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Research Paper

Near-freezing temperature storage prolongs storage period and improves quality and antioxidant capacity of nectarines

Handong Zhao, Chang Shu, Xinguang Fan, Jiankang Cao, Weibo Jiang*

College of Food Science and Nutritional Engineering, China Agricultural University, Beijing, 100083, PR China

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ABSTRACT

To avoid postharvest quality loss of nectarine fruits during storage, the method of near freezing temperature (NFT) storage was established and applied. This study evaluated the postharvest characteristics, nutritional quality and antioxidant potential of nrctarines fruits after NFT storage. Nectarines were stored at NFT (−1.5 °C to −1.2 °C), 0 °C or 5 °C, until the fruits visually spoiled. NFT showed the longest storage period (70 d) and reduced ethylene production, softening, delay rate, titratable acidity loss and accumulation of malondiadehyde and anthocyanins. NFT storage also retarded peel discoloration and improved the content of soluble solids, ascorbic acid, phenolics and flavonoids in the nectarines. The antioxidant properties of nectarines were also improved by NFT storage. The radical scavenging activity, reducing power, antioxidant activity and metal-chelating ability of the pulp were significantly enhanced by NFT storage at the end of storage. These results suggested that NFT storage could prolong the storage period and improve the postharvest quality and antioxidant capacity of nectarines.

1. Introduction

Nectarine (*Prunus persica* (L.) Batsch, var. *nectarina*) is a very popular fruit, owing to its delicious flavor and high nutritional value; it contains compounds such as vitamins, phenols, flavonoids and anthocyanins (Durst and Weaver, 2013). These bioactive compounds, which are product of normal plant cell metabolism (Carocho and Ferreira, 2013), act as antioxidants that neutralize free radicals to improve human health and prevent chronic disease (Noratto et al., 2009).

However, nectarine is a specific kind of climacteric fruit that ripens quickly under ambient conditions, because the sharp rise in ethylene production limits the postharvest storage time and ahhects other biochemical features of the fruits (Tsunashima et al., 2001). Therefore, a long-standing goal for producers and traders has been to prolong the storage duration and minimize postharvest losses of nectarines. Various chemical and physical treatments, including 1-methylcyclopropene, polyamines, hot water dipping and modified atmosphere, have been used to delay ripening and improve the postharvest quality of nectarines (Khan and Singh, 2007; Khan and Singh, 2010; Jemric et al., 2011; Özkaya et al., 2016). But these treatments described above may have potential safety hazards or influence sensory appreciation (Bassett and Mcclure, 2008). Currently, the primary method of delaying ripening and prolonging the storage life of nectarines is low-temperature storage (Echeverría et al., 2015; Zhang et al., 2011). Unfortunately, low temperatures may adversely influence the sensory quality and induce some postharvest physiological disorders, such as chilling injury (Lurie and Crisosto, 2005).

Near-freezing temperature (NFT), between super-cooling point and freezing point of an individual material, is within the range of minimal non-frozen temperatures, and has been used for the storage of animal organs and fresh fish (Okamoto et al., 2008; Zhu et al., 2016). Study has shown that storage of green beans at NFT could preferably preserve physiological and commercial qualities (Guo et al., 2008; Elfalleh et al., 2015).

Because NFT is very close to the biological freezing point of the stored fresh product, large temperature fluctuations during storage can lead to freezing injury for the NFT-stored fresh plant products. Therefore a precise and stable temperature environment is vital to achieve NFT storage of fresh vegetables and fruits.

However, there is no literature focus on the quality and physiological changes of fresh fruits at NFT storage. This objective of this study was to investigate and define a promising storage method for nectarines, and to research the effects of the NFT storage on the storage period, sensory quality, nutritional attributes and changes in antioxidant properties of nectarines after harvest.

* Corresponding author.
E-mail address: jwb@cau.edu.cn (W. Jiang).

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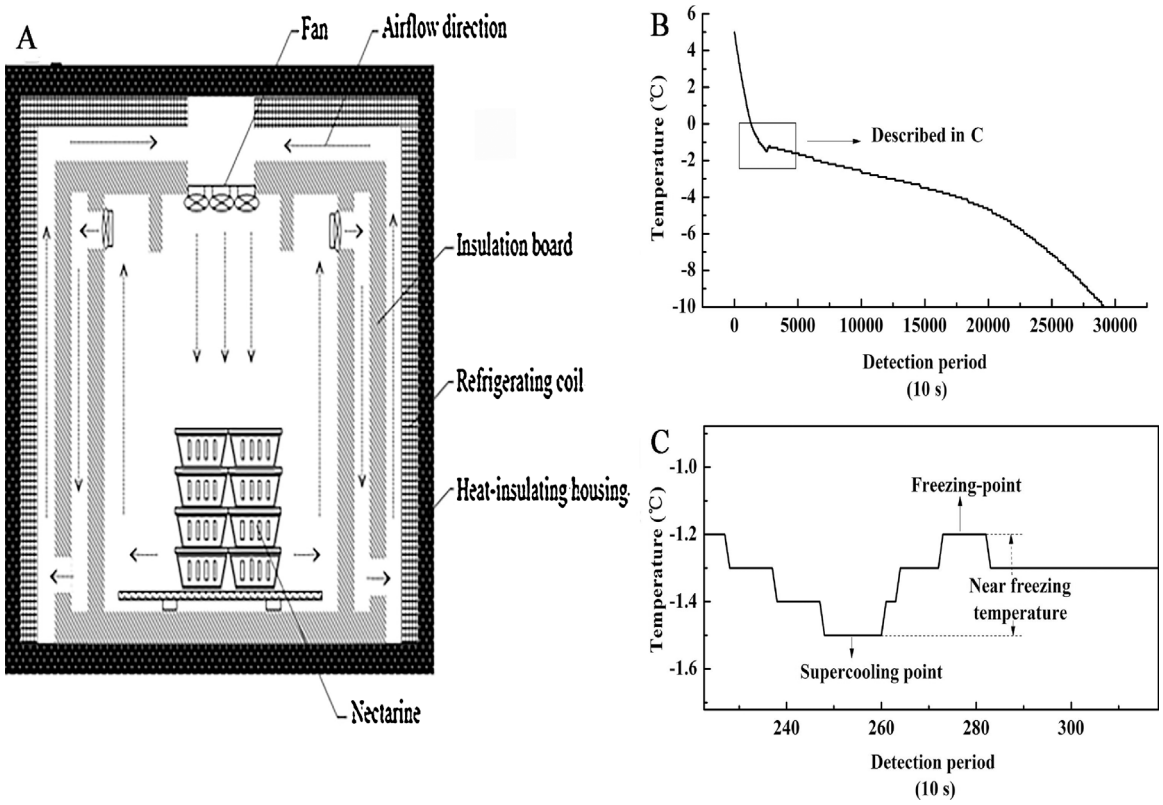

Fig. 1. Schematic of near freezing temperature (NFT) storage system (A) and freezing point curve of nectarine (B and C).

2. Material and methods

2.1. NFT storage equipment preparation, plant material preparation and freezing point determination

For precise temperature control, we modified the traditional refrigerated storage system with microcontrollers, temperature sensors, temperature alarm device and temperature-controlling. The NFT system (Fig. 1A) could display and set temperature in real-time. When the temperature exceeded the setting range, fans would regulate the airflow to keep the temperature within the selected parameters.

Nectarine fruits were obtained at commercial maturity stage (firmness was about 65 N; soluble solids content [SSC] was about 8.5%) from an experimental orchard in Beijing, China. Fruits with uniform size, color and no visual defects were selected and transported to the laboratory immediately. Nectarine fruits were precooled in an experimental temperature-controlled wind tunnel at 0 °C for 24 h. After precooling, the fruits were randomly divided into three groups of 400 each for storage at 5 °C, 0 °C or NFT (determined using a freezing point curve). All fruits were stored in permanent darkness and with a relative humidity (RH) of 90% ± 2%. Samples were removed on designated days (every 14 days) for quality and biological analysis during storage. In order to measure the biochemical parameters, samples were immediately used or frozen in liquid nitrogen and stored at −80 °C for further analysis. All experiments were performed in triplicate.

We modified Wang's method (2003) to measure the biological freezing point of the nectarines. Selecting fifteen fruits from each group, we measured the freezing point using the HP34970A data collector. Before measurement, the thermocouple was calibrated using a 0 °C mixture of water and ice. The samples with thermocouples were then placed in a freezer (−20 °C) and the temperature data was recorded every 10 s. These measurements were used to construct a freezing point curve for the nectarine. (Fig. 1B and C).

2.2. Chemicals and reagents

Gallic acid, β-carotene, dithiothreitol, Folin-Ciocalteu's reagent, pyrocatechol violet, ascorbic acid, 2,20-azino-bis-(3-ethyl-benzothiazoline-6-sulfonic acid) diammonium salt (ABTS), 2,2-Diphenyl-1-picrylhydrazyl (DPPH), 2,4,6-tris(2-pyridyl)-s-triazine, 6-hydroxy-2,5,7,8-tetramethyl chroman-2-carboxylic acid (Trolox, a hydrophilic derivative of tocopherol), linoleic acid, neocuproine were purchased from Sigma-Aldrich Chemical Co. (St. Louis, MO, USA). Other chemicals used were of standard analytical grade.

2.3. Postharvest quality of nectarine fruit during storage

2.3.1. Color evaluation of fruit

Photographs were taken during storage to show the extent of internal browning. Fruit peel color was determined using a reflectance spectrophotometer (Model NF333, Nippon Denshoku Industries, Tokyo, Japan). During measurements, the probe was placed on four positions along the width and length of the sample skin surface, each assignment had 6 fruits, and the values of hue angle and chroma of the peel color for each position were read and recorded.

2.3.2. Determination of ethylene production, weight loss, firmness, SSC, titratable acid (TA), SSC/TA ratio, decay rate and malondialdehyde (MDA) content

To analyze ethylene production after storage at different temperature, nine fruits from each group were enclosed in three 1 L airtight glasses containers per group for 12 h prior, respectively. Gas sample was determined using gas chromatography and ethylene production was expressed as nmol C_2H_4 kg^{-1} s^{-1}. Nectarine fruits were weighted after pre-cooling and every 14 days during storage period. The weight loss of fruits was expressed as the percentage loss compared to initial weight. To collect analytical samples, six fruits from each replicate (three replicates were used per group) were randomly selected at