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Effects of Hot Water Immersion on Storage Quality of Fresh Broccoli Heads

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Summary

Freshly harvested broccoli heads were immersed for 0, 1, 4 or 8 min into hot water at 45 °C, and then were hydrocooled rapidly for 10 min at 10 °C. Following these treatments, the broccoli were air-dried for 30 min, then packed in commercial polymeric film bags, and, finally, stored for 16 days at –1, 1, and 12 °C. The samples treated with hot water maintained high contents of chlorophyll concentrations, their yellowing rate was delayed, and fungal infection and chilling or freezing injury were inhibited markedly. Compared to non-heat-treated broccoli, a lower level of peroxidase activity with a relatively higher chlorophyll concentration was observed when broccoli were treated with hot water. Among these heat treatments, immersion in hot water for 4 min at 45 °C was the most effective for maintaining the quality of harvested broccoli heads.

Key words: broccoli, hot water immersion, quality, storage

Introduction

Broccoli have a short shelf life due to high respiration and transpiration rates (*1*) and become unmarketable after 2 to 3 days at ambient temperature (*2*). Rapid cooling, optimum low storage temperature and high humidity, adequate packing and atmospheric circumstances can effectively extend storage life of broccoli (*3–6*). Since low temperature, high humidity, and optimum atmospheric conditions are difficult to maintain throughout the whole marketing chains, significant quality loss of harvested broccoli occurs due to wilting and yellowing.

Postharvest heat treatments have been used for disinfection and, moreover, exhibited remarkably beneficial effects on the maintenance quality and the extension of storage life of postharvest fruits and vegetables (*7–9*). The heat treatments also delayed degreening or yellowing, slowed down softening and improved chilling tolerance (*8,10–15*).

The effects of heat treatments on the storage life of harvested broccoli have been investigated. Kazami *et al.* (*16*) found that dipping broccoli into water at 45 °C for 14 min delayed yellowing during storage at 20 °C. Forney (*17*) suggested that immersion of broccoli into hot water for 2 min at 50 °C was the most effective in delaying yellowing and reducing decay of broccoli stored at 20 °C. Tian *et al.* (*18,19*) reported that heat treatments inhibited respiration and ethylene production of the broccoli held at 20 °C. However, there was not enough information on overall investigation into quality maintenance and shelf life extension of broccoli caused by heat treatments in relation to chilling or freezing injury during storage at –1 °C, which is applied to postharvest fruits and vegetables.

In the previous investigation we found that hot water treatment at 45 °C for short period of time was effective in delaying yellowing and reducing decay of broccoli during storage. Further objective of this study was to determine the optimum heat treatment time and then to investigate the overall effects of the heat treatment on

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sensory quality, yellowing, fungal infection and chilling or freezing injury of broccoli during storage at 12, 1 and –1 °C.

Materials and Methods

Plant materials and treatments

Broccoli (*Brassica oleracea* L.) cv. Yuguan were harvested from a local farm in Foshan, Guangdong on the 15th May, 2003 and transported to handling facilities within 1 h. All broccoli heads were trimmed into 120–150 mm total length with about 20 mm in diameter of stem, and only blemish- and defect-free heads were used. Three broccoli heads were placed into a plastic cage and immersed into a 35-L thermostatic bath with 25 L of distilled water at 45 °C for 0 (control), 1, 4 or 8 min. In the previous experiments, we investigated three different temperature degrees (42, 45 and 52 °C) and six treatment times (0.5, 1, 3, 5, 10 and 20 min) and found that the temperature of 45 °C for short treatment time (less than 10 min) was effective in delaying yellowing and reducing decay of broccoli during storage. Thus, 45 °C was chosen as the treatment temperature, while treatment time with a range from 0 to 8 min was used in this study. Afterwards, the broccoli were immediately immersed into cool water at 10 °C for 5 min, and then air-dried for 30 min at 25 °C. Following these treatments, three broccoli heads were packaged in commercial polymeric film bags (0.02 mm thick, supplied by Guangzhou Plastic Factory) as a replicate, and then stored for 16 days at 12, 1 and –1 °C, respectively. Each treatment consisted of 3 replications. The experiments were repeated twice in the 2003 season. Similar results were observed from the two experiments. The data from the second experiment are presented.

Evaluation of sensory quality

Sensory quality of each replicate broccoli was evaluated by the method described by Gorny *et al.* (*20*) with a few modifications, based on colour (no yellowing to complete yellowing), texture (crisp to very soft) and flavour (normal to strong off-flavour). The following hedonic scale used by a six-member panel was: 9, excellent; 7, very good; 5, good, limit of marketability; 3, fair, limit of unacceptability; and 1, poor in terms of the assessment of the combination of colour, texture and flavour, with an emphasis on freshness.

Evaluation of yellowing rate and assaying chlorophyll concentration

Yellowing of broccoli heads was assessed from 30 individual broccoli heads by the method of Forney (*17*), and rated as 0 = no yellow to 10 = completely yellow. The yellowing rate was calculated as:

Σ(yellowing scale × percentage of corresponding head within each class).

Total concentrations of chlorophylls (chlorophyll a + chlorophyll b) were determined using N,N´-dimethylformamide (*21*), and expressed as a percentage. The chlorophyll concentration in broccoli before the heat treatment was taken as 100 %.

Evaluations of chilling or freezing injury and fungal infection

Chilling or freezing injury was rated as 0, no injury; 1, slight (a few water-soaked areas like patches); 2, moderate (the water-soaked areas covering 5–30 % of the head surface); and 3, severe (the water-soaked areas covering >30 % of the head surface). The index of chilling or freezing injury was calculated by the method of Porat *et al.* (*14*).

Mould development was assessed by observing visible fungal growth on the surface of each broccoli head and expressed as a percentage of the flower buds infected to total buds (*6*).

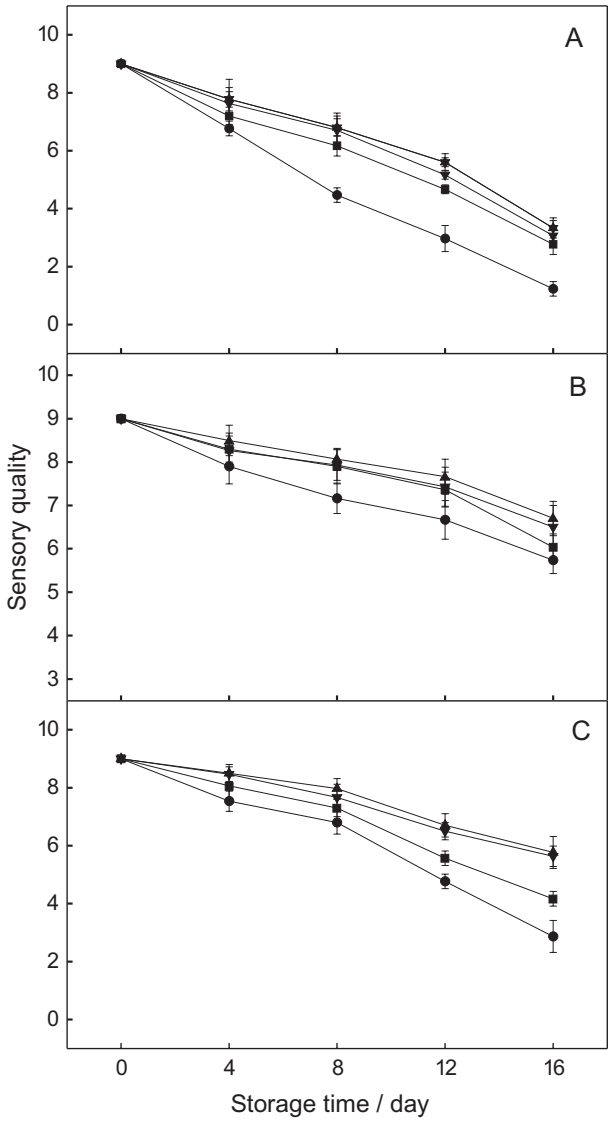

Fig. 1. Effects of hot water immersion on sensory quality of broccoli during storage. Broccoli heads were immersed for 0 (●), 1 (■), 4 (▲) or 8 min (▼) into hot water at 45 °C and then stored at 12 °C (A), 1 °C (B) and –1 °C (C). Sensory quality scales used by a six-member panel were: 9, excellent; 7, very good; 5, good, limit of marketability; 3, fair, limit of unacceptability; and 1, poor in terms of the assessment of the combination of the colour, texture and flavour with an emphasis on the freshness. Each value is a mean of individual replicates, and the vertical bars indicate standard errors

Peroxidase (POD) assay

The amount of 5 g of the sample was taken from the central part of each of 3 broccoli heads with three replications, then mixed uniformly, and finally homogenised. POD was extracted and the enzymatic activity was assayed by the procedure of Pen and Jiang (*22*). The increase in absorbance at 470 nm was recorded for 3 min. One unit of enzyme activity was defined as the amount of enzyme that caused a change of 0.01 in absorbance per minute.

Statistical analysis

Experiments were arranged in a completely randomised design. Each comprised of three replicates, except sensory quality, yellowing rate, chilling or freezing injury and fungal infection, for which 30 individual broccoli heads were used. All data were tested by the analysis of variance (ANOVA procedure), and mean values were separated using Fisher's LSD at $P \leq 0.05$.

Results and Discussion

Sensory quality

Sensory quality of broccoli heads decreased markedly during storage at 12, 1 and –1 °C (Fig. 1). Broccoli heads treated with hot water for 4 or 8 min exhibited higher sensory quality than those treated with hot water for 1 min or the control. Furthermore, the best treatment was observed when immersed in hot water for 4 min. Ping and Wu (*23*) found that heat treatments had no effect on maintaining the quality of broccoli when stored at 0 °C, which may be due to effective inhibition of physiological process at 0 °C, resulting in reduced beneficial effects on the quality of broccoli.

Adequate hot water treatment was beneficial for shelf life extension, quality maintenance and reduction of chilling injury of postharvest avocado, grapefruit and guava fruits during storage (*10–12,24*). However, too

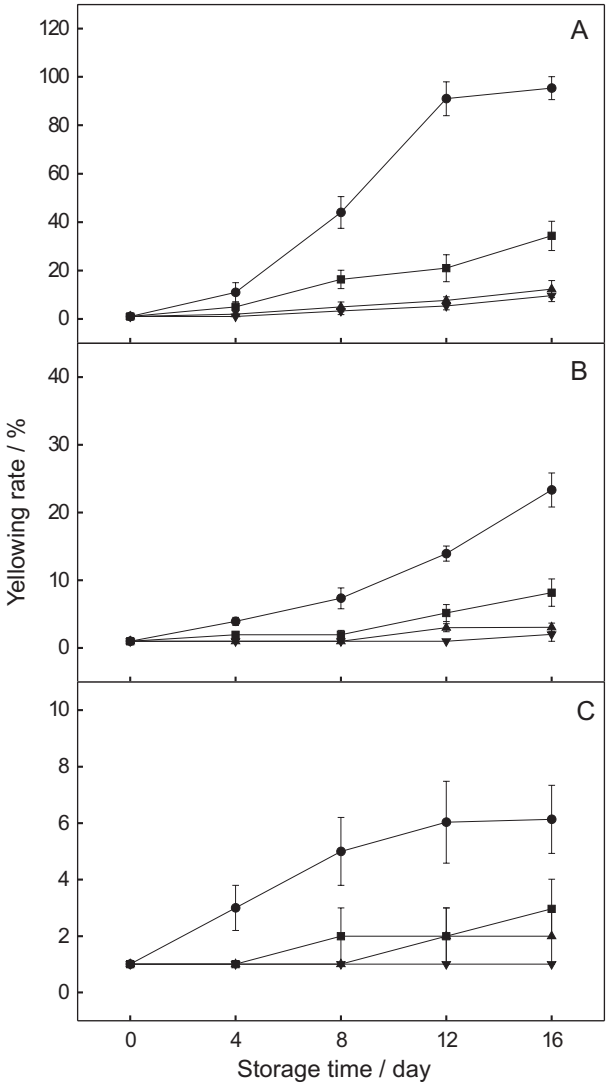

Fig. 2. Effects of hot water immersion on yellowing rate of broccoli during storage. Broccoli heads were immersed for 0 (●), 1 (■), 4 (▲) or 8 min (▼) into hot water at 45 °C and then stored at 12 °C (A), 1 °C (B) and –1 °C (C). Each value is a mean of individual replicates, and the vertical bars indicate standard errors

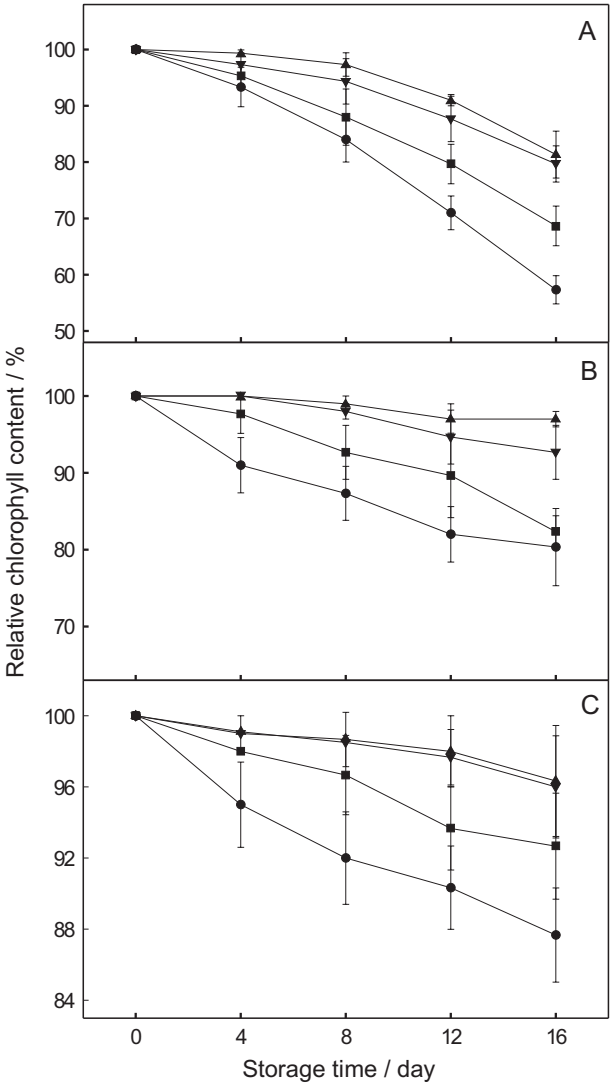

Fig. 3. Effects of hot water immersion on chlorophyll concentration in broccoli during storage. Broccoli heads were immersed for 0 (●), 1 (■), 4 (▲) or 8 min (▼) into hot water at 45 °C and then stored at 12 °C (A), 1 °C (B) and –1 °C (C). Each value is a mean of three replicates, and the vertical bars indicate standard errors

high temperature or excess of exposure duration could cause external or internal heat damage (*8*). Forney (*17*) reported that broccoli immersed for 3 min in water at 52 °C had a distinct off-odor. In the present study, no damage by heat treatments was observed on broccoli surface.

Yellowing rate and chlorophyll content

Yellowing is an important factor that limits the storage life of broccoli. There was a tendency toward the increase in yellowing rates and the decrease in chlorophyll concentrations during storage of broccoli heads (Figs. 2 and 3). Low storage temperature delayed yellowing and reduced loss in chlorophyll concentration. Compared to the broccoli treated with hot water, the non-heat-treated broccoli stored for 16 days at 12, 1 and –1 °C had the highest yellowing rate and the lowest chlorophyll concentration (Figs. 2 and 3), which demonstrated that heat treatment obviously inhibited the yellowing of broccoli. Forney (*17*) and Tian *et al*. (*18,19*) reported that dipping the broccoli in water at 42–55 °C could reduce yellowing during storage. Similar results were observed with tomato and citrus (*9,15*), degreening was delayed and the rate of chlorophyll loss was reduced in these fruits.

Fungal infection and chilling or freezing injury

There were 11.8 and 5 % of fungal infection on the non-heat-treated broccoli and the broccoli treated with hot water for 1 min after 16 days of storage at 12 °C, respectively, but no obvious disease development on the broccoli treated with hot water for 4 or 8 min was observed (Table 1). Furthermore, there was not disease development on the non-heat-treated broccoli or the heat-treated broccoli when stored for 16 days at 1 and –1 °C due to effective inhibition of pathogens by low temperature. In addition, no visible bacterial lesions were observed on the surface.

There were no symptoms of chilling or freezing injury on broccoli during storage at 1 and 12 °C, but chilling or freezing injuries were observed when broccoli were treated with hot water for 0 (control), 1, 4 and 8 min, respectively, before storage at –1 °C (Table 2). Obviously, chilling or freezing injury enhanced with the increase of storage time. Heat treatments inhibited the occurrence of chilling or freezing injury, which may be attributed to the expression of genes and new synthesis of new proteins, inducing an increased resistance to low temperature (*8*). However, the underlying biochemistry and physiology of the enhanced resistance to low temperature caused by heat treatment need further investigation.

Table 1. Effects of hot water immersion on fungal infection (%) of broccoli heads stored at 12 °C

Treatment time/min	Fungal infection/%	
	Storage time/day	
	8	16
0	4.9 ± 0.56^a	11.8 ± 1.21^a
1	1.0 ± 0.5^b	5.0 ± 0.5^b
4	0.1 ± 0^c	0.1 ± 0^c
8	0.1 ± 0^c	0.1 ± 0^c

Each value is a mean and standard error of 30 individual replicates. Mean values within a column followed by the same letter are not significantly different at the 5 % level

Table 2. Effects of hot water immersion on chilling or freezing injury (%) of broccoli heads stored at –1 °C

Treatment time/min	Chilling or freezing injury/%	
	Storage time/day	
	8	16
0	10.93 ± 1.11^a	34.83 ± 1.76^a
1	6.93 ± 1.01^b	24.67 ± 1.53^b
4	1.0 ± 0.5^c	5.0 ± 1.01^c
8	0^d	3.3 ± 1.08^c

Each value is a mean and standard error of 30 individual replicates. Mean values within a column followed by the same letter are not significantly different at the 5 % level

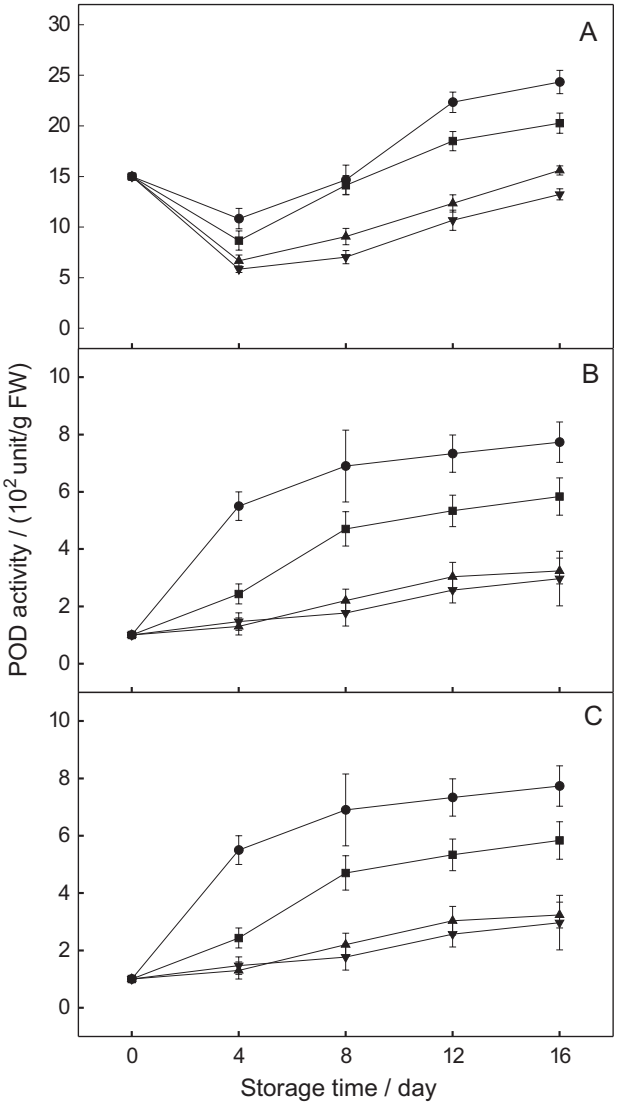

Fig. 4. Effects of hot water immersion on POD activity in broccoli during storage. Broccoli heads were immersed for 0 (●), 1 (■), 4 (▲) or 8 min (▼) into hot water at 45 °C and then stored at 12 °C (A), 1 °C (B) and –1 °C (C). Each value is a mean of three replicates, and the vertical bars indicate standard errors

POD activity

POD could be involved in the degradation of chlorophyll (*25–27*). Funamoto *et al*. (*25*) reported that POD activity increased markedly during yellowing of broccoli. In the present study, POD activity of either the non-heat-treated broccoli or the broccoli treated with hot water for 1 min increased rapidly and maintained higher levels (Fig. 4), while broccoli treated with hot water for 4 or 8 min exhibited a relatively lower increase in the POD activity. Moreover, the lowest POD activity (1.0 unit/g of fresh weight (FW)), with the highest chlorophyll content (100 %), was observed prior to heat treatment, and the highest POD activity (24.3 unit/g FW), with the lowest chlorophyll content (57.3 %), was found in the non-heat-treated broccoli after 16 days of storage at 12 °C. Thus, heat treatments inhibited markedly chlorophyll-degrading POD activity and reduced the loss of chlorophyll concentration.

In conclusion, in terms of the maintenance of sensory quality, delay in yellowing, and inhibition of fungal infection and chilling or freezing injury, treatment with hot water for 4 min at 45 °C could be considered for commercial application to broccoli heads during storage.

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Utjecaj uranjanja svježih glavica brokule u toplu vodu na kvalitetu skladištenja

Sažetak

Netom ubrane glavice brokule uranjane su 0, 1, 4 ili 8 min u toplu vodu (45 °C), a zatim naglo hlađene 10 min vodom pri 10 °C. Nakon toga je brokula sušena na zraku tijekom 30 min te pohranjena u vrećicama od polimernoga materijala 16 dana pri –1, 1 i 12 °C. Uzorci obrađeni toplom vodom zadržali su veliku koncentraciju klorofila, usporena im je brzina žućenja, bitno inhibirana fungalna infekcija, te usporena oštećenja pri hlađenju ili zamrzavanju. Brokula obrađena toplom vodom imala je nižu razinu peroksidazne aktivnosti uz relativno veliku koncentraciju klorofila u usporedbi s brokulom koja nije bila toplinski obrađena. Od toplinskih obrada najučinkovitije je bilo uranjanje u toplu vodu od 45 °C tijekom 4 min.