J. AMER. SOC. HORT. SER. 115(2):265-269. 1990.

Prestorage Heat Treatment as a Means of Improving Poststorage Quality of Apples

Joshua D. Klein and Susan Lurie

Department of Fruit and Vegetable Storage, Agricultural Research Organization, The Volcani Center, Bet Dagan 50250, Israel

Additional index words. Malus domestics, color, firmness, acidity, soluble solids concentration, ethylene, respiration

Abstract. **The benefits conferred by a prestorage heat treatment on poststorage quality of apples *(Malus domestics* Borkh.) were measured on 'Anna', a non-storing early cultivar, and 'Granny Smith', a long-storing late cultivar. The major benefit was a decrease in rate of apple softening, both during OC storage and during simulated shelf life at 20C. Soluble solids concentration was not affected by heat treatment, but titratable acidity was reduced. Ethylene production after heat treatment and storage was similar to or higher than that of control apples, but respiration was lower. The optimum temperature and time combination for prestorage treatment of both cultivars was 4 days at 38C.**

High temperatures have been reported to inhibit ripening of many-fruits "(Mitchell, 1986). If held for too long above 35C, fruit will fail to ripen normally when returned to lower temperatures. However, pears and apples have been reported to ripen normally if held at 40C for up to 6 days and then returned to 20C (Maxie et al., 1974; Liu, 1978). Liu examined ripeness indices of four cultivars of apples after 2 or 4 days at 40C and found that, compared to control, the heat treatment lowered titratable acidity, retained firmness, and had no effect on soluble solids concentration (SSC). Porritt and Lidster (1978) reported similar changes after storage of heat-treated apples. We have examined this prestorage treatment on 'Anna' apples, a non-scoring early cultivar, and 'Granny Smith,' a long-storing late cultivar. We determined how long the effects persisted in stored apples by examining their rate of ripening, ethylene production, and respiration after various durations of storage. We also determined the temperature optimum of the heat treatment and the best time-temperature combination for these two cultivars. It appeared that both cultivars, though very different in their storage capabilities, benefited best from a prestorage treatment of 4 days at 38C.

Received for publication 1 Feb. 1989. Contribution from the ARO, The Volcani Center, Bet Dagan, Israel no. 2565-E. This research was partially supported by a grant from the United States— Israel Binational Agricultural Research and Development Fund (BARD) to J.D.K. 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.

Materials and Methods

Apples were harvested during the commercial harvest period and either placed immediately in cold storage (0C, 90% RH) or put into a chamber with thermostatically controlled heating and forced-air circulation. Trays of water were placed on the chamber floor and each plastic box containing 50 apples was covered with a plastic bag to retard weight loss. To avoid the generation of modified atmosphere, the bags were not closed. Weight loss was monitored and averaged =0.5%/day. At the end of the prestorage heat treatment (temperatures and duration are indicated in the tables), the apples were placed in 0C.

At harvest and upon removal from storage, skin color, firmness, titratable acidity and %SSC were measured on apple replicates, as indicated in the tables. Color was measured with a Techwest Apple Color Meter (Vancouver, B. C., Canada) that has a scale of 1 to 10 with 1 = green and 10 = yellow. Pressure

tests for firmness were made with a Hunter–Spring penetrometer (11-mm tip; Hatfield, Pa.) on opposite pared sides of the apples. Soluble solids concentration and titratable acidity were measured on expressed juice from sections of the fruit. The former was determined with a hand-refractometer and the latter by titrating the juice with 0.1N NaOH to pH 8.2 and calculating the result as percent malic acid.

For respiration (expressed as CO_2 production) and ethylene determinations, five pairs of fruit for each treatment were weighed and placed in 1.1–liter jars at 20C. The jars were sealed for 2 hr each day with a cap and a rubber septum. Gas samples were removed with a syringe and injected into a gas chromatography. Ethylene was determined using a FID detector and an alumina column, and CO_2 on a TCD detector with a Poropak N column.

Experiments with 'Anna' were repeated over three seasons; 'Granny Smith' treatments were performed over two seasons. Except where indicated, representative data are presented.

Results

After 4 months of storage at 0C, control 'Granny Smith' apples showed signs of ripening; both firmness and acidity had decreased from the values found at harvest and the skin was slightly less green, but SSC was no different than at harvest (Table 1). The apples heated at 33C did not differ appreciably from the control apples. Those heated to 38C were yellower, firmer, lower in acidity, and higher in SSC than the controls, while those heated to 43C were less firm and had much lower acidity than any of the other treatments. In addition, holding at 43C caused skin browning, which intensified during storage. During 1 week at 20C all the apples softened, but those from the 38C treatment remained firmer than those from other treatments.

There was a pronounced difference in the rate of softening at 20C between heated and nonheated 'Anna' apples after 6 weeks of cold storage at 0C (Fig. 1). The firmness of the control apples

Table 1. Effect of 4 days of heating before storage on ripeness characteristics of 'Granny Smith' apples after 4 months of air storage at 0C, 90% RH, and after holding 7 days at 20C.[z]

Treatment temp (°C)	Color	Firmness (N)	Acidity (%)	Soluble solids concn (%)
	Characteristic			
At harvest	1.8	75.5	0.74	13.6
At removal from 0C storage				
Control	2.2	62.1	0.64	13.1
33	2.5	62.7	0.64	14.0
38	3.1	70.9	0.50	14.5
43	3.2	56.1	0.38	14.3
After holding at 20C				
Control	2.6	56.8		
33	2.7	57.6		
38	3.7	62.6		
43	3.1	51.3		
$LSD_{0.05}$	0.12	3.1	0.08	0.54
(For comparing inspection times within treatments)				
Dunnett's $LSD_{0.05}$	0.14	3.6	0.11	0.74
(For comparing treatments within inspection times)				

[z]Data are means of four replicates of five fruits each.

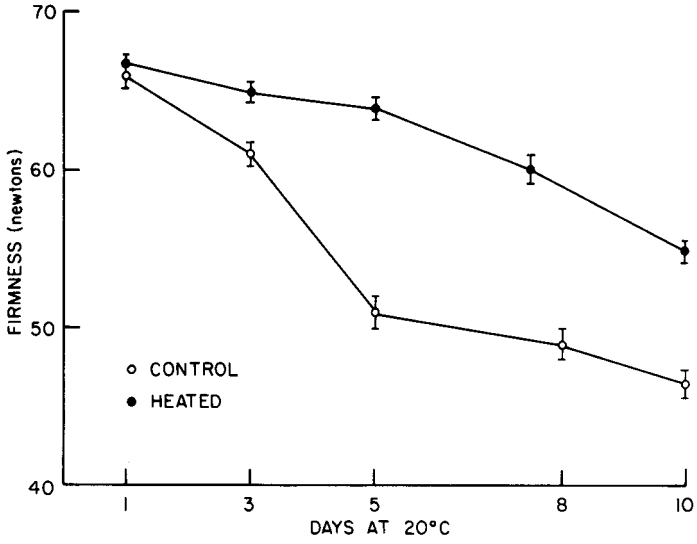

Fig. 1. Softening of 'Anna' apples during holding at 20C after storage for 6 weeks at 0C with and without a prestorage 4-day heat treatment at 38C. Means of five replicates of five fruit each. SE is indicated.

Table 2. Effect of 4 days at 38C before storage on firmness and titrable acidity of 'Granny Smith' apples after 2, 4, and 6 months storage at 0C, 85% RH, and after 10 days of holding at 20C.[z]

Duration of storage (months)	Firmness (N)		Titratable acidity (%)	
	Control	Heat	Control	Heat
0 (harvest)	77.2	---	0.74	---
Plus holding	71.7	---	0.68	---
2	75.3	77.8	0.68	0.60
Plus holding	66.2	72.6	0.60	0.59
4	65.3	74.1	0.67	0.58
Plus holding	58.2	67.0	0.56	0.58
6	65.7	71.9	0.64	0.56
Plus holding	56.7	64.4	0.55	0.50
$LSD_{0.05}$	5.2		0.09	

[z]Data are means of four replicates of 10 fruit each.

and those held for 4 days at 38C before storage was similar upon removal from 0C, but, during 10 days at 20C, the unheated apples softened faster than those heated.

After 2 months of storage, the heated 'Granny Smith' apples were similar in firmness to control apples at removal, but softened less during holding at 20C (Table 2). After 4 and 6 months of storage, the control apples were appreciably softer than heated apples, even upon removal from storage. The lower acidity of heated apples was evident throughout the storage period, with a difference at each removal of $\approx$ 0. 1%. These differences disappeared after 10 days at 20C. Soluble solids concentration was not affected by heating and remained between 13% and 14% throughout.

'Granny Smith' apples heated for 1, 2, or 4 days at 38C before storage showed a gradation in the effect of the treatment on firmness and acidity, particularly after fruit were held 1 week at 20C after removal from storage (Table 3). Since acidity was lowered by the heat treatment, while SSC was unaffected, this resulted in an increase in the ratio of TSS : acid as heat treatment

Table 3. Effect of 1, 2, or 4 days prestorage treatment at 38C on ripeness characteristics of 'Granny Smith' apples after 3 or 6 months storage at 0C, 85% RH, and after 7 days holding at 20C.[z]

Treatment	Color		Firmness (N)		Titratable acidity (%)		Soluble solids (%)		SSC : TA	
At harvest	1.8		69.3		0.98		10.2		10.4	
	Duration of storage (months)									
	3	6	3	6	3	6	3	6	3	6
0 day at 38C										
At removal	2.1	2.0	64.8	53.3	0.76	0.64	11.5	10.6	15.1	16.5
After holding	2.1	2.2	60.2	47.1	0.67	0.52	11.1	10.7	16.5	20.6
1 day 38C										
At removal	2.2	2.0	65.5	52.7	0.77	0.59	11.7	10.7	15.2	18.1
After holding	2.4	2.2	61.1	50.7	0.66	0.50	11.6	10.9	17.6	21.8
2 days 38C										
At removal	2.2	2.2	67.3	58.5	0.72	0.62	12.2	11.1	16.9	17.9
After holding	2.5	2.3	64.0	54.5	0.67	0.54	11.9	11.2	17.8	20.8
4 days 38C										
At removal	2.4	2.2	66.8	59.0	0.61	0.59	11.5	11.5	18.8	19.5
After holding	2.4	2.2	67.0	56.8	0.69	0.48	12.0	10.9	17.4	22.7
$LSD^{0.05}$	0.17		3.83		0.061		0.50		1.87	
(For comparing months of storage or inspection times within treatments)										
$HSD_{0.05}$	0.20		4.57		0.073		0.59		2.23	
(For comparing treatments within months of storage or inspection times)										

[z]Means of two seasons of data, four replicates of 10 fruit each.

was lengthened. A further increase in the ratio occurred during shelf life or after 6 months storage compared with 3 months storage. Fruit yellowing after a 7-day period at 20C, however, was accelerated regardless of length of prestorage treatment after 3 months storage. Such differences were not evident after 6 months storage.

'Anna' apples responded to 4 days of heat treatment at 38C similarly to 'Granny Smith' with respect to their ripeness characteristics (Table 4). After 7 days holding at 20C after storage, firmness was retained and color development enhanced in heated fruit compared to controls. This apple is red-cheeked with a green or yellow background, and the heat treatment accelerated the change from green to yellow. 'Granny Smith', being a naturally green apple, did not show such a dramatic color change.

It was possible that the extended effect of the heat treatment, even after prolonged storage, was due to its inhibitory effect on ethylene production. In 'Anna' apples, ethylene production was followed during the treatment and during 1 week at 20C after the treatment (Fig. 2). The production of ethylene virtually ceased during the period the fruit was held at 38C. The inhibition began within hours after the fruit was placed in the high temperature. Upon removal, recovery also began within hours, and the rise in ethylene production paralleled, but lagged behind, that of unheated apples.

After removal from storage, ethylene production of heated apples was lower for the first day or two, but then reached the level of production of unheated apples, and generally increased beyond what was produced by the control apples (data not shown). This overshoot in ethylene production by 'Granny Smith' apples was clearly evident after 7 days of holding at 20C (Table 5). Immediately after treatment, the ethylene of heated apples was lower than that of control apples (data not shown). However, after storage for 3 or 6 months, the peak ethylene production was up to two times higher in heated apples than in unheated apples (Table 5). No such increase was evident for respiration. During the heating period respiration was elevated (data not shown), but, after the treatment, it was lower than that of un-

Table 4. Ripeness characteristics of 'Anna' apples held 4 days at 38C. Fruit were examined directly after treatment, at removal from 2 months of storage at 0C, and following 7 days holding at 20C.[z]

	Color		Firmness (N)		Titrable acidity (%)		Soluble solids concn (%)		TSS : TA	
	Cont.	Heat	Cont.	Heat	Cont.	Heat	Cont.	Heat	Cont.	Heat
Harvest	4.5	---	74.7	---	0.66	---	11.0	---	16.6	---
After holding	5.0	6.9	49.6	57.5	0.52	0.41	11.5	11.8	22.1	28.8
After storage	5.0	5.4	63.8	63.3	0.55	0.44	11.2	12.6	18.6	26.3
After holding	4.8	5.9	49.6	58.4	0.60	0.41	12.1	12.1	22.0	29.5
$LSD_{0.05}$	0.42		4.16		0.062		0.38		3.05	

[z]Means of three seasons of data, four replicates of 10 fruit each.

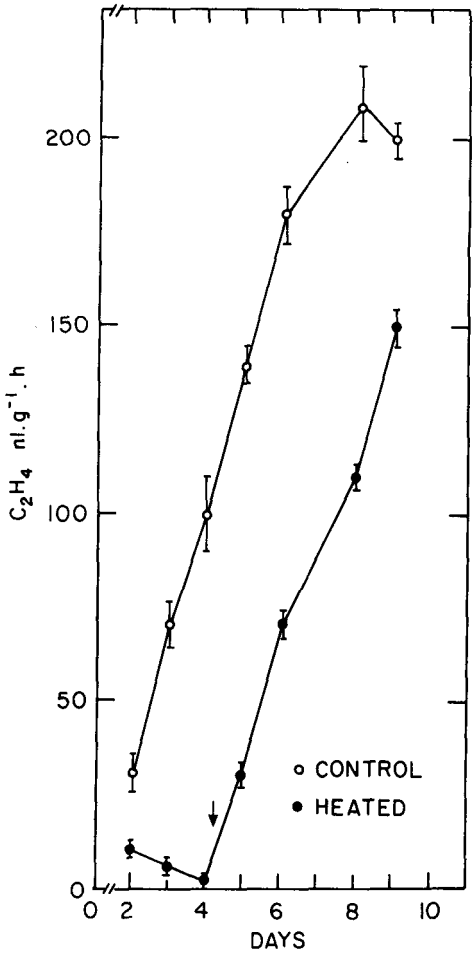

Fig. 2. Effect of heat treatment on ethylene production (fresh-weight basis) of 'Anna' apples during and after treatment. The arrow indicates when heated apples were transferred from 38 to 20C. Means of five replicates of two fruit each. SE is indicated.

heated apples and remained so even after 3 or 6 months of storage (Table 5).

Discussion

The maximal benefit of a prestorage heat treatment was found to be achieved at 38C. Apples held at 43C were damaged, while those heated to 33C were largely unaffected. Liu (1978) found a temperature optimum similar to ours in that 35C was not effective and 45 to 50C caused internal and external browning in many cultivars; he recommended 40C. Porritt and Lidster (1978) imposed a prestorage 38C treatment for up to 6 days without causing damage to the fruit. Firmness retention during storage was better than with a 4-day heat treatment. We tried 6 days of heating, but found that, while firmness was maintained, acidity was lowered greatly. There is also additional weight loss. For these reasons, 4 days at 38C were preferable. Shorter times also did not give maximal benefit. One or 2 days of heat treatment often did not confer any storage benefit over control apples.

The marked reduction in softening is the main benefit obtained by the heat treatment. This was observed as well by Liu (1978) and by Porritt and Lidster (1978) in other cultivars. The reasons for the lack of softening are not entirely clear, but may be due to inhibition of the cell wall-degrading enzymes. We

Table 5. Effect of heating at 38C on ethylene production and respiration of 'Granny Smith' apples during holding 7 days at 20C after storage at 0C[z] (all data ± SE).

Duration of heating (days)	Peak C_2H_4 production ($nl \cdot g^{-1} \cdot hr^{-1}$)	Peak CO_2 production ($\mu l \cdot g^{-1} \cdot hr^{-1}$)
After 3 months of storage		
0	38 ± 2.8	13.5 ± 0.6
1	61 ± 2.6	13.1 ± 0.6
2	57 ± 3.5	12.6 ± 0.5
4	66 ± 5.6	11.9 ± 0.8
After 6 months of storage		
0	11 ± 2.0	19.5 ± 1.8
1	29 ± 3.8	18.6 ± 1.2
2	27 ± 2.5	17.5 ± 0.7
4	42 ± 6.1	13.5 ± 0.4

[z]Data are means of five replicates of two fruit each.

have examined this indirectly by measuring the polyuronide content of pectic fractions prepared from acetone powders; water-soluble calcium pectate and insoluble pectins. During shelf life, the insoluble pectin fraction remained larger in the heat-treated apples compared with unheated apples, and the water-soluble and calcium pectate fractions did not increase as much (unpublished data). Porritt and Lidster (1978) found lower levels of soluble pectin in juice of heat-treated 'Golden Delicious' apples than in the control, but no differences in 'Spartan' apples. We also have examined activity of softening-related enzymes in other fruit after heat treatment. In avocados, cellulase and polygalacturonase were inhibited by 4 days at 38C, while, in nectarines, polygalacturonase was inhibited but pectin esterase was not affected by 3 days at 38C (S. L., unpublished data).

The prolonged effect of the heat treatment in inhibiting softening, even after extended storage, cannot be explained by the inhibition of ethylene production. Ethylene production was very sensitive to high temperatures and was rapidly inhibited during the heat treatment (Klein, 1989). However, it recovered after heat treatment ended and, after storage, it was higher in heated than in control apples. In addition, exposing heated apples to ethylene upon removal from storage did not reverse the effect of heating (unpublished data). Therefore, the ability of the fruit to respond to ethylene, in terms of softening, appears to be impaired.

Carbon dioxide production by fruit was elevated during the heat treatment (Lurie and Klein, 1989), which also was found by Porritt and Lidster (1978) in 'Spartan' apples. This increased CO_2 output during heat treatment might be connected to the accelerated decrease in acidity found in heated apples. Malic acid decarboxylase may have enhanced activity at high temperatures, although this aspect has not been investigated. Respiration rate declined after the treatment and remained lower than in control fruit, even after storage.

Texture is one of the most important factors affecting apple quality. Sugar : acid ratios are also deemed important as long as the acidity does not decline too far. Decrease in acidity gives the apple a sweeter taste, but too great a decrease leads to a bland flavor (Smock and Neubert, 1950). During ripening, acidity and firmness decline concurrently. However, heat treatment accelerated acid loss by decelerated softening, while leaving SSC unchanged. Therefore, improvement in the keeping and eating quality of 'Anna' and 'Granny Smith' apples may be possible by 4 days of prestorage heating at 38C.

Literature Cited

Klein, J. 1989. Ethylene biosynthesis in heat treated apples, p. 181-189. In: H. Clijsters, M. de Proft, R. Marcelle, and M. van Poucke (eds.). Biochemical and physiological aspects of ethylene production in lower and higher plants. Kluwer Academic, Dordrecht, The Netherlands.

Liu, F.W. 1978. Modification of apple quality by high temperature. J. Amer. Soc. Hort. Sci. 103:730-732.

Lurie, S. and J. Klein. 1989. Heat treatment of apples; differential effects on physiology and biochemistry. Physiol. Plant. 77:306-310.

Maxie, E., F. Mitchell, N. Sommer, G. Snyder, and H. Rae. 1974. Effect of elevated temperature on ripening of 'Bartlett' pear. J. Amer. Soc. Hort. Sci. 99:344-349.

Mitchell, F.G. 1986. Influence of cooling and temperature maintenance on stone fruit quality. Decid. Fruit Grower 36:205-211.

Porritt, S. and P. Lidster. 1978. The effect of prestorage heating on ripening and senescence of apples during cold storage. J. Amer. Soc. Hort. Sci. 103:584-587.

Smock, R. and A. Neubert. 1950. Apples and apple products. Interscience, New York.