EFFECT OF POSTHARVEST SHORT HOT-WATER RINSING AND BRUSHING TREATMENT ON DECAY AND QUALITY OF STRAWBERRY FRUIT

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ABSTRACT

*Strawberry (*Fragaria ananassa*) cv. "Feng xiang" was treated with hot water rinsing and brushing (HWRB) at 20C (control), 55C (HWRB-55), 60C (HWRB-60) and 65C (HWRB-65) for 20 s. The effect of these heat treatments on fruit decay and quality was investigated after either ambient temperature storage (20C) for 3 days or cold storage (0C) for 12 days.*

Results showed that HWRB treatments could significantly reduce the epiphytic microbial population on fruit surface, decay development and weight loss. Fruits treated with HWRB-65 had the lowest decay incidence and decay index, but about 60% of the treated fruits showed heat damage and became commercially unacceptable. Fruits treated with HWRB-60 showed less decay than the control fruits, and cold storage could enhance the effect of HWRB treatments. There were no negative effects of HWRB-60 on fruit surface color, firmness, soluble solids content and titratable acidity.

PRACTICAL APPLICATIONS

This research investigated the effects of hot water rinsing and brushing (HWRB) treatments on decay and quality of strawberry fruit, which was susceptive of decay. HWRB treatments at 60C for 20 s significantly reduced

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fruit decay, did not affect its quality and could be suggested as a potential postharvest heat treatment on strawberry fruit. On a commercial scale, this short HWRB treatment would be a desirable method for treating freshly harvested produce to maintain fruit quality during postharvest period. Future work on exploring HWRB technology to a broader range of freshly harvested commodities with improved fruit quality and meeting the quarantine requirements, will help the fruit industry to develop environmentally friendly and technically effective HWRB technologies, and possibly reduce the current extensive reliance on chemical pesticides.

INTRODUCTION

Strawberry (*Fragaria ananassa*) is an important berry fruit because of its high nutritional and commercial value. The disadvantage of that fruit includes short storage life, a result of decay caused by fungi pathogens and quick softening rate. The susceptibility of freshly harvested strawberries to postharvest diseases increases during storage and enables pathogens to develop in the fruits (Vicente *et al.* 2006). Currently, the harvested fruit are commonly treated by a variety of fungicides to maintain the product quality. With several negative effects of chemical fungicides on food safety and environment, there is an urgent need to develop an alternative nondamaging physical treatment to chemical fungicides.

Postharvest heat treatment offers a pesticide-free method to kill or weaken plant pathogens, control insect infestations and maintain fruit storage quality (Barkai-Golan and Phillips 1991; Shao *et al.* 2007). A new technology has been proposed for simultaneously cleaning and disinfecting fruits using hot water rinsing and brushing (HWRB). Recently, HWRB treatments are studied extensively because of their higher temperature and shorter exposure time than traditional hot water immersions or dips. HWRB treatments could not only remove the heavy dirt, pesticides and fungal spores on the freshly harvested produce, but could also improve general product appearance and maintain product quality (Fallik 2004). Because this technology has been designed to be a part of the commercial packing house sorting line and successfully used on the postharvest fresh-keeping treatment of sweet pepper (Fallik *et al.* 1999) and mango (Prusky *et al.* 1999), HWRB treatments would be desirable for treating freshly harvested produce on a commercial scale (Porat *et al.* 2000a).

There have been many studies on the application of hot water immersions and dips on strawberry to control decay and maintain fruit quality (García *et al.* 1995; Couey and Follstad 1996; Vicente *et al.* 2003). To our knowledge, however, there is little report on the effect of HWRB treatments on strawberry

under different storage conditions. Thus, the purpose of our study was to examine the effect of HWRB treatments on the decay and quality of strawberry fruits and determine whether HWRB treatments are suitable to be used as practical postharvest treatments and commercial implementations for strawberry fruit.

MATERIALS AND METHODS

Materials and Treatments

Strawberries (*F. ananassa* "Feng xiang") were harvested from a commercial orchard in Nanjing, Jiangsu Province, China. The fruits were then packed into fiberboard cartons and transferred to the laboratory on the same day. Uniform size and damage-free fruits at the ripening stage, with 50~70% of the fruit surface showing red, were picked out and randomly distributed into four batches; each batch contained 200 fruits. Three batches of fruits were applied with HWRB treatment at 55C (HWRB-55), 60C (HWRB-60) and 65C (HWRB-65), respectively, for 20 s, and then allowed to dry in air as described by Fallik (2004). As a control, the fourth batch of fruits was rinsed and brushed with tap water (20C) for 20 s. After HWRB treatments, one-half of each batch of fruits was kept at 20 ± 1C for 3 days (ambient temperature storage) and another half was kept at 0 ± 1C for 12 days (cold storage). The relative humidity (RH) was 90 ± 5% at both storage conditions.

The epiphytic microbial population of strawberry fruits surfaces was assessed immediately after HWRB treatments. Fruit decay incidence, decay index, weight loss, firmness, soluble solids content (SSC), titratable acidity (TA) and color values of L^*, a^* and °H were assessed before and after storage.

Effect of HWRB Treatments on Epiphytic Microbial Population

The epiphytic microbial population was measured as described by Fallik *et al.* (2000). After HWRB treatments, three fruits were picked out from each batch of control, HWRB-55, HWRB-60 and HWRB-65 to examine for the epiphytic microbial population. Each fruit was immersed into 150 mL of sterile distilled water containing 0.03% Tween-20 and incubated for 10 min on a shaker (TY-80; Nanda Biological Development Company, Jiangsu, China). Serial dilutions up to 10^{-5} were prepared and 100 µL of each dilution were plated in Petri dishes containing potato dextrose agar amended with 250 µg/L of chloramphenicol to inhibit bacterial growth. The number of colony-forming units (CFU) was expressed as $\log_{10}$ cfu/fruit.

Effect of HWRB Treatments on Fruit Decay Incidence and Decay Index

After the ambient temperature or cold storage, the percentage of decayed fruits and decay severity was determined. Fruit decay incidence was represented as the percentage of decayed fruits over 30 fruits in total in each treatment. Whole fruit decay originating from quiescent infections was evaluated subjectively by a modification of the method of Fallik *et al.* (1993) and scored as 0 (no decay development); 1 (one to three small spots of berry decayed); 2 (one-quarter to one-half of berry decayed); 3 (one-half to three-quarters of berry decayed); and 4 (three-quarters to whole fruit rotted). Results were expressed as decay index:

$$\begin{aligned}\text{Decay index} = (&0 \times \text{fruit number of } 0 + 1 \times \text{fruit number of } 1 \\ &+ 2 \times \text{fruit number of } 2 + 3 \times \text{fruit number of } 3 \\ &+ 4 \times \text{fruit number of } 4)/30\end{aligned}$$

Effect of HWRB Treatments on Fruit Quality Attributes

Thirty fruits of each batch were used for measurement of weight loss. The fruits were weighted and the results were expressed as percentage of weight loss over the initial value (Vicente *et al.* 2003). Ten fruits of each treatment were used to measure both color and firmness. Two readings per fruit were taken on opposite checks of the strawberry. Firmness was measured with a tester (FT-327, Fruit Pressure Tester, Alfonsine, Italy) using a 0.78-cm diameter tip. Results were expressed as kg/cm^2. External color of fruit was measured with a Minolta Chromameter (Model CR-300; Minolta, Tokyo, Japan) in CIE L^* a^* b^* mode under CIE Standard Illuminant C. Changes in hue angle (°H) were calculated as $°H = \arctan b^*/a^*$ (°). SSC and TA were measured with juice obtained from 30 fruits per treatment by a method modified from Lara *et al.* (2006). SSC was determined with a hand refractometer (WYT-4; Quanzhou Optical Instrument Co. Ltd, Quanzhou, China), and results were expressed as percent soluble solids in juice at 20C. A 10-mL aliquot of the filtered fruit juice was diluted with 50 mL distilled water, and the dilution was titrated with 0.1N NaOH to pH 8.1. TA results were expressed as percent of citric acid.

Statistical Analysis

All the tests were repeated three times and the means with standard errors of the three experimental results were presented. Results were analyzed using one-way analysis of variance and Duncan's multiple range test at $P = 0.05$ with SAS 8.2 (SAS institute, Cary, NC).

RESULTS AND DISCUSSION

Effects of HWRB Treatments on Epiphytic Microbial Population, Decay Incidence and Decay Index of Strawberry Fruits

Compared with the control, all the HWRB treatments significantly reduced the epiphytic microbial populations on the fruit surface and an additional 0.31, 1.52 and 1.71 log reductions in the population of epiphytic microorganisms were observed after hot water rinsing and brushing at 55, 60 and 65C, respectively (Fig. 1) ($P < 0.05$). Other studies (Fallik *et al.* 2000) found that HWRB could simultaneously clean the disinfected "Galia" melon, resulting in surface free from spores and dust particles. Moreover, in organic citrus fruit subjected to HWRB treatments, platelets flattened while crack and most stomata appeared partially or completely plugged by melted wax, thereby providing a mechanical barrier against wound pathogens (Porat *et al.* 2000a).

HWRB treatments showed different effects on reducing decay incidence (Fig. 2). After ambient temperature storage, 70.0% of control fruits decayed, while 63.3%, 51.7% and 53.3% of HWRB treated fruits decayed at 55C, 60C and 65C, respectively. After cold storage, all HWRB treated fruits showed

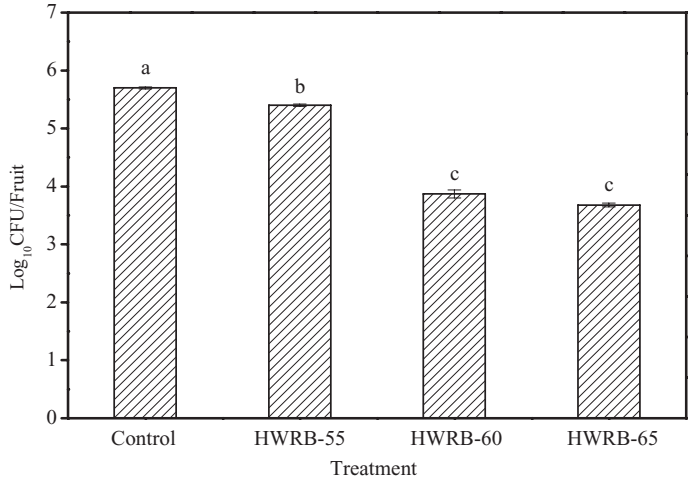

FIG. 1. EFFECT OF HWRB TREATMENTS ON THE EPIPHYTIC MICROBIAL POPULATIONS (cfu) OF STRAWBERRBY FRUITS AFTER TREATMENT FOR 20 S AT 20C (CONTROL), 55 (HWRB-55), 60C (HWRB-60) OR 65C (HWRB-65)
Means of three independent treatments followed by the same letter are not significantly different at $P = 0.05$ according to analysis by Duncan's multiple range tests. Vertical bars represent standard errors of the mean over three independent replicates.
HWRB, hot water rinsing and brushing.

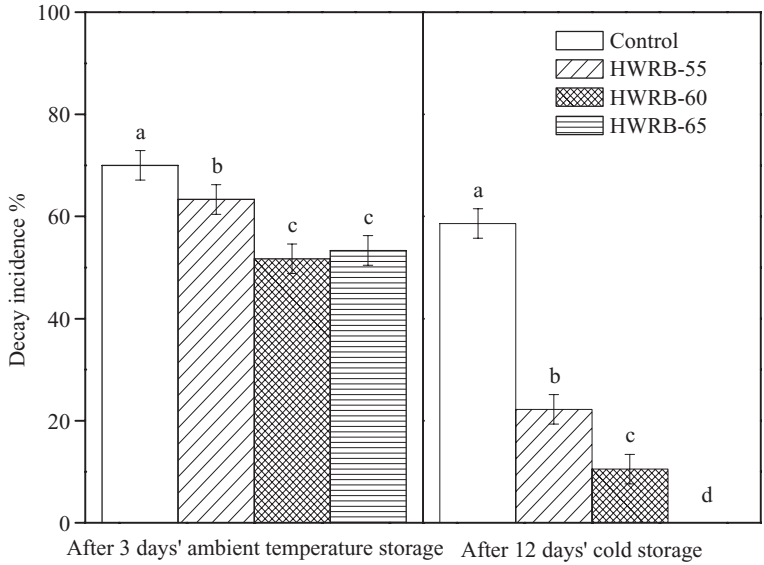

FIG. 2. EFFECTS OF HWRB TREATMENTS ON DECAY INCIDENCE OF STRAWBERRY FRUITS FOR 20 S AT 20C (CONTROL), 55 (HWRB-55), 60C (HWRB-60) OR 65C (HWRB-65) AFTER AMBIENT TEMPERATURE OR COLD STORAGE
Means of three independent treatments followed by the same letter are not significantly different at $P = 0.05$ according to analysis by Duncan's multiple range tests. Vertical bars represent standard errors of the mean over three independent replicates.
HWRB, hot water rinsing and brushing.

lower decay incidence (0–22.2%) as compared with 58.6% of control fruits. Similarly, HWRB treatments could significantly ($P < 0.05$) reduce the decay index (Fig. 3). The decay development was significantly reduced after a 20 s HWRB treatment at 55C, and the prevention effect of decay was enhanced by 60C and 65C HWRB treatments ($P < 0.05$) (Fig. 3). This was probably because the HWRB treatment effectively disinfected the fruit from pathogenic fungi through high temperatures at 60–65C. On the other hand, HWRB treatments also made a clear redistribution of the epicuticular wax layer, which prevented the pathogen penetration. The exposure time of fruit to HWRB treatments lasted only seconds, rather than minutes or hours of traditional heat treatments, yet these former treatments were sufficient to induce heat resistance of certain fruits against pathogen infection. Porat *et al.* (2000b) reported that 59C or 62C 20 s HWRB induced accumulation of pathogen-related proteins such as chitinase, β-1, 3-glucanase and heat shock proteins (Fallik *et al.* 1993). Further studies are still needed to explore whether there existed other induced heat resistance on strawberry fruit by HWRB treatments.

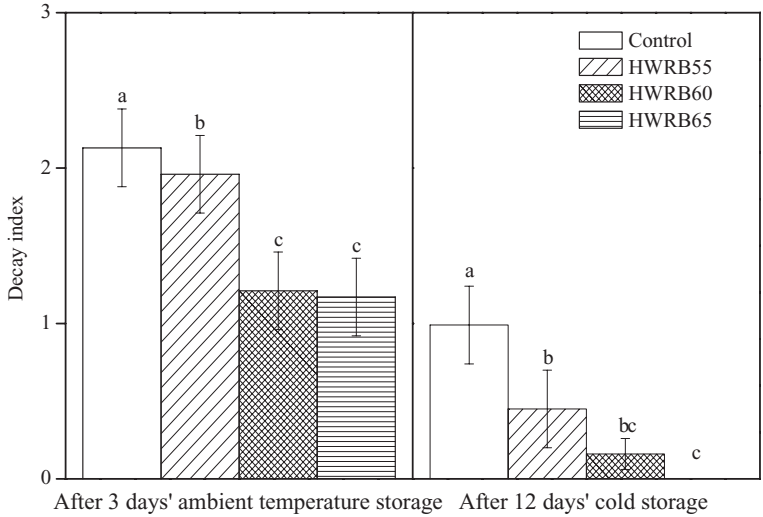

FIG. 3. EFFECTS OF HWRB TREATMENTS ON DECAY INDEX OF STRAWBERRY FRUITS FOR 20 S AT 20C (CONTROL), 55 (HWRB-55), 60C (HWRB-60) OR 65C (HWRB-65) AFTER AMBIENT TEMPERATURE OR COLD STORAGE

Means of three independent treatments followed by the same letter are not significantly different at $P = 0.05$ according to analysis by Duncan's multiple range tests. Vertical bars represent standard errors of the mean over three independent replicates.

HWRB, hot water rinsing and brushing.

Results of our study showed that 20 s HWRB treatment at 65C damaged about 60% of strawberry fruits, in which shrinking of the outer layers epicarps occurred, while fruits treated with 55C or 60C HWRB treatment had no heat damage. This was in good agreement with the observed heat damage on HWRB-treated fruit generally at temperatures above 60C (Fallik 2004). High temperatures of treatment might cause surface damage in specific susceptible citrus cultivars (Mulas *et al.* 1997; Schirra and D'hallewin 1997; Porat *et al.* 2000a), but it may have some positive effects (Fallik *et al.* 2000; Porat *et al.* 2000b), and these diverse responses of fruits to heat treatments might be caused by differences among heating procedures and cultivars.

Effects of HWRB Treatments on Postharvest Quality of Strawberry Fruits

HWRB treatments significantly reduced the weight loss of fruits after ambient temperature storage ($P < 0.05$), but there was no significant difference between HWRB-treated and control fruits after cold storage ($P > 0.05$) (Table 1).

TABLE 1.
EFFECTS OF HWRB TREATMENTS ON POSTHARVEST QUALITY OF STRAWBERRY FRUITS FOR 20 S AT 20C (CONTROL), 55 (HWRB-55), 60C (HWRB-60) OR 65C (HWRB-65) BEFORE STORAGE OR AFTER AMBIENT TEMPERATURE OR COLD STORAGE

Storage condition	Treatments	Weight loss (%)	Firmness (kg/cm^2)	SSC (%)	TA (%)
Before storage	Control	0.00 a	1.80 a	7.69 a	1.16 bc
	HWRB-55	0.00 a	1.73 a	7.96 a	1.23 b
	HWRB-60	0.00 a	1.74 a	7.89 a	1.21 b
	HWRB-65	0.00 a	1.78 a	7.76 a	1.32 a
3 days ambient storage	Control	1.61 a	1.80 c	6.91a	1.15 a
	HWRB-55	1.07 b	2.00 a	7.06 a	1.12 ab
	HWRB-60	0.76 bc	1.90 b	6.91 a	1.12 ab
	HWRB-65	0.56 c	2.07 a	7.11 a	1.11 ac
12 days cold storage	Control	1.86 ab	1.95 a	6.69 ab	0.94 ab
	HWRB-55	1.78 a	2.06 a	6.99 ab	1.11 a
	HWRB-60	1.65 ab	2.05 a	6.99 ab	1.07 a
	HWRB-65	1.58 b	2.01 a	7.16 a	1.11 a

Means of three independent samples within a column and within a day followed by the same letter are not significantly different at $P = 0.05$ according to analysis by Duncan's multiple range tests.
HWRB, hot water rinsing and brushing; SSC, soluble solids content; TA, titratable acidity.

After HWRB treatments, the heat-treated fruits showed low firmness when compared with the control, but the difference was not significant before storage ($P > 0.05$) (Table 1). The firmness of control fruits had no obvious changes after storage, but those of heat-treated fruits had higher firmness than control after ambient temperature storage ($P < 0.05$). There was no significant difference of firmness between the three treatments after cold storage ($P > 0.05$) although they were slightly higher than the control. Thus, HWRB treatments increased fruit firmness after ambient storage and these results were in accordance with hot water-dipped strawberry (García *et al.* 1995). The higher firmness value of heat-treated fruit could be due to the diminution of cell wall degrading enzymes, caused in turn by the delay of ripening (Pan *et al.* 2004). Lara *et al.* (2006) also reported that heat treatments preserved strawberry fruit firmness.

There was no significant difference of SSC, TA and superficial color indexes (L^*, a^* and °H) between control and HWRB-treated fruits before and after storage ($P > 0.05$) (Table 2).

Consequently, these results suggested that HWRB treatments significantly reduced fruits decay by reducing the epiphytic microbial population, especially at HWRB-60 and HWRB-65 treatments. HWRB treatments also inhibited fruits weight loss, but 60% of HWRB-65 treated fruits showed heat damage and lost commercial value. On the other hand, HWRB-60 treated

TABLE 2.
EFFECTS OF HWRB TREATMENTS ON COLOR INDEX OF STRAWBERRY FRUITS FOR 20 S AT 20C (CONTROL), 55 (HWRB-55), 60C (HWRB-60) OR 65C (HWRB-65) BEFORE STORAGE OR AFTER AMBIENT TEMPERATURE OR COLD STORAGE

Storage condition	Treatments	Value of *L**	Value of *a**	Value of °H
Before storage	Control	53.86 ab	27.88 b	51.70 a
	HWRB-55	54.80 ab	29.73 ab	50.02 ab
	HWRB-60	53.10 b	28.92 b	51.39 a
	HWRB-65	55.55 a	29.01 b	48.19 b
3 days ambient storage	Control	44.72 a	36.28 a	40.19 a
	HWRB-55	45.08 a	36.82 a	42.20 a
	HWRB-60	46.64 a	36.69 a	41.88 a
	HWRB-65	46.05 a	34.72 a	42.33 a
12 days cold storage	Control	58.02 a	35.57 a	45.30 a
	HWRB-55	55.50 b	36.82 a	45.45 a
	HWRB-60	54.64 b	36.07 a	45.18 a
	HWRB-65	54.85 b	34.72 a	46.67 a

Means of three independent samples within a column and within a day followed by the same letter are not significantly different at $P = 0.05$ according to analysis by Duncan's multiple range tests.
HWRB, hot water rinsing and brushing.

fruits had lower decay development than control and HWRB-55 treated fruits, and did not affect fruits external quality and contents of SSC and TA. This suggested that the HWRB treatment at 60C for 20 s provided a potential heat treatment for postharvest decay controlling of strawberry fruits.

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REFERENCES

BARKAI-GOLAN, R. and PHILLIPS, D.J. 1991. Postharvest heat treatment of fresh fruits and vegetables for decay control. Plant Dis. *75*, 1085–1089.

COUEY, H.M. and FOLLSTAD, M.N. 1996. Heat pasteurization for control of postharvest decay in fresh strawberries. Phytopathology. *56*, 1345–1347.

FALLIK, E. 2004. Prestorage hot water treatment (immersion, rinsing and brushing). Postharvest. Biol. Technol. *32*, 125–134.

FALLIK, E., KLEIN, J., GRINBERG, S., LOMANIEC, E., LURIE, S. and LALAZAR, A. 1993. Effect of postharvest heat treatment of tomatoes on fruit ripening and decay caused *B. botrytis cinerea*. Plant Dis. *77*, 985–988.

FALLIK, E., GRINBERG, S., ALKALAI, S., YEKUTIELI, O., WISEBLUM, A., REGEV, R., BERES, H. and BAR-LEV, E. 1999. A unique rapid hot water treatment to improve storage quality of sweet pepper. Postharvest. Biol. Technol. *15*, 25–32.

FALLIK, E., AHARONI, Y., COPEL, A., RODOV, V., TUVIA-ALKALAI, S., HOREV, B., YEKUTIELI, O., WISEBLUM, A. and REGEV, R. 2000. Reduction of postharvest losses of "Galia" melon by a short hot-water rinse. Plant Pathol. *49*, 333–338.

GARCÍA, J.M., AGUILERA, C. and ALBI, M.A. 1995. Postharvest heat treatment on Spanish strawberry (*Fragaria* × *ananassa* cv. Tudla). J. Agric. Food Chem. *43*, 1489–1492.

LARA, I., GARCÍA, P. and VENDRELL, M. 2006. Post-harvest heat treatments modify cell wall composition of strawberry (*Fragaria* × *ananassa* Duch.) fruit. Sci. Hort. *109*, 48–53.

MULAS, M., GONZALES-AGUILAR, G., LAFUENTE, M.T. and ZACARIAS, L. 1997. Polyamine biosynthesis in flavedo of "Fortune" mandarin as influenced by temperature of postharvest hot water dips. Acta. Hort. *463*, 377–384.

PAN, J., VICENTE, A.R., MARTINEZ, G.A., CHAVES, A.R. and CIVELLO, P.M. 2004. Combined use of UV-C irradiation and heat treatment to improve postharvest life of strawberry fruit. J. Sci. Food Agric. *84*, 1831–1838.

PORAT, R., DAUS, A., WEISS, B., COHEN, L., FALLIK, E. and DROBY, S. 2000a. Reduction of postharvest decay in organic citrus fruits by a short hot water brushing treatment. Postharvest. Biol. Technol. *18*, 151–157.

PORAT, R., PAVONCELLO, D., PERETZ, J., WEISS, B., DAUS, A., COHEN, L., BEN-YEHOSHUA, S., FALLIK, E., DROBY, S. and LURIE, S. 2000b. Induction of resistance to *Penicillium digitatum* and chilling injury in "Star Ruby" grapefruit by a short hot-water rinse and brushing treatment. J. Hort. Sci. Biotech. *75*, 428–432.

PRUSKY, D., FUCHS, Y., KOBILER, I., ROTH, I., WEKSLER, A., SHALOM, Y., FALLIK, E., ZAUBERMAN, G., PESIS, E., AKERMAN, M. *et al.* 1999. Effect of hot water brushing, prochloraz treatment and waxing on the incidence of black spot decay caused by Alternaria alternata in mango fruit. Postharvest. Biol. Technol. *15*, 165–174.

SCHIRRA, M. and D'HALLEWIN, G. 1997. Storage performance of Fortune mandarins following hot water dips. Postharvest. Biol. Technol. *10*, 229–238.

SHAO, X.F., TU, K., ZHAO, Y.Z., CHEN, L., CHEN, Y.Y. and WANG, H. 2007. Effects of pre-storage heat treatment on fruit ripening and decay development in different apple cultivars. J. Hort. Sci. Biotech. *82*, 297–303.

VICENTE, A.R., MARTÍNEZ, G.A., CHAVES, A.R. and CIVELLO, P.M. 2003. Influence of self-produced CO_2 on postharvest life of heat-treated strawberries. Postharvest. Biol. Technol. *27*, 265–275.

VICENTE, A.R., MARTÍNEZ, G.A., CHAVES, A.R. and CIVELLO, P.M. 2006. Effect of heat treatment on strawberry fruit damage and oxidative metabolism during storage. Postharvest. Biol. Technol. *40*, 116–122.