Response of Tarocco Oranges to Picking Date, Postharvest Hot Water Dips, and Chilling Storage Temperature

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Tarocco blood oranges (*Citrus sinensis* Linn. Obsek) were harvested monthly from November to April and dipped in water at 53 °C for 3 min before storage at 3 °C for 10 weeks and 1 additional week at 20 °C, which simulated a marketing period (SMP). Untreated fruit were used as control. No treatment damage was observed in fruit harvested in March. In contrast, hot water dipping caused severe damage to the peel in fruit picked earlier and later in the season. Susceptibility to chilling injury (CI) was greatest in fruit harvested between November and January, less in February, and negligible in March and April. Prestorage hot water dipping effectively alleviated CI in all samples, especially those which showed greater susceptibility. There was little rotting in fruit harvested between November and Januay, while fruit harvested between February and April exhibited a greater susceptibility, which varied with picking date. Hot water dipping gave beneficial effects on decay control of fruit harvested in February and March but was detrimental for fruit harvested in April. Fruit mass loss gradually increased with maturity stage and was seen to be promoted by hot water dips during both cold storage and SMP. The influence of hot water dipping on respiration rate, endogenous ethylene, maturity index (evaluated by °Brix/juice titratable acidity ratio), ethanol concentration in the juice, and electrolyte leakage from the flavedo tissue was nonsignificant. It was concluded that prestorage hot water dipping at 53 °C may be viable in limiting CI and decay control of Tarocco oranges during 10 weeks of cold storage and subsequent SMP when they are harvested at mid-season, January−February, but may be harmful to fruit harvested early or late in the season.

Keywords: *Citrus; chilling injury; harvest date; heat treatments; storage; rots; fruit quality*

INTRODUCTION

Among the citrus cultivars grown in Italy, blood (pigmented) oranges have the greatest economic importance as they represent over 35% of total orange production (*ca*. 790 000 tons). In comparison to nonpigmented orange cultivars, blood oranges show higher susceptibility to chilling injury (CI). Symptoms of CI appear after 2−3 weeks of storage at temperatures below 8 °C (Pratella et al., 1969) as peel pitting of various sizes and shapes that depend on the extent of damage. As storage proceeds, damaged surfaces may coalesce to cover most of the fruit surface. Such occurrences are often accompanied by an increase in susceptibility to decay and in the accumulation in the juice of those respiratory byproducts that are thought to be responsible for the appearance of off-flavors (Cohen et al., 1990). The seriousness of such features may become greater when fruit are moved to warmer temperatures. Studies with grapefruit have shown that susceptibility to CI may depend upon climate (Young, 1961; Yelenosky, 1978), cultural practices (Eaks, 1991), fruit position in the canopy (Purvis, 1980), exposure to the sun (Purvis, 1984; Nordby and McDonald, 1995), circadian temperature (Nordby et al., 1987), winter field temperature (Kawada et al., 1978), and picking date (Pantastico et al., 1968; Grierson, 1974). Temperature before refrigeration also affects susceptibility to CI (Purvis and Yelenosky, 1993; Paull and McDonald, 1994), and the severity of damage may be alleviated by prestorage heat treatments (Klein and Lurie, 1992).

So far, studies on citrus fruit have mainly dealt with grapefruits; there were no studies that we could find in the literature on the chilling of sensitive blood oranges. This investigation was therefore undertaken to study the influence of chilling storage temperature on Tarocco blood oranges in relation to picking date and postharvest hot water dips. Fruit conditions in terms of CI, decay, quality attributes, and various physiological, physical, and chemical changes were assessed at harvest, during chilling temperature storage, and during subsequent simulated shelf life.

MATERIALS AND METHODS

Fruit. The experiment was carried out on Tarocco oranges (*Citrus sinensis* Linn. Obsek) grown in an experimental grove (southern Sardinia, 39° 55′ N) receiving standard horticultural care. Trees were globe raised on sour orange rootstock and spaced 6 × 6 m. Fruit were picked at monthly intervals, from the first week of November (before full orange color, immature fruit) to April (overmature fruit). Each harvest involved a random sampling from 15 trees subdivided into 3 groups of 5 trees (replications); 20 fruit were picked from the exterior of the canopy of each tree, placed in plastic boxes, delivered to the laboratory immediately after harvest, and left overnight. Nondefective oranges were selected and grouped into two treatment lots (5 boxes containing 60 fruits each), correspond-

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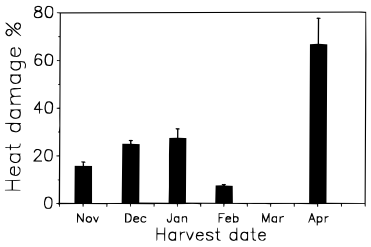

Figure 1. Influence of harvest date on susceptibility to heat damage of Tarocco oranges after 10 weeks of storage and 1 additional week at 20 °C. Vertical bars indicate SE.

ing to 3 min 53 °C water dipped fruit and untreated fruit, the latter used as control.

Treatments and Storage. Dip treatments were performed in a bath fitted with 3.96 kW/h heating elements and an electronic recirculation pump (22 L/min water flow). Two hundred liters of water was used for dipping one box per run. The bath was constantly maintained within ±0.4 °C of the required temperature by an electronic thermostat (OEM/HT, Carel, France) and probe (PTC 40, Carel, France). Following treatment, the fruit were left to dry at room temperature for 5−6 h. Each treatment group was then divided into three subgroups. The first subgroup (three boxes) was used for evaluation of chilling injury, rot incidence, heat damage, and freshness rating. Fruits of the second subgroup (one box) were numbered and individually weighed for the determination of transpiration rate as fruit mass loss. Fruits of the third subgroup were used for measurement of electrolyte leakage and for chemical analyses.

Finally, fruit were moved to a storage room and kept at 3 °C and 90−95% relative humidity (RH) for 10 weeks, with a complete air change every hour (chilling storage conditions). At the end of storage they were maintained at 20 °C and about 80% RH for 1 week to simulate a marketing period (SMP).

Visual Assessment and Fruit Weight Loss. During cold storage and after SMP, fruit were examined weekly for treatment damage, CI, and rot incidence. CI was rated as 0 (no damage), 1 (slight, <10% peel pitting), 2 (moderate, 10−30% peel pitting), or 3 (severe, >30% peel pitting). To obtain a weighted average for the chilling index, the number of fruits with each CI rating was multiplied by the rating number and an average was taken. Decay was categorized as rots caused by *Penicillium italicum* Wehmer, by *Penicillium digitatum* Sacc., or as miscellaneous rots of unidentified fungi, and the total decay percentage was calculated. Fruit freshness (overall visual quality) was evaluated at the end of cold storage and after SMP and subjectively rated into one of five categories [9 (excellent), 7 (good), 5 (fair), 3 (poor), and 0 (very poor)] by an informal panel of three people familiar with citrus fruit. Fruit mass loss was determined after 5 and 10 weeks of storage and after SMP.

Chemical Analyses. Before treatment, at the end of cold storage and after SMP, 3 replicates of 20 healthy fruit were randomly selected for physiological (respiration and ethylene production rates) and internal quality attributes. The latter included ethanol content in the juice, total soluble solids concentration (SSC), titratable acidity (expressed as percent of anhydrous citric acid), and maturity index calculated as °Brix-titratable acidity ratio. All analyses were carried out as previously described (Schirra et al., 1997).

Rate of electrolyte leakage from the peel tissue excised from fruit was determined 6 h after dip treatment and after SMP. Five fruits per replication (eight replicate samples) were used. The peel was carefully removed, and 10 mm disks were cut from it with a cork borer. Samples of 10 disks per replication were weighed, placed in a 200 mL dark glass bottle, twice washed with deionized water, and then incubated in 100 mL of deionized water at 20 °C. Conductivity of the incubation medium was measured with a digital conductivity meter (J. Bibby Science Products Limited, U.K.) after 4 h of incubation under constant shaking. After readings were taken, the flasks

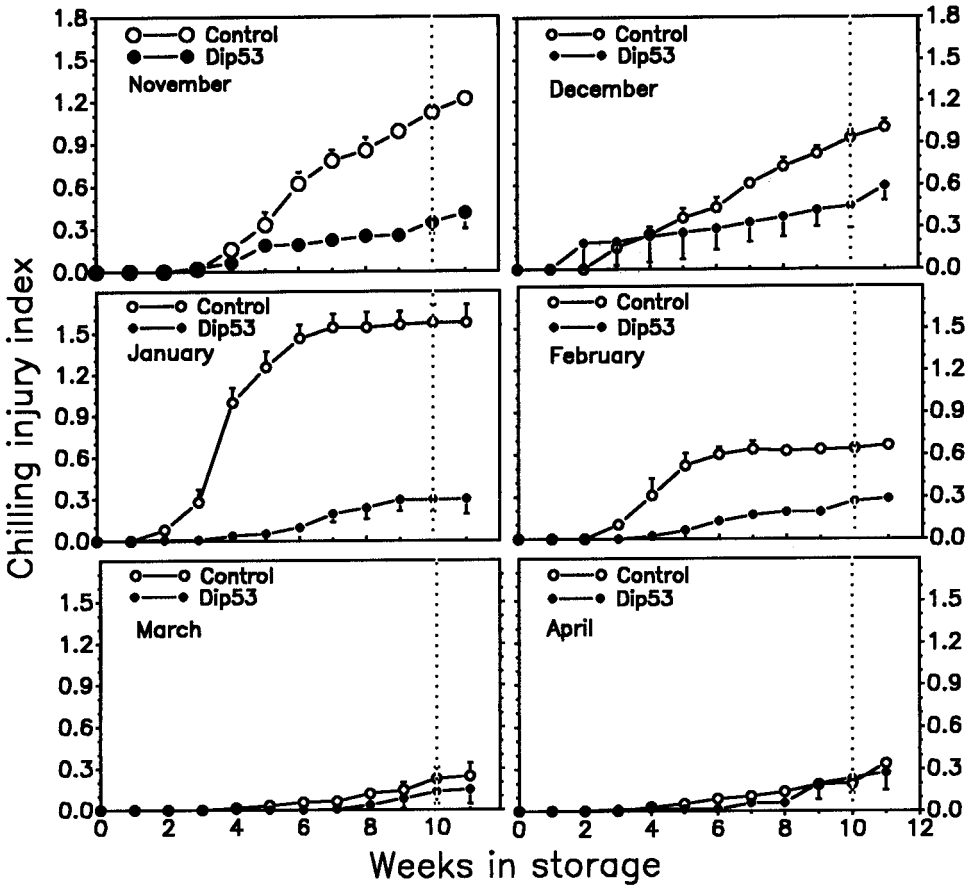

Figure 2. Influence of harvest date and postharvest 53 °C water dipping (Dip53) on CI index in Tarocco oranges during 10 weeks of storage at 3 °C and 1 additional week at 20 °C. Vertical bars indicate SE.

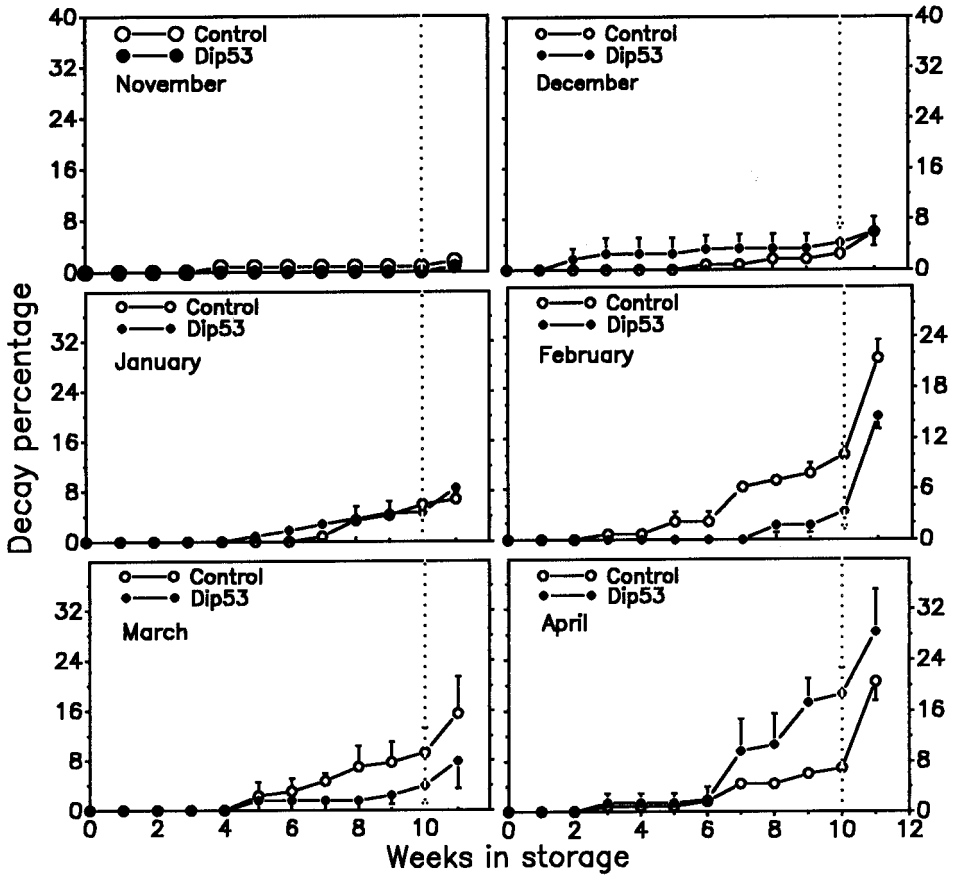

Figure 3. Influence of harvest date and postharvest 53 °C (Dip53) water dipping on decay development in Tarocco oranges during 10 weeks of storage at 3 °C and 1 additional week at 20 °C. Vertical bars indicate SE.

were autoclaved at 120 °C for 90 min and cooled to 20 °C and conductivity was measured again for total electrolyte determination. Rate of ion leakage was expressed as percentage of the total.

Statistical Analysis. Analysis of variance (ANOVA) was performed by MSTAT-C software. Mean separations were calculated by Duncan's multiple range test ($P = 0.05$), where appropriate.

RESULTS

Heat Damage. Hot water dipping caused little damage to the peel of fruit harvested in February and no damage in fruit harvested in March (Figure 1). Conversely, fruit harvested earlier and later than that period showed heat damage as rind browning, which appeared between the third and fourth weeks with a percentage of damaged fruit ranging between 20 and 30% after SMP in oranges picked before February and approximately 70% in those harvested in April.

CI. The expression of CI was greatly affected by harvest time (Figure 2). The first visible symptoms of CI were noticed between the second and third weeks of storage. Afterward, they progressively increased in all samples, depending on picking date and type of treatment. Susceptibility to CI was greatest in fruit harvested between November and January, less in fruit harvested in February, and negligible in fruit harvested in March and April, when fruit was overmature. Heat treatment greatly reduced CI magnitude with a higher efficacy obtained in fruit with greater susceptibility.

Rots. There was very little rotting after SMP in fruit harvested between November and January (Figure 3). Mature and overmature fruit exhibited a greater susceptibility mainly to *P. digitatum* decay, notwithstanding the low storage temperature, with differences depending on picking date. Hot water dipping gave beneficial effects on decay control in fruit harvested in February and March but was detrimental to fruit harvested in April.

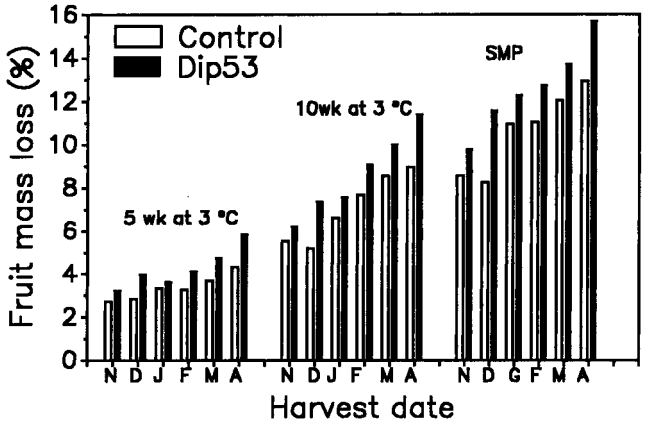

Figure 4. Influence of harvest date and postharvest 53 °C water dipping (Dip53) on fruit mass loss in Tarocco oranges after 5 and 10 weeks of storage at 3 °C and 1 additional week at 20 °C (SMP). Vertical bars indicate SE.

Fruit Mass Loss. Fruit mass loss was affected by maturity stage (Figure 4): the more mature the fruit, the greater the mass loss. Hot water dipping resulted in an increase in fruit weight loss during both cold storage and SMP.

Overall Fruit Quality. The external appearance of both untreated and treated fruit after 5 weeks of storage was judged to be excellent. At the end of cold storage, fruit appearance declined but remained fairly good. After SMP, external appearance was judged to be old

Table 1. Changes in Respiration Rate, Endogenous Ethylene Concentration, Ethanol Amount in Juice, Maturity Index, and Electrolyte Leakage in Tarocco Oranges in Relation to Picking Date and Storage Conditions

	picking date					
time	Nov	Dec	Jan	Feb	March	April
	Respiration Rate[a] (mg of CO_2 kg^{-1} h^{-1})					
before storage	22.9 ± 0.5	25.0 ± 2.0	23.3 ± 0.6	17.8 ± 0.6	23.5 ± 0.4	24.7 ± 0.4
10 weeks at 3 °C	15.2 ± 1.0	17.9 ± 1.7	14.0 ± 1.4	15.1 ± 1.2	16.3 ± 0.9	14.3 ± 1.6
10 weeks at 3 °C + 1 week at 20 °C	26.0 ± 1.8	29.7 ± 2.6	29.0 ± 3.4	24.4 ± 3.4	35.7 ± 2.1	38.0 ± 2.3
	Endogenous Ethylene[a] (μL L^{-1})					
before storage	0.15 ± 0.01	0.14 ± 0.05	0.11 ± 0.01	0.13 ± 0.02	0.15 ± 0.01	0.15 ± 0.01
10 weeks at 3 °C	0.35 ± 0.05	0.18 ± 0.08	0.11 ± 0.04	0.16 ± 0.05	0.15 ± 0.03	0.11 ± 0.02
10 weeks at 3 °C + 1 week at 20 °C	0.59 ± 0.12	0.21 ± 0.07	0.16 ± 0.02	0.27 ± 0.05	0.24 ± 0.09	0.24 ± 0.05
	Ethanol[a] (mg 100 mL^{-1})					
before storage	8.9 ± 0.8	21.3 ± 1.8	42.7 ± 1.7	51.6 ± 3.6	66.3 ± 4.4	104.6 ± 3.1
10 weeks at 3 °C	81.7 ± 5.0	118.8 ± 5.0	216.7 ± 17.7	95.8 ± 20.0	147.9 ± 15.1	193.9 ± 7.3
10 weeks at 3 °C + 1 week at 20 °C	95.0 ± 2.2	171.8 ± 7.5	236.2 ± 5.2	191.6 ± 34.2	164.5 ± 14.7	395.3 ± 20.6
	Maturity Index[a]					
before storage	4.4 ± 0.2	5.5 ± 0.5	5.3 ± 0.4	7.5 ± 0.6	7.6 ± 0.5	8.4 ± 0.6
10 weeks at 3 °C	4.9 ± 0.2	5.8 ± 0.2	6.6 ± 0.3	8.4 ± 0.4	8.3 ± 0.5	9.7 ± 0.3
10 weeks at 3 °C + 1 week at 20 °C	5.4 ± 0.4	6.3 ± 0.4	6.7 ± 0.2	8.7 ± 0.4	9.2 ± 0.5	10.1 ± 0.6
	Electrolyte Leakage[b] (%)					
before storage	48.5 ± 5.9	50.5 ± 3.2	48.3 ± 6.7	60.8 ± 2.3	59.5 ± 3.4	67.3 ± 2.5
10 weeks at 3 °C	48.7 ± 4.3	62.4 ± 4.8	55.7 ± 2.1	63.3 ± 3.3	64.8 ± 1.5	62.2 ± 3.5
10 weeks at 3 °C + 1 week at 20 °C	49.8 ± 3.3	60.2 ± 6.8	55.2 ± 3.2	60.5 ± 2.3	63.1 ± 4.6	61.6 ± 1.4

[a] Mean values of 6 replicate samples ± SD. [b] Mean values of 16 replicate samples ± SD.

but still acceptable in all measurements. No appreciable differences could be detected in fruit flavor between untreated and treated fruit after SMP (data not shown).

Physiological and Chemical Changes. No significant treatment differences were found in physiological and chemical features before storage as well as before and after SMP; therefore, all data are shown as means of six replicate samples (three untreated plus three treated) ± SD (Table 1). Respiration rates did not reveal important changes with respect to picking date. At the end of storage respiration rate decreased with respect to the initial values and increased after SMP. Endogenous ethylene concentration underwent an increase in December and then remained fairly constant throughout the season. Cold storage and especially SMP conditions caused increases in most samples. Ethanol concentration in the juice increased markedly between November and March and sharply in April. After SMP, ethanol amounts rose drastically, from 1.6 to 10.7 times the initial levels, depending on picking date. The highest rate increases with respect to the initial levels were found between November and January, that is, in fruit with the greatest susceptibility to CI. Maturity index gradually increased during the season, going from 4.4 in November to 8.4 in April, mainly because of a concomitant decrease in juice acidity (data not shown). Average values of electrolyte leakage remained fairly constant until January and exhibited gradual increases later in the season. Changes after cold storage and SMP were minimal in most samples.

DISCUSSION AND CONCLUSIONS

Susceptibility of Tarocco oranges to CI was dependent on the fruits' maturity stage. Indeed, susceptibility to CI was found to be high in immature fruit and to decrease by as late as the end of February. Seasonal susceptibility to CI had been previously observed on grapefruits (Pantastico et al., 1968), mandarins (Verker, 1994), and lemons (Hunderhill et al., 1995). Such occurrences had been associated with the general growth regulator balance in the tree at the time of harvest (Grierson, 1974). In Mediterranean countries Tarocco oranges are harvested between January and February, that is, when fruit are still highly sensitive to CI. Sometimes fruit are left until March for sweetness. A late harvest may offer the advantage of a better endurance of the fruit to CI but may be risky because of the high dropping rate of Tarocco oranges, which can be >80% in March.

Fruit weight loss over chilling temperature storage has been recognized as being a cause involved in CI development in grapefruits (Purvis, 1984). In addition, factors such as treatment types or storage conditions that hinder fruit water loss also ameliorate CI (Purvis, 1985). Nonetheless, besides water loss, other causes may contribute to the expression of CI (McDonald et al., 1993): high temperature conditioning or wax application to grapefruits reduced weight loss and CI, treatment with squalene alleviated CI but did not reduce weight loss, while wiping fruit with hexane decreased weight loss but not CI.

The present results indicate that 53 °C water dipping of Tarocco oranges remarkably reduced CI while augmenting fruit weight loss. In addition, no relationship was found between aptness of fruit to weight loss and seasonal susceptibility to CI, as indeed the former gradually increased throughout the season, in agreement with previous findings on grapefruits (McGuire and Reeder, 1992), whereas the latter did not show any definite trend. It has been reported (Coggins, 1969) that in citrus fruit albedo and flavedo cells enlarge, become highly vacuolated, and change in shape during maturation and senescence; tissues become structurally weak and spongy, and the epicuticular wax layer hosts a network of microcracks (Freeman et al., 1979), thus offering diminished resistance to the escape of water vapor from the peel.

Increases in fruit weight loss following hot water dipping (Schirra and D'hallewin, 1997) or hot air treatment (McGuire and Reeder, 1992) have been reported on Fortune and Marsh grapefruits, respectively, while studies on kumquats showed the opposite trend (Rodov et al., 1994). However, the cause of increase or decrease

in fruit water loss following heat treatment remains to be elucidated.

In agreement with the current view, susceptibility of Tarocco oranges to decay increased as fruit became physiologically older. This had been associated with the declining levels of naturally occurring antifungal compounds in the flavedo tissue (Ben-Yehoshua et al., 1992) as well as with the high levels of green mold spores by that time present and coming from dropped fruit in the grove that caused a spore concentration buildup in the refrigerated room (Eckert and Eaks, 1985). Hot water treatment provided some measure of decay control in fruit harvested in February and March but promoted decay development in fruit harvested in April. This increase may be related with the diminished capability of cells to respond to pathogen following heat damage. The influence of treatment on physiological response of fruit and its internal quality attributes was negligible.

As far as the tolerance of Tarocco oranges to heat stress is concerned, it was found that it is dependent on the age of the peel, supporting previous findings on grapefruit following 46−50 °C hot air treatment (McGuire and Reeder, 1992). The greatest difficulty given by upgrading heat treatment to commercial scale lies in the need this may create to operate with times and temperatures which are often very close to conditions harmful to the fruit and, in light of the present results, that may change remarkably with respect to the maturity stage reached by the fruit itself at harvest.

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