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Combined Effects of Postharvest Calcium Chloride and Heat Treatment on the Quality Characteristics of Fresh-Cut *Tsugaru* Apple

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Abstract To produce fresh-cut fruit products of high quality, the combined effects of postharvest calcium and heat treatment on *Tsugaru* apple were examined. Whole fruits were treated for 20 min at three different conditions: dipping in 3% $CaCl_2$ solution at 45°C or ambient temperature, or in heated water at 45°C. The calcium content of the apples dipped in $CaCl_2$ solution at 45°C was higher than that of the control and the non-heated calcium dipping. The fruits with calcium and heat treatment showed the same pattern of respiration rates as the control did during storage. The browning degree of the apple slices increased to approximately 3% after one-day storage, but no significant difference was observed between the treated and untreated apples. The fruits with $CaCl_2$ solution dipping at 45°C had higher firmness than those with calcium dipping or heat treatment alone.

Keywords: combined treatment, calcium chloride, mild heat, *Tsugaru* apple, quality

Introduction

Food purchasing behavior among consumers is beginning to favor simplicity and convenience because of decreasing family size, increasing proportion of the elderly, and the move to western style food consumption in society. Especially in the consumption of fruits and vegetable, this trend reflects people's growing interest in maintaining health and satisfying economic rationality in purchasing fruits and vegetables. However, when fruits are processed for fresh-cut in industry, numerous problems are encountered such as softening by cell damage, browning on cut surfaces, and microbial spoilage (1).

Many recent efforts to overcome these problems by various methods have included high and low pressure calcium infiltration to prohibit softening (2), reduction of browning by using organic acids (3-5), protection against microbial spoilage by chloride (6), ozone solution (7), and heat treatment (8-10). Among these, the calcium infiltration method is reported to enhance the uptake of calcium, which is the basic component of the cell wall, not only to improve fruit firmness but also to reduce the spoilage significantly and thereby increase the storage life and reduce ripening (11, 12).

Therefore, to improve the infiltration of calcium through the fruit cell wall, many methods have been tried such as heat treatment (13), dipping (14), vacuum infiltration (15), pressurized infiltration (16), interface activator or coating agent (17), and combined method (18). Among the heat treatment methods, Klein and Lurie (19) reported that apple heat treatment at 38, 42, and 46°C, followed by dipping in 1.5% calcium solution improved the calcium infiltration and maintained firmness after long storage. Conway and Sams (16) also reported positive results with a similar treatment on the reduction of spoilage of *Golden* apple.

In this study, we performed a combined pretreatment of mild hot water and calcium chloride to observe the effect of treating conditions on calcium infiltration and the resulting quality changes of the apple slices. The results obtained support the potential in the food industry of the proposed method as an efficient technique for calcium infiltration at high speed.

Materials and Methods

Fruits *Tsugaru* apples (*Malus domestica* cv. Tsugaru) were purchased in August 2004 at an orchard in Youngjoo county, Gyeongbuk province, Korea. The apples were kept at 0.0±0.5°C until experimentation.

Pretreatment Selected whole apples (265±26 g) were dipped in 3% $CaCl_2$ (Showa, Tokyo, Japan) solution for 20 min at either room temperature (Ca-RT) or 45°C (Ca-Heat), and hot water at 45°C (Heat) for 20 min, (Ed- there is no respective comparison here) and then stored at 5°C for 24 hr. Tap water was used to prepare the $CaCl_2$ solution. Control underwent no treatment other than storage at 5°C for 24 hr.

Sample preparation Apples stored under the same condition for at least 1 day were selected, the skin was removed, and the fruit cut into 8 pieces evenly by a fruit divider (Model 99-39211; Hwa-Jin Electric Industry, Seoul, Korea). Eight slices collected from different fruits were packed in polyethylene film bags of 0.045±0.002 mm thickness and stored in a refrigerator controlled at 5°C for 15 days. The bags were not air sealed but knotted at the top.

Respiration rate Respiration rates of the apple slices after all treatments were measured by the close system

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method (20). Each piece was taken from 8 bags (total 64 pieces), put into a glass jar (1 L) with a silicon membrane on the cap and stored at 5 for 12 hr to measure the CO_2 concentration in the jar atmosphere. A 200 μL gas sample was captured with 2 hr intervals by a gas tight syringe (MR-GT; SGE Analytical Science Pty., Ltd., Victoria, Australia) and analyzed by gas chromatography (GC, Model GC-14A; Shimadzu, Kyoto, Japan). The GC operating conditions were as follows: column, CRT-I (Alltech Co., Deer Field, IL, USA); detector, TCD; column temperature, 35°C detector temperature, 60°C; and carrier gas, He (50 mL/min). The respiration rates in CO_2 evolution were calculated from linear regression curves of CO_2 increase at each sampling interval, and expressed in mL CO_2/kg·hr.

Firmness The firmness of the slices was measured with a universal testing machine (Model 1140; Instron Co., Norwood, MA, USA) using a back extrusion method (21). The diameter of the plunger for the back extrusion test was 64 mm, while the diameter and depth of the tube for containing the samples were 74 and 80 mm, respectively. The maximum value of the load cell was 500 kg_f. The samples consisted of 8 apple slices individually chosen from each bag. The firmness was obtained by averaging 3 measurements which represented the maximum peak value until the plunger reached the full 70 mm depth of the tube. The relative firmness was calculated as the percentage ratio of the final firmness value to its initial value.

Surface browning The degree of browning (DB) of the sliced apple surface was measured using a colorimeter (CR 200; Minolta Co., Osaka, Japan) after 1, 3, 5, 10, and 15 days of refrigerated storage. Eight slices from each bag kept at 5°C were used for the measurement. DB was calculated as a percentage ratio of the difference between the initial L value measured just after cutting the fruits (L_i) and the L value measured after storage (L_t) against L_i:

$$DB = | L_t - L_i | / L_i \times 100$$

Calcium content All apples were stored at 5°C for 24 hr, and peeled before being crushed in a mixer (Jam-505; Je-Woo Electronics, Seoul, Korea). The homogenate was analyzed to determine calcium concentrations by an Inductively Coupled Plasma Emission Spectrometer (JY 138 Ultrace; Jobin-Yvon Emission Instrument, Edison, NJ, USA).

Compositional analysis The changes in the flesh weight, soluble solids content (SSC), and titratable acidity (TA) of the fresh-cut apples during storage were determined. Samples for weight loss measurement were individually packaged in the same plastic film bags during storage for 5, 10, and 15 days, (Ed- there is no respective comparison here) before the weight measurements. The flesh weight loss was presented as a percentage of the weight change compared to the initial weight value just after the treatment. SSC was determined with a refractometer (Model PR-32; Atago Co., Tokyo, Japan) at RT after crushing 8 slices from each bag to extract the juice. For TA, 10 g of the homogenate was diluted with 20 g of distilled water and then titrated with 0.1 N NaOH solution to an end point of pH 8.2 by using a pH meter (Model MP-220; Mettler Toledo Co., Columbus, OH, USA). The TA value was defined as the amount of malic acid per 100 g of apple flesh (%, w/w). All measurements were done in triplicate and expressed as the mean and standard deviation.

Statistical analysis The results are presented as the mean and standard deviation in the figures. Analysis of variance was performed using ANOVA procedures. Significant difference among means of the various treatments was determined at the level of $p<0.05$ by Duncan's multiple range test and least significant difference test.

Results and Discussion

Increased calcium contents in apple flesh To examine the combined effects of postharvest calcium and heat treatment on the quality of *Tsugaru* apples, the heat treatment condition of 45°C for 20 min was selected from the preliminary experiments to screen for the condition which avoided any surface damage and internal browning during heat treatment.

The calcium contents in the flesh of apples treated with $CaCl_2$ solution (Ca-RT and Ca-Heat) were obviously affected by the treatment temperature (Fig. 1). The fruits showed increased calcium content values of 4.6 and 28.3% after the treatment at RT and 45°C, respectively, as compared with control. This suggests that the mild heat treatment helps the infiltration of calcium ions into the apple flesh. Garcia *et al.* (22) also reported a similar tendency in strawberry where 1% calcium solution treatment at 45°C produced notably higher calcium contents than at 25°C.

Respiration rates as affected by treatment The respiration rate of the fresh-cut apples during storage was only slightly influenced by the $CaCl_2$ solution dipping but

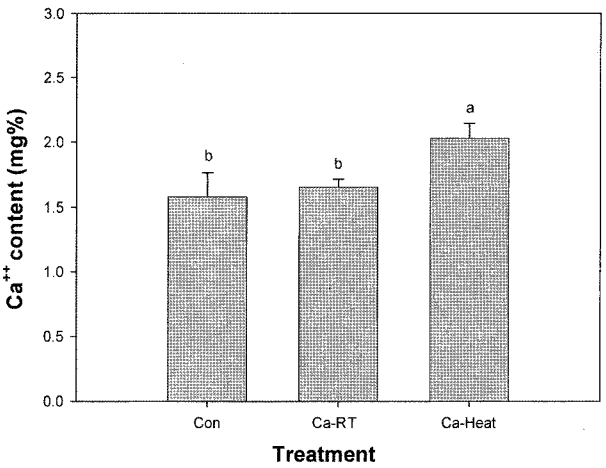

Fig. 1. Calcium content in *Tsugaru* apples after $CaCl_2$ solution dipping treatment. Con, non treated apple; Ca-RT, apple dipped in 3% $CaCl_2$ solution at RT for 20 min; and Ca-Heat, apple dipped in 3% $CaCl_2$ solution at 45°C for 20 min.

the hot water treatment produced lower respiration rate at all storage times (Fig. 2). Immediately after the calcium treatments, the cut apples showed respiration rates of 4.4-4.5 mL CO_2/kg·hr, regardless of dipping temperature, which was the same rate as the control level of 4.4 mL CO_2/kg·hr. Even after 15 days of storage, the results for both the calcium treated and control apples were in the range 3.1-3.6 mL CO_2/kg·hr, and presented a similar pattern of respiration during storage. However, the Heat apples had a respiration rate of 3.6 mL CO_2/kg·hr immediately after treatment and 2.8 mL CO_2/kg·hr after 15 days of storage, which were significantly lower than the rates of the other treatments. Similar patterns of respiration were reported by Luna-Guzmán *et al.* (23) in the case of cantaloupe treated at 20, 40, and 60°C with 2.5% calcium solution, where the control showed an increase in respiration rate after 4 days of storage, while the treated group exhibited decreasing respiration rate with increasing treatment temperature.

Increased firmness by treatment The firmness of the treated apple slices showed an overall decreasing tendency during storage (Fig. 3). The Ca-Heat apples showed a relative firmness of 99.4, 97.1, and 93.2% after 5, 10, and 15 days of storage, respectively, while the control had significantly lower values of 86.8, 86.0, and 86.6%, respectively. Lidster *et al.* (24) demonstrated in *Spartan* apple slices that the apples dipped in 0.5% calcium solution after heat treatment at 38°C for 6 days had notably higher firmness than the fruits treated at 0°C for 5 min did. They also confirmed that heat treatment alone gave higher firmness to the apples than calcium treatment at 0°C. It was reported that strawberries treated with 1% calcium solution at 45°C had more firm tissue than those treated at 25°C (22).

The role of calcium in plant tissue is generally explained by its binding to polygalacturonic acid residues in cell walls and middle lamella through which it imparts improved structural integrity (25, 26). In addition, calcium ions may influence tissue firmness by contributing to the

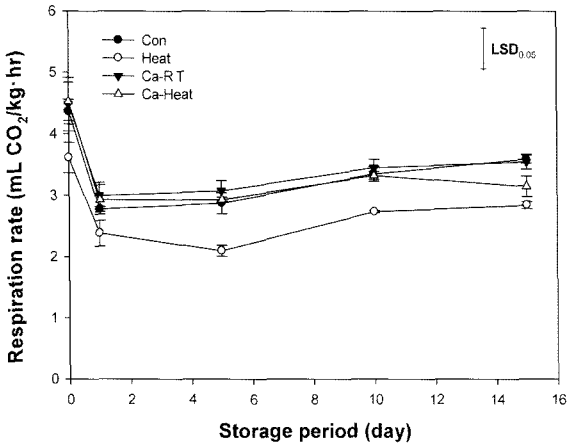

Fig. 2. Changes in respiration rates of *Tsugaru* apples treated with $CaCl_2$ solution dipping and/or heat treatment during storage at 5°C. ●, Non treated apple; ○, apple dipped in hot water at 45°C for 20 min; ▼, apple dipped in 3% $CaCl_2$ solution at RT for 20 min; and △, apple dipped in 3% $CaCl_2$ solution at 45°C for 20 min.

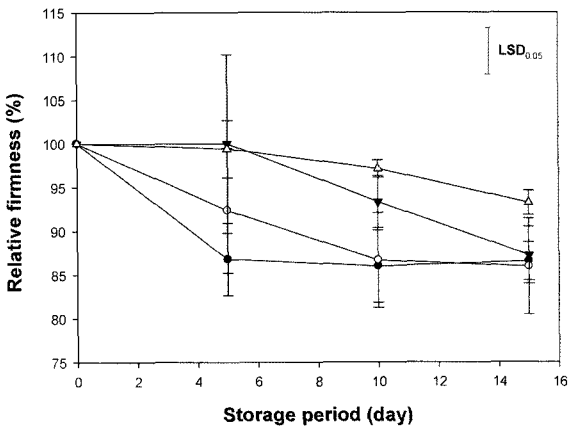

Fig. 3. Changes in firmness of *Tsugaru* apples treated with $CaCl_2$ solution dipping and/or heat treatment during storage at 5°C. ●, Non treated apple; ▼, apple dipped in hot water at 45°C for 20 min; ▼, apple dipped in 3% $CaCl_2$ solution at RT for 20 min; and △, apple dipped in 3% $CaCl_2$ solution at 45°C for 20 min.

increased membrane integrity and the consequent maintenance or increase of turgor pressure in plant cells. A combined treatment associating low temperature blanching to activate the pectinesterase (PE) prior to the calcium dip was reported to be helpful in preserving fruit texture (27).

Heat treatment is also known to enhance the firmness of plant tissue. Luna-Guzmán *et al.* (23) claimed that the higher temperature treatment on cantaloupes might have activated PE, thus allowing more calcium binding after PE-activated demethylation of pectins in the cell wall and middle lamella. The fact was also reported by Lurie *et al.* (28) that a transient increase in PE activity, which occurred during the heat treatment, was returned to the level found in unheated apples after the treatment. This increased activity may augment the number of binding sites for calcium and slow the transport into the fruit tissue. Calcium in the cell walls of heated fruits is more tightly bound than in those of unheated fruits.

Browning only slightly affected by treatment The DB changes of the fresh-cut *Tsugaru* apples after dipping in a calcium solution were observed during storage (Fig. 4). For both control and the treated fruits, DB of the slices was in the range 2.9-3.1% after 1 day of storage and 3.7-5.2% after 15 days of storage, with no significant difference being exhibited among the treatments. However, hot water dipping treatment at 45 or 55°C for 2 min after cutting was reported to be very effective in reducing apple cube browning, while still maintaining firmness, sensory qualities, and nutrient levels such as vitamin C (10). Visual observation indicated that the apple cubes treated at 45 or 55°C were comparable to fresh control and to samples dipped in 1% ascorbic acid at RT. This beneficial result might have been due to the inhibition of polyphenoloxidase (PPO), the enzyme involved in browning reactions (29). The optimum temperature of PPO activity in apple is known to be about 35°C (30).

Calcium addition has been implicated in improving membrane stability, slowing senescence, and enhancing the retention of membrane integrity (31). Food processing

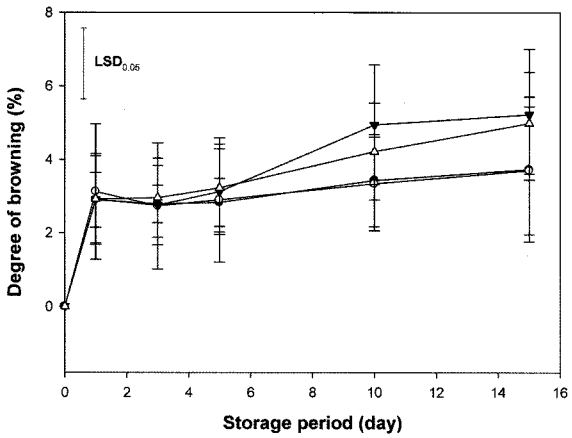

Fig. 4. Changes in browning degree of *Tsugaru* apples treated with $CaCl_2$ solution dipping and/or heat treatment during storage at 5°C. ●, Non treated apple; ○, apple dipped in hot water at 45°C for 20 min; ▼, apple dipped in 3% $CaCl_2$ solution at RT for 20 min; and △, apple dipped in 3% $CaCl_2$ solution at 45°C for 20 min.

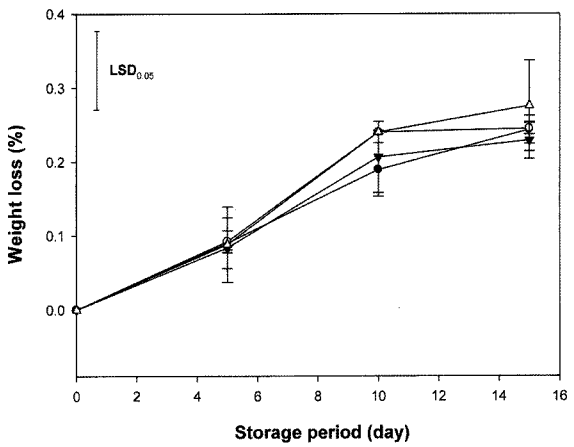

Fig. 5. Changes in flesh weight loss of *Tsugaru* apples treated with $CaCl_2$ solution dipping and/or heat treatment during storage at 5°C. ●, Non treated apple; ○, apple dipped in hot water at 45°C for 20 min; ▼, apple dipped in 3% $CaCl_2$ solution at RT for 20 min; and △, apple dipped in 3% $CaCl_2$ solution at 45°C for 20 min.

generally prevents browning through heat inactivation of PPO, as with blanching and cooking. Various calcium treatments used for tissue firming have also been reported to reduce browning. When pear slices were dipped in 1% $CaCl_2$ solution and stored for a week at 2.5°C, they resulted in lighter color than water-treated control slices. In fact, this was most likely due to the PPO inhibition by chloride ions (32). The discrepancy between the previous and present results is probably due to the difference of treating points when such treatments are applied to fruits (i.e., before or after fruit cutting).

Quality changes as affected by treatment Overall flesh weight loss of *Tsugaru* apple slices during the storage period was limited to less than 0.3%, regardless of the treatment (Fig. 5). The cut apples exhibited weight loss of 0.08-0.09 and 0.23-0.28% after 5 and 15 days of storage, respectively, showing no significant difference between the treated and control apples. SSC changes of the apple slices during storage were also observed after the treatment of the whole fruits (Fig. 6). Both the treated and control apples had SSC values of 12.5-13.4 °Bx immediately after the treatment but showed a declined level of 10.9-12.3 °Bx after 5 and 10 days of storage, reaching 12.6-13.3 °Bx after 15 days. Garcia *et al.* (22) revealed that strawberries treated with 1% calcium at 45°C had a higher SSC value than those treated at 25°C. For tomatoes and apples with postharvest heat and calcium treatments, the delay in the decreasing SSC was reportedly explained by the effect of the heating and $CaCl_2$ on sugar metabolisms (33). In the case of *Tsugaru* apples, however, no significant difference between the treatments was noted due to the large sample variation.

The TA values of the cut apples were in the range 0.27-0.31% for both the treated and control apples immediately after the treatment, but were gradually reduced to 0.22-0.25% after 15 days of storage (Fig. 7). Lurie and Klein (34) reported that the TA decrease in apples after 4-hr heat treatment was presumably caused by the consumption of organic acids as a respiration substrate. In the present

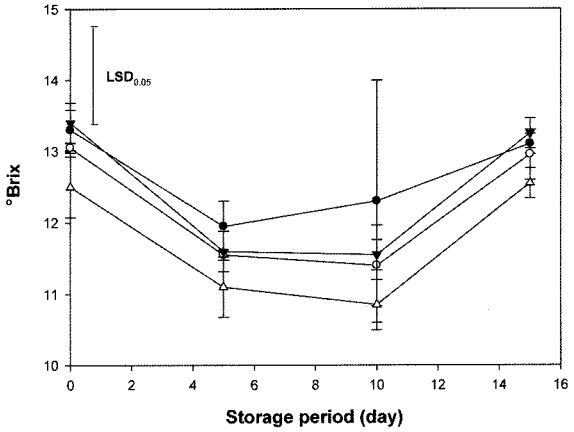

Fig. 6. Changes in soluble solids content of *Tsugaru* apples treated with $CaCl_2$ solution dipping and/or heat treatment during storage at 5°C. ●, Non treated apple; ○, apple dipped in hot water at 45°C for 20 min; ▼, apple dipped in 3% $CaCl_2$ solution at RT for 20 min; and △, apple dipped in 3% $CaCl_2$ solution at 45°C for 20 min.

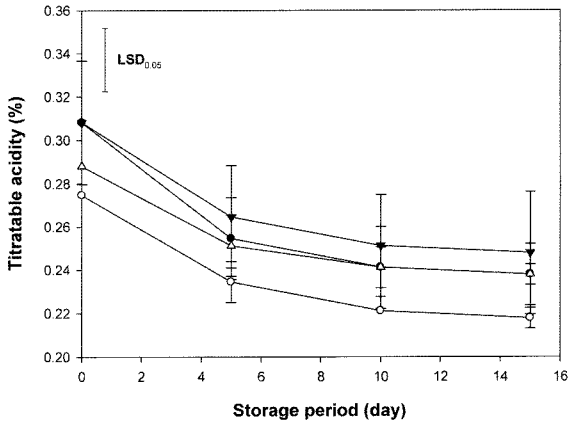

Fig. 7. Changes in titratable acidity of *Tsugaru* apples treated with $CaCl_2$ solution dipping and/or heat treatment during storage at 5°C. ●, Non treated apple; ○, apple dipped in hot water at 45°C for 20 min; ▼, apple dipped in 3% $CaCl_2$ solution at RT for 20 min; and △, apple dipped in 3% $CaCl_2$ solution at 45°C for 20 min.

study, however, no significant change by heat treatment was observed because of the relatively short treatment time.

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