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Reduced chilling injury and delayed fruit ripening in tomatoes with modified atmosphere and humidity packaging

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ABSTRACT

To prolong shelf life and reduce chilling injury of tomato, the effects of modified atmosphere packaging (MAP) on tomato were investigated using Xtend MA/MH bulk packaging (XF) and polyethylene (PE) bags during storage at 4 °C and 12 °C for 14 days and under shelf-life conditions at 20 °C. The O_2 concentrations in PE bags stored at 4 °C and 12 °C were 19.9–20.3% and 20.6–20.9%, respectively, whereas those in the XF package were reduced to 14.9–16.7% and 17.8–18.5%, respectively. The XF package showed a higher CO_2 content (4.2–7.3%) than PE (0.5–1.2%) packages stored at 4 °C and 12 °C. Relative humidity (RH) was saturated within the PE bags but not within XF after 7 days of storage. MAP retarded the ripening process and delayed colour development compared to the non-packaged control during cold storage. In particular, XF effectively reduced the pitting score and decay rate of fruits stored at 4 °C for 14 days and transferred to 20 °C for 3–8 days, and increased gene expression of protease inhibitor II and catalase. Enhanced CO_2 and reduced O_2 levels and optimal RH (95%) provided by modified atmosphere and humidity could be used to reduce chilling injury and extend the shelf life of tomatoes.

1. Introduction

Tomato is susceptible to chilling injury (CI), a postharvest physiological disorder caused by improper storage temperatures that results in surface pitting, disease susceptibility, and inhibition of colour development and ripening (Cheng and Shewfelt, 1988). Tomatoes are chilling-sensitive at temperatures below 15 °C for longer than two weeks or at 5 °C for longer than 6–8 days (Suslow and Cantwell, 2009). Therefore, an optimum storage temperature of approximately 12 °C is recommended for tomato during postharvest (Cheng and Shewfelt, 1988). Low-temperature storage is frequently used to prolong postharvest quality and extend the shelf life of a broad range of horticultural commodities, although its use is sometimes limited by CI. At low temperatures, controlled atmospheres (CA) with modified O_2 and CO_2 concentrations may extend the storage life of different fruits and vegetables. Modified atmosphere packaging (MAP) has long been used to prolong shelf life by reducing respiration, minimizing mechanical damage, and alleviating water stress (Khan et al., 2016; Mangaraj et al., 2009). MAP may be produced as a result of respiration (passive MAP) or by the addition and removal of gases from food packages (active MAP) to manipulate the levels of O_2 and CO_2. Reduced O_2 and/or enriched CO_2 levels can reduce respiration, retard textural softening, and slow down compositional changes associated with ripening, thereby resulting in extension of shelf life (Daş et al., 2006).

The effectiveness of MAP depends on the variety, ripening stage, temperature, and storage length. MAP achieves significant benefits when plant products are maintained under optimal temperature, humidity, and atmosphere composition conditions (Zhuang et al., 2014). Many MAP systems are designed for tomatoes to be kept between 5 °C and 10 °C (Bailén et al., 2006; Fagundes et al., 2015). CI symptoms appear when tomatoes are transferred to non-chilling temperatures such as 20 °C following low-temperature storage for longer than one week (Lurie and Sabehat, 1997). In particular, tomatoes from export companies are more susceptible to CI because of transfer to warmer environments such as retail displays or household racks after a cold chain system. MAP also reduces CI of chilling-sensitive crops (Porat et al., 2004; Serrano et al., 1997; Wang and Qi, 1997). MAP and modified humidity packaging (MHP) effectively reduce CI symptoms in mango after three weeks of storage at 12 °C followed by one week at 20 °C (Pesis et al., 2000). In this study, we determined the effects of MAP and MAP/MHP on quality attributes, CI, and decay of tomato during storage at optimal (12 °C) and chilling (4 °C) temperatures and under shelf-life conditions (20 °C).

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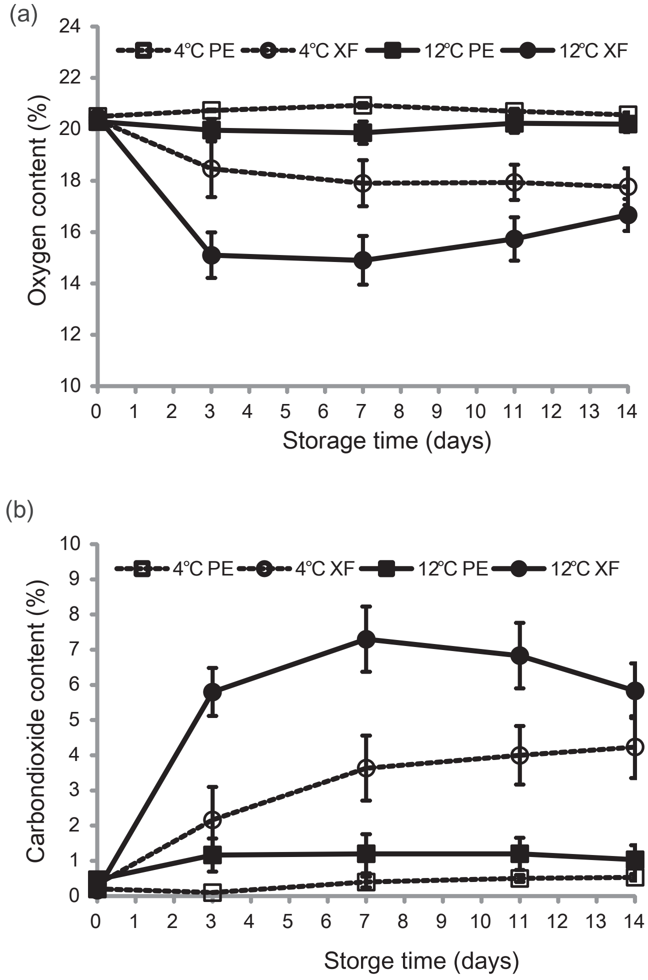

Fig. 1. Oxygen (A) and carbon dioxide (B) contents inside "box-in-bag" 'Defunis' tomato packaged using PE or XF and stored at 4 °C and 12 °C for 14 days. Data are presented as the mean ± SE of three replicates.

2. Materials and methods

2.1. Plant material and packaging treatment

Tomatoes (*Lycopersicon esculentum* L cv. Defunis) were obtained from a commercial packing house in Jeongyeup (South Korea) in October and used a day after harvest. Defunis tomato fruits were collected at mature green to breaker stages. Upon arrival, the fruit were packed in a commercial card box (~4 kg, 30 fruits). Fruit boxes were randomly divided into three lots and packed with one of the following treatments: (1) control fruit (without packaging); (2) PE, polyethylene film bag (50 μm thickness; Tebangparteck, Korea); and (3) XF, Xtend MA/MH bulk package with antifog (Cod: 815-ST2, StePac, Israel). Packaged boxes were tightly closed with nylon tape. Fruit were stored at 4 °C and 12 °C for 14 days and transferred to 20 °C for another 3–8 days. After transfer to shelf-life conditions at 20 °C, the bags were opened.

2.2. Atmosphere analysis

The CO_2 and O_2 concentrations in the packages were determined using a combined CO_2/O_2 analyser (Checkmate 3, PBI- Dansensor, Denmark).

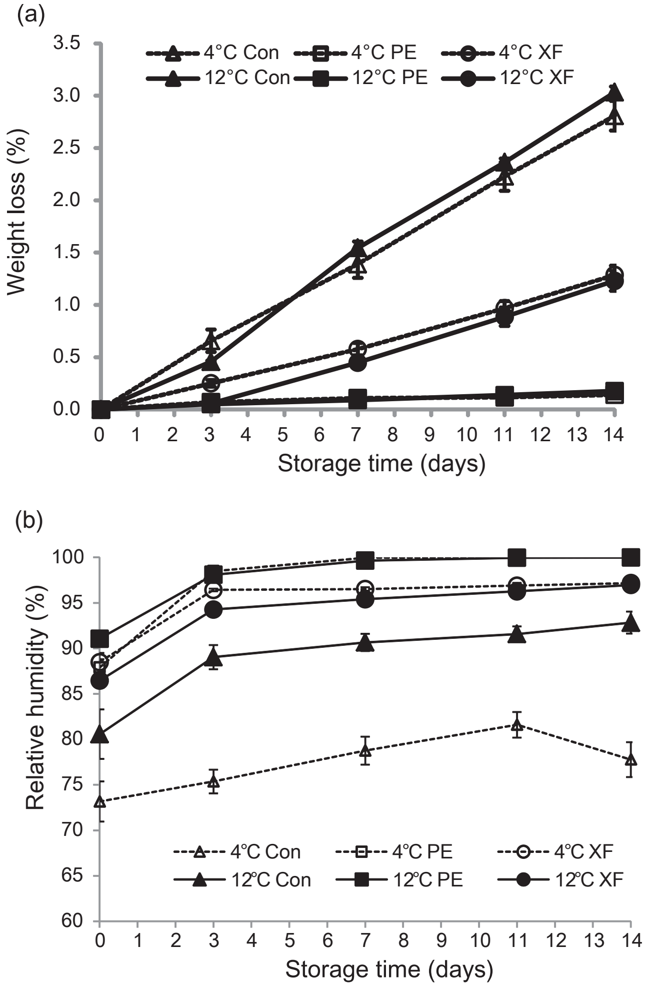

Fig. 2. Weight loss (A) and relative humidity (B) inside "box-in-bag" 'Defunis' tomato packaged using PE or XF and stored at 4 °C and 12 °C for 14 days. Data are presented as the mean ± SE of three replicates.

2.3. Measurement of relative humidity and weight loss

To monitor the temperature and humidity in the packages, a data logger (Watch dog, Spectrum Technology, USA) was placed inside three packages for each treatment and set to record temperature and relative humidity (RH) every hour. Three packages per treatment were also weighted before and after storage to assess weight loss, expressed as a percentage of the initial weight.

2.4. Fruit quality evaluation

Fruit skin colour was determined using a colour difference meter (Minolta CR-400 model, Osaka, Japan) and reported as Hunter's scale L*, a*, and b*. Thirty tomatoes per treatment were randomly selected for colour measurements, with two readings on two opposite sides of the equatorial region. The firmness of each peeled fruit (20 tomatoes with three readings per treatment) was determined using a texture analyser (TA Plus Lloyd Instruments, Fareham, Hamshire, UK) at a rate of 2 mm s^{-1} with a 5-mm diameter plunger head. The total soluble solids (TSS) content of samples was determined using a digital refractometer (PAL-1, Atago, Japan). The titratable acidity (TA) content was determined by titrating 5 mL of juice with 0.1 N NaOH to pH 8.2 using an auto pH titrator (Titroline easy; SCHOTT instruments GmbH, Mainz, Germany) and expressed in grams of citric acid per 100 g pH of sample juice.

CI was measured as described by Ding et al. (2001): 0 = no pitting;