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Research paper

Temperature abuse timing affects the rate of quality deterioration of postharvest broccoli during different pre-storage stages

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ABSTRACT

In this study, the changes in weight loss, color, tissue electrolyte leakage rate (REC), sensory (overall visual quality, off-odor and tightness), total chlorophyll and ascorbic acid (Vc) levels in broccoli heads were examined during three pre-storage stages and at three storage, simulating temperature abuse from retail organizations to the customer. Packed broccoli heads were pre-stored for 1 day, 30 days or 60 days at (1 ± 0.5) °C and then stored for 13 days at 4 °C, 10 °C or 25 °C with 60%-70% relative humidity in the dark. All the measured indicators in broccoli heads during storage were significantly affected by temperature and were demonstrated to deteriorate together with increasing storage temperature. The color, REC, overall visual quality, off-odor, chlorophyll and Vc contents of broccoli were significantly affected by the pre-stored stages, and the broccoli pre-stored for 60 days deteriorated faster and a shorter shelf life than the broccoli pre-stored for 1 day and 30 days. The results indicate that lower retail temperatures and shorter pre-storage time can prolong the shelf life of postharvest broccoli heads.

1. Introduction

Broccoli is a vegetable eaten worldwide with high nutritional value and health benefits (Jones et al., 2006). It is harvested at an immature stage and its florets senesce and turn yellow quickly after harvest at ambient temperatures, resulting in the loss of their commercial value (Hasperué et al., 2011). Methods for the extension of the shelf life and maintenance of visual quality by an extra day after harvest will contribute to reducing economic loss for growers and provide much fresher vegetables for consumers. Many studies show that storage temperature is the primary factor affecting the quality of postharvest broccoli heads (Jones et al., 2006; Winkler et al., 2007), and maintaining a cold chain and packaging can effectively extend the shelf life (Jacobsson et al., 2004; Serrano et al., 2006; Starzyńska et al., 2003). Unfortunately, temperature abuse incidents often occur during the retail store displays when products reached their later shelf life stage (Kou et al., 2014). The sensitivity of different pre-stored period broccoli heads to retail temperatures was different (Rybarczyk-Plonska et al., 2016a,b, 2014). Therefore, this study, combined with previous research results, used the modified atmosphere package (MAP) combined with a low storage temperature to investigate the effect of retail temperature abuse on the shelf life quality of broccoli heads with different pre-storage stages, which will provide pertinent information to the industry.

2. Materials and methods

2.1. Sample and storage facility

Fresh broccoli (*Brassica oleracea* var. Italica) heads were harvested from a planting base in Jintang County, Sichuan Province, China during the North Hemisphere. Healthy broccoli heads of marketable maturity and size were harvested at 8 a.m. and immediately transported to the laboratory within 2 h, where they were stored at 1 ± 0.5 °C overnight. Broccoli heads free of insect pests, disease symptoms and mechanical damage were selected for use in the experiment. Each broccoli head was packaged in sealed polyethylene bags (30 cm × 25 cm, Lianyi plastic packaging Inc., Chengdu, China) with selected film O_2 and CO_2 transmission rates of 16398.3 $cm^3/m^2 \cdot 24\ h \cdot 0.1\ MPa$ and 68644.9 $cm^3/m^2 \cdot 24\ h \cdot 0.1\ MPa$, respectively (the permeability of the films was tested by Labthink Inc., Shandong, CN), pre-stored in the dark at 1 ± 0.5 °C for 60 days, and then placed at their assigned storage temperature for 30 days. Before each transfer day, every packing bag had five holes

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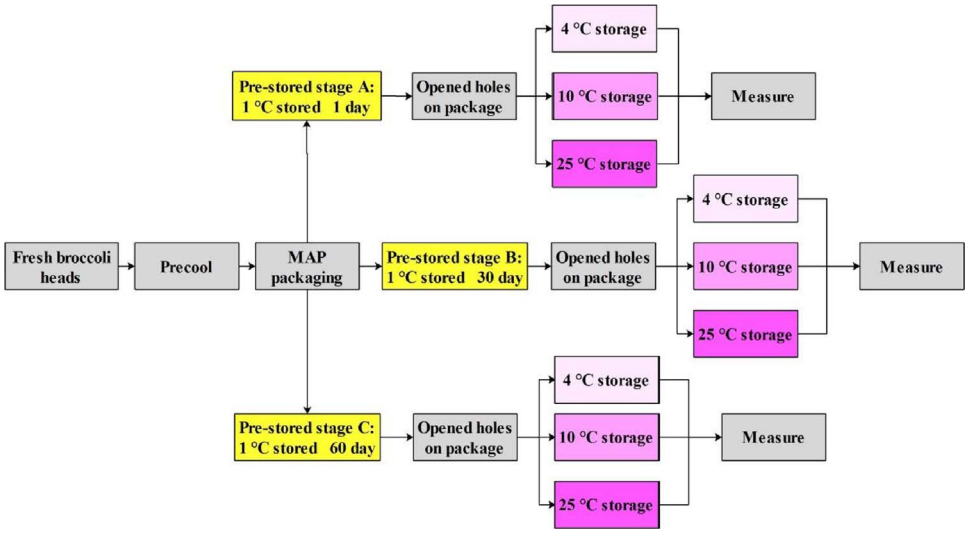

Fig. 1. Flow chart of the experimental design.

(0.8 cm diameter) opened in it on both sides of the four edge corners and the center.

2.2. Temperature abuse timing and post-processing (Fig. 1)

To simulate retail temperature abuse, three pre-stored stages at three temperatures were applied. The first pre-storage stage of post-processing on arrival day 1 (A), the second pre-storage stage on day 30 (B) and the third on day 60 (C) were modeled. During each pre-stored stage, seventy perforated packing broccoli heads were transferred to storage at 4 °C, 10 °C or 25 °C with 60%–70% relative humidity (RH) to simulate retail temperature abuse. The samples were evaluated on days 1, 3, 5, 7, 9, 11 and 13, and discontinued when the scores for overall visual quality decreased to below an acceptable marketable level.

2.3. Weight loss

The initial weight of broccoli heads was recorded immediately before each temperature abuse transfer day. The same heads for all treatments were then weighed on each evaluation day. Weight loss was evaluated as the percentage of the initial weight and was labeled weight loss (%).

2.4. Color assessment

Superficial color coordinates (L^*, a^*, b^*) were measured directly on the top of each broccoli head using a colorimeter (CR-400 Chroma Meter, Konica Minolta Optics. INC., Tokyo, JP) and by calculating the *hue angle* (Hue°) using the following formulas: $\text{Hue}^\circ = \tan^{-1}$ (b/a) when $a > 0$ and $b > 0$, $\text{Hue}^\circ = 180^\circ + \tan^{-1}$ (b/a) when $a < 0$ and $b < 0$. The instrument was calibrated with a white tile (Y = 94.0, x = 0.3130 and y = 0.3191). Measurements were taken for L^*, $b^*$and *hue angle* values at 10 random locations on each replication (one assayed head), with 10 replications per treatment.

2.5. Tissue electrolyte leakage

Tissue electrolyte leakage was measured following a modified procedure (Wang et al., 2004). The contents of 20 ± 0.5 g floret cuttings from each head were submerged in 200 mL of deionized water for 30 min at 20 °C. The electrolyte content of the solution was determined by measuring the electrical conductivity (EC) with a conductivity meter (model DDSJ-308A, INESA Instrument, Inc., Shanghai, China). The total electrolytes of the broccoli samples were determined by measuring the EC after repeatedly freezing at −20 °C for 24 h and thawing at room temperature. The relative tissue electrolyte leakage (REC) was expressed as a ratio of fresh over total electrolytes.

2.6. Sensory attributes

A four-member trained panel comprising 2 women and 2 men ages 25–49 conducted the sensory evaluation of broccoli samples after removal from storage. Prior to the evaluation, training sessions were provided for the panelists on scoring the quality attributes. A five-point scale of damage incidence and severity was scored for visual quality, tightness and off-odor (Olarte et al., 2009). Overall visual quality was assessed with a 1–5 hedonic scale where 5 = like extremely, fresh, 3 = neither like nor dislike, limit of marketability, 1 = dislike extremely. Tightness was assessed by handling the ball-flowers using fingers and scored on a 1–5 scale where 5 = very tight, 3 = becoming loose, and 1 = very soft. Off-odor was rated on a 1–5 scale, where 5 = no off-odor, 3 = slight off-odor, and 1 = strong off-odor. The acceptable or marketable range for visual quality, tightness and off-odor was a score of 3 or above.

2.7. Chlorophyll and Vc

Fresh broccoli florets (1.0 g) were processed in a mill, added to 25 mL acetone/water (80/20) and homogenized. The homogenate was vortexed for 15 s and centrifuged (model 5810R, Eppendorf, Germany) at 6000 × *g* for 5 min. The supernatant was collected and the extraction procedure was repeated with the addition of 25 mL of acetone/water (80/20). The chlorophyll content was determined spectrophotometrically (model TU-1810, PERSEE, Inc., Beijing, China) according to Nath Lichtenthaler (Lichtenthaler, 1987) and expressed as mg/100 g of chlorophyll on a fresh weight basis.

The ascorbic acid (Vc) contents of broccoli floret samples on a fresh weight basis were determined spectrophotometrically according to the method of Kampfenkel et al. (Kampfenkel et al., 1995). A 10.0 g sample of fresh material was milled and ground in 100 mL 10 g/L of freeing trichloroacetic acid/water (w/v) on ice. The homogenate was centrifuged at 10000 × *g* at 4 °C for 10 min and the resulting supernatant was immediately used for the Vc analysis. The results were expressed as mg per 100 g of fresh weight (mg/100 g).

2.8. Experimental design and statistical analysis

Ten replications (ten heads) per treatment were evaluated on each evaluation day. The data were analyzed using SPSS 16.0 according to a multivariate (storage stage, temperature and duration) linear model