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The Potential Use of Hot Water Rinsing and Brushing Technology to Extend Storability and Shelf Life of Sweet Acorn Squash (*Cucurbita pepo* L.)

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Abstract: Acorn squash fruits (*Cucurbita pepo* L.) are very sweet and are an excellent source of nutrients and vitamins. Very little information is available about their optimal storage temperature or how to extend their shelf life. The present goal was to elucidate the best storage temperature of this fruit, and to evaluate hot water rinsing and brushing (HWRB) technology to maintain fruit quality for several months. The optimal storage temperature was found to be 15 °C. However, treating the fruits with HWRB at 54 °C for 15 s and then storing them at 15 °C significantly maintained fruit quality for 3.5 months, as indicated by higher fruit firmness, lower decay incidence, and improved retention of green skin color.

Keywords: quality; postharvest; prolonged storage; shelf-life

1. Introduction

Acorn squash are an old cultivar-group of *Cucurbita pepo* L. subsp. *texana* (Scheele) Filov [1]. The fruits have a distinctive turbinate shape with several longitudinal ridges and furrows [2], and they are rather small, weighing 300–1500 g. Most acorn squash cultivars have a dark green rind with a deep-orange flesh and sugar content of 12%–18% [3]. The fruit is an excellent source of nutrients and vitamins and can be stored for about 2 months at temperatures not lower than 10 °C without developing chilling injury and losing its dark color, which is a good indicator for freshness and marketing [4]. Under the hot Israeli climate, the fruits lose their dark-green rind color, become dull orange or yellow within a short time after harvest, and thereby lose value. Because of its dark green color and distinctive taste after cooking, this fruit is called Dela'at Armonim (chestnut pumpkin) in Hebrew [3].

A technology of cleaning and disinfecting fresh-harvested produce in hot water (45–62 °C) over brushes for a very short time (15–25 s) is used commercially in Israel [5]. This technology is applied to several fruits and vegetables to reduce decay development and maintain fresh produce quality through prolonged storage and shelf life.

Very little information is available about the storage life of sweet acorn squash. Therefore, the goal of this research was to determine the best storage temperature for acorn squash fruits and to evaluate the use of hot water rinsing and brushing technology to clean and disinfect the fruits before prolonged storage for 3.5 months.

2. Materials and Methods

2.1. Plant Materials

Acorn squash fruits (*Cucurbita pepo* L. cv. Or) (Origene Seeds, Ltd., Giv'aat Brener, Israel), uniform in color and size with no defects, were harvested with a clipper from a commercial field in the central region of Israel. They were selected according to commercial maturity indexes (initial color ~125 Hue°; unit weight about 600–700 g).

2.2. Experiments and Treatments

In a marketing simulation in 2016 dry-brushed fruits were kept at 10, 15 or 20 °C, and 95, 95 or 70% RH, respectively for 2.5 month, followed by 3 days at 20 °C. In 2017, in light of preliminary results, the fruits were subjected to hot water rinsing and brushing (HWRB) treatment at 54 ± 1 °C for 15 s as described by Fallik [6] and kept at 15 or 20 °C for 3.5 months, and then for 3 days at 20 °C. Untreated fruits and those treated by tap water rinsing and brushing (TWRB) served as controls.

2.3. Quality Evaluation

Fruit quality was evaluated after 3.5 months at 15 or 20 °C followed by 3 days at 20 °C as follows: Weight loss percentage was calculated from the weights of 10 fruits before and after storage. Total soluble solids (TSS) contents were measured in 10 fruits by removing and squeezing a segment of flesh (from the peel to the seedbed) onto a digital refractometer (Atago, Tokyo, Japan); the same 10 fruits were tested for color, firmness and weight loss, Fruit epidermal color was evaluated with a Minolta Chroma Meter (Minolta, Ramsey, NJ, USA) that was calibrated against a white standard tile; two sides of each of 10 fruits were measured near the equator, and the results expressed as Hue angle (h°). Firmness was measured in newtons (N) (C-peak mode) with a motorized Chatillon penetrometer equipped with a 6-mm conic plunger (John Chatillon & Sons, New Gardens, NY, USA); each measurement was applied on opposite sides of each of 10 fruits, near the equator. Decay was expressed as the percentage of fruits with visible fungal mycelia on the peel.

2.4. Statistical Analysis

Three experiments/harvests were conducted each year. Each treatment consisted of 2 cartons, each consisted 14–15 fruits per carton (28–30 fruits per treatment), two repetitions per treatment. All data were subjected to one- or two-way statistical analysis at $P = 0.05$ with the JMP-11 Statistical Analysis Software Program (SAS Institute, Cary, NC, USA).

3. Results

3.1. Experiments in 2016

The best storage temperature, based on weight loss, decay incidence and color quality parameters after 2.5 months storage, was found to be 15 °C (Table 1). At 10 °C, although fruits lost less weight and were much greener, decay incidence was significantly higher than in the other treatments. At 20 °C, fruits lost significantly more weight and their color was greenish/orange, but decay incidence was similar to that at 15 °C (Table 1).

Table 1. The influence of storage temperature on Acorn squash quality parameters after 2.5 months in cold storage plus 3 days at 20 °C.

Storage Temperature	Weight Loss (%)	Decay (%)	Color (Hue°)
10 °C	6.4 b [z]	55.3 a	103 a
15 °C	6.9 b	6.3 b	90 b
20 °C	13.4 a	8.3 b	78 c

[z] Values in the same column followed by the same letter are not significantly different at $P = 0.05$ according to Fisher's least significant difference test.

3.2. Experiments in 2017

Storing the fruits at 15 °C for 3.5 months significantly maintained fruit quality, based on firmness, decay development and color (Table 2, Figure 1). At this storage temperature, fruits were significantly firmer, showed less decay incidence, and were significantly greener than those in other treatments. TSS was not affected by storage temperature (Table 2; mean value at each temperature). Use of HWRB maintained significantly better fruit quality than that of untreated controls and TWRB-treated fruits (Table 2; mean value in each treatment; Figure 1). HWRB-treated fruits were very firm, had significantly less decay, and were significantly greener than untreated controls and TWRB-treated fruits. No significant differences were observed in TSS content although it was higher in HWRB-treated fruits (Table 2). No interaction between storage temperature and wash treatment was observed (Table 2).

Table 2. The influence of tap water rinsing and brushing (TWRB) and hot water rinsing and brushing (HWRB = 54 ± 1 °C for 15 s) on Acorn squash quality parameters after 3.5 months at 15 or 20 °C plus 3 days at 20 °C.

Treatment-Wash	Temperature	Firmness (N)	Decay (%)	TSS (%)	Color (Hue°)
Control [z]	15 °C	83 b *	7.0 b	9.2 a	77.0 bc
TWRB [y]	15 °C	86 ab	3.7 cd	9.5 a	79.0 bc
HWRB [x]	15 °C	102 a	0.7 e	9.9 a	91.3 a
Control	20 °C	66 c	10.0 a	9.1 a	73.0 c
TWRB	20 °C	78 bc	4.7 bc	9.0 a	73.0 c
HWRB	20 °C	89 ab	1.7 de	9.8 a	80.7 b
LSD [w]		**7.31**	**1.21**	**1.96**	**3.34**
Mean values at each temperature					
15 °C		90.6 a	3.8 b	9.5 a	82.4 a
20 °C		77.8 b	5.4 a	9.3 a	75.6 b
LSD		**4.21**	**0.70**	**1.13**	**1.93**
Mean values in each treatment					
Control		74.8 b	8.5 c	9.1 a	75.0 b
TWRB		82.3 ab	4.2 b	9.3 a	76.0 b
HWRB		95.3 a	1.2 c	9.9 a	86.0 a
LSD		**5.16**	**0.86**	**1.39**	**2.36**
Table of Variance (F-value)					
Treatment (Tr)		*	*	NS	***
Temperature (Te)		**	***	NS	**
Tr × Te		NS	NS	NS	NS

[z] Untreated control; [y] Tap water rinsing and brushing for 15 s; [x] Hot water rinsing and brushing for 15 s; [w] LSD, Least significance difference at $\alpha = 0.05$; [v] Means within columns followed by the same letter are not significantly different at $P \leq 0.05$, based on the least significant difference test; ***, **, *, NS indicate statistical significance at $P \leq 0.001$, 0.01, and 0.05, and not significant, respectively.

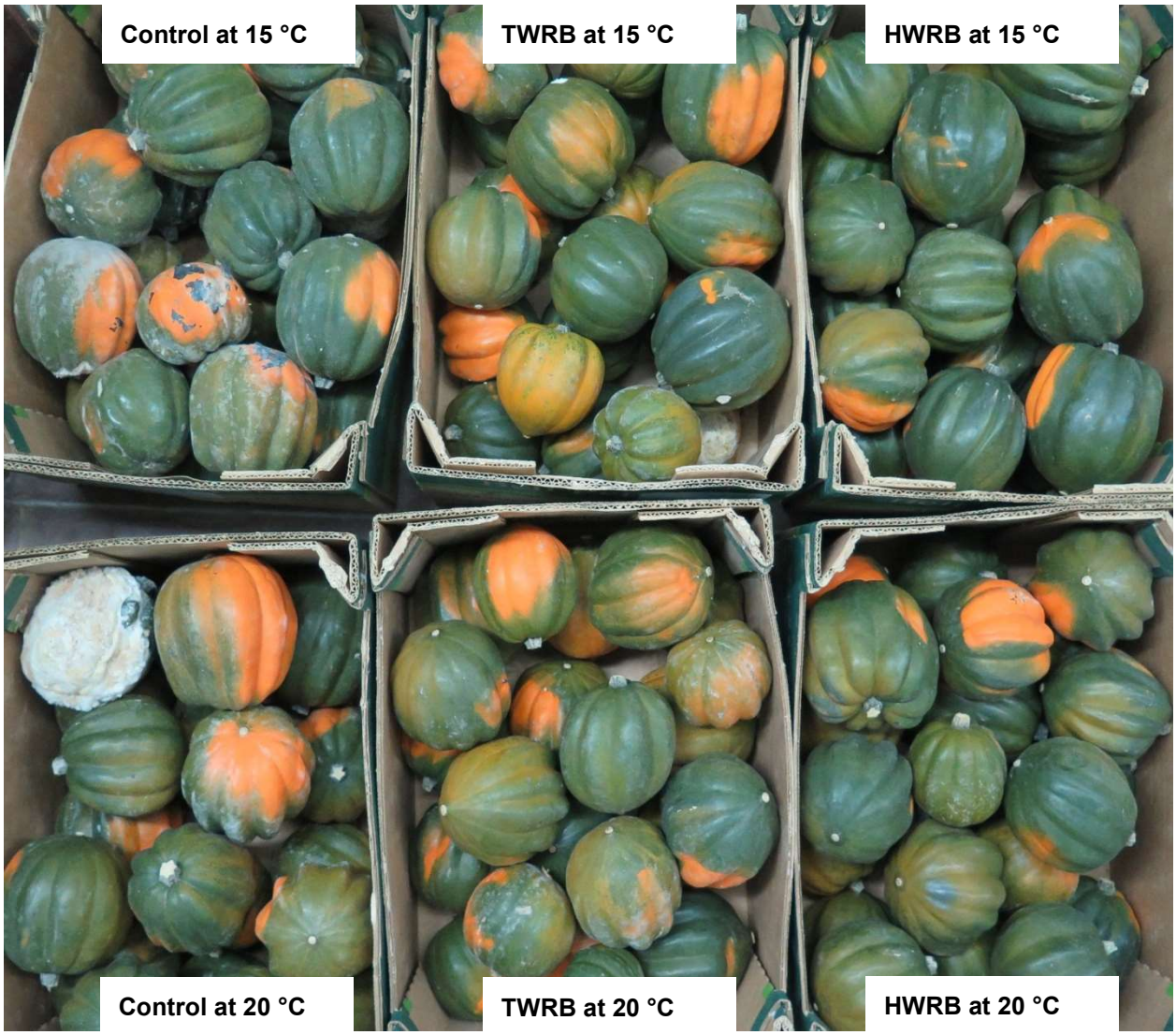

Figure 1. The influence of storage temperature and water treatment on Acorn squash quality after 3.5 month at 15 or 20 °C plus 3 days at 20 °C (TWRB = tap water rinsing and brushing; HWRB = hot water rinsing and brushing at 54 ± 1 °C for 15 s).

4. Discussion

Acorn squash has characteristic inedible, hard, thin skin, and firm flesh. The flesh is very sweet with a nut-like flavor after baking, microwaving, sautéing, or steaming. This squash is an excellent source of nutrients, including carotenoids, ascorbic acid, and vitamin C [7]. It is best known as a source of carotenoids—primarily b-carotene—and lutein, which are beneficial, respectively, as a provitamin A compound and for general health [8]. Market opportunities for growers have extended into the fall/winter season and Acorn squash occupies an important late-season niche in Israel, therefore it is anticipated that this market has scope for increased growth in Israel and elsewhere [9].

To the best of our knowledge, there is very little published information about the optimal temperature for prolonged storage of Acorn squash. Acorn squash is considered a winter squash that can be stored at 10–12 °C for 2–3 months, while lower temperatures cause chilling injuries, and those above 20 °C increase weight loss and decay incidence [10]. In the present study 15 °C was found the best temperature to keep the fruit for 3.5 months. However, to keep the fruit at 15 °C for several months without affecting its quality, it is necessary to use HWRB treatment, whose beneficial effects on

fresh-harvested produce were reported by Fallik [5,6]. HWRB treatments can remove fungal pathogens from the fruit surface through the brushing effect, and the natural wax platelets could be melted and smoothed to seal stomatal openings or invisible surface cracks, thereby reducing decay development and water loss and, in turn, increase fruit firmness (Tables 1 and 2) [5]. The lower decay incidence in HWRB-treated Acorn squash could also be attributed to the induction of pathogenesis-related proteins and the accumulation of enzymes such as chitinase and β-1,3-glucanase, which hydrolyze the fungal cell walls and inactivate the pathogens [5]. This treatment also was reported to delay fruit ripening, which may partially account for the delayed color development of the HWRB-treated fruits (Tables 1 and 2; Figure 1).

In conclusion, a prestorage HWRB treatment at 52 °C for about 15 s, followed by storage at 15 °C can maintain Acorn squash quality and marketability for several months. However, more research is needed to extend Acorn squash storability beyond 3.5 months, by evaluating new varieties and other prestorage treatments such as plant-growth regulators that delay chlorophyll degradation during prolonged storage, or by using edible coating materials.

Author Contributions: D.C., S.A.-T. and M.Z.-P. are research engineers in Elazar Fallik's laboratory; they conducted the experiments, evaluated fruit quality, and analyzed the data in both 2016 and 2017. E.F. planned the research, harvested the fruits, analyzed the results and wrote the manuscript.

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