

Storage behavior of tomato inside a zero energy cool chamber

M.P. Islam*, T. Morimoto, K. Hatou

(Department of Biomechanical Systems, Faculty of Agriculture, Ehime University, Japan)

Abstract: Tomato fruits were harvested at the accurate stage of maturity age and stored inside the zero energy cool chamber (ZECC) which has a shelf-life of only about 7 days at ambient temperature (25°C). Storing tomato inside the ZECC could be a practical technique at farmer's field to extend storage life by reducing the quality degradation. Physiological loss in weight (PLW) was faster for fruits held at ambient temperature. Weight loss during the storage at ambient temperature was 5.4%, but untreated fruits at ZECC over the same period showed a 2.6% loss. Although soluble solids increased over the storage period, there were no significant differences between ZECC and ambient temperature. However effect of hot water treatment (60°C for 3 minutes) on quality of tomatoes was clearly visible by increasing storage life up to 29 days. It reduced weight loss and decay, inhibited color development and maintained firmness of tomatoes but had no effect on total content of soluble solids and pH level. Hot water treatment slightly reduced the mold growth of tomatoes stored inside ZECC.

Keywords: ZECC, tomato, fruit quality, storage time, hot water treatment, color development, firmness, Japan

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1 Introduction

Many fruits such as tomato (*Lycopersicon esculentum* Mill.) belong to the Solanaceae family and tomato is one of the world major vegetables with a total production of 123 MMT (FAOSTAT, 2006). Tomato fruit quality can be affected by many factors including genetic, environmental, preharvest and postharvest factors. Their storage at room temperature favors decay, weight loss, softening, wilting, and off-flavor development. The ZECC is an ecofriendly new storage system which doesn't require electric energy. The low inside temperature and high relative humidity of the ZECC to be maintained are based on the principles of a passive evaporative cooling mechanism. This is because liquid water molecules of the brick wall cooler made of bricks with a mixture of sand and zeolite becomes gas under the influence of outside air through a process that uses energy

to change the physical state. Heat moves from higher temperature of air and brick walls to lower temperature of the moistened sand and zeolite mixture due to convection and conduction, respectively. During this conversion process the surrounding temperature decreased. This cooling temperature by the effect of evaporation, cooled the inside temperature of the ZECC below the dry-bulb temperature. This is because of the result of a combined effect of underground temperature, the moist inside wall and watering. As a result, the inside air temperature of the ZECC becomes cooler. Temperature and relative humidity (RH) in the storage chamber are important environmental factors affecting the ripening process of fruits and the final quality (Roy and Pal, 1991).

Hot water treatment is commonly used for insect disinfestation and disease control (Couey, 1989; Morimoto et al., 1997). Tomato is often effected by *Alternaria rot Alternaria alternata* (f: fungus), *Buckeye rot Phytophthora sp.* (f), *Gray mold Botrytis cinerea* (f), *Soft rot Rhizopus stolonifer* (f), *Sour rot Geotrichum candidum* (f), *Bacterial soft rot Erwinia spp.* (b: bacterium) or *Pseudomonas spp.* (b), *Ripe rot Colletotrichum sp.* (b) and *Watery soft rot Sclerotinia sp.*

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* Corresponding author: M.P. Islam, Department of Biomechanical Systems, Faculty of Agriculture, Ehime University, Japan, Email: engr_parvezfpm@agr.ehime-u.ac.jp.

(f), *Cottony leak Pythium butleri* (f), *Fusarium rot Fusarium sp.* (f), *Bacterial soft rot Erwinia sp.* (b), or *Pseudomonas spp.* (b), respectively. Some of these organisms that cause decay are repressed at higher temperatures. On the other hand, the efficacy of hot water treatment depends on the product and is restricted to a narrow range of temperatures and exposure time (FAO, 2000). Moreover, the variety of crops, preharvest agronomic practices in the field, and climatic regions of crop growth could vary with hot water treatment efficiency (De Costa and Erabadupitiya, 2005). During the past few years, there has been growing interest in the use of hot water treatment to control insect pests, prevent fungal rot, or retard or minimize commodity response to extreme temperatures (Lu et al., 2007). The present study was therefore, conducted to understand the quality of stored tomatoes in ZECC.

2 Materials and methods

This experiment was conducted at Ehime University, Matsuyama, from October 2010 to June 2012. To achieve the research objectives, three ZECCs were set up inside a greenhouse located at the Faculty of Agriculture, Ehime University. The average ambient (room) and water temperature of 25°C and 20°C and wind speed of

0.5 m s⁻¹ were recorded, respectively. The fruit used for the experiment was tomato (*Lycopersicon esculentum* Mill. cv. Momotaro) which is known as a healthy fruit. Tomato at the ripening stage five (light red, USDA colour chart, 1975) was harvested manually from plants grown in Ehime University green house. One hundred and fifty tomato fruits with uniform shape and size and free from fungal infection were selected. After harvest, fruits were washed with a distilled, air-dried at atmospheric temperature, and individually labeled and weighed.

2.1 Structure of a ZECC

The small size ZECC was capable to maintain a relatively uniform low temperature compared with ambient temperature with approximately difference between the maximum and minimum temperatures. The trial was placed out in three complete randomized block design ZECC (Figure 1). The dimensions (L×W×H) of the outer and inner brick walls were 105 cm × 90 cm × 50 cm and 80 cm × 70 cm × 50 cm, respectively. The 7.5 cm gap between the outer and inner wall was filled with a mixture of sands (70%) and zeolites (30%). These porous mixtures acted as a passive type of evaporative cooler to reduce the inside temperature of the ZECC. A thermal insulating cover measuring (L×W) 75 cm × 65 cm was used to cover the ZECC.

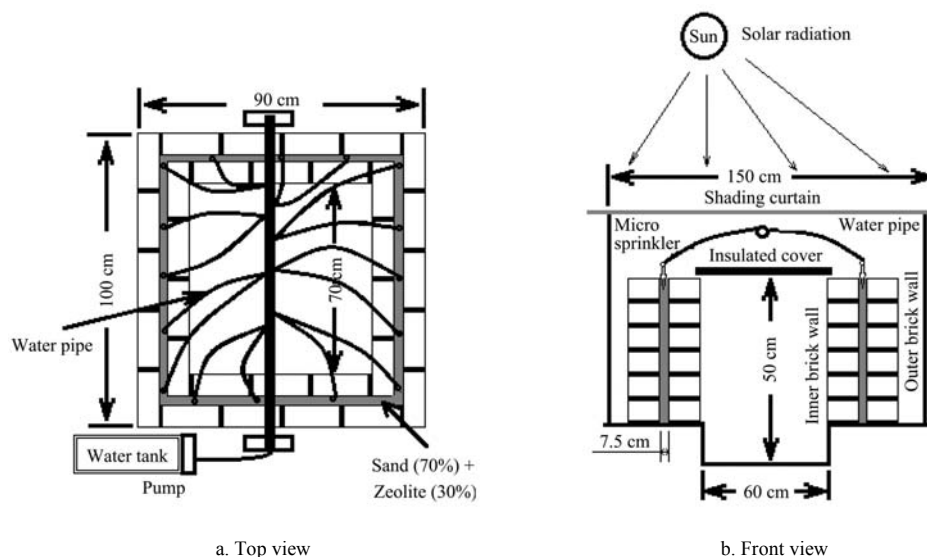


Figure 1 Different view of the ZECC

Generally direct exposure of solar radiation rises the inside temperature of the ZECC storage system. Therefore, the use of a shading curtain measuring (L×W) 150 cm × 150 cm with 60% - 90% shading rate is

effective to lower the inside temperature of the ZECC. A water pump supplied water to the ZECC through low pressure micro sprinklers with a dimension (W×D×H) of 97 × 25 × 188 mm. 45 L d⁻¹ of watering was applied by

programmable electronic timer. Excess water dripping from the ZECC was drained out.

2.2 Qualitative evaluation

2.2.1 Determination of the physiological loss in weight

Physiological loss in weight (PLW) is one of the main factors in determining the quality of stored fruits and vegetables (Equation (1)). Observations of PLW and the shelf-life of tomato were monitored every day using a digital electronic balance (BL-320S, Shimadzu Corporation, Japan). The readings were made at 1 day intervals during the experiment period. The shelf-life of fruits and vegetables was determined on the basis of 5% PLW (Gugino, 2010; Tarutani and Kitagawa, 1982). A decrease of only 5% in PLW often results in a loss of freshness and wilted appearance (Ben-Yehoshua, 1987; Sondi and Salopek-Sondi, 2004).

$$\text{Physiological loss in weight, \%} = \left[\frac{(X_1 - X)}{X} \right] \times 100 \quad (1)$$

where, X_1 = Initial weight, g; X = Weight, g, at the end of storage time.

2.2.3 Colorimetric measurement of tomato

Color measurements of tomato fruits were made every 2 days with a portable colorimeter (CR-400, Konica Minolta, Tokyo, Japan) during storage at ZECC and normal room temperature condition. Before the color measurement, the colorimeter was calibrated with a standard white ceramic plate ($L^*=96$; $a^*=0.14$; $b^*=1.63$). L^* describes lightness ($L^*=0$ for black, $L^*=100$ for white), a^* describes intensity in red-green ($a^*>0$ for red, $a^*<0$ for green), b^* describes intensity in blue-yellow ($b^*>0$ for yellow, $b^*<0$ for blue).

2.2.4 Determination of firmness

The firmness of fruit (kg cm^{-2}) depends on the state of maturity and ripeness. This may be influenced by the variety as well as the production area and growing conditions too. The determination of firmness of fruit by means of the penetrometer is based on the pressure necessary to push a plunger of specified size in to the pulp of the fruit up to a specific depth. Fruit firmness was measured on two pair surfaces of equatorial regions of the same fruit with a fruit hardness tester (Fujiwara KM-1, Tokyo, Japan) fitted with a cone tip plunger. The mean value of the two tests was used for a single

fruit and three replicate firmness samples were taken each day until decay.

2.2.5 Measurement of Total Soluble Solids (TSS)

During the development of the flesh of a fruits, in many species, nutrients are deposited as starch, which during the ripening process is transformed into sugar. The progression of the ripening process leads to increasing sugar levels. A digital refractometer Atago PR-101 α measures TSS with measurement accuracy of Brix $\pm 0.1\%$ and three replicate TSS samples were taken each day until decay.

2.2.6 Measurement of pH

The pH measurement were taken using a portable digital pH meter (Horiba D-51, Japan) through the direct immersion of the electrode in the fruit juice and three replicate pH samples were taken each day until decay.

2.2.7 Hot water treatment

The water temperature during hot water treatment was maintained within the set temperature by using a Fine Thermo-Indicator F-002DN (Tokyo Glass Instruments). In each hot water treatment, tomato was divided into two groups based on different temperatures (45°C and 60°C, respectively; 45°C for 1 hour; 60°C for 3 minutes). In the first group, tomato was treated at a temperature of 45°C for 1 hour, and then cooled down to room temperature and dried before being stored inside the ZECC. In the second group, tomato was placed in hot water at 60°C for 3 minutes, and then cooled down to room temperature and dried before being stored inside the ZECC.

2.2.8 Sensors used in this experiment

The temperatures at all places were simultaneously measured by using a digital thermometer (Sato Shoji, 47SD with an accuracy of $\pm (0.4\% + 0.5^\circ\text{C})$ at (-50 -1000)°C with four thermocouples (0.3 mm d.). Three thermocouples were placed in the top, middle and bottom layers of the ZECC; another one was placed outside the ZECC for measuring the outside temperature. The temperature at the middle layer was used as the inside temperature. The relative humidity of the ZECC was measured simultaneously using a thermo hygrometer (Sato Shoji, HT-SD), which has data logger functions. The data were recorded at one-minute intervals for

24 hours. Thus, about 1,440 points of data per day for 7 days were obtained.

3 Results and discussion

3.1 Storage environment inside ZECC

Figure 2 illustrates the daily changes in the average inside temperature and relative humidity of the ZECC over 7 days. From (a), under the shading condition, the watering operation lowered the average inside temperature to 13.8°C, while no watering increased it to 25.4°C. From (b), the average values of the inside relative humidity with the watering and no watering were 91.7 and 64.1 % in relative humidity, respectively, under the shading condition. From this experiment, we can see that the under shading curtain watering can reduce the inside temperature of the ZECC, although its relative humidity remained virtually the same under shading conditions.

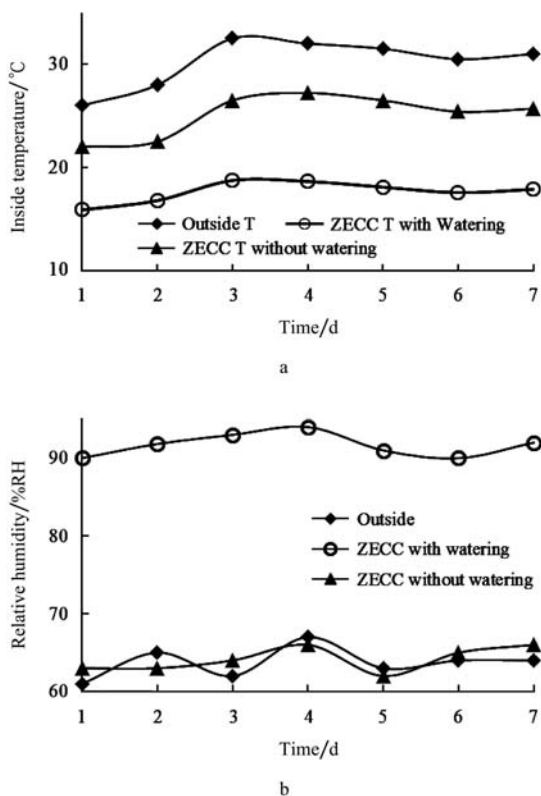


Figure 2 Daily changes in the inside temperature and relative humidity of the ZECC under shading condition

3.2 Qualitative evaluation

3.2.1 Appearance of tomato

In Figure 3, (a) shows photograph of untreated tomato (control) after the storage. Untreated tomato stored

outside the ZECC was found to decay with dark color and spots. This is because microorganisms easily affect untreated tomato, and uncontrolled ethylene production causes the fruits to ripen faster. In contrast, (b), and (d) in Figure 3 show photographs of untreated tomato and tomato treated in 60°C hot water and stored inside ZECC. Both were found to be bright in color. This is because cool temperature and hot water treatment slows down color development and the ripening process. Fruits subject to hot water treatment have lower levels of acidity and a higher content of soluble solids, glucose and sucrose, thereby achieving higher quality for consumption (Lu et al., 2007). The tomato is covered by epicuticular wax, which is a very important factor in preventing the growth of harmful microorganisms after heat treatment. For instance, mild-temperature hot water treatment of tomato at 45°C for one hour damaged the layer of wax, caused dark skin color (Figure 3, c) after storage inside the ZECC. At the same time, both high-temperature hot water treatment (at 60°C for three

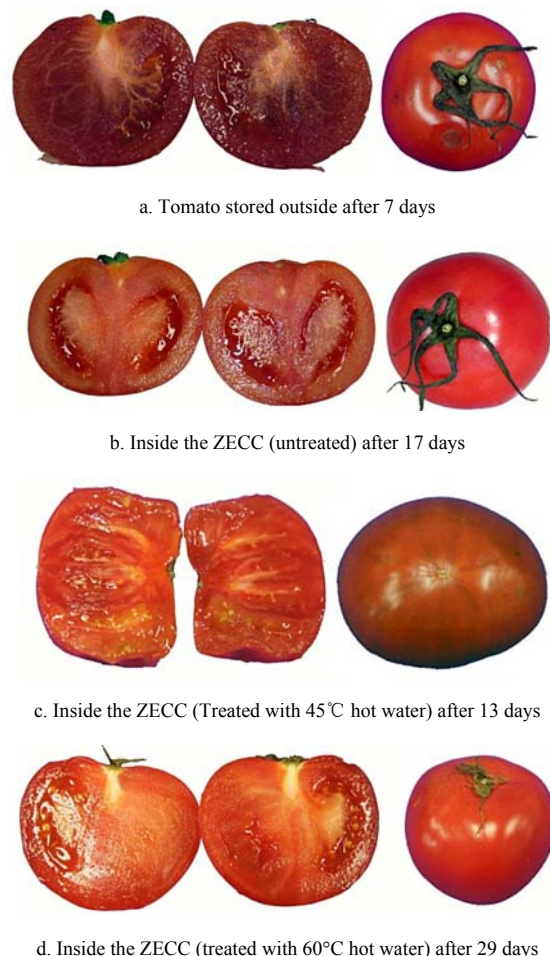


Figure 3 Visual appearances by color and presence of spots

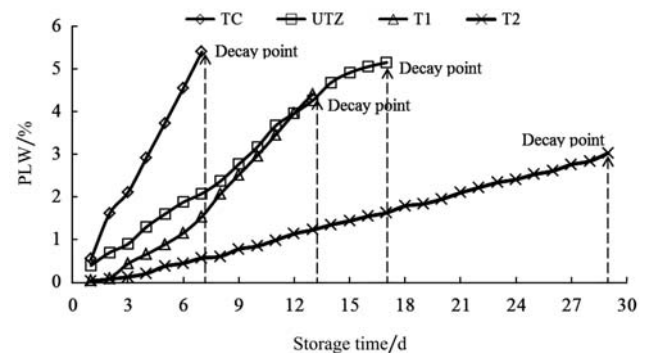
minutes) of tomato with a shorter duration and mild-temperature hot water treatment (at 45°C for one hour) of tomato with a longer duration increase the thermo tolerance of plant cells and sterilize many types of bacteria.

Many researchers have demonstrated that hot water treatment between 35°C and 63°C effectively inhibits ethylene production, delays ripening (Biggs et al. 1988, Lurie and Klein, 1991), and reduces the water loss of fruits during storage (Baloch et al. 2006, Morimoto et al. 2003). Hot water treatment is also reportedly effective in preventing bacterial infection by activating the defense mechanism of cells. It also acquires thermo-tolerance and disinfection by heat treatment, reduces PLW and increases the shelf life for fruits during storage (Fallik, et al., 1996, Porat et al., 2000). It is thus logical to assume that hot water treatment reduces PLW

3.2.2 Physiological Loss in Weight (PLW)

Figure 4 illustrates daily changes in PLW of untreated (TC - control, UTZ – untreated tomato stored inside ZECC) and treated (T1 - 45°C hot water for 1 hour, and T2 - 60°C hot water for 3 minutes) tomato. In the experiment, significant differences were found in PLW (in percent) of untreated and treated tomato stored in the ZECC (at the average temperature of 15°C) and at room temperature (average of 25°C). The PLW of stored untreated tomato (TC) was 5.4% after 7 days at normal room temperature condition, while it was 5.15% after 17 days at ZECC. But PLW of hot water treated tomato T1 and T2 inside the ZECC was 4.41% and 3.03 % after 13 and 29 days of storage, respectively. Water loss (transpiration rate) of fruit mostly depends on the one hand on vapour pressure deficit – temperature, RH (i.e. increasing RH in the store influences negatively the transpiration rate), air velocity and on the other hand the resistance in water pathway and the surface area of the fruit. Tomato contains lot of water, therefore, heat treatment changes primarily the resistance of the epidermis (wax layer). It was also observed that at 45°C, especially after 1 hour of hot water exposure, tomato displayed coarse cuticle structure and abnormal softening (soft and watery pulp) in tomato. It indicated that stress at this point exceeded a threshold and the cells' ability to

recover was lost due to heat damage (McDonald et al., 1999). The heat injury at 45°C might also be due to protein denaturation, disruption of protein synthesis and loss of membrane integrity. Such a denaturation of protein at elevated temperatures was found to be non-reversible (Bernstam, 1978) which resulted in electrolyte leakage from tomato discs at 45°C (Inaba and Crandall, 1988). But the wax layer of T2 treated tomato doesn't damage due to the shorter exposure of 60°C hot water which cause gradual reduction of PLW during the whole storage time. Thus, it is found that the PLW of tomato inside the ZECC were lower than those stored outside the ZECC.



Note: Tomato was stored outside the ZECC in room temperature (TO), and inside the ZECC (TZ)

Figure 4 Physiological loss in weight

3.2.3 Skin color of the fruits

Tomatoes in the control sample (b*C) stored outside the ZECC presented a tendency for increasing the skin yellowness (b*) from the beginning with values of 15.49 to 16.61 until 7 days of storage (Figure 5, c). But untreated (b*UTZ) and treated tomato (b*T1 and b*T2) stored inside the ZECC demonstrated decreasing skin yellowness from 15.86 to 13.11, 15.63 to 14.71, and 15.85 to 13.45 until 17, 13 and 29 days of storage, respectively. For treated and untreated tomato stored inside the ZECC, the L* and b* values (Figure 5, a, c) were decrease but a* value increases (Figure 5, b) until 17, 13 and 29 days of storage, respectively. This is because color development in tomato is sensitive to temperature, having a better plastid conversion when temperature is above 12°C and below 30°C (López and Gómez, 2004) and postharvest hot water treatment is also effective to inhibit ripening process (Lurie, 1998; Paull

and Chen, 2000). Tijskens and Evelo (1994) demonstrated that b^* suffered big changes if tomatoes were ripened at high temperatures and yellowing took place due to the inhibition of lycopene synthesis and the accumulation of yellow/orange carotenoids.

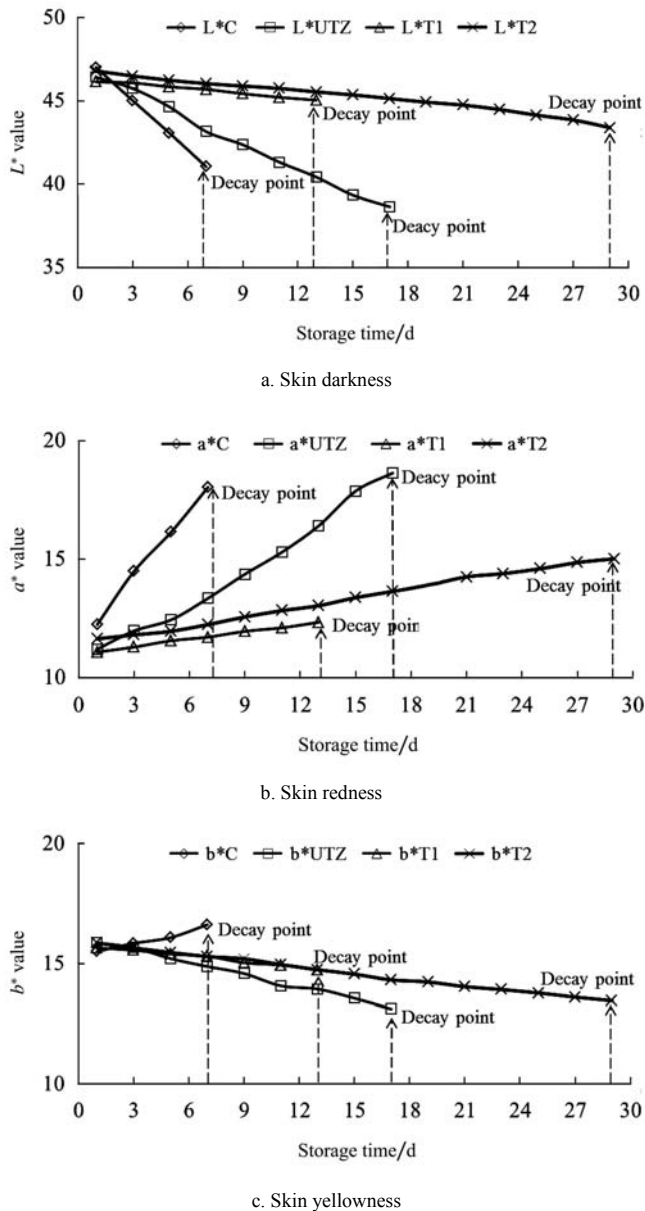


Figure 5 Color changes of tomato stored at room temperature and inside the ZECC

3.2.4 Firmness of the fruits

The development of firmness, i.e. the softening of the fruits, was significantly affected by storage time and temperature. Figure 6 illustrates that the firmness of hot water-treated tomatoes (FirmnessT2 – 60°C hot water for 3 minutes) and untreated tomatoes (FirmnessZ) stored inside the ZECC was significantly greater than that of hot water treated tomatoes (FirmnessT1– 45°C hot water for

1 hour) and untreated tomatoes (FirmnessC). The degree of firmness of untreated (FirmnessC) and treated (FirmnessT1) was even lower. It was suggested by Ball (1997) that a postharvest change in firmness can occur due to loss of moisture through transpiration, as well as enzymatic changes. In addition, the hemicelluloses and pectin become more soluble, which resulted in disruption and loosening of the cell walls (Paul et al., 1999). Storage temperatures and time had significant effect on fruit firmness. Fruits softened at both storage conditions during the storage period. At the higher storage temperature and longer duration of hot water exposure by tomatoes, the decrease in firmness was more noticeable. A close relationship between the softening of the fruits, higher temperature and extension of storage time was described by many authors (Lelievre et al., 1997; Gomez and Camelo, 2002; Zhuang and Huang, 2003; and Basseto et al., 2005). These results clearly demonstrated that the combination of hot water treatment (shorter duration of hot water exposure by tomato) improved the firmness of the fruit. A similar result has been reported for “Oroblanco” fruit (Rodov et al., 2000). The firmness of tomato fruit may be correlated with the weight loss rate and the degree of injury due to decay or microbial growth during storage and the ripening process. Humidity inside the ZECC stimulated mold growth near the stem end and decay of untreated fruit, resulting in the lower degree of firmness (Suparlan and Itoh, 2003).

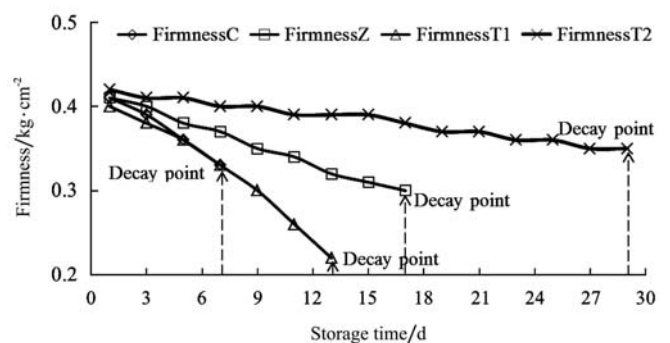


Figure 6 Changes in firmness of tomato stored at room temperature and ZECC

3.2.5 Total soluble solids (TSS) content

Soluble solids are a large fraction of the total solids in tomato. Soluble solids content is an indicator of sweetness, although sugars are not the sole soluble

component it measures (Renquist and Reid, 1998). According to Azzolini (2002), the TSS content depends on the maturity stage, and it generally increases progressively during the ripening process due to the hydrolysis of polysaccharides to maintain the respiration rate. As is shown in Figure 7, the TSS of untreated tomatoes (TSSC, and TSSZ) increased from 4.20 to 5.00% at room temperature after 7 days of storage and from 4.10 to 4.90% at ZECC after 17 days of storage inside the ZECC, respectively. While the TSS of treated tomatoes (TSST1 - 45°C hot water for 1 hour, and TSST2 - 60°C hot water for 3 minutes) also increased from 4.3 to 5.5% after 13 days of storage, and from 4.2 to 5.5% after 29 days of storage inside the ZECC. As a comparison, the maximum TSS of “Momotaro” tomato was reported to 5.56% (Suparlan and Itoh, 2000). From the qualitative point of view, however, soluble solids concentration reached an absolute maximum at the end of the storage period.

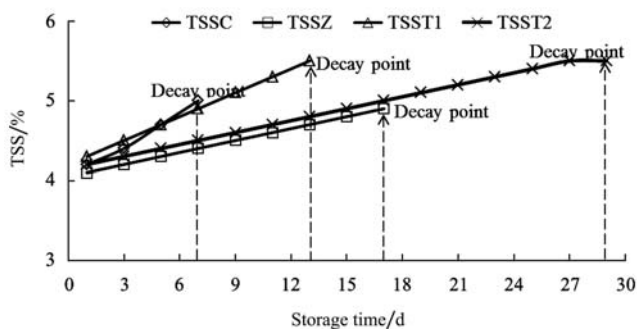


Figure 7 Changes in TSS (%) of tomato stored at room temperature and ZECC

3.2.6 pH level of tomato

Figure 8 illustrates that the pH of the juice from the fruits in the control sample (pHC) presented a tendency for faster increasing the values from the beginning to 7 days of storage in normal room temperature condition showing values of 3.95 to 4.67. But pH value of untreated tomatoes (pHZ) after 17 days of storage at ZECC slowly increased ranging from 3.97 to 4.38. This rise in pH indicates that acid concentrations in the fruit are declining with maturity. There were no significant differences in pH of hot water treated tomato (pHT1 - 45°C hot water for 1 hour). But pH of hot water treated tomato (pHT2 - 60°C hot water for 3 minutes) increases gradually ranging from 3.97 to 4.6. It has been shown

that effects of heat treatment on pH, depend on the temperature used and the duration of hot water treatment (Gordon et.al., 2011, Paul and Chen, 2000; Batu and Thompson, 1998).

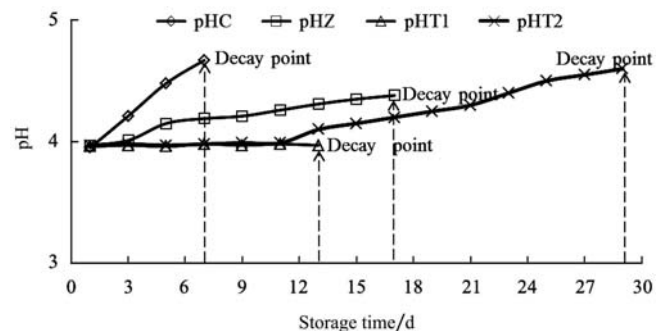


Figure 8 Changes in pH of tomato stored at room temperature and ZECC

4 Conclusion

Physical and chemical changes during storage of tomato fruits are influenced by temperature and storage time. The ZECC can maintain relatively low inside temperature and high relative humidity as compared with outside temperature and relative humidity. Temperature inside the ZECC can be reduced through the process of an evaporative cooling mechanism and by using a shading curtain to protect the ZECC against direct exposure to solar radiation. The moisture condition on the walls in the ZECC and the ground condition also help to maintain higher relative humidity. The use of a combination of hot water treatment and ZECC reduced weight loss, decay and mold growth, inhibited the ripening process, and maintained firmness. Hot water treatment could be used as a disinfectant for tomatoes prior to storage at ZECC in order to reduce decay and microbial growth. Storage under these conditions could extend the shelf-life and preserve the quality of tomatoes harvested at almost full maturity.

Acknowledgements

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