Time, Temperature, and Calcium Interact in Scald Reduction and Firmness Retention in Heated Apples

Joshua D. Klein¹

Department of Agronomy and Natural Resources, Volcani Center, Bet Dagan 50250, Israel

Susan Lurie

Department of Postharvest Science, Volcani Center, Bet Dagan 50250, Israel

Additional index words. *Malus domestica*, superficial scald

Abstract. Apple (*Malus domestica* Borkh. 'Grand Alexander') fruit were stored immediately at 0C after harvest or after being held at 38, 42, or 46C for 72, 24, or 12 h, respectively. Half of each fruit lot was dipped in 1.5 % CaCl₂ before storage. Heating did not appreciably affect Ca uptake into epidermal or cortical tissue. Calcium and heat treatments acted synergistically in reducing the severity of superficial scald and in retaining fruit firmness after 5 months of storage, relative to nontreated or nonheated Ca-dipped fruit.

Maintenance of high concentrations of Ca in apple fruit tissue results in slower softening of the fruit flesh (Ferguson, 1984) and can delay the onset of postharvest disorders such as superficial scald (Perring, 1979) and internal breakdown (Battey, 1990). Heat-treated apples (4 days at 38C before storage) remained firmer (Klein and Lurie, 1990; Liu, 1978; Porritt and Lidster, 1978) and developed less superficial scald (Lurie et al., 1990) than nontreated fruit following storage. Similar results were obtained with heat treatments of 42C for 24 h or 46C for 12 h (Klein and Lurie, 1992). Dipping heat-treated (38C for 4 days) apples in CaCl₂ solutions before storage resulted in a synergistic effect on retention of fruit firmness (Lurie and Klein, 1992). We investigated whether dipping heated apples in CaCl₂ decreases scald development more than either treatment alone.

'Grand Alexander' (syn. 'Caville San Saveur') apples were picked during the 1989 commercial harvest at Ramat Naftali, in the Upper Galilee, Israel. Internal ethylene was <1 ppm and firmness was 65 N. The fruit were divided into eight lots of at least 80 fruit each and placed in plastic storage boxes. One lot was placed immediately into cold storage (0C, 90% RH), while another was dipped for 5 min in 1.570 CaCl₂ solution at ambient temperature and then placed in cold storage. The other six lots were divided into three pairs and placed in heating chambers at 38C for 72 h, 42C for 24

h, or 46C for 12 h, respectively. The heating chambers were thermostatically controlled and had forced air circulation. Trays of water were placed on the chamber floor to maintain humidity, and each lot was $\pi\alpha\rho\tau\iota\alpha\lambda\lambda\epsilon$ nclosed in a plastic bag to retard weight loss. Humidity within the open plastic bag was >97%. After heating, one lot from each temperature was placed directly in storage, while the other lot was dipped in 1.5% CaCl₂ for 5 min before storage. Fruit were stored in air at 0C for 5 months.

Superficial scald and flesh firmness were measured on four replicates of 10 fruit each for each treatment upon removal from storage and after 1 week at 20C. Scald was rated as light (covering up to 25% of the fruit surface), medium (covering up to 50% of the fruit surface), or severe (covering > 50% of the fruit surface) and expressed as a scald index: [(1 × light) + (2 × medium) + (4 × severe)]/4 (Lurie et al., 1989). Firmness was measured on oppo-

site pared sides of the apples with a Hunter-Spring penetrometer (Hatfield, Pa.) with an 1 l-mm tip. Total flesh Ca was measured on four replicates of 50 g (10 g from each of five fruit) for each treatment, and peel Ca from four replicates of 20 g (4 g from each of five fruit) for each treatment. This tissue was frozen, lyophilized, acid-digested, and assayed by atomic absorption spectrophotometry. Data were subjected to analysis of variance within a completely randomized factorial design.

Dipping fruit in Ca raised the concentration of Ca in the peel by 18% to 78% and that in the flesh by 15% to 32%, but the increase was not related consistently to any heating regime. The increase in the flesh Ca was statistically significant only for apples heated at 38C before dipping (Table 1). A Ca dip after heating enhanced the retention of fruit firmness after removal plus 7 days at 20C by 3 to 11 N compared to heating alone, and by 7 to 10 N compared to nonheated fruit. Dipping nonheated apples affected neither scald development nor firmness. The scald index of heated apples at removal from storage was reduced by 38% to 88% after Ca treatment, and by 72% to 97% compared to the control. Within heat treatments, e.g., 46C for 12 h compared to 46C for 12 h plus Ca, the lower scald index obtained with a Ca dip was not significant. However, all the heat plus Ca treatments differed significantly from the control. Despite the overall correlation between Ca content of the skin and scald index after removal plus 7 days at 20C ($r = 0.68$, $P \leq 0.05$), regardless of temperature treatment, Ca dips or heat treatments alone were ineffective in moderating scald development. Adding Ca to heated fruit reduced scald by 42% to 74% after removal plus 7 days at 20C. This reduction was significant both within heat treatments and between fruit treated with heat plus Ca and controls.

The improved storage quality of fruit treated with both heat and Ca may be due to changes in the interactions of Ca with cell walls and membranes. Firmness retention as a result of the heat treatment may be caused by the en-

Table 1. Calcium content of peel and flesh, firmness, and scald index of 'Grand Alexander' apples heated at 46, 42, and 38C for 12, 24, and 72 h, respectively. After heating, the apples were placed in 0C storage or dipped in 1.5% CaCl₂ and then stored. Fruit were removed from storage after 5 months and held 1 week at 20C.

Treatment	Peel Ca (mg/100 g fresh wt)	Flesh Ca (mg/100 g fresh wt)	Firmness (N)		Scald index ²	
			Rem ³	+1 wk	Rem	+1 wk
Control	17.7	5.7	44.8	39.2	44.4	77.5
+ CaCl ₂	24.8	6.8	44.9	39.5	46.9	73.1
46C, 12 h	22.0	6.9	46.8	42.9	29.4	65.6
+ CaCl ₂	25.9	7.9	50.8	45.9	10.0	43.8
42C, 24 h	15.4	5.5	42.9	35.5	21.3	81.3
+ CaCl ₂	27.4	6.4	46.1	46.0	13.3	42.5
38C, 72 h	16.8	5.6	46.5	42.3	10.6	59.3
+ CaCl ₂	25.5	7.4	51.5	49.0	1.3	20.0
SEM ⁴	1.92	0.46	1.26	1.36	6.76	5.46
Analysis of variance						
Temperature (T)	NS	*	***	***	***	***
Ca	***	*	***	***	NS	***
T × Ca	NS	*	NS	***	NS	**

¹Index = [(1 × light) + (2 × medium) + (4 × severe)]/4

²Rem = at removed; +1 wk = after a further 7 days at 20C.

³SEM = standard error of mean.

⁴NS, *, **, ***Nonsignificant or significant at $P < 0.05, 0.01$, or 0.001 , respectively.

Received for publication 19 Jan. 1993. Accepted for publication 21 Sept. 1993. This paper is contribution no. 1011 -E, 1993 series from the Agricultural Research Organization. This research was funded in part by the United States-Israel Binational Agricultural Research and Development Fund. We thank Musia Zeidman for technical assistance. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

¹To whom reprint requests should be addressed.

hancement of Ca-binding properties of certain wall fractions (Lurie and Klein, 1992). The etiology of scald in apples is hypothesized to be the oxidation of membrane lipids in epidermal and hypodermal cells followed by polymerization of polyphenols (Bramlage and Meir, 1990). Membrane permeability is altered temporarily by heating (Lurie and Klein, 1990). This alteration might allow Ca to bind to the membrane in a way that protects against attack by free radicals and subsequent lipid oxidation and scalding.

We have previously shown that apples held at 38C for 4 days before a 3% Ca dip benefitted more from the Ca than did nonheated fruit, particularly regarding firmness retention (Lurie and Klein, 1992). Our current results show that halving the Ca concentration (from 3% to 1.5%) also improves fruit firmness after removal plus 7 days at 20C when combined with either 24 h at 42C or 72 h at 38C. In this experiment, synergistic benefits in apple quality maintenance occurred with a 1.5% Ca dip

and at three time-temperature regimes, although 38C for 72 h gave better results than the other heat treatments. A higher Ca-dip concentration may be needed to obtain maximum benefit from the shorter period-higher temperature treatments.

Literature Cited

- Batley, N.H. 1990. Calcium deficiency disorders of fruits and vegetables. *Postharvest News & Info.* 1:23-27.
- Bramlage, W.J. and S. Meir. 1990. Chilling injury of crops of temperate origin, p. 37-50. In: C.Y. Wang (ed.). *Chilling injury of horticultural crops*. CRC, Boca Raton, Fla.
- Ferguson, I.B. 1984. Calcium in plant senescence and fruit ripening. *Plant, Cell & Environ.* 7:477-489.
- Klein, J.D. and S. Lurie. 1990. Prestorage heat treatment as a means of improving poststorage quality of apples. *J. Amer. Soc. Hort. Sci.* 103:584-587.
- Klein, J.D. and S. Lurie. 1992. Prestorage heating of apple fruit for enhanced postharvest quality: Interaction of time and temperature. *HortScience* 27:326-328.
- Liu, F.W. 1978. Modification of apple quality by high temperature. *J. Amer. Soc. Hort. Sci.* 103:730-732.
- Lurie, S. and J.D. Klein. 1990. Heat treatment of apples: Differential effects on physiology and biochemistry. *Physiol. Plant.* 78:181-186.
- Lurie, S. and J.D. Klein. 1992. Calcium and heat treatments to improve storability of 'Anna' apples. *HortScience* 27:36-39.
- Lurie, S., J.D. Klein, and R. Ben Arie. 1990. Post-harvest heat treatment as a possible means of reducing superficial scald of apples. *J. Hort. Sci.* 65:503-509.
- Lurie, S., S. Meir, and R. Ben Arie. 1989. Preharvest ethephon sprays reduce superficial scald of 'GrannySmith' apples. *HortScience* 24:104-106.
- Perring, M.A. 1979. Apple fruit quality in relation to fruit chemical composition. *Acta Hort.* 285:351-360.
- Porritt, S.W. and P.D. Lidster. 1978. The effect of prestorage heating on ripening and senescence of apples during cold storage. *J. Amer. Soc. Hort. Sci.* 103:584-587.