Hot Water Treatment: A Non-Chemical Alternative in Keeping Quality During Postharvest Handling of Citrus Fruits

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ABSTRACT

Citrus fruits are an essential component of some of the human nutritional requirements like vitamins, minerals and organic acids. Preservation of these products, however, is one of the central problems encountered by producers worldwide. The postharvest losses of fruit and vegetable stands at 20-40% in the average. The use of synthetic chemicals on harvested fresh produce is becoming more difficult to justify due to the concerns about human health risks associated with the chemical residues particularly in the diets of children, the widespread occurrence of fungicide-resistance isolates, the environmental problems associated with the disposal of water used in packing operations, and a lack of approved fungicides for the control of sour rot. Therefore, the interest in “non-conventional” methods for postharvest decay control of fruits and vegetables has become increasingly important. Hot water treatments to control postharvest diseases of citrus avoid residue and disposal issues associated with chemical treatment. Heat treatment technologies are currently a relatively simple, non-chemical alternative to methyl bromide that can kill quarantine pests in perishable commodities, as well as control some postharvest diseases. Unlike methyl bromide, heat treatments do not pose significant health risks from chemical residues and, as a result, are more appealing to consumers than methyl bromide fumigation. This paper reviews some of the developments in hot water treatment and its effect on the quality of citrus fruits.

Key words: Hot water, heat treatment, citrus diseases, postharvest

1. INTRODUCTION

Postharvest decay is the major factor limiting the extension of storage life of many fresh harvested commodities. All fresh fruits and vegetables for domestic or export markets should be free of dirt, dust, pathogens and chemicals before they are packaged. The susceptibility of freshly harvested produce to postharvest diseases increases during prolonged storage as a result of physiological changes that enable pathogens to develop in the fruits (Fallik, 2004b). The concept of killing pathogenic fungal spores by heat treatment is not new. In the early 1930s, fruits were passed through hot dips for a few minutes at 49^{o}C to kill mold spores on citrus fruit. What is new is the initiative to use non-chemical means of mould control (Lemessa et al., 2004). Heat treatments, however, not only affect the pathogen but can have beneficial effects on the fruit. Research in Israel has shown that if citrus fruit are held at 35^{o}C in a humid environment (95-99% RH), mould infection does not occur and prevents decay (Fallik, 2004a). This is due to the enhanced formation of lignin, which is a related compound that prevents invasion by mould spores.

In the first decades of the 20th century, postharvest heat treatment was used on a commercial scale to control fungal diseases and insect infestation of horticultural crops. However, with the development of synthetic fungicides, the use of heat treatment was abandoned because of the greater advantages of fungicide treatments in terms of effectiveness, lower cost and ease of application. Many factors, however, have recently contributed to the implementation of strategies for reducing the dependence on agrochemicals. These include the enhanced proliferation of resistant strains of fungus due to prolonged use of agrochemicals; the prohibitive costs of selecting, synthesizing and testing new active ingredients; and the difficulties of registering them (Lichter et al., 2000).

Increased consumers awareness has, in recent years, brought about a resurgence of interest in the use of non-chemical treatment for the preservation of fresh produce. The use of heat is a method which has been studied for a number of fruits species (Barkai-Golan and Douglas, 1991). These same studies reported that short form protection against fungus and bacteria were effective. The heat was applied mainly by immersing the fruits in a hot water bath (in general, the lowest temperature were used with the longest heating times) although moist air has also been applied.

Heat treatments in the form of either moist hot air or hot water dips have had some commercial application for the control of postharest wastage in fruits. The advantage of hot water dipping is that it can control surface infections as well as infections that have penetrated the skin, without leaving no chemical residues on the produce (Fallik et al., 2000). The principal benefit of hot water (or air) treatments is that they can kill the organisms on and below the fruit surface. Postharvest fungicides only kill surface pathogens. The heat may affect ripening behavior by slowing it, which could be good or bad (Fallik et al., 2001). Postharvest heat treatment also can reduce chilling injury in many wounds of fruits during subsequent low temperature storage as well as reduce pathogens level and disease development.

Hot water treatment on citrus fruits was first reported in 1922 to control decay. After then, its use has been extended to disinfestations of insects on the surface of the fruits. Hot water may be supplied to fruits in many ways: by hot water dips, vapor heat, hot dry air or by hot water rinsing and brushing. According to Fallik (2004a), vapor heat treatment was mainly for insect control, while hot dry air has been used for fungal and insect control. Since water is a more efficient heat transfer medium than air, it is preferred as medium for most applications. Treatment with hot water has become increasingly accepted commercially, and significant improvement has been made with the addition of brushing (Ilic et al., 2001).

Practical systems have used either vapor heat or hot water. Fruits are dipped in water at 50-55^{o}C for 15 min before storage for control of fungus. Hot water dips before storage have been tried on a number of fruits. The problem with most of the treatments is that the high temperature necessitated by the short time of treatment (up to 60 min) can easily damage fruit tissue. The use of heat needs to be controlled as problems can be encountered with excess heat application leading to enhanced ageing of the fruit and hence a reduction in quality. Heat treatments have also been found to be accompanied by the development of off-flavors.

The advantages achieved by hot water treatment on fruits include (Fallik, 2004c):

- Slowing the ripening of climacteric fruits to obtain longer shelf life;
- Reducing the sensitivity of subtropical fruits to low temperature, thereby allowing the longer storage of these fruits at a temperature which would normally cause chilling injury;
- Reducing post harvest rots by either inactivation of pathogenic or enhancement of host resistance;
- Controlling insect pests as a quarantine treatment;
- Making possible the use of postharvest fungicides at lower concentrations.

Generally, it was proved that hot water treatment induced resistance either by directly inhibiting pathogen development, or by inducing resistance to the pathogen causing agents in the citrus fruits (Droby et al., 1993, Porat el al., 2000b and Fallik et al., 2002).

2. RESEARCH DEVELOPMENTS

Hot water treatments for the control of decay in different citrus species and cultivars have been investigated. The most common postharvest diseases are green mold caused by *Penicillium digitatum*, blue mold caused by *Penicillium italicum* and sour rot caused by *Geotrichum citrii-aurantii.* (Droby et al., 1993). Symptoms of these diseases are shown in Figure 1. The two main commercial hot water treatments are hot water immersion (dipping) and hot water rinsing and brushing (Fallik, 2004a). Plate 1 shows the hot water treatment equipment for citrus designed and fabricated by the Agricultural Research Organization (ARO), The Volcani Center, Israel. The picture was taken by the author during demonstration of the equipment to the 2004 course participants in Postharvest Biology and Technology in Israel.

Schirra and D'hallewin (1997) found that pre-storage dipping of ' Fortune ' mandarins in water at 50, 52 or 54^{o}C for 3 min reduced decay both during cold storage at 6^{o}C and simulated shelf-life at 20^{o}C without causing adverse effect to the rind surface. However, temperatures of 56-58^{o}C induced heat damage in the form of rind browning, dull-coloration and resulted in enhanced

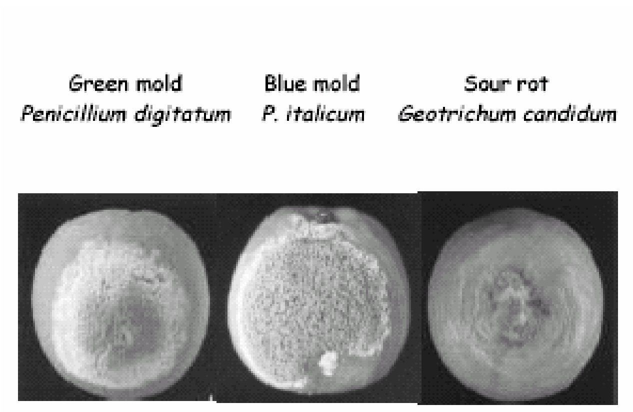

Figure 1: Citrus fruits showing symptoms of green mold, blue mold and sour rot
(Source: Droby et al., 1993a)

Plate 1: The hot water treatment equipment (*picture taken in Israel by the author*)

decay development and water loss. Physiological behavior and the internal quality attributes between the untreated and those treated at 50-54^{o}C were minimal. Those dipped at 58^{o}C however, developed off-flavor, which was probably due to the increased ethanol level.

A significant improvement had been made to hot water treatment by combining hot water rinsing and brushing (HWB) (Porat et al, 2000; Fallik, 2004a). The advantages of this technique are that it simultaneously cleans and disinfects the fruit, it fits into the packinghouse sorting line, and it requires a much shorter exposure time (10-30 sec) than conventional hot water dip treatments, which usually require a few minutes.

HWB has been found to be very effective in reducing decay in organic citrus. To establish a postharvest HWB treatment that is efficient in disinfecting organically grown citrus fruit, the effects of various heating periods on the in-vitro spore germination of the green mold pathogen *P. digitatum* was examined (Porat et al., 2000a). Results have shown that a minimum exposure period of 20 sec at 56^{o}C was required to inhibit the pathogen. Short exposures of 10 or 15 sec at 56^{o}C only delayed spore germination, but a longer exposure of 20 sec at the same temperature markedly inhibited spore germination to zero after 24 h and 32% after 48 h. Heating at 59 or 62^{o}C was more effective in inhibiting spore germination than 56^{o}C but may cause surface damage in susceptible citrus cultivars such as ‘Shamouti’ oranges. In vivo studies carried out on ‘Star Ruby’ red grapefruit and ‘Minneola’ tangerines to determine the effects of HWB on eradication of established infections indicated that HWB at 56, 59 and 62^{o}C for 20 sec reduced decay development in the infected wounds to only 20, 5 and less than 1%, respectively, of that in untreated control fruits or fruits treated with tap water. Rinsing and brushing the fruit with tap water alone reduced the naturally occurring epiphytic microflora population on the fruit surface twofold to only 1.4% of that on control unwashed fruit. HWB treatments at 56, 59 and 62°C resulted in a further reduction in microbial counts (CFU) to only 24, 12 and less than 1%, respectively, of those observed on tap water washed fruit. Similar results were observed with ‘Minneola’ tangerines. In storage experiments with ‘Minneola’ tangerines, ‘Shamouti’ oranges and ‘Star Ruby’ red grapefruit, the HWB treatment at 56°C for 20 sec reduced decay development to only 45, 55 and 52%, respectively, of that on fruit from commercial organic packing houses, which was not treated with HWB. In all cultivars tested, the HWB treatment at 56°C for 20 sec did not cause any damage, and did not affect fruit weight loss and internal quality parameters, such as the percentage of TSS in the juice, and the juice acidity. Moreover, the HWB treatment markedly improved fruit appearance, making them cleaner and glossier.

Smilanick et al. (2003) using a fabricated high volume, low pressure hot water drench equipment to treat California lemons and further corroborated many aspects of the works of Porat et al. (2000a). Green mold incidence was reduced from 97.9% and 98% on untreated lemons and oranges, respectively, to 14.5% and 9.4% by 30 sec treatment with 62.8^{o}C water. However, the hot water drench treatments were less effective in controlling decay compared with immersion of the fruit in sodium carbonate, a practice used in California and accepted as a certified organic treatment. Sour rot incidence on lemons averaged 84.3% after all water treatments, and was not significantly reduced by any of them. Conversely, immersion in sodium carbonate for 30sec reduced sour rot to 34.7%. Yeast and mold populations, initially log106.0 per fruit, were reduced to log103.3 on lemons and log104.2 on oranges by 15 sec treatment at 62.8^{o}C. Water-treated oranges had more surface blemishes after treatment than untreated fruit, but none had visible injuries associated with increases in the duration of treatment or water temperature. Lemons were not visibly changed by any treatment. Water temperatures that killed spores of *P. italicum* and *P. digitatum* were similar and higher that killed arthrospores of *G. citri-aurantii*. However, a temperature regime capable of controlling green mold did not control sour rot. The failure of the hot water treatment to control sour rot may be attributed to the fact that lesions characteristic of sour rot developed deeply in the fruit and presumably were protected from heat, while those of green mold typically were limited to the albedo. Table 1 summarizes the optimal temperature and time of exposure for control of postharvest decay, quarantine treatment or for preserving quality of citrus fruits.

All the methods currently being employed to reduce decay by heat treatment are fungistatic but not fungicidal (Fallik, 2004a). The beneficial effect of hot water may be related to a partial removal and/or inhibition of pathogen spores. The pathogen is markedly inhibited by both thermal inhibitions as well as by the enhanced resistance of the fruit against the pathogen. Pavoncello et al. (2001) showed that HWB treatment at 62°C for 20 sec induced resistance against *P. digitatum* in ‘Star Ruby’ grapefruit. The main factor responsible for the induction of disease resistance by the HWB treatment was the exposure to the high temperature, since rinsing and brushing the fruit with tap water (approximately 20°C) or with hot water at 53°C did not affect the percentage of decay development nor the rot diameter in the infected wounds. HWB using heated water induced the accumulation of heat shock and pathogenesis-related proteins, which were not observed in HWB using unheated tap water.

Table 1: Hot water treatments for horticultural crops, optimal temperature and aim of heat treatments

Crop	*Treatment*	*Optimal temp ^{o}C (time)*	*Aim*
Clementine	HWT	45(2.5min)	Decay control
Grapefruit (cv."Hass") g	HWRB	59-62(20s)	Decay control, chilling and decay resistance better quality
Kumquatg	HWRB	58(20s)	Decay control, better quality
Lemon	HWT	52-53(2min)	Decay control, decay resistance
Lemon	HWRB	62.8(15s)	Decay control, quality maintenance
Mandarin (cv. Fortune)	HWT	50-54(3min)	Decay control
Orange (cv.Shamouti) g	HWRB	56(20s)	Decay control, better quality
Orange (cv. Tarocco)	HWRB	62.8(15s)	Decay control
	HWT	53(3min) f	Decay control, chilling resistance
Tangerine (cv. Minneola) g	HWRB	56(20s)	Decay control

f Season-dependent.; g Commercial treatment.
(Source: Fallik, 2004a)

An important part of enhanced resistance is related to the 'welding' of the epicuticular surface, filling the cracks of the cuticle and preventing the use of these occluded cracks as invasion sites of various pathogens (Fallik, 2004a). A scanning electron microscope (SEM) examination of 'Minneola' tangelos after HWB at 56 for 20 sec indicated that the treatment cleaned the fruit, and removed fungus spores and hyphae from its surface (Porat et al., 2000). Moreover, the HWB treatment smoothed the fruit epicuticular waxes, so that it covered and sealed the stomata and microscopic cracks on the fruit surface. See Figure 2. Similar structural changes of the epicuticular wax were observed in grapefruit subjected to hot water dips at 50°C (Schirra et al., 2000). Platelets flattened while cracks and most stomata appeared partially or completely plugged by melted wax, thereby providing a mechanical barrier against wound pathogen such as *P. digitatum*. Such beneficial effects however, may be thwarted during long-term storage or shelf-life conditions as cracks tend to reappear and a number of stomata are seriously damaged (D'hallewin and Schirra, 2000), becoming more vulnerable to infection by fungal hyphae.

3. ECONOMIC IMPORTANCE

Discussion and interest in the research aspect of heat treatment can obscure the particularities of establishing and running such a system. There is widespread use of hot air and hot water systems in several countries. The major requirements for heating technologies are for systems, which are effective in terms of pathogens control or insect mortality whilst minimizing impact on quality control (Ilic et al., 2001). At the same time they must be economically viable. Hot water immersion, high temperature forced air and vapor heat are effective quarantine alternatives to methyl bromide fumigation for fruits and vegetables that are not susceptible to heat damage, particularly tropical and subtropical commodities, with proven efficacy against pest and diseases. Methyl bromide treatment systems can range in cost from $21,000 to as much as $291,000

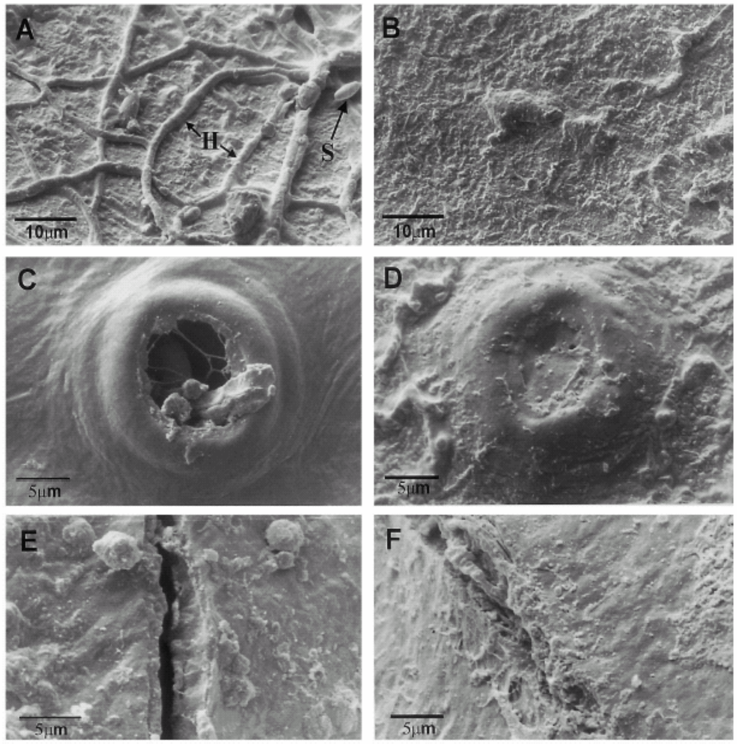

Figure 2: SEM images of ‘Minneola’ tangerine fruit surfaces after an HWB treatment. Fruits were kept as controls (A, C, E) or rinsed and brushed at 56°C for 20 s (B, D, E). A, surface of control fruit. B, surface of rinsed and brushed fruit. C, stomata of control fruit. D, stomata of rinsed and brushed fruit. E, crack on the surface of control fruit. F, crack on the surface of rinsed and brushed fruit. A, B, magnification -1500; and C-F, magnification -3500. H, hyphae; S, spore

Source: (Porat et al., 2000)

depending on the commodity and quantity being treated. On the other hand hot water immersion systems can be easily assembled, are durable, mobile and inexpensive. While hot water immersion is inherently more efficient than vapor as a heat transfer medium and hot water treatment can be assembled for less than $8,000, it can damage some fruits and vegetables (Lemessa et al., 2004).

Commercial hot water treatment facilities are becoming more and more important in countries such as Mexico, Israel, Haiti, Puerto Rico, and South America, Florida. The cost for each facility averages about $200,000. Alternatively vapor heat and forced hot air are less damaging to commodities and more versatile than other treatment system. However, they are more expensive. For example both vapor heat and hot air treatment systems may initially require large capital investments ranging from $20,000 to $200,000 for large commercial facilities (Lemessa et al., 2004). A comparison of the capital and operating cost of these technologies is provided in Table 2. Capital costs for both vapour/forced air heat and methyl bromide treatments were calculated by dividing the cost to set up commercial treatment systems i.e., capacities of 45,375 tons/year and 275,862 tons/year for forced air for apples and methyl bromide treatment systems respectively. It was assumed that treatment of systems was operational 250 days of the year and that three forced air/vapor, and one methyl bromide treatment could be completed each day. Operating costs included labor, energy maintenance, insurance and chemical costs in the case of methyl bromide. As shown in the Table 2, the capital cost for heat treatment are only slightly higher than that for methyl bromide on a per ton commodity basis. Operating cost for heat treatments, on the other hand are eight times higher than for methyl bromide attributably primarily to longer treatments and higher energy costs. It is likely that operating cost will decrease in the future as the number of commercial heat treatments facilities increases. Furthermore, other related costs (i.e., harvesting, packaging, storage, processing and transportation costs to bring the commodity to the market) further reduce the percent contribution of heat treatment, making it a relatively insignificant cost overall. As a result, heat treatment can be a very viable alternative to methyl bromide for commodity treatment.

Table 2: Capital and operating cost comparison ($/tone)

Cost Factor	**Forced air-vapor heat**	**Methyl Bromide**
Capital Costs	4.41	1.33
Operating Costs	25.00	3.04
Total	29.41	4.37

(Source: Lemessa et al., 2004)

4. CONCLUSIONS

In view of environmental and health concern, a determined effect has been made to reduce the use of chemicals to control diseases of citrus fruits. Regulatory agencies have reacted to public pressure and introduced a comprehensive legislation to reduce the application of chemicals. The hot water dip is viewed as potential visible anti microbial postharvest treats of citrus fruits. All citrus fruits may not respond to heat treatment in same way. Water loss from the hot water treated fruits may be a problem when stored. This may be reduced by wax addition to the hot water or rinse water. Wax is nowadays often applied to reduce water loss and improve the storage life of the citrus fruits. The challenge is for development of simple, low cost hot water treatment facilities as a non-chemical alternative in keeping quality during postharvest handling of citrus fruits

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