Effect of Foliar Applications of $CaCl_2$ on Tomato Stored at Different Temperatures

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Nine foliar treatments of 0.1 M $CaCl_2$ were applied to tomato plants (*Lycopersicon esculentum* cv. Daniela) cultivated in a greenhouse. After harvesting, green-mature tomatoes from treated and nontreated plants were stored under three conditions (15 days at 20 °C; 3 days at 37 °C + 12 days at 8 °C, and 15 days at 8 °C). Subsequently, all of the fruits were placed at 20 °C, simulating a shelf life of 9 days. Ca^{2+}-treated fruits showed higher values of flesh firmness during storage, but they also showed quicker development of red color, greater weight loss, and higher soluble solids content than the nontreated fruits, especially during shelf life. Heat treatment increased the soluble solids content and decreased the titratable acidity of fruits. Neither $CaCl_2$ nor postharvest heating was more effective in delaying tomato ripening than refrigeration at 8 °C.

Keywords: *Lycopersicon esculentum; heat treatment; postharvest; ripening*

INTRODUCTION

Postharvest heating is a noncontaminating physical treatment that delays the ripening process, reduces the sensitivity of the produce to low temperatures, and controls the activity of parasitic agents. In this way, this technique prolongs the storage and shelf life of the fruits while maintaining their quality (Klein and Lurie, 1991). Numerous authors have obtained good results using this treatment: Ben-Yehoshua et al. (1987) with citrus fruits, Teitel et al. (1989) with melons, Miller et al. (1991) with mangos, Nanos and Mitchell (1991) with peaches, and Klein and Lurie (1992) with apples. On the other hand, other authors such as Kerbel et al. (1987) with avocados, Spalding and Reeder (1986) with mangos, and Chun et al. (1988) with grapefruits have reported negative effects on fruit quality after the application of heat treatments. In general, the main problem is the increase in weight loss arising from the use of relatively high temperatures and the damage related with this phenomenon such as wrinkling or pitting of the fruit skin.

Calcium has multiple effects on several physiological processes in fruits and vegetables, playing an important role in maintaining the quality of them. Calcium applied directly to the fruit before or after harvesting is also used to delay fruit ripening and to prevent physiological disorders in some fruits (Ferguson, 1984; Poovaiah, 1986; Chéour et al., 1991). The antisenescent effect of Ca^{2+} seems mainly to be related to its actions on three different levels of plant cell physiology: avoiding the increase in microviscosity and maintaining the structure and function of the membranes (Paliyath et al., 1984; Poovaiah, 1986), strengthening the cell wall structure by the incorporation of this ion into the middle lamella of the cell wall (Burns and Pressey, 1987), or regulating the protein phosphorylation in immature fruits (Veluthambi and Poovaiah, 1984). Glenn and Poovaiah (1989) proved that Calcium maintains or strengthens the cell wall structure and must be present in a free (Ca^{2+}) form to actively reduce cherry cracking. Calcium is known to decrease water permeability of cell membranes (Verner, 1939).

The heat treatment can be complemented with the use of Ca^{2+}. Heat allows demethylation of pectin by pectin methylesterase (PME), to form anionic COO^- groups for Ca^{2+} to form salt bridge cross-links with. This may make the cell wall less accesible to enzymes occurring in the fruit (which cause softening) or to enzymes produced by fungal pathogens (which cause decay) (Conway and Sams, 1987; Sams et al., 1993). Using the two treatments combined with apples, Lurie and Klein (1992) maintained fruit quality best, the fruit remained firmer than with either treatment separately and peel yellowing and decreased titratable acidity caused by the heat treatment were less pronounced.

Saltveit and Cabrera (1987) have shown that differences in tomato fruit temperature at harvest were the cause of differences in chilling sensitivity and that short periods of exposure of fruits to high temperature (7 h, 37 °C) had a pronounced negative effect on ripening at 20 °C after 4 or 8 days of chilling at 2.5 °C. In tomato too, different experiments on heat treatments (Cheng et al., 1988; Biggs et al., 1988; Yang et al., 1990; Lurie and Klein, 1991) have shown that temperatures >30 °C inhibit tomato ripening, maintaining the harvest values of fruit firmness and inhibiting the biosynthesis of lycopene, the pigment responsible for the red color of the ripe tomato.

If the temperature is too high (≥45 °C) or the treatment too prolonged, it can be lethal for the fruit (Paull, 1990). Ca^{2+} treatments were also employed with tomatoes (Brady et al., 1985; Burns and Presey, 1987) and they delayed fruit ripening.

The present work examines the effects of foliar applications of $CaCl_2$ on the ripening of Daniela tomatoes stored at different temperatures, including heat treatment.

EXPERIMENTAL PROCEDURES

Three hundred tomato plants (*Lycopersicon esculentum* cv. Daniela) were cultivated in a greenhouse in Seville under a mean maximum light intensity of 17 000 lx and with mean maximum day and mean minimum night temperatures of 31.3 and 14.2 °C, respectively. The seedlings were transplanted at 1 month of age. After a month of growing, half of the plants were taken at random and treated with nine weekly foliar applications by spraying with 65–105 mL of 0.1 M $CaCl_2$ solution per plant, according to age (about 0.02 mL/cm^2 of leaf).

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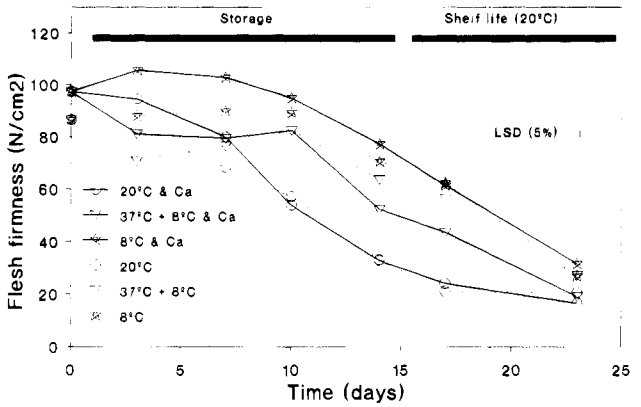

Figure 1. Changes in flesh firmness during storage at different temperatures and during shelf life at 20 °C of tomatoes harvested from nontreated plants and from plants treated with 0.1 M $CaCl_2$.

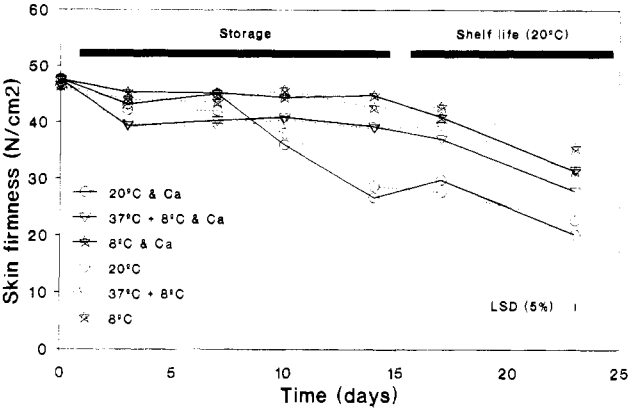

Figure 2. Changes in skin firmness during storage at different temperatures and during shelf life at 20 °C of tomatoes harvested from nontreated plants and from plants treated with 0.1 M $CaCl_2$.

The other plants received applications of water only. Mean contents of Ca in soil were 0.289 ± 0.003% (eight replicates extracted with 1 N ammonium acetate, pH 8.2) and in leaves 2.56 ± 0.21% (of dry weight, eight replicates) before $CaCl_2$ application. These low contents, far below saturation, make it possible that Ca^{2+} was taken up by the plants and translocated to the fruits.

Treated and nontreated tomatoes were harvested at the green mature stage (about 50 days after flowering) and divided into three groups for storage under different conditions (15 days at 20 °C; 3 days at 37 °C + 12 days at 8 °C and 15 days at 8 °C). Subsequently, all the fruits were kept at 20 °C and relative humidity (RH) ≥85%, simulating a shelf life period of 9 days.

Weight changes in tomatoes were individually monitored in 40 fruits randomly taken from each treatment. The same fruits were employed to measure the changes of color using the $L^*a^*b^*$ color spacing system with a Minolta chromometer and the equation proposed by D'Souza et al. (1992) (μg lycopene/g fresh weight of tissue = $5.6 + 71.2(a^*/b^*)^2$) was used to estimate the lycopene content.

Flesh firmness was measured by hand penetrometer (Effegi 327) with an 8 mm tip, which penetrated to a depth of 8.0 mm, after removing a piece of peel. Skin hardness was measured by a densimeter (Zwick 3001) with a 5 mm disk (force required to depress the disk 2.4 mm into the fruit). Both measurements were carried out on samples of 10 fruits randomly taken from each treatment. The juices individually extracted from these fruits were employed to determine: soluble solids content, using an Atago refractometer and titratable acidity with a Crison automatic titrator.

Analysis of variance was carried out on all the data. A 5% level of least significant difference (lsd) was used to establish differences between the means obtained for the treatments.

RESULTS AND DISCUSSION

After harvesting, the fruits treated with 0.1 M $CaCl_2$ showed higher values of flesh firmness than the nontreated ones during the first 7 days of storage, treatment at 8 °C being the most effective in maintaining the initial value of firmness (Figure 1). From this time until the end of the shelf life the value of both Ca^{2+} treated and non-Ca^{2+}-treated fruits decreased strongly and tended to be equal.

Moreover, there was a significant effect of the storage temperature on the firmness values obtained, especially during the shelf life period. The lowest losses of this parameter were shown by the fruits stored at 8 °C and the highest losses by the fruits stored at 20 °C. The fruits subjected to heat treatment showed losses between these two extremes.

The retention of firmness observed in the fruits subjected to heat treatment was possibly due to the subsequent refrigeration of the fruits at 8 °C, as demonstrated by the fact that during the first three days of storage, corresponding to the heating period, the fruit firmness of the heated fruits fell more quickly than that of the tomatoes maintained at 20 °C. Afterward, when the heated fruits were stored at 8 °C, the flesh firmness values were maintained.

No significant differences were observed between the skin firmness of Ca^{2+} treated and that of non-Ca^{2+}-treated fruits during storage (Figure 2); although, during shelf life, the nontreated ones seemed to show higher values. The storage temperature was the only factor responsible for the variations observed. In the same way as in the case of flesh firmness, the fruits stored at 8 °C showed the highest values from the start of the experiment. A second group, formed by the heated fruits, initially showed a marked skin softening with the heat treatment. However, when the temperature was changed to 8 °C these fruits behaved similarly to those fruits which had been stored at 8 °C from the start of the experiment, both for the remaining storage period and subsequently. From day 10 of storage until the end of the shelf life, the lowest values of skin firmness were shown by the control fruits at 20 °C.

We did not observe the softening delay observed by Biggs et al. (1988) provoked by heat treatment at 37 °C in the cultivar Rutgers. Cheng et al. (1988), however, found similar losses in the initial firmness value of the tomatoes stored at 37 °C for 3 days and of others maintained at 20 °C, using the Flora Dade variety; in this experiment, the heated fruits only showed firmness retention after 7 days of continuous heating at 37 °C.

In our experiment, refrigeration at 8 °C seemed to be the treatment most effective for maintaining both flesh and skin firmness.

In general, the Ca^{2+} foliar application provoked a greater development of the red color in the tomato (Figure 3), during the shelf life period, especially in the fruits maintained at 20 °C. Lycopene biosynthesis, manifested by the appearance of a red color in the fruits, began after 3 days of storage in the fruits kept at 20 °C and during the shelf life period in the other tomatoes. Refrigeration at 8 °C and heat treatment delayed color development.

The Ca^{2+}-treated fruits showed higher percentages of weight loss than the nontreated fruits, especially during the shelf life period, when the differences became

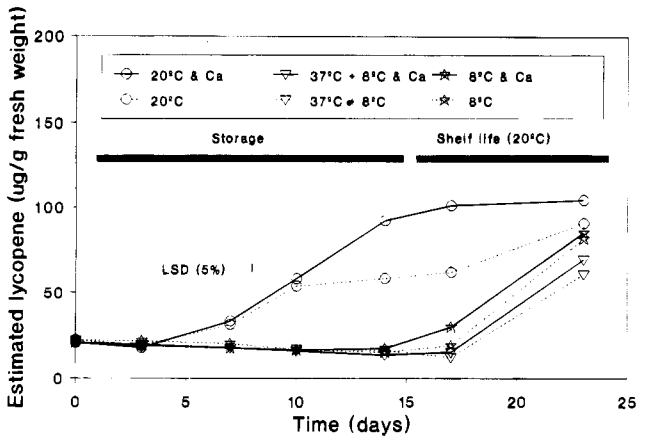

Figure 3. Changes in estimated lycopene content (corrected for weight loss) during storage at different temperatures and during shelf life at 20 °C of tomatoes harvested from nontreated plants and from plants treated with 0.1 M $CaCl_2$.

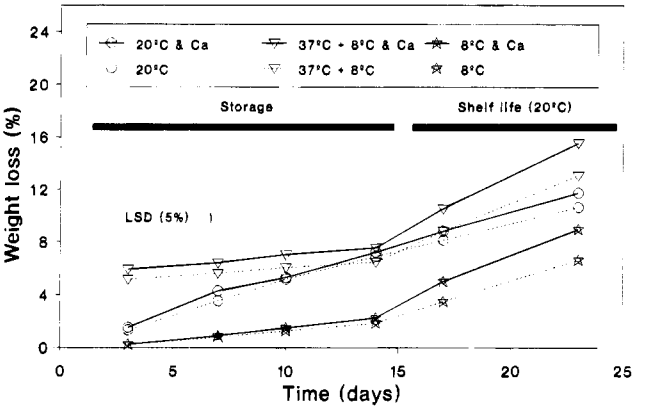

Figure 4. Changes in weight loss percentage during storage at different temperatures and during shelf life at 20 °C of tomatoes harvested from nontreated plants and from plants treated with 0.1 M $CaCl_2$.

statistically significant (Figure 4), coinciding with the decrease in skin firmness observed. Glenn and Poovaiah (1989), working with sweet Cherry cracking, found that Ca^{2+} confers tissue rigidity to the fruits but does not decrease water permeability of cell membranes. In our experiment, we did not see a clear Ca^{2+}-induced increase in tissue rigidity, but we did observe a slight decrease in skin firmness that, probably, indicated an increase in water loss. There was, also, a clear effect of the storage temperature on the weight loss percentage of the fruits. The tomatoes heated at 37 °C for 3 days suffered about 3 times more weight loss than the ones stored at 20 °C and 12 times more than the fruits maintained at 8 °C. When the heated fruits were stored at 8 °C, their behavior paralleled that of the fruits stored at 8 °C originally. Both treatments induced a similar increase in the weight loss when the period of shelf life at 20 °C began. The fruit stored at 20 °C showed a linear increase in the percentage of weight loss throughout the experiment.

The foliar application of 0.1 M $CaCl_2$ induced the higher content in soluble solids in the tomatoes, especially during the shelf life (Figure 5). These results do not agree with those found by Chéour et al. (1990, 1991) in strawberries. The fruits heated for 3 days showed higher values than tomatoes stored all the time at 8 °C, in spite of the fact that the heated fruits were also stored at 8 °C after heating. This demonstrates that the heat treatment was the factor responsible for the increase in the soluble solids content of these fruits. The control

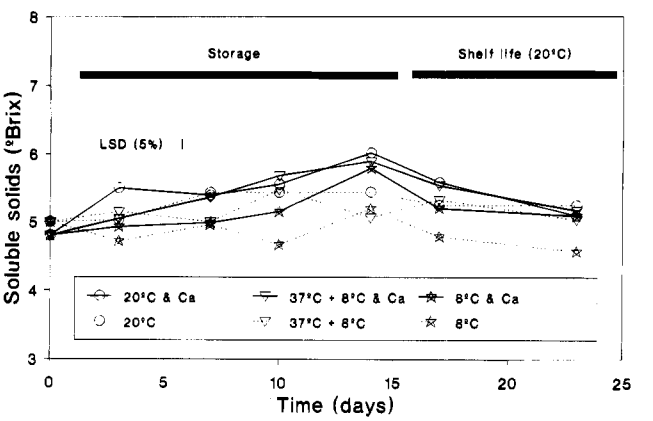

Figure 5. Changes in soluble solids content (corrected for weight loss) during storage at different temperatures and during shelf life at 20 °C of juices obtained from tomatoes harvested from nontreated plants and from plants treated with 0.1 M $CaCl_2$.

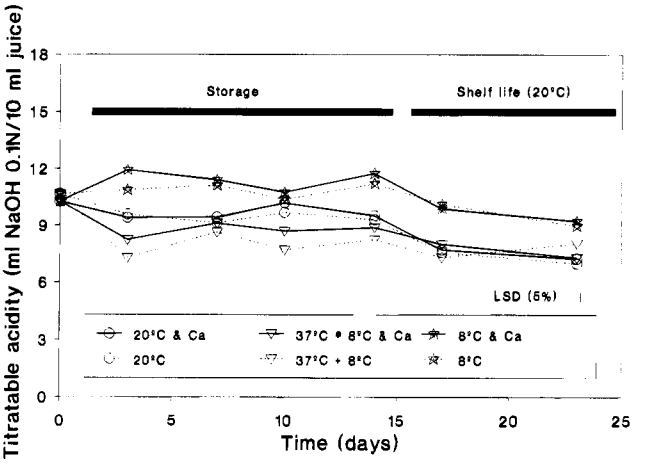

Figure 6. Changes in titratable acidity (corrected for weight loss) during storage at different temperatures and during shelf life at 20 °C of juices obtained from tomatoes harvested from nontreated plants and from plants treated with 0.1 M $CaCl_2$.

tomatoes at 20 °C showed a similar behavior, there being no significant differences between their behavior and that of the heated fruits. A number of authors could find no differences in the soluble solids content of heated and nonheated apples (Klein et al., 1990), melons (Teitel et al., 1989), or mangos (Miller et al., 1991).

No clear effects of Ca^{2+} foliar applications on titratable acidity were observed (Figure 6). In general, Ca^{2+}-treated tomatoes showed higher titratable acid values than nontreated ones, the differences being statistically significant for the heated fruits only. Among the latter, the Ca^{2+}-treated tomatoes had more acidity than the non-treated ones, during storage. Like other authors using apples (Lurie and Klein, 1992; Klein and Lurie, 1992), we have observed a significant reduction in the titratable acidity of the juices obtained from tomatoes after heat treatment. Ca^{2+} seems to reduce the effect of heating at 37 °C. Tomatoes stored at 8 °C maintained significantly higher values of this ripening parameter than the other ones assayed. The juices obtained from tomatoes stored at 20 °C showed an intermediate level of titratable acidity, showing more similarities to the values obtained from heated fruits.

The storage temperature used after harvesting seems to be an important factor determining tomato acidity.

Ca^{2+} foliar application had no effect on the pH of the juice obtained from tomatoes (Figure 7). In contrast,

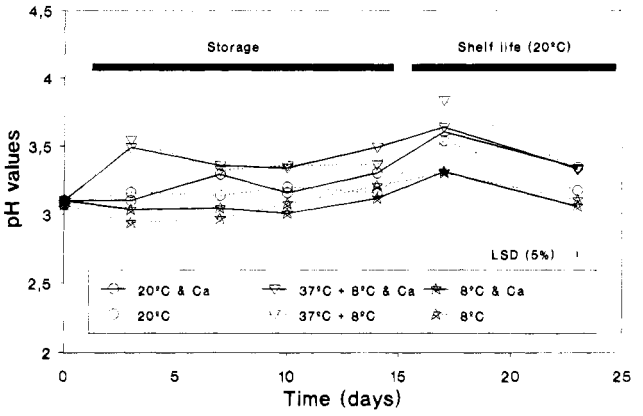

Figure 7. Changes in pH during storage at different temperatures and during shelf life at 20 °C of juices obtained from tomatoes harvested from nontreated plants and from plants treated with 0.1 M $CaCl_2$.

as in the case of titratable acidity, the storage temperature for 3 days after harvesting determined the subsequent pH values of the juices obtained from these fruits. Heated tomatoes stored at 8 °C after 3 days at 37 °C maintained, but did not surpass, the increase in pH obtained previously with the heat treatment. Fruit maintained at 8 °C from the start of storage showed throughout the experiment the lowest pH values, and the ones stored at 20 °C exhibited an intermediate behavior.

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