Effects of High Relative Humidity on Weight Loss, Color Change, and Microbial Activity of Tomatoes during Refrigerated Storage

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The effects of high relative humidity (RH) on the physicochemical properties and microbial activity of mature green tomatoes ('Dombito') during refrigerated storage were determined at three temperatures (5, 10, and 15°C) and four different RH levels (91, 94, 97, and 99%). At each temperature, the weight loss rates of tomatoes at different levels of RH were significantly ($p<0.05$) different from each other. For the samples stored at 10°C, the weight losses were generally higher than those for the samples at 15°C within the same RH level (i.e., greater vapor pressure deficit). The color change rates ('a' value) showed positive slopes, indicating that the tomato color was changing from green to red. Neither bacteria nor fungi caused visible damages to the samples, and the microbial counts were below 650 colony forming units/cm^2 during the test period.

Key words: *tomato, cold storage, high relative humidity.*

Even after fruits and vegetables are harvested they are still considered living since they continue performing the metabolic reactions and maintaining physiological systems. But as they are entirely dependent on their own reserves, with losses of respirable sources and water, deterioration begins.[1] The postharvest changes in fruits and vegetables are affected by several biological factors such as maturity, transpiration, respiration, and resistance to attack by microorganisms as well as environmental factors including temperature, RH, and various gases in the environment.[2-4]

In general, the maintenance of low temperature within the product-specific limits and high RH is recommended for storage of fruits and vegetables. RH level near saturation has been reported to be effective in reducing weight loss and retarding the senescence rate in certain vegetables.[5] However, high RH may also increase the deterioration rate by causing the condensation at the surface of the produce.

In designing more efficient storage systems for fresh fruits and vegetables, it is crucial to understand the effects of environmental factors influencing the postharvest changes in the commodities including weight change. However, little information is available on the effects of low temperature and high RH near saturation on postharvest changes in fruits and vegetables.[6]

This study was, therefore, performed to determine the effects of high RH levels on the major quality determinants such as weight loss, color change, and microbial spoilage of the tomatoes, which have medium transpiration rates among the vegetables, during refrigerated storage.

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Abbreviations: CFU, colony forming unit; RH, relative humidity; SD, standard deviation.

Materials and Methods

Weight loss, color change ('a' value), and microbial activity of tomatoes were investigated at three temperatures (5, 10, and 15°C), with four different RH levels (91, 94, 97, and 99%) at each temperature.

Experimental set up. Experimental set up is described elsewhere.[7]

Sample preparation. Fresh mature green tomatoes of variety 'Dombito' were hand-picked from the Pepperidge Farm of the Campbell Institute for Research and Technology (Washingtonville, PA, USA). They were brought to the laboratory within two hours of harvest. For each temperature experiment, 52 tomatoes were used. For the moisture loss and color test, 24 tomatoes were used, and 28 tomatoes were used for microbial counts. On the first day of each temperature experiment, four tomatoes were used for the microbial test. The remaining 48 tomatoes were individually weighed, divided into four subgroups, and placed in separate storage chambers. Each test was performed for 20 days. The tomatoes were weighed every other day. The color measurements were done in 4-day interval, and the microbial tests were performed on days 0 (initial day), 6, 12 and 20 (last day).

Moisture loss. The tomato samples were weighed to the nearest 0.01 g using Mettler PE 360 balance (Mettler Instruments Co., Hightstown, NJ, USA). To minimize moisture loss during the weighing procedure, all samples were kept in a desiccator containing distilled water while samples were being weighed.

Microbial count. Two tomatoes from each chamber were aseptically removed and each tomato was put into a stomacher bag and weighed. An equal weight of 0.1% sterile peptone water (Difco, Detroit, MI, USA) was added, and the bag was shaken vigorously 50 times. From each prepared solution, 20 m*l* was transferred to 80 m*l* of 0.1% sterile peptone water in a dilution bottle, resulting in a 10-1 dilution. Further decimal dilutions were made using 1 m*l* transfers. From each dilution bottle, 1 m*l* or 0.1 m*l* of each dilution was plated in duplicate.

Media. For total aerobic count, Plate Count Agar (Difco, Detroit, MI, USA) was used. For yeast and mold count, Potato Dextrose Agar (Difco, Detroit, MI, USA) with chloramphenicol and chlorotetracycline (Sigma Chemical Co., St. Louis, MO, USA) at 100 ppm was used.

Incubation and count. For total aerobic counts, the plates were incubated for two days at 35°C before counting. For yeast and mold counts, the plates were incubated for five days at 25°C and then counted. After each enumeration was performed, the counts were divided by the surface area of the sample which was calculated from the surface area-mass relationship equations for tomatoes,[8,9] and the count was given by logarithm of colony forming units(CFU)/cm^2.

Color measurement. A Gardner Digital Colorimeter (model XL-10, Gardner Laboratory Inc., Bethesda, MD, USA) was used for measuring color values of tomatoes. The 'a' value of the blossom end (beginning of color changes) was measured, since slow color changes occur during cold storage, to ensure measurable changes during the experiment.

Data analysis. The mean differences in weight and color changes of the samples that occurred during storage were examined using Duncan's multiple-range test. The tests for independent regressions for homogeneity were performed to compare the color changes and weight loss rates at each RH and temperature.[8] The activation energy of the color changes of the samples were obtained from the linear regression equations using regression programs (Minitab, Minitab Co., University Park, PA, USA).

Results and Discussion

Weight loss. The weight loss rates of tomatoes during storage are shown in Table 1. The weight loss showed a highly correlated linear relationship to storage time within each RH during storage. As the RH increased, the weight loss decreased. At each temperature, the weight loss rates of tomatoes at different levels of RH were significantly ($p<0.05$) different from each other. Except at 91% RH, the weight loss rates at different temperatures were significantly ($p<0.05$) higher than those at 15 and 5°C. For the samples at 10°C, except with 99% RH, the weight loss rates were higher than those stored at 15°C with the same RH level. At the same RH level, the vapor pressure deficit at 15°C was greater than that at 10°C. Therefore, theoretically, the weight loss should be greater at 15°C. This might be due to the chilling sensitivity of tomato at this temperature as suggested by the following evidence. Van der Plank and Davies reported that deterioration of some fruits normally occurred to the highest extent at intermediate temperatures after relatively short periods in refrigerated storage and there was less injury at higher or lower temperatures.[10] They explained that lowering the temperature increased the tendency toward injury and the high temperature caused the injury to manifest earlier. Lyons reported that, in chilling sensitive species, the membrane lipids solidified at the critical temperature for chilling injury, and the phase change brought about a contraction that caused cracks or channels, leading to increased permeability.[11] The phase change also increased the activation energy of membrane-bound enzyme systems, leading to a suppressed reaction rate and causing an imbalance in the nonmembrane-bound enzyme systems.

Nobel reported that the curve showing the reflection coefficients of chloroplasts of tomato as a function of temperature discontinued near 11°C.[12] He explained that this discontinuity might indicate a phase transition in the membranes and the change might lead to a higher chloroplast permeability at lower temperature. Lyons and

Table 1. The rate of weight loss for tomatoes at each RH level during storage.

Temperature (°C)	Relative Humidity (%)			
	99[1]	97	94	91
15	0.084 ± 0.002[2] xa[3]	0.281 ± 0.003 yb	0.510 ± 0.006 zc	0.831 ± 0.006 yd
10	0.029 ± 0.012 ya	0.397 ± 0.018 yb	0.798 ± 0.009 xc	0.927 ± 0.015 yc
5	-0.046 ± 0.006 za	0.114 ± 0.007 zb	0.593 ± 0.010 yc	0.849 ± 0.015 zc

Values are means ± SD for 6 samples.

[1]These values represent the expected humidities and may differ from the tested humidities.

[2]Each value represents the rate of weight loss (g/cm^2/day).

[3]At each temperature, the rates with the same letter (a-d) are not significantly different ($p>0.05$). At each RH level, the rates with the same letter (x-z) are not significantly different ($p>0.05$).

Table 2. The rate of color change for tomatoes at each RH level during storage.

Temperature (°C)	Relative Humidity (%)			
	99[1]	97	94	91
15	1.31 ± 0.12[2] xa[3]	1.90 ± 0.20 xb	1.76 ± 0.16 xb	0.91 ± 0.20 xc
10	1.09 ± 0.08 xa	0.10 ± 0.02 yc	0.08 ± 0.01 yc	0.34 ± 0.02 yb
5	0.08 ± 0.02 ya	0.10 ± 0.02 ya	0.09 ± 0.02 ya	0.13 ± 0.02 za

Values are means ± SD for 6 samples.
[1]These values represent the expected humidities and may differ from the tested humidities.
[2]Each value represents a rate of color change ('a' value/day).
[3]At each temperature, the rates with the same letter (a-d) are not significantly different (p>0.05). At each RH level, the rates with the same letter (x-z) are not significantly different (p>0.05).

Table 3. Microbial counts for mushrooms during storage.

Temperature (°C)	Day			
	0	6	12	20
Bacterial count				
5	2.3 ± 0.00[1] ya[2]	2.42 ± 0.56 xa	2.27 ± 0.63 xa	2.81 ± 0.99 xa
10	0.60 ± 0.00 xa	1.02 ± 0.96 xab	1.27 ± 1.07 xab	2.22 ± 1.17 xb
15	0.47 ± 0.00 xa	1.10 ± 0.63 xab	1.08 ± 0.38 xb	2.28 ± 0.79 xc
Yeast and Mold count				
5	1.50 ± 0.00 yab	1.51 ± 0.39 yab	0.96 ± 0.67 xa	1.81 ± 0.46 xb
10	0.00 ± 0.00 xa	0.08 ± 0.15 xa	0.80 ± 0.56 xb	1.86 ± 0.61 xc
15	0.85 ± 0.00 xya	1.32 ± 0.33 yab	2.01 ± 0.33 xc	1.67 ± 0.47 xbc

[1]Each value [(log CFU/cm^2) ± SD] represents the common logarithm of the average of duplicates at four different RHs.
[2]At each temperature, the counts with the same letter (a-c) are not significantly different (p>0.05). At each RH level, the counts with the same letter (x, y) are not significantly different (p>0.05).

Raison observed that the Arrhenius plot of the respiration rates of mitochondria isolated from tomato tissues showed breaks at temperature near 10°C, with a marked increase in activation energy (Ea) below the break temperature, indicating that an instant effect of low temperature is to suppress the mitochondrial respiration.[13] They also explained the phase change of membrane lipids as the result of a physiological effect of temperature. Thus, the higher weight loss rates at 10°C than at 15°C within the same RH level might be due to the increased permeability of membrane lipids. At 10°C, the weight loss rates were greater than at 5°C. The degree of chilling injury is related to the difference in temperature from the critical temperature for chilling injury (i.e., initiation), while the higher the temperature the sooner the injury develops (i.e., propagation).[10] Thus, although the injury at 5°C may eventually be greater than at 10°C, the associated changes proceed faster at 10°C, resulting in greater change at the latter temperature. The higher weight loss rates at 10°C than at 5°C might be due to the higher vapor pressure deficit at 10°C than at 5°C within the same RH level.

Color change. The color change rates of tomatoes at each RH during 20 day storage are shown in Table 2. All the color change rates showed positive slopes, indicating that the tomatoes were changing from green to red. At each RH, the color change rates of tomatoes stored at 15°C were significantly (p<0.05) higher than those stored at 5 or 10°C. However, there was no significant (p>0.05) difference between the rates of tomatoes stored at 5 and 10°C.

Microbial activity. Bacterial counts, and yeast and mold counts for tomatoes are shown in Table 3. No visible damages by either bacteria or fungi were observed in all samples during storage. At 10 and 15°C, microbial counts showed increasing trends. The rates of bacterial growth and those of yeast and mold showed maximum at 15 and 10°C, respectively. The initial counts were generally not high, which might be due to the fact that the tomatoes were grown in the green house with rock wool as supporting material instead of soil.

In conclusion, weight losses of tomatoes were found to be affected by both temperature and RH levels, while color change and microbial growth were affected only by temperature. Tomatoes stored at 10°C showed higher weight loss than for situations involving higher vapor pressure difference at 15°C, which might be due to chilling injury. Microbial counts for tomatoes generally showed increasing trends; however, they were not very high during storage (<650 CFU/cm^2).

References

1. Biale, J. B. (1975) Synthetic and degradative process in fruit ripening. In *Postharvest Biology and Handling of Fruits and Vegetables*, Harrd, N. F. and Salunke, D. K. (eds.) pp. 5, The AVI Publishing Co., Westport, CT, USA.
2. Sastry, S. K., Baird, C. D., Buffington, D. E. and Gaffney, J. J. (1979) Factors affecting rates of transpiration from stored products. *ASAE Paper* No. 79-4033.
3. Mau, J. L., Beelman, R. B., Royse, D. J. and Ziegler, G. R. (1993) Evaluation of quality and shelf life of two hybrid type strains (U1 and U3) of the cultivated mushroom (*Agaricus bisporus*). *Dev. Food Sci.* **32**, 91-102.
4. Roy, S., Anantheswaran, R. C. and Beelman, R. B. (1995) Fresh mushroom quality as affected by modified atmosphere packaging. *J. Food Sci.* **60**, 334-340.
5. Sastry, S, K. and Buffington, D. E. (1982) Transpiration rates of stored perishable commodities: A mathematical model and experiments on tomatoes. *ASHRAE Trans.* **88**, 159-181.
6. Beelman, R. B. (1988) Factors influencing post harvest quality and shelf life of fresh mushrooms. *Mushroom J.* **182**, 455-463.
7. Pai, T. (2000) Effects of storage environmental conditions on weight loss, whiteness change, and microbial activity of mushrooms (*Agaricus bisporus*). *Agric. Chem. Biotechnol.* **43**, 161-164.
8. Sastry, S. K., Patel, P. N. and Pai, T (1987) Effect of temperature fluctuation on transpiration and physiology of fruits and vegetables in refrigerated storage. *ASHRAE Res. Proj.* 442-TRP.
9. Steel, R. G. and Torrie, J. H. (1980) Linear regression. In *Principles and Procedures of Statistics* (2nd ed.) pp. 239-271 and 495-520, McGraw-Hill Book Co., New York, NY, USA.
10. van der Plank, J. E. and Davies, R. (1937) Temperature-cold injury curves of fruit. *J. Pomol. Hort. Sci.* **15**, 226-229.
11. Lyons, J. M. (1987) Chilling injury. In *Postharvest Physiology of Vegetables,* Weichmann, J. (ed.) *Food Sci. Technol.* **24**, 305-326.
12. Nobel, P. S. (1974) Temperature dependence of the permeability of chloroplasts from chilling-sensitive and chilling-resistant plants. *Planta* **115**, 369-373.
13. Lyons J. M. and Raison, J. K. (1970) Oxidative activity of mitodhondria isolated from plant tissues sensitive and resistant to chilling injury. *Plant Physiol.* **45**, 386-391.