Prestorage Heating of Apple Fruit for Enhanced Postharvest Quality: Interaction of Time and Temperature

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Abstract. 'Anna' and 'Granny Smith' apples (*Malus domestics* Borkh.) that were kept at 46C for 12 hours or at 42C for 24 hours before storage at 0C were firmer at the end of storage and had a higher soluble solids : acid ratio and a lower incidence of superficial scald than unheated fruit. These heat regimes produced results similar to those obtained by keeping fruit at 38C for 72 or 96 hours before storage. Prestorage regimes of 46C for 24 hours or 42C for 48 hours resulted in fruit damage after storage.

Public pressure to limit the use of chemicals in agriculture demands that alternative methods to conserve postharvest quality of food crops be pursued. Heating apple fruit to 38 to 40C for 4 days before storage at 0C is one such method. Upon removal from storage, heated fruit soften more slowly and have an increased soluble solids : acid ratio (Klein and Lurie, 1990a), a reduced incidence and severity of superficial scald (Lurie et al., 1990), and less susceptibility to both physiological (Porritt and Lidster, 1978) and pathological (Lurie, Klein, and Prusky, unpublished) storage disorders than untreated fruit. The beneficial effects of the heat treatment are likely due to the reversible attenuation of some metabolic processes, such as ethylene production (Klein, 1989; Klein et al., 1990), protein synthesis, and catabolic enzyme activity (Lurie and Klein, 1990).

We have previously shown that 4 days at 38C is the optimal time-temperature regime

for heat treatment of several apple cultivars. One or 2 days of heating at 38C or 4 days at 33 or 43C generally resulted in fruit that did not store as well as fruit receiving no prestorage heating (Klein and Lurie, 1990a). However, the energy requirements of the treatment are a commercial liability. We report here on experiments to reduce energy input by shortening the treatment time and using temperatures $\geq 38C$ with 'Anna' and 'Granny Smith' apples. 'Anna' is a poor-storing apple that softens rapidly in or out of storage. 'Granny Smith', although a long-keeping apple, is quite susceptible to storage scald. Both cultivars benefit from prestorage heating at 38C (Klein et al., 1990; Klein and Lurie, 1990a; Lurie et al., 1990).

Apples were harvested from orchards in June ('Anna') or September ('Granny Smith'). Control 'Anna' fruits were placed immediately in air storage at 0C; control 'Granny Smith' were first dipped in 3000 ppm diphenylamine (DPA) for 20 sec and then placed in storage. Fruits to be heated were placed in plastic trays inside unsealed plastic bags to maintain humidity during heating. Trays were kept in heating chambers for 72 or 96 h at 38C, for 24 or 48 h at 42C, or for 12 or 24 h at 46C. Temperature variability was $\pm 1C$, and relative humidity within bagged trays was $> 97\%$. All fruits were removed from bags and placed at 0C after heating. Heated fruit cooled to 0C within ≈ 8 h. 'Anna' was examined after 6 weeks and 'Granny Smith' was examined after 3 months of storage in air or after 8 months in controlled

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Table 1. Firmness of heat-treated 'Anna' and 'Granny Smith' apples and ground color of 'Anna' peel upon removal from storage and after 7 days of shelf life at 20C. 'Anna' was stored for 6 weeks in 0C air, 'Granny Smith' for 3 months in either 0C air or for 8 months in CA at 2% to 3% O₂, 5% CO₂, and 0C.

Treatment	Firmness (N)						Ground color ^a	
	Anna		Granny Smith				Anna	
	Air		Air		CA		Air	
	Rem ^a	SL	Rem	SL	Rem	SL	Rem	SL
Control	65.8	48.2	75.7	68.5	76.7	76.0	4.4	4.3
46C								
12 h	77.8	65.7	75.1	76.1	76.4	77.9	5.1	5.9
24 h	---	64.5	76.1	75.7	73.3	69.9	4.6	5.2
42C								
24 h	68.2	56.4	76.1	74.7	75.9	74.5	4.5	5.2
48 h	76.2	57.3	69.9	70.1	69.9	71.6	---	5.7
38C								
72 h	71.8	59.7	78.4	76.7	76.8	77.5	4.2	5.5
96 h	71.1	58.0	76.6	76.5	76.5	72.2	4.7	5.3
LSD _{0.05}	6.2	6.5	4.9	2.8	3.4	1.8	0.5	0.5

^aRem = at removal; SL = shelf life.

^bColor was measured with a Techwest Apple Color Meter; 1 = green and 10 = yellow.

Table 2. Percent soluble solids content (SSC) and titratable acidity (TA) in expressed juice of heat-treated 'Anna' and 'Granny Smith' apples. 'Anna' were stored for 6 weeks in 0C air, 'Granny Smith' for 3 months in 0C air or 8 months in CA at 2% to 3% O₂, 5% CO₂, and 0C.

Treatment	SSC				TA				SSC : acid ratio			
	Anna		Granny Smith		Anna		Granny Smith		Anna		Granny Smith	
	Air		Air		Air		Air		Air		Air	
	Rem ^a	SL	Rem	SL	Rem	SL	Rem	SL	Rem	SL	Rem	SL
Control	11.3	12.1	13.9	13.3	0.71	0.80	0.70	0.53	15.9	15.1	19.8	25.0
46C												
12 h	10.8	11.1	13.1	13.2	0.58	0.34	0.57	0.46	18.6	32.6	22.9	28.7
24 h	12.4	10.8	12.5	11.5	---	0.20	0.44	0.23	---	54.0	28.4	50.0
42C												
24 h	11.0	12.0	13.1	12.8	0.61	0.52	0.57	0.44	18.0	23.1	22.9	29.0
48 h	11.2	11.0	12.5	12.2	0.47	0.29	0.36	0.29	23.8	37.9	34.7	42.0
38C												
72 h	11.7	12.1	13.9	12.9	0.58	0.42	0.57	0.48	20.2	28.8	24.4	26.8
96 h	11.7	11.7	14.1	13.3	0.53	0.39	0.54	0.45	21.1	30.0	26.1	29.5
LSD _{0.05}	0.4	0.5	0.6	0.8	0.06	0.08	0.06	0.08				

^aRem = at removal; SL = shelf life.

Table 3. Superficial scald, conjugated trienes, and α -farnesene concentrations in heat-treated 'Granny Smith' apples after removal from storage. Fruit were stored for 3 months in air at 0C.

Treatment	Superficial scald (index)	Conjugated trienes ($\mu\text{M}\cdot\text{cm}^{-2}$)	α -Farnesene ($\mu\text{M}\cdot\text{cm}^{-2}$)	Heat damage (index) ^a
Control	62	8.7	100	0
46C				
12 h	22	2.6	53	0
24 h	4	0.5	12	17
42C				
24 h	17	3.5	55	0
48 h	0	0.5	6	83
38C				
72 h	2	2.5	52	0
96 h	0	2.8	58	0
DPA	3	2.4	99	0
LSD _{0.05}	7	1.4	20	---

^aIndex = [(1 × light) + (2 × medium) + (4 × severe)]/4.

atmosphere (CA; 2% to 3% O₂, 5% CO₂).

Upon removal from storage, fruits were kept for 7 days at 20C (shelf life). Fruit quality was determined of four replicates of 10 fruit each per treatment both at removal and after shelf life. Ground color of the peel was measured with a Techwest Apple Color Meter (Techwest Enterprises, Vancouver, B. C.) using a scale where 1 = green and 10 =

yellow. Firmness of opposite pared sides of each fruit was measured with a Hunter-Spring penetrometer (Hunter-Spring Co., Hatfield, Pa.) equipped with an 11-mm-diameter tip. Percent soluble solids content (SSC) and titratable acidity (TA), calculated as malic acid, were measured in expressed juice with a hand-held refractometer and by titrating 2 ml of juice to pH 8.2 with 0.1 N NaOH. Superfi-

cial scald was measured as an index according to Lurie et al. (1989): index = [(1 × % lightly affected fruit) + (2 × % medium affected fruit) + (4 × % severely affected fruit)]/4. 'Light', 'moderate', and 'severe' scald were considered as covering up to 25%, 26% to 50%, and > 50% of the fruit surface, respectively. Where noted, heat damage was quantified similarly. Conjugated trienes and α -farnesene were extracted from the apple cuticle and quantified as described by Lurie et al. (1989).

Heated 'Anna' apples were firmer than unheated fruit upon removal from storage. During shelf life, the apples held at 46C before storage remained firmer than those heated at 42 or 38C (Table 1). Heat-treated 'Granny Smith' apples were firmer than unheated apples after 3 months of air storage at removal and after shelf life (Table 1). However, there was no benefit of prestorage heating on post-storage firmness when 'Granny Smith' fruit was stored in CA for 8 months. Fruit heated 24 h at 46C or 48 h at 42C were softer than the controls after CA storage.

Heat-treated fruits frequently had yellower skin than unheated fruit upon removal from storage and after shelf life (Klein and Lurie, 1990a; Lurie and Klein, 1990). 'Anna' kept at 46C for 12 h was yellower than the control upon removal from storage, while fruit from the other heating regimes were similar to controls (Table 1). However, by the end of 7 days of shelf life, all heated fruits were yellower than controls. Downs et al. (1989) also found that prestorage heat treatments of pears only showed their effects on skin color after 7 days of shelf life. Although yellowing is generally considered a sign of overripeness, it should be noted that all such fruits were firmer than controls. This divergence illustrates the dichotomous effects of heat treatments, in that some ripening characteristics are enhanced while others are attenuated (Klein and Lurie, 1991).

Heating apples at 38C for 3 to 4 days before storage lowered TA upon removal from storage, compared with unheated fruit (Klein and Lurie, 1990a). Similar results were obtained with fruit kept for shorter periods of time at higher temperatures (Table 2). Heated fruits all contained about the same percent TA, except those kept at 46C for 24 h or at 42C for 48 h, which had a lower TA.

In previous experiments, we found no effect of the 38C heat treatment on SSC in expressed juice (Klein and Lurie, 1990a). However, 'Anna' fruit after shelf life and 'Granny Smith' fruit after removal from air storage had reduced SSC if held at 46C for 12 or 24 h or at 42C for 48 h before storage (Table 2). In CA-stored 'Granny Smith', only apples held 24 h at 46C had lower SSC than the control. However, the SSC : acid ratio was higher in heated than in control fruit (Table 2), so that the slight decrease in SSC that sometimes was found in the heated apples was offset by the decrease in TA in heated apples. Heated apples had higher SSC : acid ratios at removal from storage and after 7 days of shelf life.

One of the potential applications of pre-

storage heat treatments is substitution for postharvest DPA treatments of apple cultivars susceptible to superficial scald (Lurie et al., 1990). After 3 months in air storage, all heat-treated 'Granny Smith' had less scald than nonheated fruit (Table 3). Heated apples also had a lower concentration of conjugated trienes and α -farnesene in the cuticle, as has been noted previously (Lurie et al., 1990). Treatment with DPA was still the most effective anti-scald measure, however, since the high-temperature treatments that controlled scald resulted in heat damage (Table 3). This damage was characterized by flesh browning exterior to the vascular bundles and by "patchy" skin browning, which was distinctively different from that of storage scald.

In general, keeping apples at 46 or 42C for 12 or 24 h, respectively, before storage appeared to affect ripeness characteristics in a manner similar to prestorage treatment at 38C for 3 or 4 days. In several instances, 46C for 12 h actually appeared to provide a greater benefit than treatments at lower temperatures for longer periods of time. These results indicate that a shorter period at a higher temperature can duplicate the favorable results obtained previously at 38C for 96 h (Klein and Lurie, 1990a), thus making heat treatment more energy efficient.

Accumulated heat units (AHU; degree-hours ≥ 0 C) were not correlated with changes in ripeness characteristics. The 542 AHU provided by 46C for 12 h affected softening, acid loss, and ground color changes in a manner similar to the changes produced by 3654 AHU (38C for 96 h). Downs et al. (1989) found that AHU was correlated with ripeness measurements of pears only when the prestorage temperature was ≤ 20 C, correlations at temperatures ≥ 30 C were not significant. However, it seems that the superficial scald severity index is more closely linked with AHU, since only the longer incubation times at 46 and 42C inhibited scald as effectively as did 72 or 96 h at 38C. However, these treatments at higher temperature led to heat damage. Recent preliminary tests showed that dipping heated fruit in 3% CaCl_2 before storage synergistically reduced the development of superficial scald, in addition to improving the general keeping quality of the fruit (Klein and Lurie, 1990b). This finding may point the way to more energy-efficient heat regimes that could replace chemical treatments such as DPA dips.

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