.5 °C were conducted for the duration of two, four and six minutes (HWD 50⁰C 2', HWD 50⁰C 4' and HWD 50⁰C 6') in a specially constructed apparatus with thermostatic temperature control.

Thermal camera recording

Thermal camera recording was conducted in the laboratory of the Department of Pomology, Faculty of Agriculture of the University of Zagreb. For the purposes of this research, the FLIR T620 infrared camera and the FOL25 lens were used (FLIR, USA). The fruits from each heat treatment were photographed once every minute after treatment for the total duration of 12 minutes. Before recording, the camera was calibrated with a special black tape which was placed on a heat-treated fruit to determine the emissivity coefficient and perform camera calibration.

Data analysis

Data gathered from the thermal camera were analysed on the Materials Department of the Faculty of Civil Engineering. This data was analysed in the SAS 9.4 statistical package (SAS Institute, Cary, NC, USA) by ANOVA and Tukey's (HSD) test with the significance level of $P \leq 0.05$. Photographs captured with the infrathermal camera were analysed in the Thermacam reporter professional 9.0 application (FLIR, USA).

Physical and chemical analyses of the fruit

After the heat treatment, the fruit was placed in a cooled storage unit under normal atmosphere at the temperature of 0 °C for eight weeks. Following that period, the fruit was brought out of the storage unit and held for one week at room temperature to simulate the fruit's shelf life. At the end of that period, a visual inspection of the fruit was conducted to detect any possible damage incurred by the heat treatment. The damage was visible only at the end of shelf life period in the form of the browning of the fruit skin (Fig. 3). Damage from high temperature was classified in four categories: 0 – healthy fruit, 1 – low damage, 2 – moderate damage and; 4 – severe damage.

Heat damage index was calculated according to the following formula:

$$index = \frac{(n_0 \times 0) + (n_1 \times 1) + (n_2 \times 2) + (n_3 \times 3)}{n_0 + n_1 + n_2 + n_3} \times 100$$

with the following parameters:

n_0- number healthy fruit

n_1- number of fruits with low damage (up to 25 % of surface damaged)

n_2- number of moderately damaged fruits (between 26-50 % of surface damaged)

n_3- number of severely damaged fruits (between 51-100 % of surface damaged)

The damage resulting from high temperatures were determined through visual observation and determination of the percent of damaged surface of the fruit in relation to the overall surface of the fruit. (Fig. 3).

Results and discussion

ANOVA of the effect of heat treatment duration on the maximal and minimal temperature of the fruit in our study showed that both the duration of heat treatment and the duration of cooling period had a significant impact on the maximal and minimal temperature of fruit surface, but the interaction between those two factors was not statistically significant (Table 1). The maximal temperature of fruit surface was significantly different for all three exposures and it remained significantly different for the whole cooling time (Fig. 1).

Table 1. ANOVA data of maximal and minimal temperature of fruit surface of heat-treated 'Idared' apples during 12 min. cooling time

Source of variability	Maximal temperature (^{0}C) sum of squares	Minimal temperature (^{0}C) sum of squares
Heat treatment (T)	480.67***	353.53***
Cooling period (V)	2047.70***	1028.61***
TxV	10.31 ns	67.15 ns

ns, *** - non significant or significant at $P \leq 0.001$, respectively

The highest maximal temperature of fruit surface was recorded on fruit from HWD 50^0 C 6' treatment (50.6^0 C), followed by HWD 50^0 C 4' treated fruit (48.2 ^{0}C), with HWD 50^0 C 2' treated fruit having the lowest maximal temperature (44.3^{0}C) of fruit surface (Figure 1). From these parameters, it is obvious that the duration of heat treatment is an important factor in fruit damage occurrences as the temperature itself. Li et al. (2015) reported cell damage at a temperature of 65 °C and above, while Moscetti et al. (2013) claim that this happens even at lower temperatures, after tissue has being exposed to high temperature (45 °C) for 10 minutes or longer. Symptoms of heat damage (Fig. 3) in present study were visible only in fruit treated by HWD 50^{0}C 6', while no damage occurred in other treatments. Heat damage index was 1.95, and the largest portion of fruit (40%) showed symptoms of severe heat damage (Table 2). The majority of areas on

Table 2. High temperature damage percentage and index of 'Idared' apple fruit treated with HWD 50^{0}C 6' heat treatment and stored in air for eight weeks at 0 °C plus one additional week at room temperature

The extent of damage	Number of fruit	% of sample
None (0)	2	10
Low (1)	5	25
Moderate (2)	5	25
High (3)	8	40
High temperature damage index		1.95

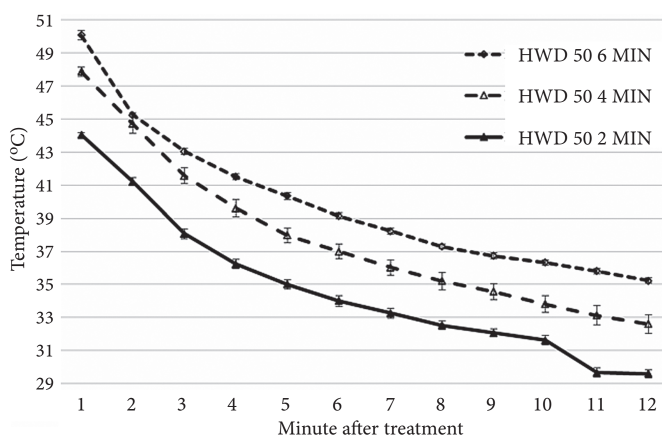

Figure 1. The dynamic of reduction of maximal temperature in heat-treated 'Idared' apples after hot water dip (HWD) on 50 °C for the duration of 2, 4 and 6 minutes (vertical lines represent the standard error calculated on the basis of thermographic data from three fruits; differences among the treatments were statistically significant for the whole recording time).

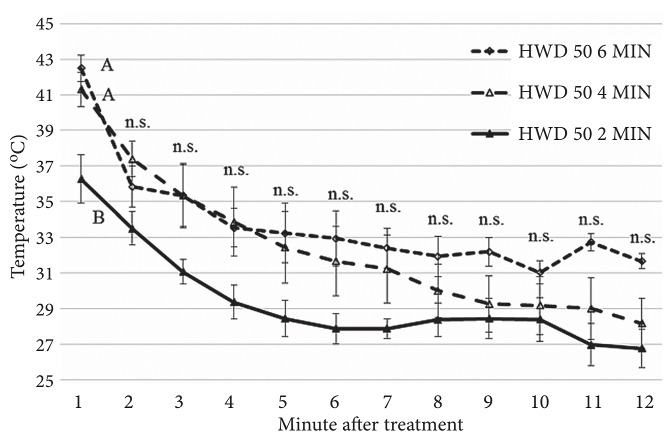

Figure 2. The dynamic of reduction of minimal temperature in heat-treated 'Idared' apples after hot water dip (HWD) on 50 °C for the duration of 2, 4 and 6 minutes (vertical lines represent the standard deviation calculated on the basis of thermographic data from three fruits; values marked with different letters are statistically significant according to Tukey's HSD test at P ≤ 0.05; n.s. – not statistically significant)

Figure 3. The appearance of heat damage on the 'Idared' apple incurred by exposure to HWD 50^{0}C 6' heat treatment

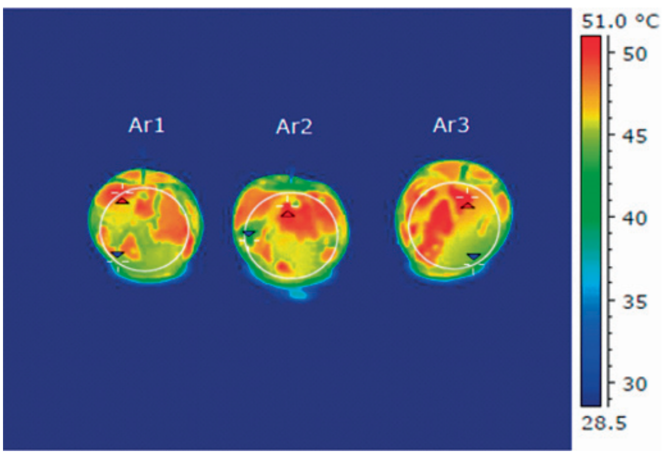

Figure 4. Thermogram of fruit from HWD 50 ^{0}C 6' treatment recorded after first minute of cooling time

the fruit surface showing the symptoms of heat damage (Fig 3) had good overlap with areas on the fruit surface exposed to high temperatures showed on the thermogram (Fig. 4).

This shows that apple tissue can be damaged at temperature around 50^0 C, even when it lasted less than one minute, as shown in Figure 1. This finding is contrary to the results published Li et al. (2015). Possible explanation can be found in the fact that in present study, heating medium was water, while Li et al. (2013) used indirect heating method in water bath through insulation layer. Water has high heat transfer rate and this caused heat damage at lower temperatures within shorter time. Moscetti et al (2013) also used HWD, but maximum temperature was set to be 45^{0}C, although it lasted for as long as 10 min. This temperature is much lower than temperature used in the present study (50 ^{0}C) which caused heat damage at longest exposure (6 min). Beside temperature and exposure, the genetic factor should not be overlooked since it is possible that reaction to heat treatment is cultivar specific, as stated by Maxin et al. (2005).

The dynamics of fruit cooling is shown on Figures 1 and 2 (the maximum temperature of fruit surface and the minimum temperature of fruit surface, respectively).

Although average minimal temperature was also dependent on the duration of the treatment (Table 1), the differences in minimal temperatures were not statistically significant for any individual cooling time, except in the first minute after treatment, when fruit from HWD 50^0 C 2' had significantly lower temperature of fruit surface (36.3 ^{0}C) compared to HWD 50^0 C 4' and HWD 50^0 C 4' (42.5 and 41.3 °C, respectively) (Fig. 2). These temperatures were below threshold that can cause heat damage (Jemric et al., 2006; Moscetti et al., 2013; Li et al., 2015).

Conclusion

On the basis of this research, it can be concluded that the duration of heat treatment has a significant impact on the intensity of fruit cooling. The longer the fruit was treated, the hotter it became and the longer it took to cool down. This effect lasted for the whole recorded cooling time (12 min).

Thermal cameras are seldom used in research of postharvest treatments, and no research was conducted to find the connection between the maximal temperature and the areas of the fruit damaged by high temperature. Our study thus shows the possible application of thermography for better understading of heat treatment effect on fruit and its optimisation.

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