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Hot-water Dips Extend the Shelf Life of Fresh Broccoli

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Abstract. **Freshly harvested heads of 'Cruiser' or 'Paragon' broccoli (*Brassica oleracea* L. Italica group) were heated by immersing in water at 42, 45, 48, 50, or 52C. Immersion times were decreased as treatment temperatures were increased and ranged from 20 to 40 minutes at 42C to 1 to 3 minutes at 52C. Control heads, dipped in 25C water for 0, 10, or 40 minutes, began to turn yellow after ≈3 days storage at 20C and 80% to 90% relative humidity. Immersion in 42C water delayed yellowing by 1 or 2 days; immersion in 45, 48, 50, or 52C prevented yellowing for ≤7 days. Water loss of broccoli during storage at 20C increased by ≤1% per day by some hot-water treatments. Immersion in hot water decreased the incidence of decay during storage at 20C. Immersion in 50 or 52C water for 2 minutes was most effective in controlling decay development. Broccoli immersed in 52C water for 3 minutes had a distinct off-odor. Control and treated broccoli held at 0C for 8 days following hot-water dips were similar in quality. Yellowing of heat-treated broccoli was inhibited when broccoli was warmed to 20C following storage at 0C. Hot-water treatments also delayed senescence at 20C when broccoli was treated following 3 weeks of storage at 0C. Immersion of broccoli in 50C water for 2 minutes was the most effective treatment for reducing yellowing and decay while not inducing off-odors or accelerating weight loss.**

Broccoli is a highly perishable fresh vegetable. When held at ambient temperatures, broccoli will yellow and become unmarketable in 1 to 3 days (Gnanasekharan et al., 1992; Wang and Hruschka, 1977). Refrigeration is the primary means of maintaining broccoli quality and reducing the rate of senescence. Broccoli held at 2.5C will be in good condition after 3 weeks of storage (Ryall and Lipton, 1979). Controlled-atmosphere storage or modified-atmosphere packaging can also extend the storage life of broccoli at nonoptimal temperatures (Barth et al., 1993; Lipton and Harris, 1974). Atmospheres enriched with 10% CO_2 can retard yellowing and double the storage life of broccoli held between 5 and 20C. However, atmosphere modification requires specialized storage facilities or packaging, and the beneficial effect is lost when the broccoli is removed.

Heat treatments can alter senescence of fruit by affecting the rates of softening, chlorophyll loss, ethylene synthesis, respiration, and protein synthesis (Paull, 1990). Kazami et al. (1991a) reported that dipping broccoli in 45C water for 14 min was effective in delaying yellowing for 2 to 3 days at 20C. Immersion in hot water also slowed the loss of soluble proteins and L-ascorbic acid and reduced the rate of respiration and ethylene production (Kazami et al., 1991b). Kazami et al. (1991a, 1991b) did not evaluate the effect of hot-water immersion on other quality factors, such as water loss, decay, or aroma. My objective was to identify optimum treatment times and temperatures to maximize storage life of fresh broccoli.

Material and Methods

Plant materials. 'Cruiser' or 'Paragon' broccoli heads were obtained on the day of harvest from a commercial packinghouse. Heads were trimmed to 100 to 120 mm long, and only heads free of visible decay were used. Heads were weighed and evaluated for color and quality before treatment.

Heat treatments. The duration plant tissues tolerate exposure to temperatures >45C decreases exponentially as exposure temperature increases (Couey, 1989). Kazami et al. (1991a) reported that hot-water dips of 45C for 14 min or 48C for 6 min were optimum for minimizing chlorophyll loss from fresh broccoli held at 20C. Plotting Kazami's optimum time and temperature combinations using a log scale for time allowed exposure to be extrapolated from 42 to 52C; these combinations were designated as medium. Short and long exposures then were chosen to bracket the medium exposure at each temperature (Table 1). Exposures for the 25C controls were chosen to bracket the extreme dip times and account for any effect of the water dip. Three heads of broccoli for each time–temperature combination were placed into a stainless-steel cage with a mesh lid. The cage ensured complete immersion of the broccoli while allowing water to circulate around each head. The cage was placed into a 35-liter insulated container filled with 25 liters of distilled water. Temperature of the water was controlled by an immersion circulator (model E8; Haake, Berlin, Germany). Broccoli temperature was monitored in initial experiments by placing a thermocouple in the center of the stem. Pulp temperature rose rapidly following water immersion and was within 1C of the water temperature in <1 min. Following treatment, broccoli heads were centrifuged at 500× *g* for 2 min to remove excess water in a centrifuge (model C50; International Equipment Co., Boston), equipped with a stainless-steel cage rotor (21 cm in diameter).

Storage conditions. Treated broccoli was held at 20C and 80% to 90% relative humidity in darkness immediately following treatment. In separate experiments, 'Paragon' broccoli was placed in perforated polyethylene bags and held at 0C for 8 days following heat treatment or 3 weeks before heat treatment. Following these 0C holding periods, broccoli was evaluated during 1 week at 20C.

Quality evaluation. Color, weight loss, turgidity, decay, and odor evaluations were made on the same heads before broccoli heads were placed into storage and each day during storage at 20C for 1 week. Commission Internationale de l'Eclairage L* (L value), C* (chroma), and H° (hue angle) were determined with a chromameter (model CR-200; Minolta, Ramsey, N.J.) equipped with an 8-mm measuring aperture and calibrated with a white standard tile. Measurements of flower buds were taken at the center and four locations equally spaced around each head and averaged. Heads were weighed daily to determine fresh weight (FW) loss. Subjective rankings of flower bud yellowing, stem turgidity, flower bud decay, and odor were made using the criteria of Wang and Hruschka (1977). Traits were rated on the following scales: yellowing, 0 = no yellow (dark green), 10 = completely yellow; turgidity, 0 = limp and shriveled, 10 = turgid; decay, fungal spotting, and bacterial soft rot, 0 = none, 10 = leaky mass; and odor, 0 = normal, 10 = nauseating.

Data analysis. Daily measurements of color and other quality attributes for each broccoli head were fitted to straight lines using linear regression. Slopes of these lines, representing rates of change per day, were analyzed using analysis of variance (ANOVA) in Genstat 5 (Payne et al., 1993). In the main experiment, slopes were analyzed using a split-plot design

Table 1. Temperature and time combinations used to treat fresh broccoli.

Temp	Time (min)		
(°C)	Short	Medium	Long
25	0	10	40
42	20	30	40
45	10	15	20
48	4	6	8
50	2	4	6
52	1	2	3

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Table 2. Mean squares for mean daily change in quality characteristics of 'Cruiser' and 'Paragon' broccoli held at 20C for 7 days following immersion in 25, 42, 45, 48, 50, or 52C water for various durations.

		Mean square							
Source	df[z]	Yellowing	L value	Chroma	Hue angle	% Fresh wt loss	Turgidity[z]	Decay	Odor
Cultivar (Cv)	1	0.84	0.52	8.09	17.27	209.54*	87.01	1.88	---
Error	2	5.38	2.22	10.19	22.25	3.68	158.00	21.49	
Temperature (Tp)	5	7.42***	22.14***	27.98***	201.11***	13.07***	80.45***	0.74***	1.07***
Time (Tm)	2	1.27***	5.19***	2.77*	29.40***	3.30*	0.36	1.17***	1.32***
Tp × Tm	10	0.17***	0.49	0.7	2.12	1.46	22.83***	0.22	0.14
Tp × Cv	2	0.21**	4.00***	18.01***	9.35***	6.90***	48.75***	0.70***	---
Tm × Cv	2	0.09	0.07	0.12	6.78*	1.83	0.57	0.61*	---
Tp × Tm × Cv	10	0.17***	0.46	0.37	1.67	2.68***	28.34***	0.17	---
Error	178 (89)[y]	0.05	0.52	0.88	1.90	0.84	6.17	0.15	0.14

[z]Mean square × 10^2.
[y]df for odor.
*,**,***Significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

with two replications. The two cultivars were the main blocks, and the subblocks consisted of a 3 × 6 factorial with time and temperature treatments (Table 1). Within each treatment of each subblock, three heads of broccoli were analyzed. Only 'Paragon' was evaluated for odor. In the additional experiments in which 'Paragon' broccoli was held at 0C before evaluation at 20C, slopes were analyzed using a completely randomized design using the same 3 × 6 factorial.

Results

Cultivar effects. Cultivar had no significant main effect on any of the quality attributes, except for FW loss (Table 2). However, there was a cultivar × treatment temperature interaction for all criteria. The rate of yellowing of control 'Paragon', treated at 25C, exceeded that for 'Cruiser'. All heat treatments reduced the rate of yellowing in both cultivars, and the difference between cultivars, observed in the controls, was absent in treated broccoli. An ANOVA on the data from just the heat-treated broccoli, excluding the 25C controls, showed no significant cultivar × temperature interaction for any of the quality attributes.

Broccoli color. Heat treatments inhibited yellowing in fresh broccoli (Table 2, Fig. 1). The 25C control broccoli had a daily increase in yellowing score of 1.6, and after ≈3 days at 20C, it had an average score of 4.8, indicating "slight yellowing." All of the heat-treated broccoli yellowed more slowly and remained green. Of the treatment temperatures tested, 42C was least effective; 45 to 52C reduced the rate of yellowing similarly. As exposures increased at a given temperature, rates of yellowing decreased. The most effective treatments to reduce yellowing were the long exposures to 48, 50, and 52C.

The inhibition of yellowing was reflected in the small daily change in L value, chroma, and hue angle in treated broccoli (Fig. 2). Hue angle gave the best indication of greenness and averaged 132.5° in freshly harvested broccoli. In previous work, a hue angle value of 106° correlated with visual yellowing scores of 4, indicating a yellowing of the broccoli (data not shown). As with yellowing, hue angle values of control heads declined to unacceptable values of ≈110° after 3 days. Immersion in hot water reduced this rate of decline. Treatments most effective in reducing the decline in hue angle corresponded with subjective yellowing ratings. The average initial L and chroma values of nontreated broccoli were 42.0 and 16.4, respectively. Both of these values increased 2 to 3 units per day in control broccoli, but in broccoli treated at temperatures ranging from 45 to 52C, this increase was reduced to less than one unit per day.

Fresh weight loss and turgidity. The rate of fresh weight loss of heat-treated broccoli was as much as 1% per day more in treated broccoli than in the controls (Fig. 3). Rates of fresh weight loss of control broccoli averaged ≈4.6% per day, and some of the heat-treated broccoli lost as much as 6.0% per day. Rates of water loss tended to be higher with low-temperature heat treatments and may relate to longer immersion times. Subjective scores of turgidity corresponded with changes in fresh weight.

Decay. Decay that developed on the broccoli flower buds was a combination of fungal spotting and bacterial rots. Decay scores decreased with increasing treatment temperature but increased with increasing treatment time at a given temperature (Fig. 3). Rates of decay were lowest in the 52C–2 min, 52C–1 min, 50C–2 min, and 48C–4 min treatment combinations. None of the heat treatments increased the rate of decay of flower buds over that of the controls.

Odor. "Green floral" off-odors were induced by high temperatures and long exposures (Fig. 3). Off-odor increased more rapidly as treatment temperatures and exposure times increased. Broccoli treated at 48 to 52C combined with medium and long exposure times developed off-odors more rapidly than controls. Off-odor was most noticeable in the 52C–3 min treatment combination and was present immediately following treatment.

Refrigerated storage. When broccoli was stored for 8 days at 0C following heat treatment, there was no difference in the yellowing, turgidity, or decay of control and treated heads. However, when heads were held an additional week at 20C, quality of heads changed in a manner similar to heads held at 20C immediately after treatment (data not shown).

Heat treatments were still effective in in-

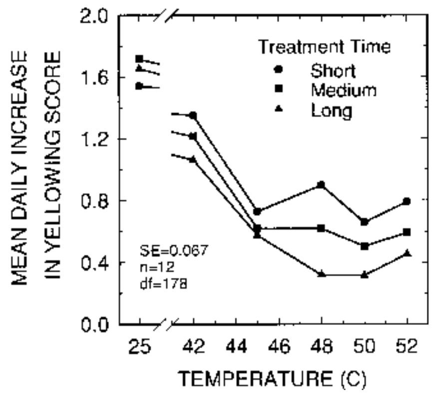

Fig. 1. Mean daily increase in yellowing scores of fresh broccoli heads following exposure to water for various duration–temperature combinations and then held 7 days at 20C. Rates of increase were calculated from the regression of daily yellowing scores.

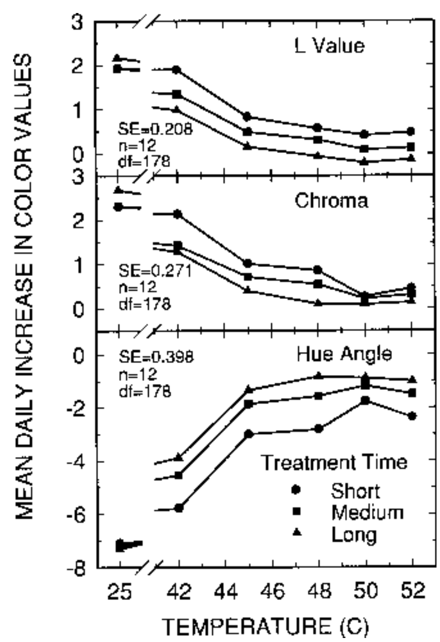

Fig. 2. Mean daily increase of the L value, chroma, and hue angle of fresh broccoli heads following exposure to water for various duration–temperature combinations and then held 7 days at 20C. Rates of increase were calculated from the regression of daily measurements.

hibiting yellowing of heads when broccoli was stored for 3 weeks at 0C before treatment (Fig. 4). Broccoli stored at 0C for 3 weeks yellowed more rapidly than fresh broccoli. Control heads exposed to 25C water turned yellow at a rate 60% greater than freshly harvested broccoli (Fig. 1), resulting in heads being yellow after ≈2 days at 20C. Heat treatments were less effective in delaying yellowing of stored broccoli than of fresh broccoli. However, the higher temperature treatments, 50C for 4 or 6 mins and 52C for 1 to 3 mins, inhibited yellowing so that the rate was similar to that for fresh broccoli. The effect of heat treatments on fresh weight loss, turgidity, decay, and odor was similar to that observed with freshly harvested broccoli.

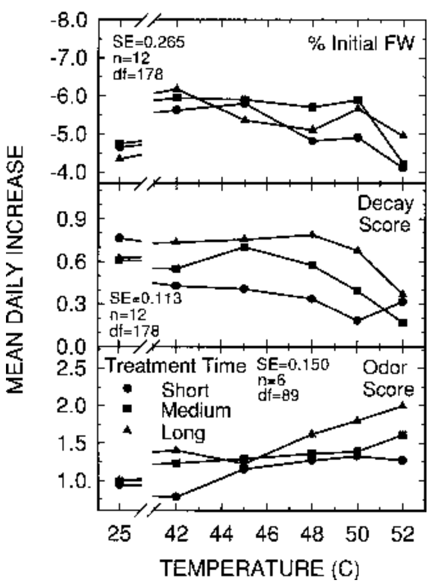

Fig. 3. Mean daily increase of fresh weight (FW), decay score, and odor score of fresh broccoli heads following exposure to water for various duration–temperature combinations and then held 7 days at 20C. Rates of increase were calculated from the regression of daily values.

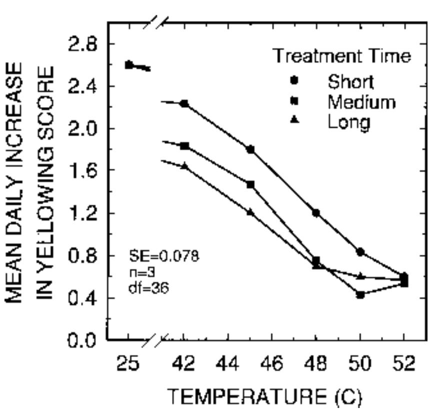

Fig. 4. Mean daily increase in yellowing scores of broccoli heads following exposure to water for various duration–temperature combinations and then held 7 days at 20C. Broccoli was held 3 weeks at 0C before treatment. Rates of increase were calculated from the regression of daily yellowing scores.

Discussion

Yellowing of broccoli flower buds occurs rapidly at ambient temperatures. At 20C, 'Cruiser' and 'Paragon' broccoli began to turn yellow in ≈3 or 2.5 days, respectively. These rates of yellowing were similar to those reported in other studies (Kazami et al., 1991a; Wang and Hruschka, 1977). Yellowing also was reflected by a decline in the hue angle of the flower buds (Fig. 2C). Hue angle of broccoli held at 21C in air decreased from ≈128° to 84° in 7 days (Gnanasekharan et al., 1992), but that of 'Shogun' broccoli held at 20C in the dark decreased from 132° to 112° in 3 days (Tian et al., 1994). The increase in L value (Fig. 2A) and chroma (Fig. 2B) was less dramatic than the change in hue angle but was similar to that observed by Gnanasekharan et al. (1992).

Inhibition of yellowing caused by immersion in 42 to 52C water also was reported by Kazami et al. (1991a), who found that broccoli treated at 45C for 14 min remained green for 5 days when held at 20C. In addition, they reported that exposure to 48C for ≥10 min caused browning and shrinkage of the flower head after 2 days at 20C. Browning or shrinkage of broccoli was absent following exposure to 48C for <8 min. Immersion of broccoli in 52C water for 3 min, however, altered the waxy bloom, making the flower buds appear dark green rather than the gray-green of nontreated broccoli. Heat treatments inhibit fruit yellowing, with storage at >30C inhibiting yellowing of papaya (*Carica papaya* L.) (An and Paull, 1990). 'Breaker' tomatoes *(Lycopersicon esculentum* Mill.) held for 12 to 24 h at 43C remained green, failing to become red during 6 days of ripening at 20C (Hall, 1964). However, color development of some fruit, such as mangos (*Mangifera indica* L.), was stimulated by 2 days at 38C (McCollum et al., 1993).

The slight increase that I found in FW loss induced by some of the hot-water treatments was not observed by Kazami et al. (1991a), who found similar weight losses for heat-treated broccoli and controls. Hot-water treatment does increase FW loss in some fruit (Hallman, 1991; Kerbel et al., 1987; McGuire, 1991).

Hot-water immersion can be an effective way to control decay of stored horticultural products (Couey, 1989). Hot-water dips that are effective in controlling decay of rose (*Rosa hybida*) or carnation (*Dianthus carpophyllus* L.) flowers included 50C for 20 to 40 sec, but a 60C dip for 60 sec increased rates of decay (Elad and Volpin, 1991). Incidence of decay on broccoli responded similarly in that longer treatment times were less effective in reducing decay, but none of the treatments tested increased decay of flower buds beyond the level of the controls. Although decay of the stem was not rated, the cut surface of the stem appeared to have a greater incidence of shriveling and decay in some treatments than in the controls.

Off-odor induced by high temperature–long duration, hot-water treatments appeared to be the first indication of physiological injury caused by the heat treatments. The nature of odor produced by heat-treated broccoli was different from the "rotten cabbage" odor induced by anaerobic stress (Forney et al., 1991), indicating that the induced volatiles were qualitatively and/or quantitatively different. Analysis of the composition of these induced volatiles could provide insights into the nature of physiological injury caused by heat treatments. Heat treatments also induced off-flavors in papaya (An and Paull, 1990) and caused a loss of fresh flavor in avocados (*Perea americana* Mill.) (Kerbel et al., 1987).

Hot-water treatments are effective in extending the shelf life of fresh broccoli. Of the treatments tested, immersion of broccoli in 50C water for 2 min seems to be most effective in reducing yellowing and decay while not inducing off-odors or weight loss. The injury that heat treatments cause on cut stem ends needs to be evaluated, but could be eliminated if stem ends are cut following treatment. This procedure would be practical if treatments were applied before packing or cutting into florets. In addition to extension of shelf life, hot water may be an effective technique to remove *Lepidoptera* larvae from broccoli, based on our observations and those of Kazami et al. (1991a).

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