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Establishing CO_2 Tolerance of Pink Tomatoes in Modified Atmosphere Packaging at Elevated Handling Temperatures

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Fresh tomatoes are chilling sensitive, with the sensitivity decreasing as the fruit ripen, but the fruit can suffer aroma loss even at handling temperatures that are at or above the putative chilling threshold for unripe tomato fruit of 12.5 °C (54.5 °F). Modified atmosphere packaging (MAP) with reduced O_2 and elevated CO_2 retards ripening and has been reported to reduce tomato chilling injury. Tomatoes can tolerate different concentrations of CO_2 depending on the temperature and duration of exposure, but the effect of ripeness stage on CO_2 sensitivity is unclear. In this study, pink ripeness stage tomatoes were evaluated to establish CO_2 tolerance levels in MAP during storage at elevated handling temperatures. Tomatoes were stored at 12.5 °C, 15 °C (59 °F), and 18 °C (64.4 °F) for 20 days. Gas exchange was allowed through three different sizes of holes in the packages, 6.35 mm (1/4 inch), 12.7 mm (1/2 inch), and 19.0 mm (3/4 inch), which were covered by a microporous film. CO_2 was injected into the packages immediately after sealing to establish 3% to 10% CO_2 (expected equilibrium concentrations). Color changes, titratable acidity, total soluble solids, firmness, and decay appearance were evaluated. CO_2, O_2, and ethylene concentrations were also measured in the headspace of the packages. CO_2 concentrations were about 6.5%, 7%, and 8% in the containers that had 6.35-mm holes after an equilibration period of 5 days at 12.5, 15, and 18 °C, respectively. Severe CO_2 injury symptoms developed only in fruit stored at 12.5 °C in packages with 6.5% CO_2. The symptoms included streaky external color development and green internal color along with lower firmness than would normally be expected for a given stage of color development.

The demand for fresh market tomatoes has increased over 30% between 1970 and 2000 (Lucier et al., 2000), requiring prolonged storage of tomato fruit that would allow long-distance shipping. Tomatoes harvested for fresh consumption are usually picked at mature green or early ripe stages and transported to retailers using various forms of controlled conditions (temperature, atmosphere, relative humidity). The fruit are harvested mature green or at an early ripeness stage to achieve a longer shelf life and so that they will have the appropriate coloration when they are put on the retailers' displays. On the other hand, previous studies have shown that tomato fruit ripened on the plant have better eating quality (Kader et al., 1977). More specifically, total soluble solids and reducing sugars contents are positively correlated with ripening of tomato fruit on the plant (Betancourt et al., 1977; Gautier et al., 2008). Based on the research that has been done, pink ripeness stage tomatoes have superior flavor and aroma properties compared to the less ripe harvested fruit.

It has been found that elevated temperatures during handling can induce ripening and result in increased postharvest losses in the fruit. Auerswald (1998) has shown that tomatoes stored at temperatures higher than the usual (12.5 °C) had higher characteristic overall scores in sensory analysis and instrumental measurements. During the transportation chain, tomatoes are typically handled at temperatures between 10 and 15 °C, which vary according to the ripeness stage of the fruit, and are also sometimes exposed to modified atmosphere conditions (Geeson et al., 1985). Modified atmosphere packaging (MAP) has been found to act synergistically with the lower temperatures in the attenuation of the biochemical processes of the plant tissue during ripening.

Tomato fruit that are stored at temperatures less than 12.5 °C for extensive periods may develop chilling injury (CI) (Morris, 1982). Consequences of CI are failure to ripen and obtain full color and flavor, premature softening, surface pitting, irregular (blotchy) color development browning of the seeds and increased decay. Immature fruit are more sensitive to chilling temperatures than pink or red tomatoes. It has been shown that firm ripe tomatoes can be stored at 7 to 10 °C for 3–5 d without reduction in flavor and aroma quality (Sargent and Moretti, 2004). However, Maul et al. (2000) reported that tomato flavor and aroma were significantly affected by low temperatures (<12.5 °C) for as short as 2-d duration for 'BHN-189' and 4 d for light-red 'Solimar' tomatoes.

The CO_2 tolerance levels of tomato fruit have not been well defined yet. According to Saltveit (2001) the optimum storage atmosphere for red ripe tomatoes is 3% to 5% O_2 plus 2% to 3% CO_2. It has been found that while elevated concentrations of CO_2 delay ripening effectively, the ripening continues normally after opening the MAP, with no obvious adverse effects on the smell, flavor, or texture of the fruit (Geeson et al., 1985). This is in accordance with a later study (Klieber et al., 1996) reporting that tomatoes stored at 20 °C with 80% CO_2 had a 1-d delay in their ripening. On the other hand the relationship between high CO_2 concentrations and CI symptoms has not been well documented yet for intact fruit. In a study by Hong et al. (2001), it was reported that slices of tomatoes stored at 5 °C showed a 3-fold increase in

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visible CI symptoms when the atmospheric composition was 1% O_2 plus 4% CO_2 (45% occurrence) compared to slices stored at 1% O_2 plus 12% CO_2 (16% occurrence). However, fruit stored at identical CO_2 concentrations and temperature (5 °C) but with near ambient O_2 conditions (20%) did not show any difference in the CI symptom occurrence (8% in both cases).

The purpose of this study was to establish CO_2 tolerance levels in MAP during storage at elevated handling temperatures for pink ripeness stage tomatoes.

Materials and Methods

'Soraya' tomatoes harvested at the pink ripeness stage were obtained from a packinghouse in Ruskin, FL. The fruit size was Large (6 × 6) according to the USDA standards (USDA, 1991). The fruit were transported in an air-conditioned vehicle to the Postharvest Horticulture Laboratory at the University of Florida in Gainesville and stored overnight at 20 °C. The next morning an additional grading was done in the lab to ensure homogeneity of the sample.

Samples of three tomato fruit (total mean fruit mass of 393.6 g ± 86.42 g) were placed into 2.6-L plastic trays with dimensions 23 × 12 × 9.5 cm (L × W × D) and the openings of the trays were heat sealed with a non-permeable polypropylene film - OPA PP- (ORVED S.p.A., Venice, Italy), using an ORVED VGP sealing machine (ORVED). To achieve different CO_2 concentrations, a microporous patch with polymer coating (BreatheWay®, Apio Technology Group, Guadalupe, CA) was attached to the side of each tray over one of three different sizes of holes. The hole sizes were 6.35 mm (1/4 inch), 12.7 mm (1/2 inch), and 19.0 mm (3/4 inch). Packages with no patch attached, but with 30 small (approximately 1-mm diameter) holes in the non-permeable sealing film made by puncturing the film with a needle served as the control. After sealing, 60 mL of 100% CO_2 were injected in the containers except for the controls, to achieve initial CO_2 concentrations close to the expected steady state concentrations of 3% to 10% that had been determined in preliminary experiments. The containers were placed at 12.5, 15, or 18 °C, in replicates of three packages per hole size and measurement day. Initial measurements were made on Day 0 and every 5 d for a period of 20 d. The O_2 and CO_2 concentrations were measured with a Bridge Analyzer (Model 900141 Lo-Ox/Hi-Ox CO_2/O_2 MAP Headspace Gas Analyzer, Bridge Analyzers, Inc., Alameda, CA) every 2 d.

Firmness was measured as resistance to deformation in Newtons (N) with an Instron analyzer (Instron®, Norwood, MA) using a flat plate and a deformation of 3 mm at the distal end of the fruit. Surface color measurements (CIE L*a*b* scale) were taken at two random spots around the distal end of each fruit using a Minolta colorimeter (Model CR-400, Konica Minolta Sensing, Inc., Osaka, Japan).

Tomatoes were homogenized in a blender into samples from each of the temperature × atmosphere treatments representing three, three-fruit samples per treatment and sampling time, and centrifuged at 18,000 × g_n at 5 °C. The resulting supernatant was filtered through cheesecloth, and stored in scintillation vials at –20 °C for later analysis. Titratable acidity, expressed as percent citric acid, was determined by titrating 1.5 g of tomato supernatant to pH 8.2 with a 0.1 N NaOH solution using an automatic titrimeter (Fischer Scientific, Pittsburgh, PA). Soluble solids concentration was measured using a tabletop digital refractometer (Abbe Mark II, Reichart-Jung, Buffalo, NY) and pH measurements were made using a digital pH-meter.

Results

After the sealing process and the injection of CO_2 into the containers, the concentrations of gases in the packages were all near the steady state with CO_2 concentrations ranging from 0 to 8% within 5 to 7 d (Fig. 1). The steady state CO_2 concentrations at 12.5 °C were 6.5%, 4%, and 2.5%; at 15 °C the CO_2 equilibrated at 7%, 5%, and 3% (Fig. 2); and at 18 °C, the CO_2 concentrations were 8%, 5%, and 3% (Fig. 3). The O_2 concentrations in the packages ranged from 20.8% in the controls down to 3% in the other packages (data not shown). Similarly, the ethylene

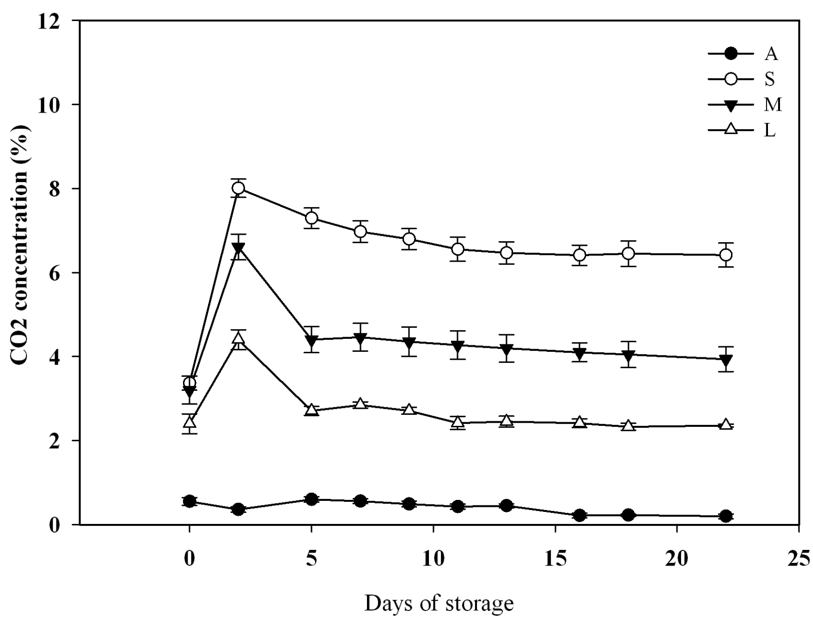

Fig. 1. Carbon dioxide concentrations for tomatoes stored in four different modified atmosphere packages (A = Air control, S = 6.35-mm hole size, M = 12.7 mm, and L = 19.0 mm) at 12.5 °C.

concentration was about 2 to 12 µL·L^{-1} in the control packages and remained below 50 µL·L^{-1} in the packages with elevated CO_2 (data not shown).

For fruit stored at 12.5 °C, the concentrations of gases were stable from 5 d after sealing throughout the storage period for all of the packages. At 15 and 18 °C, the concentrations of gases in the containers with the smallest hole size were stable after 7 d, except for an increase in CO_2 during the last 4 d of storage. For the fruit stored at 18 °C, this increase in CO_2, from approximately 8% to 10% starting on Day 16, corresponded to the appearance of decay. There could have been a breakdown in the tissue of the tomato fruit due to the higher CO_2 concentrations (compared to the other containers stored at the same temperature) that rendered the fruit vulnerable to microorganisms. Further experiments and different types of analysis have to be done to identify these microorganisms. Also, it is possible that the storage time was too short for the rest of the treatments to show negative effects of the increased CO_2 concentrations. This means that future experiments involving longer than 20 d storage may provide some useful information regarding tomatoes stored in such conditions.

The SSC did not show any significant differences during storage at any of the three temperatures and steady state CO_2 concentrations tested. The SSC values of fruit analyzed on Day 0 were around 5%, which was the same as those analyzed on

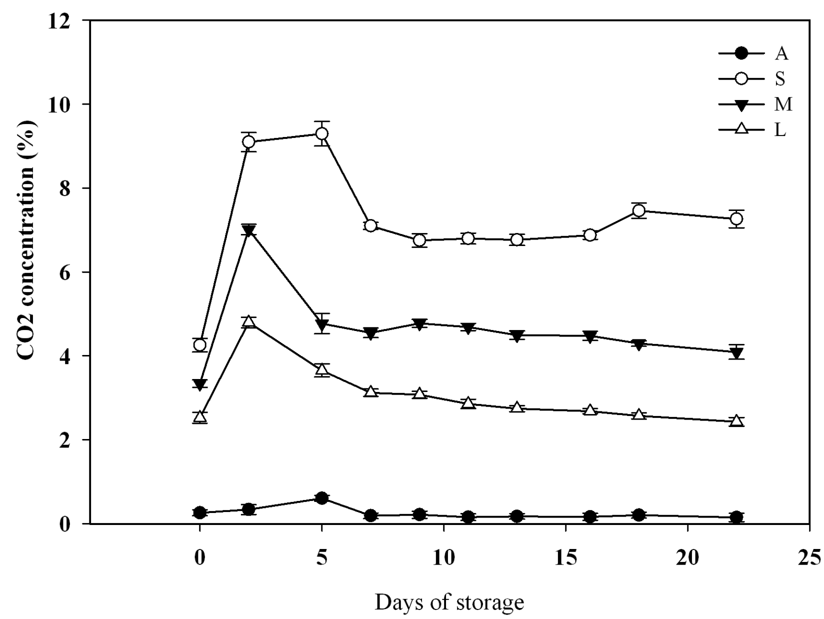

Fig. 2. Carbon dioxide concentrations for tomatoes stored in four different modified atmosphere packages (A = Air control, S = 6.35-mm hole size, M = 12.7 mm, and L = 19.0 mm) at 15 °C.

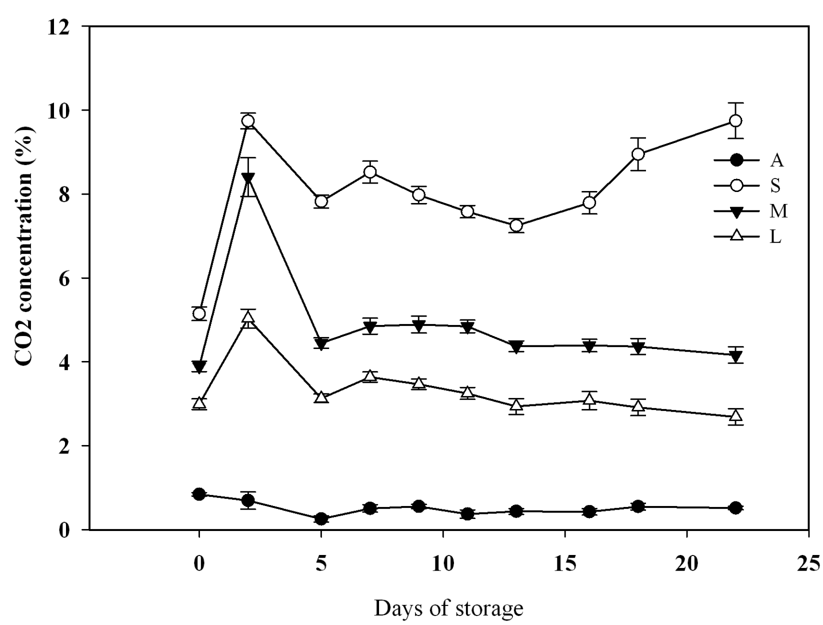

Fig. 3. Carbon dioxide concentrations for tomatoes stored in four different modified atmosphere packages (A = Air control, S = 6.35-mm hole size, M = 12.7 mm, and L = 19.0 mm) at 18 °C.

Day 20. Titratable acidity did not differ significantly during the storage period (data not shown).

Fruit stored at all temperatures ripened normally in most cases, developing red color. However, red color development was delayed in the fruit stored at 12.5 and 15 °C as well as the higher CO_2 concentrations (Figs. 4 and 5), while fruit at 18 °C developed more red color (Fig. 6). Generally, the lower temperatures and elevated CO_2 atmospheres seemed to act synergistically in delaying the ripening process. Fruit stored at the lowest temperature (12.5°) in the containers with the smallest hole size showed irregular ripening (Fig. 7). More specifically, the external color of those tomato fruit was streaky and the internal color green. Some fruit also seemed to have lower firmness than would normally be expected for a given stage of color development. These symptoms are typical for tomatoes stored at high concentrations of CO_2 (Klieber et al., 1996), which leads us to believe that these fruit developed CO_2 injury symptoms.

Storing tomatoes at elevated CO_2 concentrations (6.5%) in combination with the lowest temperature (12.5 °C) resulted in visible severe CO_2 injury symptoms. On the other hand, 4.5% CO_2 at the same temperature did not cause injury. Fruit stored at higher temperatures with similar or higher CO_2 concentrations showed less or no visible CO_2 injury symptoms (i.e., had normal red color development). This means that the CO_2 tolerance level

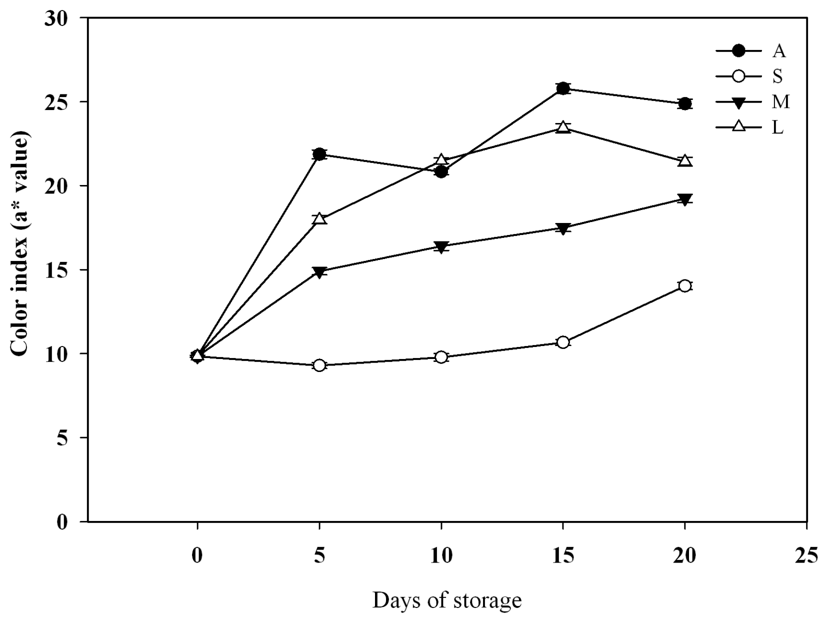

Fig. 4. Color index a* for fruit stored in four different modified atmosphere packages (A = Air control, S = 6.35-mm hole size, M = 12.7 mm, and L = 19.0 mm) at 12.5 °C.

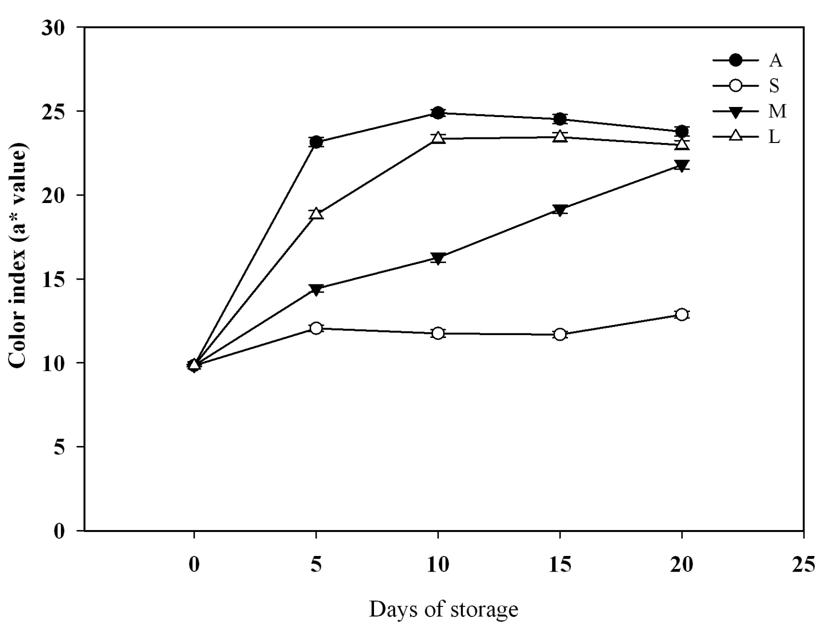

Fig. 5. Color index a* for fruit stored in four different modified atmosphere packages (A = Air control, S = 6.35-mm hole size, M = 12.7 mm, and L = 19.0 mm) at 15 °C.

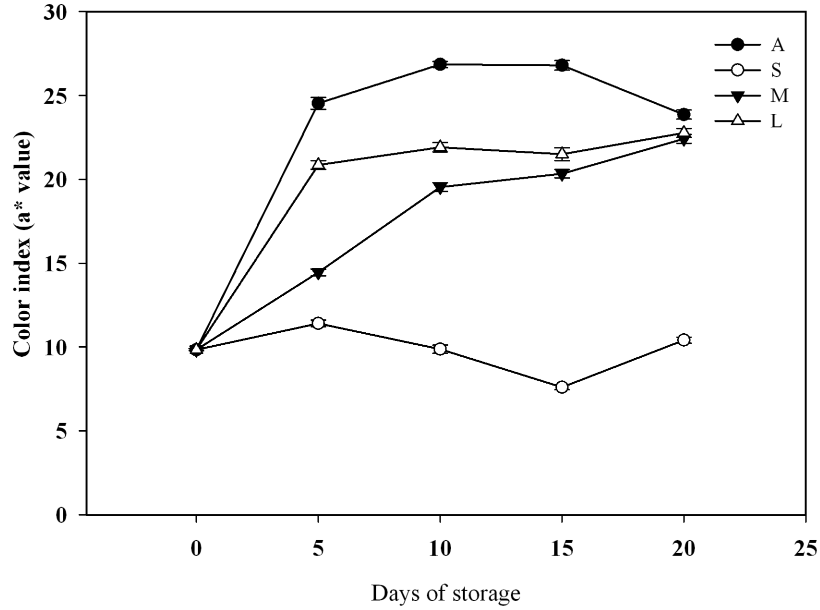

Fig. 6. Color index a* for fruit stored in four different modified atmosphere packages (A = Air control, S = 6.35-mm hole size, M = 12.7 mm, and L = 19.0 mm) at 18 °C.

Fig 7. Color of tomato fruit after 5 d of storage at 12.5 °C in air (A) or containers with small (6.35 mm) holes (B) and after 20 d of storage at 12.5 °C in air (C) or in containers with small holes (D).

of pink tomatoes at 12.5 °C appears to be between 4.5% and 6.5% CO_2, but further research is needed to confirm this. For higher temperatures (15 °C, 18 °C) CO_2 tolerance may be even higher than the concentrations tested.

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