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Effect of pressurized argon combined with controlled atmosphere on the postharvest quality and browning of sweet cherries

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ABSTRACT

Sweet cherries are in demand in domestic and international markets due to their medical and health benefits. However, storage and transportation of these cherries are difficult due to their thin skin. In this study, we investigated the effects of pressurized argon (0.5 MPa for 1 h at 0 °C), storage in a controlled atmosphere (5% O_2 + 10% CO_2 + 85% argon), and their combination on the postharvest quality and browning of sweet cherries during 63 d of storage at 0 °C. Results showed that treatment with pressurized argon, controlled atmosphere, and their combination effectively reduced the fruit decay rate (13.33 (58.54%), 15.56 (68.29%), and 18.89 (82.93%), respectively) compared with the control fruit after 63 d of storage. The treatments also effectively maintained a high good fruit rate (28.89 (72.22%), 36.67 (91.67%), and 45.56 (113.89%), respectively) compared with the control fruit after 63 d of storage and delayed the decline of lightness, saturation, and hue angle. They also inhibited reduction in firmness, levels of total soluble solid, titratable acidity, and ascorbic acid content, thus maintaining better fruit quality. The accumulation of membrane lipid peroxide malondialdehyde and increase in relative permeability was significantly decreased. The decrease in fruit phenolic compound content and increase in polyphenoloxidase and phenylalanine ammonia lyase enzymatic activity were inhibited. Ultimately, the development of fruit browning was reduced, and the browning index was maintained (11.94, 6.94, and 3.10, respectively) at a low level after 63 d of storage. Combined treatment with pressurized argon and a controlled atmosphere yielded the best results and may be considered one of the ideal methods for preserving sweet cherries.

1. Introduction

Sweet cherries have a vivid color, rich flavor, and abundant nutrients. In addition, they have great value in medical treatment and health benefits, and are thus in demand in domestic and international markets (Wang et al., 2016). However, sweet cherries are juicy and have thin skin that cannot tolerate storage and transport well. In addition, their harvesting season has high temperatures, due to which they are extremely susceptible to dehydration, browning, and decay, thus losing their market value in 3–5 d at ambient temperature (Serrano et al., 2009; Yildiz et al., 2018). Thus, alleviating the browning of sweet cherries and improving fruit quality are essential for their storage and transport.

Pressurization with inert gas is a new technology for preservation. At certain pressures, inert gases can form a special “clathrate hydrate” structure with the intercellular water in fruit and vegetables (Davidson, 1973; Yoshioki, 2010; Makino et al., 2006a,b). These structures not only restrict the activity of molecules in fruit and vegetables but also reduce their enzymatic activity, thereby inhibiting the physiological and metabolic activity of fruit and vegetables, ultimately inhibiting their browning and ripening and maintaining their quality (Rahman et al., 2002a; Zhan and Zhang, 2005; Purwanto et al., 2001). Because this technology has the advantage of lacking toxic side effects, simple operation, and clear results, it has gained increasing attention in recent years. A study by Rahman et al. (2002b) showed that xenon pressurization at 0.3 MPa could reduce the respiration rate of persimmon fruit and inhibit the development of flesh browning and decay. Treatment with 0.4 MPa xenon significantly shortened the longitudinal relaxation time and transverse relaxation time in eggplants (Rahman et al., 2001). Browning appeared on 6 d of storage in samples without xenon treatment, whereas browning did not appear even after 17 d in samples treated with 0.4 MPa xenon. Oshita et al. (2000) found that

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pressurization treatment of broccoli with 0.6 MPa xenon increased the viscosity of intracellular water and that there was no browning or dehydration during the storage period. A study by Zhang et al. (2008) found that treatment with mixed xenon and argon (Ar) pressurization inhibited increases in respiration rate, lignification, and browning in asparagus. Wu et al. (2012a) found that high-pressure nitrogen could inhibit increases in respiration rate, ethylene production, browning, and the loss of antioxidant activity in freshly cut pineapple, thereby extending its shelf life and maintaining good quality. Although studies on preservation using pressurized inert gas have yielded some results, many inadequacies still exist in the technologies for the preservation of specific fruit and vegetables. Integration of different preservation technologies is thus forming a new trend. Controlled atmosphere storage is a preservation technology in which respiration is inhibited and ripening is delayed in produce through changing the gas composition of the storage microenvironment. Currently, inert gas pressurization combined with controlled atmosphere storage is gradually gaining attention, but a vast majority of studies have concentrated on pressurization technologies combined with modified atmosphere storage technologies; in addition, studies are primarily focused on the quality of fruit and vegetables. In the storage of sweet cherries, only controlled atmosphere storage (Yu et al., 2009; Serradilla et al., 2013) and pressurization storage (Árbol et al., 2016) have been studied, whereas the integrated use of inert gas pressurization and controlled atmosphere storage has not been explored. Based on previous studies, in this study, we treated mid-to-late ripe “Lapins” sweet cherries (the test material) with pressurization with 0.5 MPa Ar for 1 h combined with a 5% O_2 + 10% CO_2 + 85% Ar atmosphere. The effects of argon pressurization, controlled atmosphere, and their combination on the browning and quality of sweet cherries during cold storage were studied, and their regulatory mechanisms in sweet cherry browning were revealed. This study thus provides a theoretical basis and technical guidance for controlling the browning of sweet cherries after harvesting.

2. Materials and methods

2.1. Materials and treatments

“Lapins” sweet cherries were used as test materials in this study. The samples of sweet cherry were obtained from twelve-year-old sweet cherry trees on the ‘Gisela 5’ rootstock, from a sweet cherry planting area in Jiang County, Shanxi Province, China (lat. 35°20′19″ N, long. 111°21′49″ W). Fruit trees were maintained with standard cultural, fertilizer, herbicide, and pesticide practices. Fruit were harvested at 80–90% commercial maturity stage (transverse diameter > 24 mm, per fruit weight > 9 g, bright red color). Within 1 h after manual harvesting, the fruit were moved to the postharvest facilities at Yuncheng University. Fruit with vivid color, uniform size, no disease-related or mechanical injury, and a similar degree of maturity were selected as the test material. The fruit were randomly divided into 4 groups (30 kg per group, 3 replicates per group, with 10 kg of fruit per replicate). The experimental design is shown in Table 1.

Sterilization treatment: The material in each group was disinfected by immersion in 0.05 g L^{-1} chlorine dioxide solution for 30 s and air dried at 1 °C.

Table 1
The experimental design.

Experimental group	Pressurization conditions	Atmospheric ratio
Control	0	0
Pressurized Ar (P A)	0.5 MPa Ar, 1 h	0
Controlled atmosphere (CA)	0	5% O_2 + 10% CO_2 + 85% Ar
Pressurized Ar + controlled atmosphere (P A + CA)	0.5 MPa Ar, 1 h	5% O_2 + 10% CO_2 + 85% Ar

2.1.1. Pressurization treatment

Fruit were placed in a custom-built high-pressure argon reactor. The air originally inside the reactor was not evacuated. Ar was added to a pressure of 0.5 MPa and maintained for 1 h. The times of pressurization and depressurization were approximately 120 s and 180 s. The pressurization process was conducted at 0 ± 1 °C environmental conditions.

2.1.2. Controlled atmosphere treatment

Fruit were arranged in plastic baskets (44 cm × 33 cm × 11 cm) and then stacked inside an atmosphere box (length/width/height: 130 cm × 62 cm × 113 cm, total volume 0.4 m^3). In total, 12 baskets were stacked inside each atmosphere box, with each basket weighing 2.5 kg. A gas mixer (MAP Mix 9000, PBI-Dansensor (Far East) Limited., Copenhagen, Denmark) was used to mix the desired concentration of O_2, CO_2, and Ar from external gas tanks to achieve specified gas combinations (5% O_2, 10% CO_2, and 85% Ar), which were stored in buffer tanks and passed to the atmosphere box as a continuous flow (100 mL min^{-1}). Gas composition of atmosphere box was monitored regularly using a gas analyzer (Gas Analyzer CheckMate II, PBI-Dansensor (Far East) Limited., Copenhagen, Denmark) to keep the fruit in a predetermined gas environment. Controlled atmosphere treatments were carried out at conditions of 0 ± 1 °C and 90–95% relative humidity.

2.1.3. Control treatment

Fruit were arranged in plastic baskets (44 cm × 33 cm × 11 cm) and a 0.03 mm polyethylene (PE) fresh-keeping bag that was left unsealed. The fruit were stored at conditions of 0 ± 1 °C and 90–95% relative humidity.

Ten samples were collected at regular intervals during the storage process and 75 fruit were collected at each time. Of these, 45 fruit were used for determination of fruit skin color, flesh firmness, total soluble solid (TSS) content, titratable acids, ascorbic acid (AsA), and cell membrane relative permeability. In addition, the fruit flesh was flash frozen in liquid nitrogen and stored in an -80 °C freezer to be used for malondialdehyde (MDA) and polyphenol content determination and browning-associated enzymatic activity. The remaining 30 fruit were used for the determination of decay index, rate of good fruit quality, and fruit flesh browning index. Each treatment was replicated three times. The experiment was conducted twice. A similar result was observed in the two experiments; thus, the data from one experiment are presented.

2.2. Index determination

2.2.1. Browning index determination

The browning index was determined as described by Yang and Wang (2016). In total, 30 fruit were collected and cut horizontally along the equator. The browning index was evaluated in each fruit individually using a five-point hedonic scale based on the percentage of cut surfaces affected by browning symptom. Browning index was scored as follows:

0, no browning of flesh; 1, browning of ≤ 1/4 of flesh area; 2, browning of 1/4 - 1/2 of flesh area; 3, browning of 1/2–3/4 of flesh area; 4, browning of ≥ 3/4 of flesh area.

Flesh browning index (%) = Σ (browning score × number of fruit with that score)/(4 × total number of fruits) × 100%

Three independent replicates were conducted for each treatment.

2.2.2. Decay index determination

In total, 30 fruit were used for decay index assessment. Fruit decay index was assessed in each fruit individually using a five-point hedonic