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# Hot Water Rinsing and Brushing of Fresh Produce as an Alternative to Chemical Treatment after Harvest—The Story behind the Technology

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**Abstract:** For decades, heat treatments have been known to reduce or eliminate decay-causing agents and slow the physiological deterioration of freshly harvested fruits and vegetables. For years, fungicides and pesticides have been used to control fungi on freshly harvested fruits and vegetables. However, these chemicals can contaminate the environment and be hazardous to those who consume fresh produce. Therefore, heat treatments, lasting only minutes or up to several days, have been developed to control insects and pathogenic fungi on fresh produce after harvest. In the 1990s, hot water rinsing and brushing (HWRB) technology to clean and disinfect fresh produce at relatively high temperatures (50 to 62 °C) for seconds (12–20 s) was developed at the Volcani Institute in Israel. This technology has been improved over time and is currently used commercially on several crops in Israel and elsewhere. This article discusses the development of this prestorage technology, from 1996 to 2006, and describes the effects of HWRB on the internal and external characteristics of fruits and vegetables, as well as the possible mode of action of this technology, as examined in the literature published since 1996.

**Keywords:** marketing; physical treatments; postharvest; prestorage; shelf life; storage



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## 1. Introduction

As a result of physiological and pathological deterioration, about one-third of fresh fruits and vegetables are lost between the field and the fork. In light of the growing world population, which is expected to reach 9 billion by the year 2050, this is unacceptable [1,2]. Synthetic fungicides have been used to control pathological deterioration for many years. However, due to concerns about impacts on human health, many traditional postharvest treatments are no longer permitted. In addition, over time, microorganisms have developed resistance to many chemicals and there is a need for new means of control [3].

Heat treatments were first developed in the 1920s for the control of brown rot in citrus fruit [4]. Since then, these treatments have been found to be very effective in controlling a variety of decay-causing agents [3,5]. Prestorage heat treatments to control the development of decay can be applied for periods of several seconds to several days [6]. Heat treatments can directly control pathogens present on the surface of the fresh produce or within the top two to three cell layers under the skin. They can also control decay development indirectly by inducing defense mechanisms in the treated produce that prevent or limit pathogen growth [6]. Among these physical treatments are hot water dip/immersion treatments, hot air treatments, vapor heat treatments, and the relatively new option of a short hot water rinsing and brushing (HWRB) treatment. Studies have demonstrated that the effects of heat treatments on freshly harvested produce depend on preharvest treatments, the maturity stage at harvest, cultivar, type of heat treatment applied, storage conditions, and, most importantly, the duration of the treatment and the temperature applied [3]. The aim of this article was to summarize the development of HWRB technology from the mid-1990s to date, and to describe how this technology can be useful for maintaining and prolonging the storage and marketing shelf-life of fresh produce. The mode of action of this technology is also discussed.

## 2. The Development of the Technology

In 1995, farmers in the desert region of southern Israel complained about the difficulties they encountered in cleaning the field dust from the calyces of sweet pepper before exporting the fruit. At the time, they were using paintbrushes to clean each individual pepper. A team from the Department of Postharvest Science and the Institute of Agricultural Engineering at the Volcani Institute developed the first hot water rinsing and brushing technology, with a design based on the machinery used in a car wash. In 1996, the first prototype (Figure 1) was developed, built, and patented by the Volcani Institute [7]. The prototype included vertical revolving brushes, a thermostat-controlled hot water tank, a pump to pressurize and recycle the hot water, and telescopic legs that could be used to adjust the slope of the machine in order to change the duration of the fruits' exposure to the treatment. The first commercial-scale machine was built in 1997 (Figure 2). That device consisted of two separate machines; the first machine was designed to clean the fruit with non-recycled tap water and the second was designed to then disinfect the fruit with recycled hot water. The duration of exposure was determined by the machine's slope and the water was heated with gas to maintain the desired temperature. This machine could also be adjusted to include different types of brushes (e.g., 30 mm long with semi-synthetic bristles), levels of water flow per nozzle, numbers of nozzles and their arrangement and orientation, and levels of water pressure. This type of machine was used to determine the best water temperature and duration of exposure for peppers (55 °C ± 1 °C for 12 to 15 s) [8]. The fruits were dried in the 6-m-long drying tunnel that was equipped with fans blowing hot air (40 °C). However, this machine had a limited produce-per-hour capacity and was very expensive. Thus, a third version was designed in 1998 with 22 parallel brushes that were divided into two compartments: 10 brushes for a non-recycled tap water rinse (TWRB; for cleaning), 12 brushes for the recycled hot water rinse (HWRB), and two extra brushes to remove the water before the peppers were sent to the drying tunnel. The fruits were then dried in a 6-m-long drying tunnel equipped with hot air fans. To meet food safety requirements, in 2000, a fourth generation of the machine was designed and built out of stainless steel with 24 brushes in the following arrangement: 10 TWRB + 12 HWRB + 2 to remove water (Figure 3). After the rinsing and brushing procedure, the fruits were dried with six fans.

**Figure 1.** First version—prototype, 1996 (photo by E. Fallik).

**Figure 2.** Second version—first commercial-scale machine, 1997 (photo by E. Fallik).

**Figure 3.** Fourth version, 2000 (photo by E. Fallik).

In 2005, the fifth generation of the machine was designed for improved cleaning, disinfecting, and drying of the treated fruit (Figure 4). The numbers of TWRB and HWRB brushes were changed to 12 and 8, respectively, and the water in the TWRB compartment was pressurized by recycling a third of the tap water, while the hot water was fully recycled. Four additional brushes at the end of the machine removed the excess water before the fruit continued to the drying tunnel. Changes were also made to the nozzles: fan-type nozzles were used for the TWRB and cone-type nozzles were used for the HWRB. The drying tunnel was shortened to 4.5 m by using two, forced-air fans and three regular fans. The capacity of this technology is between 3 to 15 tons/h, depending on the width of the machine.

**Figure 4.** Fifth version, 2005 (photo by E. Fallik).

## 3. The Effect of HWRB on the Quality of Fresh Produce

The first report on the beneficial effects of HWRB technology concerned sweet bell pepper (*Capsicum annuum* L.) [8]. The optimal treatment for cleaning and disinfecting pepper while maintaining fruit quality after prolonged storage and marketing was found to be 55 ± 1 °C for 12 ± 2 s. This treatment significantly improved the general appearance of the fruit, reduced the incidence of decay, and maintained fruit firmness [8]. A combined treatment of HWRB at 55 °C for 15 s and plastic bagging allowed the pepper fruit to be kept at 1.5 or 4 °C for 3 weeks as a quarantine treatment against the Mediterranean fruit fly (*Ceratitis capitata*), with very little effect on fruit quality [9].

Beneficial effects of HWRB on fruits and vegetables after harvest have been reported over the last two decades. Acorn squash (*Cucurbita pepo* L.) has a distinctive turbinate shape with several longitudinal ridges and furrows, a dark green rind with a deep orange flesh, and high sugar content [10]. Treating these fruits with HWRB at 54 °C for 15 s and then storing them at 15 °C significantly maintained the fruit quality for 3.5 months, as indicated by the greater firmness of the fruits, a lower incidence of decay, and improved retention of the green skin color [11]. However, the effectiveness of this treatment varied depending upon the squash cultivar [12].

HWRB at 55 °C for 15 s significantly reduced the development of decay among *Penicillium expansum*-inoculated apple fruits (*Malus domestica* Borkh. cv. Golden Delicious) after 4 weeks at 20 °C, or in naturally infected apples after prolonged storage of 4 months at 1 °C plus 10 days at 20 °C. Heat damage was observed on fruits that were rinsed and brushed at 60 or 65°C for 15 s [13]. Oster et al. [14] observed that HWRB treatment at 58 °C for 30 s effectively controlled white rot caused by *Botryosphaeria dothidea* on 'Fuji' apples. A significant reduction in the incidence of decay of apple fruit was achieved using HWRB for 20 or 25 s at 55 °C, followed by up to 100 days of cold storage at 2 °C and 14 days at 18 °C [15].

The technology has also been evaluated also for use with conventional and organically grown citrus (*Citrus* spp.) fruits. Rodov et al. [16] found that the application of HWRB at 56 or 60 °C for 10 s effectively reduced postharvest diseases, especially *Penicillium* molds, on the pomelo × grapefruit hybrid 'Oroblanco'. Porat et al. [17] reported that HWRB at 56 °C for 20 s reduced decay by 45–55% on organically grown tangerines (*Citrus reticulate* Blanco), oranges (*C. sinensis* Osbeck), and red grapefruits (*C. paradise* Macf.), with no rind injuries or adverse effects on fruit weight or internal quality parameters. HWRB at 62 °C for 20 s, in applied combination with sodium bicarbonate (2%, $w/v$) or *Candida oleophila* yeast cells ($10^8$ cells mL/L) 24 h after artificial inoculation of grapefruit with *Penicillium digitatum*, reduced decay development in infected wounds by 87 to 89%, as compared to untreated fruit [18]. HWRB at 62.8 °C for 30 s markedly controlled the development of green mold (*P. digitatum*) on oranges and lemons (*C. lemon* Osbeck) However, the incidence of sour rot caused by *Geotrichum citri-aurantii* was not significantly reduced under similar conditions [19]. Similar results were reported for orange and lemon fruits after HWRB treatment at 62 °C for 20 s [20]. On kumquat (*Fortunella margarita* Lour. Swingle) fruit, the best HWRB treatment conditions for controlling decay while maintaining fruit quality were 55 °C for 20 s [21].

The distribution of high-quality litchi (*Lychee chinensis* Sonn.) fruits to global markets depends on postharvest treatments to suppress peel browning. Treating litchi fruit at 55 °C for 20 s maintained its quality and prevented peel browning after 3 weeks of storage at 1.5 °C (95%) plus 3 or 5 days at 18 °C [22].

Melons (*Cucumis melo*) benefited from HWRB at 59 °C for 15 s. This treatment significantly reduced chilling injury when fruits were stored at 5 °C for 2 weeks [23]. The potential use of HWRB technology to clean and disinfect melon fruits destined for the fresh-cut industry was evaluated. Treating melons with HWRB at 75 °C for 20 s significantly reduced total microbial counts by 4 logs, compared to a 2.5 log reduction in 58 °C-HWRB treated fruit and 1.5 log reduction in 150 μL/L chlorine-treated fruit, at 4 days after treatment. Although, HWRB at 75 °C for 20 s severely damaged the fruit peel, if the fruit was left in storage, none of the HWRB treatments affected the taste, aroma, color, or firmness of the fresh-cut flesh [24].

In Israel, the control of the postharvest development of side and stem-end rots (*Alternaria alternata* and *Phomopsis mangifera*, respectively) of mango (*Mangifera indica* L.) fruit has included HWRB at 55 °C for 15–20 s, followed by the application of prochloraz (a.i., Sportak 45% at 125 mg/mL) in 50 mM HCl, and waxing with a polyethylene emulsion. This treatment enabled commercially successful storage at 12 °C for 3–4 weeks and ripening at 20 °C for 7 more days [25]. However, this treatment also significantly induced the development of red lenticels. Therefore, hot water rinsing was applied over rollers without the brushes [26]. Luria et al. [27] reported that HWRB at 55 °C for 15–20 s was used commercially to improve mango fruit quality and reduce postharvest disease. This treatment enabled successful storage for 3–4 weeks at 12 °C, with improved color and reduced disease development. In Brazil, *Botryosphaeria dothidea* is the major pathogen of mango, causing stem-end rot, which causes significant losses in storage and marketing. Treating the fruits with HWRB at 65 °C for 15 s or 2.5 kJ/$m^2$ of UV-C alone provided the best results, with fewer symptoms of the disease appearing during 18 days of storage. The combination of HWRB with UV-C did not improve the control of the disease, as compared to the individually applied treatments [28].

Karabulut et al. [29] reported that treating peach (*Prunus persica* L. Batsch.) and nectarine (*Prunus persica* var. *nectarina* (Ait.) Maxim.) fruit with HWRB at 60 °C for 20 s and then dipping them into a cell suspension ($10^8$ cells/mL) of *Candida* spp. 24 h after inoculation with *P. expansum* reduced decay development by 60%, compared to the controls.

HWRB treatment of red tomatoes (*Solanum lycopersicum* Mill.) at 52 °C for 15 s significantly reduced decay development on fruit after 2 weeks of storage at 12 °C [30]. This treatment completely inhibited chilling injury symptoms after 15 days of storage at 5 or 12 °C and 3 days of marketing simulation at 22 °C [31].

## 4. Mode of Action

In general, the overall quality of fresh produce that was treated at optimal water temperatures and durations of exposure was significantly better than that of untreated fruit, in terms of several external and internal quality traits. The reduction in decay development in the fresh produce treated with HWRB is mainly due to a 3–4 log reduction in the total number of colony-forming units of the microorganism population, due to the brushes and the hot water, as compared to untreated fruits [8,17,19,23,30,32]. HWRB technology was found to melt and redistribute the epicuticular wax layer, thus sealing invisible cracks and strengthening the physical barriers to pathogen penetration [8,17,23]. It is also possible that the reduction in softening among HWRB-treated fruit was due to recrystallization or melting of the wax layer of the cuticle through which water could escape. This sealing of cracks or natural openings significantly reduced fruit weight loss, so that the fruits remained firm even after prolonged storage [8,17,23,30].

HWRB treatment enhanced resistance against decay-causing agents when freshly harvested produce was inoculated 24 h after treatment. Resistance was less pronounced when the fruits were inoculated 6 h after treatment and was nonexistent among fruits inoculated 48 h after the HWRB treatment [31]. HWRB induced the accumulation of proteins that cross-reacted with citrus chitinase and ß-1,3-glucanase antibodies. The increases in the accumulation of glucanase and chitinase proteins were part of the complex of fruit disease-resistance mechanisms induced by the HWRB treatment [33–35]. Ripening inhibition was observed in terms of lower respiration rates and reduced ethylene evolution of HWRB-treated fruit during storage and marketing, as compared to untreated fruit [8,13,23,30]. In addition, ripening inhibition was also observed indirectly in several types of HWRB-treated fruit, as the inhibition of color development and the inhibition of polygalacturonase and exo- and endo- cellulase activities [11,13,30,36]. HWRB increased the phenylalanine ammonia lyase activity in mango fruit, which indirectly induced the defense mechanism in the fruit and reinforced the resistance response of the fruit to the HWRB [28].

Polyphenol oxidase (PPO) activity in litchi peel causes browning of the pulp, which limits consumer acceptance. HWRB was found to reduce PPO activity in litchi, reducing the concentration of $SO_2$ that would need to be applied to the fruit to inhibit peel browning. HWRB treatment also diminishes the naturally high surface tension of solutions on the epidermis of the fruit, to allow the uniform penetration of the HCl, which, in turn, inhibited PPO activity and kept the anthocyanins in their red-pigmented forms [22].

Despite the short duration of exposure to high temperature, the protection mechanism of HWRB included the induction and accumulation of heat-shock proteins, which reduced or eliminated the development of chilling injury when the fruit was stored at suboptimal temperatures [31–33,37].

## 5. Conclusions

There has been intensive research on HWRB technology since it was first introduced to farmers in 1996. In Israel, this technology has been used commercially on sweet corn (*Zea mays*), persimmon (*Diospyros kaki*), sweet pepper, melon, mango, avocado (*Persea americana*), orange, grapefruit, kumquat, and organic citrus fruit (Fallik, pers. comm.). All of these harvested crops are treated with the same machine (Figure 5). However, the water temperature and duration of exposure are adjusted for each crop. At the beginning of the millennium, there were 250 of these machines in small and large packinghouses across Israel. This technology has saved Israeli farmers more than $70 million by reducing labor, as farmers previously used a painting brush to clean some of the fruits, reducing losses to about 2% from the previous 15%, extending storability and marketing, and allowing the use of sea transport instead of air transport. The technology reduces the loss of water from harvested produce, better maintains fruit firmness, enhances resistance to fungal infection, reduces sensitivity to chilling injury, and improves the overall appearance of the fresh produce. The average cost of an HWRB unit that includes a dryer and heat system based on gas (100,000 Kcal), and that has a capacity of 4 tons/h, is about $65,000. Within 3 years after purchasing this technology, farmers had recovered their investments because of the higher income resulting from better fruit quality, longer fruit storability and marketing period, and significantly fewer losses. The costs of export by sea were markedly lower than previous airfreight charges.

**Figure 5.** An HWRB machine for peppers and melons (photo by E. Fallik).

In the near future, a better understanding of the physiology, pathology, biochemistry, and molecular biology of hot water-treated produce will enable the development of more precise and effective HWRB techniques. Developing very cheap technologies to heat and maintain the temperature of the water in the recycled-water tank will reduce the cost of treatment by reducing energy costs. This technology alone, or in combination with other treatments or disinfectants that could be incorporated into the TWRB and/or the HWRB compartments should be investigated for a broader range of freshly harvested crops and even for minimally processed produce and the juice industry. Furthermore, the possible enhancement of fruit tolerance to low temperatures by reducing chilling injury or by enhancing fruit resistance to decay-causing agents should be further explored in order to prolong storage at temperatures lower than those currently used. This would permit produce to be exported by sea, which is less expensive than air transport.

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