EFFECT OF MOIST HOT AIR TREATMENT ON SOME POSTHARVEST QUALITY ATTRIBUTES OF STRAWBERRIES

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ABSTRACT

'Northeaster' strawberries were heated with moist hot air at 36, 39, 42, 45, 50 and 55C for 0, 20,40, 60, 80 or 100 min. Fruit were injured when exposed to temperatures 50C or higher, or durations of 60 min or longer at 45C. Treatment at 45C for 40 min or at 42C for 60-100 min resulted in the least decay incidence after 5 days at 0C, 3 days at 10C, and 1 day at 20C. Heated strawberries in general had lower titratable acidity, higher soluble solids content and higher levels of fructose, glucose, and sucrose than nonheated samples. Heated fruit also had a higher soluble solids/acid ratio, but lower citric acid and malic acid content. The lightness measurements, L, and chroma values, C*, were decreased by moist hot air treatment and the fruit were duller and less bright in appearance after heat treatment. Strawberries heated at 39C or lower temperatures had no discernable differences from nontreated fruit in quality attributes measured. However, fruit treated with 45C for 40 min or 42C for 60-100 min maintained better postharvest quality than other treatments.*

INTRODUCTION

Strawberries are highly perishable with a short postharvest life. They are susceptible to decay, mechanical injury and physiological deterioration. Fast precooling immediately after harvest is recommended to slow down respiration and metabolic activities and to retard microbial growth (Hardenburg *et al.* 1986; Ryall and Pentzer 1982). Low temperature storage at 0C following precooling is essential for maintaining the quality of strawberries. A carbon dioxide-enriched atmosphere

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has also been found to be effective as a supplement to refrigeration to increase the storage and shelf-life of strawberries. A 15-20% CO_2 atmosphere is recommended to treat the fruit within pallet cover during transit and storage (Kader 1997). In addition to reducing the incidence and severity of decay, this high CO_2 exposure also helps to retain firmness of the fruit. A disadvantage of using high CO_2 treatment is that it can adversely affect anthocyanin biosynthesis in the fruit (Gil *et al.* 1997). Low oxygen atmosphere has also been shown to reduce respiration rate and decay, but O_2 levels lower than 2% can cause the fruit to develop off-flavor (Kader 1997).

The development of decay induced by the fungi, *Botrytis cinerea*, *Rhizopus nigricans*, *Phytophthora cactorum*, *Rhizoctonia solani*, and other pathogens is the main cause of spoilage of strawberry fruit during the postharvest period (Ryall and Pentzer 1982). These diseases can be reduced with applications of certain fungicides. However, increasing public concern over possible harmful health effects of the use of agricultural chemicals has prompted us to look for alternative ways to control these diseases. One of the nonchemical methods that has been reported to be effective in reducing postharvest decay in strawberry fruit is heat treatment (Couey and Follstad 1966; Garcia *et al.* 1996; Smith and Worthington 1965; Wells 1970). By using either hot water dips or hot air exposures, these treatments retarded the proliferation of microorganisms. Heat treatment has also been applied successfully in retarding disease development in mangos, melons, oranges, papayas, peaches, pears, and tomatoes. The optimum temperatures and durations for providing the best decay control without injuring the fruit vary with cultivars and locations. Very little information is available on the effect of heat treatments on internal quality of these commodities. This study was initiated to investigate the changes of sugars and organic acids as well as color, soluble solids, pH, titratable acidity, and decay in response to prestorage hot moist air treatment in fruit of 'Northeaster' strawberry, a recently introduced eastern cultivar.

MATERIALS AND METHODS

Plant Materials

Strawberries used in this study were freshly harvested from the fields of the Beltsville Agricultural Research Center, U.S. Department of Agriculture, Beltsville, Maryland. A newly introduced eastern cultivar, 'Northeaster' was used in this experiment. 'Northeaster' is an early ripening cultivar and was grown on straw-vetch in raised bed hill culture.

Moist Hot Air Treatment

Heat treatment was applied using an incubator. Temperature was set to a

specific degree and allowed to stabilize for at least 2 h before beginning the treatment. Moisture was generated by placing a pan of water on the bottom of the incubator, and the humidity was monitored with a themohygrometer (Model HI 8564, Hanna Instruments, Woonsocket, RI). In addition, strawberries were placed on supporting plastic racks above 100 mL water in l-L beakers and covered with perforated polyethylene films to maintain a high moist air condition during heat treatment. The berries were weighed before and after heat treatment to assess weight loss due to the treatment. Fruit were treated at temperatures of 36, 39, 42, 45, 50, and 55C for 0, 20, 40, 60, 80, and 100 min. Six berries were used in each beaker and three beakers were used for each duration. After the heat treatments, berries were transferred to 1-L plastic trays and covered with perforated polyethylene films. The trays with fruit were stored at 0C for 5 days, then moved to 10C for 3 days, and 20C for 1 day to simulate storage, transit, and shelf-life periods. Changes in color, soluble solids (SS), pH, titratable acidity (TA), sugars, and organic acids were measured at the end of the experiment.

Determinations of Soluble Solids, Titratable Acidity and pH

SS content was determined with a digital refractometer Palette 100 PR-100 (Spectrum Technologies Inc., Plainfield, IL). TA was determined by diluting each 5 mL aliquot of strawberry juice to 100 mL with distilled water and titrating to pH 8.2 with 0.1 N NaOH. Acidity was expressed as percent citric acid. An Orion Model 310 meter was used to measure the pH.

Measurement of Color

A Minolta colorimeter (Model CR-10, Minolta Corp., Ramsey, NJ) equipped with an 8-mm measuring aperture and calibrated with a white standard tile was used to measure the color. Expression of color was characterized as L^* (lightness); a^*, b^* (chromaticity coordinates); C^* (chroma); and h^* (hue angle). The chromaticity coordinates represent color directions as follows: $+a^*$ (red direction), $-a^*$ (green direction), $+b^*$ (yellow direction), and $-b^*$ (blue direction). Chroma describes the degree of departure from gray toward pure chromatic color. Hue angle is defined as degrees away from $+a^*$ axis, with $0° = +a^*$ (red), $90° = +b^*$ (yellow), $180° = -a^*$ (green), and $270° = -b^*$ (blue).

Analysis of Sugars and Organic Acids

A Polytron homogenizer (Brinkmann Instruments, Westbury, NY) was used to homogenize two grams of strawberry fruit tissue in imidazole buffer (20 mM, pH 7.0). The extracts were centrifuged and the supernatants were dried *in vacuo* in derivatizing vials. Derivatization of sugars was performed using a modification of procedures described by Li and Schuhmann (1980). An internal standard was

maintained by including a known amount of β-phenyl-D-glucopyranoside in all samples. Each sample was mixed vigorously with one mL Trisil reagent (Pierce, Rockford, IL) and then heated at 75C for 30 min. After silylation, one μL (=1 μg) of each derivatized sample was injected into a Hewlett Packard 5890 gas chromatograph (Hewlett Packard, Palo Alto, Ca.) equipped with a flame ionization detector and a 25 m crosslinked methyl silicon gum capillary column (0.2 mm ID, 0.33μm film thickness). Temperatures were as follows: injector 250C, detector 275C, and column 100 to 250C programmed at 10C/min with 0 min initial and 23 min final times. After extraction with imidazole buffer and purification with a Baker-10 solid phase extraction system, organic acids were then analyzed. Quaternary amine columns, previously conditioned with hexane and methanol, were used to pass the supernatants from the extracts. The samples were then eluted from the columns with 0.1 N HCl. The eluates were concentrated to dryness *in vacuo* in derivatized vials. The same procedures of derivatization and chromatography of sugars were used for organic acids, except that column temperature was programmed from 180 to 250C at 10C/min with 3 min initial and 12 min final times. The sugars and organic acids were quantified by comparison with derivatized standards. A Hewlett Packard ChemStation was used to calibrate the peaks, record the data, and calculate the results. Data were analyzed by analysis of variance and least significant differences were calculated using Duncan's multiple range test at $P \leq 0.05$.

RESULTS AND DISCUSSION

Heat Injury

A significant risk when using moist hot air treatment for strawberries is heat injury. Excessive temperature or duration can produce harmful responses in the fruit tissue, leading to heat injury. Treatment at 45C for 60 min or longer caused heat injury to strawberry fruit in this study (Table 1). However, no heat injuries were detected when fruit were exposed to 45C for 40 min or less, or 42C or lower temperatures. 'Northeaster' fruit exhibited severe heat injury symptoms when exposed to 50C or higher temperatures, whereas 'Chandler' fruit suffered severe damage when exposed to 42C for 30-60 min (Yoshikawa *et al.* 1992). Symptoms of heat injury first appeared as an off-coloring of the skin and then developed into spotty discoloration. Fruit with severe heat injury had a cooked appearance and leaky tissues. The severely injured fruit collapsed during storage. Therefore, fruit with severe heat injury such as those exposed to 50C or higher, were discarded before the end of the experiment and data for these treatments were omitted. In addition, although the 36 or 39C treatments used in this study did not cause heat injury, these treatments had little or no effect on quality attributes measured. Therefore, data on these treatments are also not presented.

TABLE 1.
EFFECT OF MOIST HOT AIR TREATMENT ON POSTHARVEST QUALITY OF 'NORTHEASTER' STRAWBERRIES[z]

Heat treatment							
Temp (C)	Duration (Min)	Heat injury[y]	Decay (%)	pH	Titratable acidity (TA) (%)	Soluble Solids (SS) (%)	SS/TA ratio
42	0	10.0 a[x]	93.4 a	3.7 a	0.96 a	7.1 d	7.4 f
	20	10.0 a	68.7 b	3.5 a	0.82 b	7.6 cd	9.3 e
	40	10.0 a	31.5 c	3.7 a	0.84 b	7.3 d	8.7 ef
	60	10.0 a	9.3 e	3.4 a	0.77 bc	8.4 bc	10.9 d
	80	10.0 a	11.8 e	3.5 a	0.65 d	9.8 a	15.1 ab
	100	10.0 a	7.9 e	3.4 a	0.69 cd	9.5 a	13.8 bc
45	0	10.0 a	95.1 a	3.7 a	0.98 a	7.4 d	7.6 f
	20	10.0 a	28.3 cd	3.6 a	0.79 bc	7.2 d	9.1 ef
	40	10.0 a	7.5 e	3.5 a	0.66 d	8.6 b	13.0 c
	60	7.2 b	26.2 d	3.6 a	0.61 de	9.2ab	15.1 ab
	80	3.3 c	70.8 b	3.5 a	0.66 d	9.6a	14.5 bc
	100	2.6 c	91.2 a	3.7 a	0.57 e	9.0ab	15.7 a

[z]Strawberry fruit were stored at 0 C for 5 days, 10 C for 3 days, and 20 C for 1 day.
[y]Heat injury was rated as follows: 10 = none, 5 = moderate, and 0 = severe heat injury.
[x]Mean separation with columns by Duncan's multiple range test, $P \leq 0.05$.

Decay

Percent of fruit with decay was evaluated at the end of storage. Heat-treated fruit that did not suffer heat injury had a lower incidence of decay compared with untreated fruit. Fruit treated with 45C for 40 min or 42C for 60-100 min had the least decay development (Table 1). Reduction of postharvest decay of strawberries with hot air or hot water treatments has also been reported in cultivars 'Pocahontas' and 'Sparkle' (Smith and Worthington 1965), 'Tudla' (Garcia *et al.* 1996), and 'Ananassa' (Wells 1970). The value of heat treatment as an alternative method to chemical treatment for decay control needs to be evaluated for each individual cultivar weighing against possible losses and damage due to the treatment. The potential benefit of less decay would depend on the degree of fruit tolerance to the hot temperature applied.

Soluble Solids Content, Titratable Acidity and pH

SS content in strawberries treated with 36 or 39C did not differ from that in nontreated fruit (data not shown). However, fruit heated to 42C for 60-100 min or 45C for 40 min or longer maintained 16% or higher SS content than nontreated fruit (Table 1). With increasing temperature and duration of heat treatment, TA in

strawberry fruit decreased (Table 1). A 12% or more reduction of TA was detected in fruit treated with 42 or 45C as compared with the control fruit. The reduction of TA by high temperature treatment has also been reported to occur in apples (Klein and Lurie 1990; Liu 1978) and tomatoes (Lurie and Klein 1992). The ratio of SS content/TA was markedly higher in heated strawberries than in nonheated fruit, particularly in fruit treated with 42C for 80-100 min or 45C for 45 min or longer. The pH of strawberry fruit juice was not significantly different among all treatments (Table 1). A high buffering capacity in strawberry pulp may have kept the pH from changing rapidly with various heat treatments.

Color Changes

After 7 days of storage at 0C, 3 days at 10C, and 1 day at 20C, there were significant differences in L^* values among various treatments (Table 2). Heat treated fruit in general had lower L^* readings than nonheated fruit. Treated fruit appeared to be duller and less bright in appearance than control samples. The C^* values were also lower in treated than in control fruit. Decreases in L^* and C^* values signify a decrease in brightness. No consistent patterns were detected in other color readings, a^*, b^*, or h^*, among all of the treatments.

Sugars and Organic Acids

Strawberry fruit treated with 42C for 40 min or 45C for 20 min or longer retained higher levels of fructose, glucose, and sucrose than nontreated fruit (Table 3). Lower rates of respiration and ethylene production in heated fruit might have helped to conserve carbohydrates in the tissues (Yoshikawa *et al.* 1992). Citric acid was the predominant organic acid in strawberries. Both citric and malic acids were decreased significantly by the heat treatments (Table 3). Sugar and organic acid contents in strawberry fruit were also influenced by genotypes and mulch types used in the field during the growing season (Wang *et al.* 1998).

Postharvest heat treatment can be applied as hot water dip, hot air, or vapor heat. Smith and Worthington (1965) found that hot air treatment was more effective than hot water dip in reducing decay in strawberries. Furthermore, hot water dip could cause discoloration of skin color and softening of flesh (Garcia *et al.* 1996; Smith and Worthington 1965). Smith and Worthington (1965) also reported that exposure of strawberry fruit to hot air (43C) with high relative humidity (90% or above) resulted in much less incidence of *Botrytis* and *Rhizopus* than exposure with low relative humidity (80% or below) at the same temperature. Maintaining a high degree of humidity appears to be important in increasing the effectiveness of heat treatment. The relative humidity was kept near saturation during hot air treatment in our experiment. No shriveling or weight loss of treated fruit were found after heat treatment. In our study, exposures with hot moist air at 42C for 60-100 min or 45C for 40 min were the best treatments to suppress the

TABLE 2.
EFFECT OF MOIST HOT AIR TREATMENT ON COLOR OF 'NORTHEASTER' STRAWBERRIES[z]

Heat treatment		Color				
Temp (C)	Duration (Min)	L^*	a^*	b^*	C^*	h^*
42	0	27.6 a[y]	25.8 cde	15.1 c	33.2 a	25.4 ab
	20	24.4 bcd	24.6 de	10.4 f	31.3 ab	23.1 cd
	40	25.1 bc	27.8 bc	12.8 de	28.8 bc	24.7 abc
	60	23.2 cd	30.3 ab	16.2 bc	22.9 ef	21.6 de
	80	22.6 d	32.1 a	17.5 ab	25.2 de	26.3 a
	100	23.4 cd	26.4 cde	11.6 ef	20.3 f	22.1 de
45	0	26.1 ab	26.8 cd	14.4 cd	31.7 ab	24.4 abc
	20	25.7 ab	23.5 e	12.2 ef	22.3 ef	25.7 a
	40	23.6 cd	30.6 ab	15.3 c	27.1 cd	21.0 e
	60	24.2 bcd	28.3 bc	10.2 f	21.4 f	23.5 bcd
	80	23.4 cd	24.7 de	16.4 abc	20.5 f	20.9 e
	100	22.6 d	23.6 e	18.2 a	20.8 f	22.8 cde

[z]Strawberry fruit were stored at 0 C for 5 days, 10 C for 3 days, and 20 C for 1 day.
[y]Mean separation within columns by Ducan's multiple range test, $P \leq 0.05$.

TABLE 3.
EFFECT OF MOIST HOT AIR TREATMENT ON SUGAR AND ORGANIC ACID CONTENTS OF 'NORTHEASTER' STRAWBERRIES

Heat treatment		Sugars ($mg.g^{-1}$ fresh mass)			Organic acids ($mg.g^{-1}$ fresh mass)	
Temp (C)	Duration (Min)	Fructose	Glucose	Sucrose	Malic	Citric
42	0	17.2 d[y]	15.6 d	10.2 e	0.85 a	6.92 ab
	20	17.8 d	16.3 cd	10.7 de	0.72 cd	6.35 bc
	40	20.3 bc	16.6 cd	11.9 bcd	0.76 bc	5.26 de
	60	19.6 c	20.7 a	13.2 ab	0.64 de	4.96 e
	80	22.3 ab	18.2 bc	12.8 abc	0.71 c	4.63 e
	100	24.2 a	21.4 a	13.9 a	0.56 ef	4.81 e
45	0	18.1 d	16.1 d	10.4 e	0.83 ab	7.34 a
	20	20.7 bc	18.8 b	11.7 cd	0.78 abc	6.38 bc
	40	20.2 bc	18.2 bc	14.1 a	0.62 e	5.23 de
	60	23.6 a	19.8 ab	12.8 abc	0.58 ef	6.03 cd
	80	22.8 a	21.7 a	12.5 bc	0.52 f	4.87 e
	100	20.4 bc	18.2 bc	11.6 cd	0.61 e	5.06 e

[z]Strawberry fruit were stored at 0 C for 5 days, 10 C for 3 days, and 20 C for 1 day.
[y]Mean separation within columns by Duncan's multiple range test, $P \leq 0.05$

development of diseases. The lethal effect of high temperatures on pathogens is probably the main reason for the retardation of decay. Fungal spores can be inactivated or killed by high temperatures. The host-pathogen interaction can also play a role in heat-reduced fungal infection. Heat may prevent the breakdown or enhance the production of antifungal compounds in fruits (Fallik *et al.* 1996; Prusky 1996).

In this study, we have found that hot moist air treatment not only reduced decay, but also maintained higher levels of sugars and SS content/acid ratio during the subsequent storage and marketing period. The mechanisms by which high temperatures preserve fruit quality is not known. However, elevated temperatures at 35C or higher have been found to enhance the synthesis of heat shock proteins (Vierling 1991). Whether these proteins also play a role in the improvement of fruit quality in heat treated fruit is not clear and requires further investigation.

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