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Effects of Modified Atmosphere and Storage Temperature on the Quality of Tomatoes

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Abstract

The effects of storage conditions on the quality preservation of tomatoes were investigated. Tomatoes (*Lycopersicon esculentum*, cv. Momotaro) were stored in modified natural atmospheres at temperatures of 15°C and 20°C for 12 days and then kept for 3 days in air at room temperature for ripening. Low levels of O_2 or high level of CO_2 were used to inhibit the ripening process and to reduce the respiration rate of tomatoes. Surface color, weight loss and firmness of tomatoes were affected by the gas composition inside the storage chamber and also storage temperature. Surface color of the tomatoes became overripe after storage for 6 days in natural atmosphere at 20°C. Modified atmospheres had no effect on the soluble solids content of tomatoes, except that storage in an atmosphere of 6% O_2 + 4% CO_2 tended to produce an increase in the soluble solids content. Based on the appearance and quality of tomatoes after storage and ripening, the optimum storage conditions were determined to be at 15°C in an atmosphere of 6% O_2 + 4% CO_2. Storage under these conditions can extend the shelf-life and preserve the quality of tomatoes harvested at almost full maturity.

I. Introduction

In terms of taste, it is obviously better to harvest tomatoes at almost full maturity. Kader *et al.*[1] reported that many of the problems associated with the flavor quality of fresh market tomatoes were related to the stage of maturity and/ or ripeness at harvest. The best way to ensure good flavor for the consumer is to harvest tomatoes as near to table ripe as possible and move them rapidly and carefully from the field to the consumer. McCollum and Skok[2] reported that tomatoes harvested at the mature green stage and ripened in storage would have poorer quality than fruit ripened on the plant. Kader *et al.*[3] reported that tomatoes picked at earlier stages of ripeness and ripened at 20°C were evaluated as being less sweet, more sour, less "tomato-like" and having more "off-flavor" than those picked at the table-ripe stage. In practice, however, there are a number of constraints on the current handling and marketing system of tomatoes after harvest.

Although the preservation period of many vegetables can be prolonged by low-temperature storage, the tomato is one exception and it is susceptible to chilling injury if stored at low temperature. Further, tomatoes ripen very quickly after harvesting and their quality deteriorates within 6-8 days during storage at room temperature. These problems limit the time available for transportation and distribution from the production area to the distributor or market. Therefore, several improvements to the post-harvest handling of fresh market tomatoes should be considered. One method of extending the shelf-life and preserving the quality of tomatoes is storage in a modified atmosphere.

The use of a modified atmosphere with reduced O_2 and/ or elevated CO_2 is known to inhibit the ripening of fruit, but elevated in high levels of CO_2 are not tolerated by most cultivars and can cause injury. Several reports have indicated that tomatoes are susceptible to CO_2 injury. Buescher[4)] reported that the exposure of fruit to more than 10% CO_2 for 4 and 7 days reduced the number of salable fruit. The severity of injury to fruit by CO_2 increased with increasing concentration of CO_2 and duration of exposure. Mold growth, water-soaked areas, and uneven pigmentation were the primary symptoms of injury. Further, the use of low O_2 ($< 1\%$) to store tomatoes can cause "off-flavors", objectionable odors, and other defects, such as internal browning. Therefore, the purpose of this study was to determine the optimum gas composition and temperature for the preservation of tomatoes quality (*i.e.*, surface color, weight, soluble solids content and firmness) during storage and ripening.

II. Materials and Methods

The test materials were tomatoes (*Lycopersicon esculentum*, cv. Momotaro) that were harvested at Biratori Town in Hokkaido from July to August 1999 and transported to our laboratory at Hokkaido University. In the laboratory, tomatoes were selected, designated and then divided into 8 groups, each consisting of 60 tomatoes. Tomatoes were stored in plastic containers in which the gas composition had been adjusted to a preset value. Six groups of tomatoes were stored in modified atmospheres of 3% O_2 + 4% CO_2, 6% O_2 + 4% CO_2, or 6% O_2 + 8% CO_2 at temperatures of 15°C and 20°C, respectively. The two remaining control groups were stored in natural atmospheres at 15°C and 20°C, respectively. Each group was stored for 12 days. The tomatoes were then removed from the storage chamber and kept for 3 days in air at room temperature for ripening. Every 2 days during storage, the gas inside the containers was sampled and the concentrations of O_2 and CO_2 and ethylene production were measured. After sampling, the gas composition was again adjusted to the preset value. Further, every 4 days during storage and after 3 days ripening in air, tomatoes were sampled and examined for surface color, weight loss, soluble solids content (SSC) and firmness.

Surface color was measured at 6 points on the shoulder (4 points), near the blossom end (1 point) and near the stem end (1 point) of each of 10 tomatoes from each group. Color measurement was performed using a reflectance colorimeter (Chroma Meter CR-200, Minolta Corp.). Measurement was made using the L* a* b* color system, where L* indicates lightness on scale of 0 (= black) to 100 (= white), a* indicates green (−) to red (+), and b* indicates blue (−) to yellow (+). The color of the tomatoes is expressed as the ratio a*/b*. [5,6,7,8]

Firmness was measured using a rheo meter (NRM-2002J, Fudoh Kogyo Co., Ltd.) connected to a computer. Firmness was measured at 4 points on the shoulder of each of 6 tomatoes from each group by applying a plunger of 3mm in diameter. The amount of force (kg.f) required to compress the radial pericarp surface of tomatoes at a constant speed of 10 cm/min was recorded. The firmness value of the fruit was expressed as force per unit area (MPa).

The soluble solids content of the fruit was measured using a digital refractometer (PR-100). Each sample was cut into two slices. Each slice was further divided into 3 parts, so there were 6 parts (replications) for each measurement per fruit. The juice from each part was extracted manually (> 2 drops) and then put into the refractometer. The value of soluble solids content was expressed as Brix%. The reported values represent the average of six samples with six measurements per sample.

The O_2 and CO_2 concentrations in the containers were measured pre-storage and every 2 days during storage with an M.A.P. TEST 3000, Packaging Atmosphere Analyzer. Ethylene production was measured every 2 days during storage using a gas chromatography.

III. Results and Discussion

A. Changes in O_2 and CO_2 concentrations and ethylene production during storage

Every 2 days during storage, the O_2 and CO_2 concentrations and ethylene production inside the containers were measured. After measurement the gas composition was again adjusted to the preset value. The O_2 concentration was found to decrease during each 2-day interval, while the CO_2 concentration increased. Ethylene was produced during each 2-day interval. Fig. 1 shows the average CO_2 production in the storage chambers during the 2-day intervals. Production was affected by storage temperature and gas composition inside the storage chamber. The higher the storage temperature was the higher the production of CO_2, while the lower the O_2 composition inside the storage chamber was the lower the production of CO_2 and the higher the CO_2 composition inside the storage chamber was the lower the production of CO_2.

Ethylene (C_2H_4) production was lower in containers with low O_2 and high CO_2 concentrations. Ethylene production declined with increasing CO_2 or decreasing O_2 concentration. These results showed that the use of low O_2 and high CO_2 concentrations in combination with low temperature is effective in suppressing

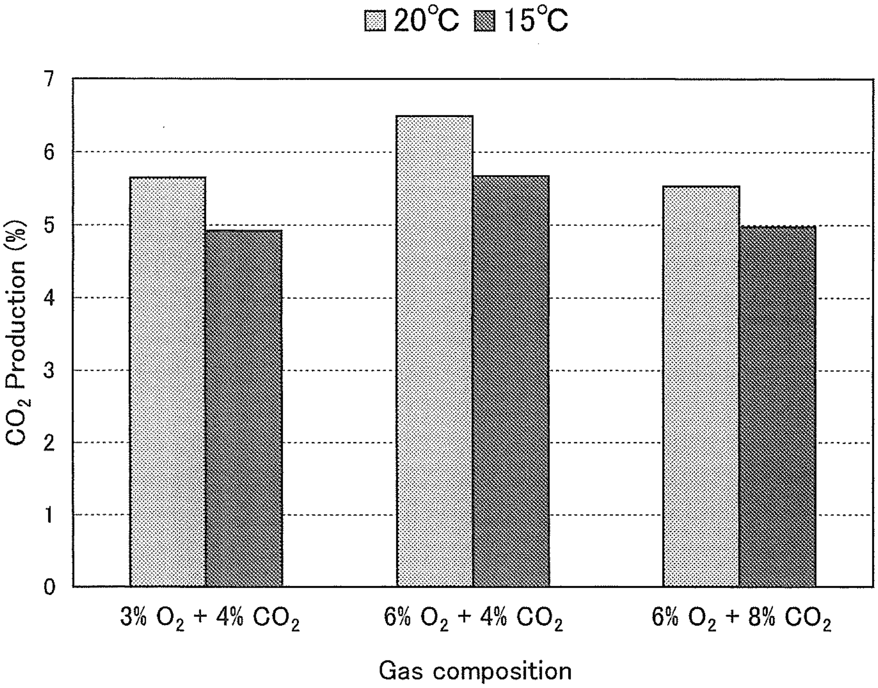

Fig. 1. The average CO_2 production in the storage chambers during the 2-day intervals.

tomato respiration.

B. Color development of tomatoes during storage and ripening

Color is one of the most important quality attributes in marketing tomatoes. Although it does not necessarily reflect nutritional or functional value or flavor, it is related to consumer preferences based on the appearance of tomatoes. Also color is used to determine the ripeness of tomato fruit. The color of tomatoes was measured by using reflectance colorimeter, which is resulted in L*, a* and b* color systems. The color development of tomatoes is expressed as an a*/b* value. Kramer, in Pomeranz. and Meloan[9] stated that the correlation with panel score of color of tomatoes is improved if two color attributes (or their ratio) such as a* (redness) and b* (yellowness) readings of the colorimeter are determined to express the color value of tomatoes.

The color development of tomatoes during storage is shown in Fig. 2. The higher the a*/b* value was the redder the surface color of tomatoes. Fig. 2 indicates that the a*/b* value of tomatoes stored in a modified atmosphere was lower than those stored in a natural atmosphere, because the ripening process of tomatoes was suppressed, resulting in less redness. The a*/b* value of tomatoes stored in a natural atmosphere increased rapidly during the first 4 days of storage

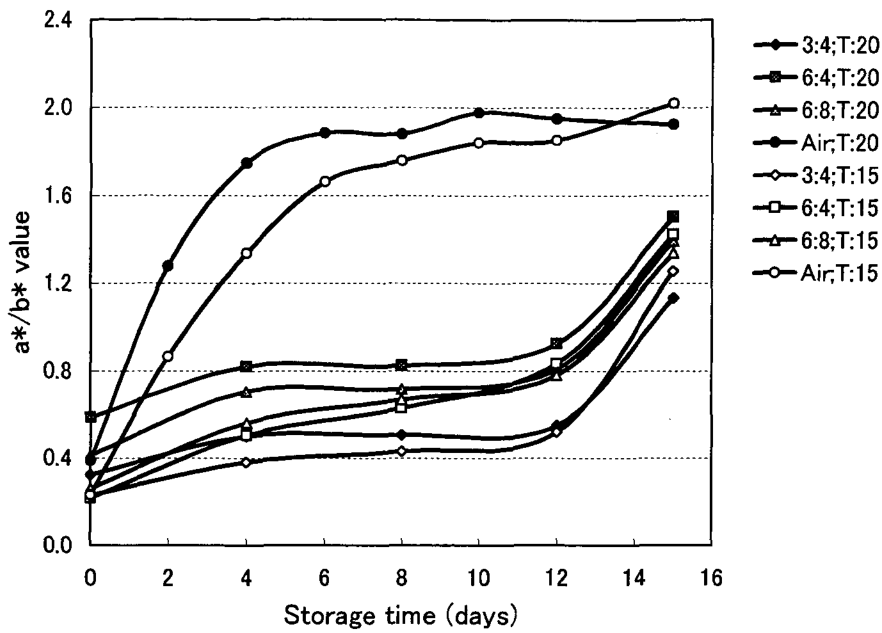

Fig. 2. Color development of tomatoes during storage and ripening.
3,4,T20 = storage in an atmosphere of 3% O_2 + 4% CO_2 at temperature of 20°C.

and became constant after 6 days. Therefore, tomatoes stored in a natural atmosphere became overripe more quickly. The color development of tomatoes was not only affected by storage condition but also by the stage of maturity at harvest. Hobson[10] reported that fruit surface color development is influenced by temperature and time. The present research has shown that storing tomatoes in low O_2 or high CO_2 atmosphere slows color development more than storage in high O_2 or low CO_2 atmosphere. Storage in an atmosphere of 3% O_2 + 4% CO_2 resulted in a*/b* value smaller than those of the other treatments (Fig. 2). However, after ripening, the a*/b* value of some tomatoes stored in an atmosphere of 3% O_2 + 4% CO_2 was less than the a*/b* value of tomatoes sold in the market; that is, about 1.3. This means that surface color of tomatoes did not develop normally after ripening. Efiuvwevwere and Thorne[6] has reported that mature green tomatoes chilled at 5°C for 9 days or 7°C for 12 days ripened to a dull red color with an a*/b* value of 0.83 to 0.90.

From the appearance of tomatoes after 3 days in air at room temperature, storage in an atmosphere of 6% O_2 + 4% CO_2 was found to give better results than the other treatments and resulted in less decay. Storage in a modified atmosphere at 20°C resulted in cracking after 6 days of storage and mold growth on the surface of tomatoes, which eventually resulted in rotting. These defects may have been caused by excessive water vapor inside the storage container.

C. Weight loss in tomatoes

The weight loss in tomatoes during the storage period is shown in Fig. 3. Weight loss was lower in tomatoes stored in a modified atmosphere than in those stored in a natural atmosphere, and it was also lower in tomatoes stored at a lower temperature. The effect of reduced storage temperature on the reduction of weight losses is clearly demonstrated here, especially for storage in a natural atmosphere. At lower temperature, the diffusion of internal moisture to the surface of tomato and the movement of moisture from the surface to storage environment is reduced. Weight loss during 12 days storage in a modified atmosphere was less than 1% at both 15°C and 20°C, while the weight loss of tomatoes stored in a natural atmosphere at 15°C and 20°C reached 2.85% and 4.82%, respectively. After tomatoes were kept for 3 days in air at room temperature, it increased rapidly, especially for those stored in a modified atmosphere.

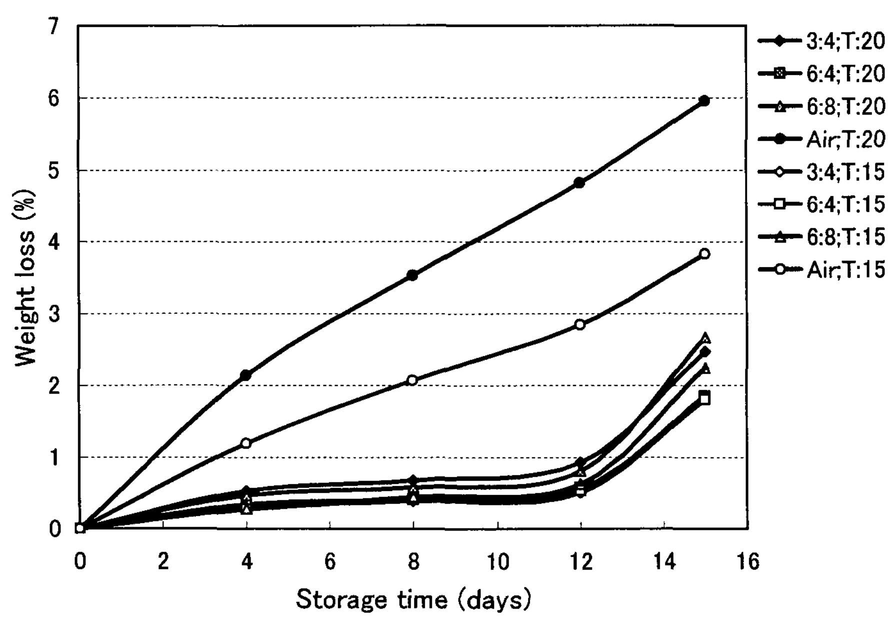

Fig. 3. Weight loss in tomatoes during storage and ripening. 3,4,T20 = storage in an atmosphere of 3% O_2 + 4% CO_2 at temperature of 20°C.

D. The soluble solids content (SSC) of tomatoes

The soluble solids content of tomatoes during storage was shown in Table 1. The soluble solids content of tomatoes stored in a natural atmosphere at 20°C increased during the first 4 days of storage and then decreased with storage time, while at 15°C the SSC was relatively constant. The SSC of tomatoes stored in a

Table 1. Soluble solids content of tomatoes during storage and ripening.

Storage time	Storage temperature of 20°C				Storage temperature of 15°C			
(days)	3+4	6+4	6+8	Air	3+4	6+4	6+8	Air
0	5.30	5.30	5.30	5.30	4.80	4.80	4.80	4.80
4	5.02	5.04	4.99	5.40	5.10	5.50	5.30	5.00
8	4.97	5.34	5.06	5.16	5.50	5.40	5.50	4.90
12	4.87	5.56	5.06	4.74	5.30	5.40	5.20	4.80
15	5.21	5.66	4.88	4.68	5.20	5.80	5.20	5.00

3+4 = storage in an atmosphere of 3% O_2 + 4% CO_2.

modified atmosphere of 6% O_2 + 4% CO_2 tended to increase after 8 days storage at 20°C and after 4 days storage at 15°C, while there were no consistent trends in the changes in soluble solids content among the other groups. After storage for 12 days and ripening for 3 days, the soluble solids content of tomatoes stored at 20°C relatively had decreased, except in those stored in an atmosphere of 6% O_2 + 4% CO_2. The SSC of tomatoes fell from 5.30% to 5.21% for those stored in 3% O_2 + 4% CO_2, 5.66% for those stored in 6% O_2 + 4% CO_2, 4.88% for those stored in 6% O_2 + 8% CO_2, and 4.68% for those stored in a natural atmosphere. On the other hand, there was an increase from 4.80% to 5.20%, 5.80%, 5.20% and 5.00% for tomatoes stored at 15°C in 3% O_2 + 4% CO_2, 6% O_2 + 4% CO_2, 6% O_2 + 8% CO_2 and in a natural atmosphere, respectively. These results indicate that the SSC of tomatoes was not greatly affected by differences in gas composition and storage temperature. This result agrees with the finding by Koskitalo and Ormrod[10] who reported that the SSC of fruits did not change significantly during ripening. Wedding and Vines, in Koskitalo and Ormrod[11] noted that the SSC increased more with lower ripening temperature, whereas Craft and Heinze[12] reported that storage temperature had no effect on SSC.

The SSC is one parameter that can be used to indicate the objective quality of tomatoes, because the major component of soluble solids is reducing sugar, which is related to the sweetness of tomatoes. Kader *et al.*[3] reported reducing sugars to be highly correlated with sweetness. Further, Bisogni *et al.*[13] found correlations between SSC and sweetness, flavor and overall quality.

E. Firmness of tomatoes

Changes in the firmness of tomatoes during storage are shown in Fig. 3. Firmness of tomatoes decreased with storage time. The decrease in firmness of tomatoes stored in modified atmospheres was smaller than in those stored in a natural atmosphere. After 12 days in storage, tomatoes stored at 15°C in atmosphere of 3% O_2 + 4% CO_2 had the highest firmness value, while those stored at 20°C in a natural atmosphere had the lowest firmness value. The firmness of tomatoes before storage was about 1.49-1.53 MPa. After 12 days in storage, it decreased to 1.33 MPa for those stored in an atmosphere of 3% O_2 + 4% CO_2 at 15°C, 0.98 MPa for those stored in a natural atmosphere at 15°C, and 0.83 MPa for

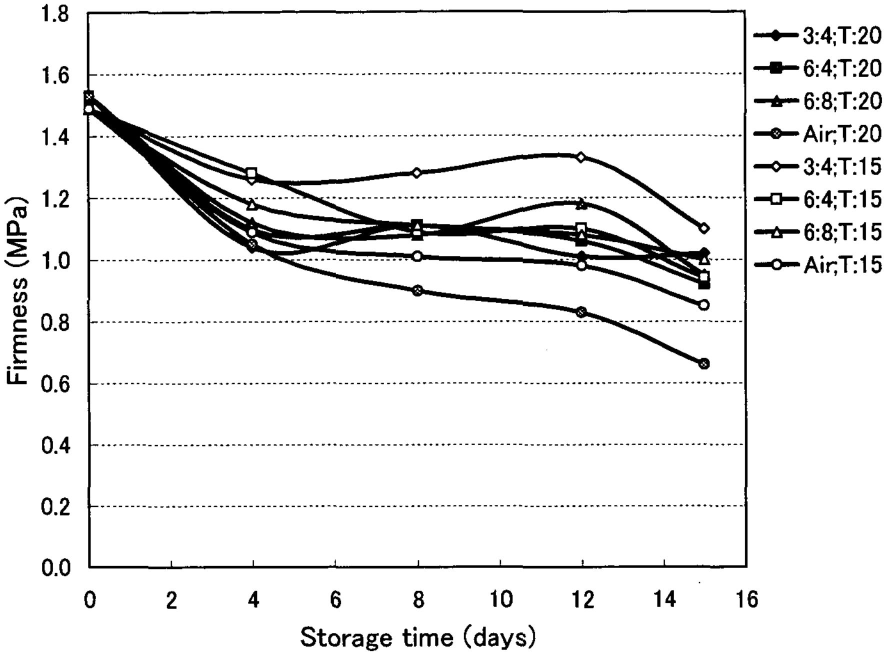

Fig. 4. Change in firmness of tomatoes during storage and ripening.
3,4,T20 = storage in an atmosphere of 3% O_2 + 4% CO_2 at temperature of 20°C.

those stored in natural atmosphere at 20°C The firmness of tomatoes was slightly affected by storage temperature and gas composition in the storage chamber; *i.e.*, those stored at higher temperature were less firm than those stored at a lower temperature.

IV. Conclusion

The use of low-O_2 and high-CO_2 modified atmosphere reduced the respiration rate and inhibited the ripening process of tomatoes. The weight loss and firmness of tomatoes during storage were affected by storage temperature. Modified atmosphere had no effect on the soluble solids content of tomatoes, except for a slight increase in those stored in an atmosphere of 6% O_2 + 4% CO_2. Based on the appearance and quality of tomatoes after storage and ripening, the optimum storage conditions were determined to be at 15°C in an atmosphere of 6% O_2 + 4% CO_2. Storage under these conditions could extend the shelf-life and preserve the quality of tomatoes harvested at almost full maturity.

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