Controlling Temperature and Water Loss to Maintain Ascorbic Acid Levels in Strawberries During Postharvest Handling

M. C. N. Nunes, J. K. Brecht, A. M. M. B. Morais, and S. A. Sargent

ABSTRACT

'Chandler', 'Oso Grande' and 'Sweet Charlie' strawberries were stored for 8 days at 1 or 10°C, or 4 days at 20°C, either unwrapped or wrapped in PVC film to retard water loss. Total ascorbic acid (AA) content was expressed on a dry weight basis to correct for water loss differences between treatments. Loss of AA was low and did not differ between wrapped treatments at 1 and 10°C, but was much greater at 20°C. Wrapping reduced AA loss by 5-fold at 1 and 10°C and by 2-fold at 20°C. The effect was not due to modification of O_2 and CO_2 levels in wrapped treatments, which was minimal. The results indicate that water loss had a greater effect on AA levels than temperature. Combining wrapping with storage at 1 or 10°C reduced AA loss by 7.5-fold compared to unwrapped strawberries stored at 20°C.

Key Words: strawberry, ascorbic acid, vitamin C, temperature, water loss

INTRODUCTION

STRAWBERRIES ARE AN IMPORTANT source of ascorbic acid (AA; vitamin C) in the human diet. The recommended dietary allowance (RDA) for AA is 60 mg/day in adults, which can be met with an average of 100g of strawberries per day (Food and Nutrition Board, 1989). However, AA is very labile and, under adverse conditions, undergoes oxidation. The oxidation of L-ascorbic acid, the active form of the vitamin, to dehydroascorbic acid (DHA) does not result in loss of biological activity since DHA is readily reconverted to L-ascorbic acid; however, the subsequent conversion to diketogulonic acid is irreversible. Therefore, it was suggested by Klein (1987) that measurements of vitamin C in fruits and vegetables in relation to their nutritional value should include both AA and DHA. The rate of postharvest oxidation of AA in plant tissues has been reported to depend upon several factors such as temperature, water content, pH, packaging, storage atmosphere, and storage time (Barth et al., 1990; Cooke and Moxon, 1982; Kirk et al., 1977; Nelson et al., 1977; Lee and Labuza, 1975).

Water loss during storage is a major cause of fruit deterioration. Reduction in turgidity as a result of water loss causes shriveling and faster depletion of nutrients (Barth et al., 1990; Aharoni and Barkai-Golan, 1987; Hardenburg et al., 1986). Although several studies have been reported on the influence of water content on AA oxidation in dehydrated foods, or simulated food systems (Desrosiers et al., 1985; Mohr, 1980; Lin and Agalloco, 1979; Kirk et al., 1977; Lee and Labuza, 1975; Labuza et al., 1970; Karel and Nickerson, 1964), little information is available on the influence of water loss on AA content of fresh fruits during handling and storage.

The objective of our study was to evaluate the relative effects of storage temperatures (1, 10 and 20°C), storage time, and water loss on the AA content of strawberries. We refer to the sum of AA plus DHA as total AA. Water loss differences were obtained by the use of PVC film as a moisture barrier compared to unwrapped controls.

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MATERIALS & METHODS

Plant material

'Chandler', 'Oso Grande' and 'Sweet Charlie' strawberries were obtained from a commercial operation near Floral City, Florida. 'Chandler' is a major strawberry cultivar grown in California (Chandler, 1990), and the Mediterranean countries of Europe (Rosati, 1990), while 'Oso Grande' is the leading cultivar grown in Florida (Chandler et al., 1992). 'Sweet Charlie' is a release from the University of Florida strawberry breeding program (Chandler et al., 1992) and a major cultivar in Florida. The strawberries were grown in double rows on raised beds covered with black plastic mulch, with drip irrigation and fertilization practices according to standard recommendations for strawberry production in Florida (Maynard et al., 1988). A total of three harvests/experiments were conducted during the 1993/1994 winter season. 'Chandler' strawberries were harvested on December 12, 'Oso Grande' on December 10, and 'Sweet Charlie' on January 7.

Packaging and storage conditions

Commercially harvested strawberry fruit packed in fiberboard flats containing 12 plastic mesh (pint) baskets of fruit were removed from the field with minimal delay after harvest and transported to the laboratory in Gainesville within 2h. A total of 1200 fruit for each cultivar were selected from 15 flats for uniformity of color development between three-quarter and full red, and freedom from defects, weighed in samples of 10 berries each, and redistributed into 120 plastic mesh (pint) baskets (10.2 cm × 10.2 cm × 6.7 cm) containing 10 berries each.

Sixty baskets per cultivar were wrapped with 0.0181 mm polyvinyl chloride (PVC) film (W44-75, RJR FilmCo., Aurora, OH). The film was overlapped on the bottom of the baskets but not sealed. This type of film is commonly used to wrap produce for retail display because of its good moisture barrier properties and relatively high permeability to O_2 and CO_2. The permeability of the film to CO_2 at STP is 618.9 m^3 m s^{-1} m^{-2} atm × 10^{14} and to O_2, 59.8 m^3 m s^{-1} m^{-2} atm × 10^{14} (Talasila, 1992). A septum to collect samples of gas inside the baskets was arranged with a rubber septum attached using silicone rubber cement on a plastic tape sticker in a corner of the basket. The other 60 baskets were used as controls (unwrapped).

Twenty wrapped and 20 unwrapped baskets per cultivar were then placed in controlled temperature rooms at 1°C and 90 to 95% RH, 10°C and 90 to 95% RH, or 20°C and 80 to 85% RH for 8 days. The berries were at ambient laboratory temperature (about 22°C) at the beginning of the experiments and reached the treatment temperatures in 1 to 6h after being placed in the storage rooms. The O_2 and CO_2 concentrations inside the wrapped baskets were monitored during storage. Four replicate samples of 10 berries (4 baskets) per treatment for each cultivar were taken after 0, 2, 4, 6 and 8 days in storage and used for headspace gas analysis, weight loss, and total AA content determinations.

Weight loss

Samples of 10 fruit (120) were weighed before and after storage, and weight loss was calculated. The strawberry dry weight was determined by drying a weighed aliquot of strawberry tissue that had been homogenized in a blender. The samples were held at 70°C until constant weight was reached and re-weighed.

Ascorbic acid

For total AA analysis, homogenized fruit tissue (5g) was combined with 100 mL of a mixture of 6% metaphosphoric acid and 2N acetic acid. The fruit-acid mixture was centrifuged for 20 min at 5,000 × *g*. The analysis was performed by the dinitrophenylhydrazine method of Terada et al. (1978). The concentration of total AA was calculated from absorbance measured at 540 nm using a standard curve. Concentrations of total AA were expressed in terms of dry weight.

Gas concentrations

Changes in concentrations of CO_2 and O_2 in the atmosphere inside the wrapped baskets were monitored daily after the third day of storage using a Gow-MAC Gas Chromatograph Series 580 equipped with a thermal conductivity detector (TCD). It was connected to two columns, one 1.90m long by 0.33 cm dia packed with 80-100 mesh Porapack, and the other 3.35m long by 0.48 cm dia packed with 60-80 mesh Molecular Sieve 13X. The flow rate for the carrier gas (helium) was 30 mL min^{-1}. The injector and the detector temperatures were set at 90°C. The temperature of the column oven was set at 40°C.

Statistical analysis

A completely randomized design was used. The treatments were a 3×5×2×3×4 factorial arrangement of three storage temperatures (1, 10 and 20°C), five storage times (0, 2, 4, 6, and 8 days) and two packaging treatments (wrapped and unwrapped) applied to three cultivars × 4 reps of 10 berries. The Statistical Analysis System computer package (SAS Institute, Inc., 1986) was used for analysis of the data. Data from each cultivar were treated by three-way ANOVAs, with storage temperature, storage time and packaging as factors. Significant differences for each cultivar/wrapping treatment combination were detected using the Least Significant Difference (LSD) at the 5% level of significance. Linear regression analyses were also used to relate strawberry water loss to total AA levels during storage.

RESULTS & DISCUSSION

'CHANDLER' AND 'SWEET CHARLIE' strawberries stored wrapped or unwrapped for longer than 4 days at 20°C developed a high amount of decay, making determination of weight loss or total AA content unreliable, and those samples had to be discarded. The weight loss of the strawberries increased with temperature in both wrapped and unwrapped samples but was 2- to 3-fold greater in unwrapped fruit (Fig. 1 and 2). Although there were no differences in weight loss between 1 and 10°C over the 8-day storage for wrapped or unwrapped samples, weight loss was higher at 20°C than at 1 or 10°C. The weight loss differences among berries stored at 1, 10 and 20°C were not strictly due to temperature, but also due to differences in vapor pressure deficits among treatments.

After 4 days storage, no differences in weight loss were observed among the cultivars for wrapped samples stored at 1, 10 or 20°C. However, for unwrapped berries, 'Chandler' lost more weight than 'Oso Grande' or 'Sweet Charlie' at 1°C and 20°C (Fig. 2). Although there were differences among cultivars, all behaved similarly in that they lost more weight when not wrapped and when storage time and temperature increased. Aharoni and Barkai-Golan (1987) studied the effect of different types of wraps on the weight loss of 'Aliso' strawberries and noted that packaging with PVC film resulted in a marked reduction in water loss. Collins and Perkins-Veazie (1993) reported lower weight loss during storage at 1 or 5°C in 'Cardinal' strawberries packed in boxes wrapped with polyethylene film than in fruit packed in boxes with plastic dome lids. Miller et al. (1983) studied the effects of different consumer units on the quality of strawberries under simulated airfreight shipping conditions. Berries packed in rigid plastic baskets with solid plastic covers were reported to lose less weight than those stored in mesh plastic baskets without covers.

The total AA content of wrapped strawberries changed little during storage for 8 days at 1 or 10°C, but decreased from 20 to 45% over 4 days at 20°C (Fig. 3). The total AA content of unwrapped strawberries declined to a much greater extent than that of wrapped strawberries. Losses in total AA content of unwrapped strawberries at 1°C ranged from 20 to 30% over 8 days, while berries at 10°C lost from 30 to 50% of the initial total AA content (Fig. 4). At 20°C, unwrapped strawberries lost from 55 to 70% of the initial total AA content in 4 days. 'Oso Grande' fruit had a lower initial content of total AA than 'Chandler' or 'Sweet Charlie'. However, after 8 days storage at 1 or 10°C, 'Sweet Charlie' retained less total AA than 'Oso Grande' and 'Chandler' for both wrapped and unwrapped samples. This result, along with the differences in weight loss among cultivars, suggests that suitability for long-term storage differs among strawberry cultivars.

There have been reports that total AA levels may increase in fruits and vegetables during postharvest storage. Eheart (1970) and Eheart and Odland (1972) reported that the total AA content of broccoli held at 3°C increased during storage. Payne (1967) also noted that total AA was higher immediately

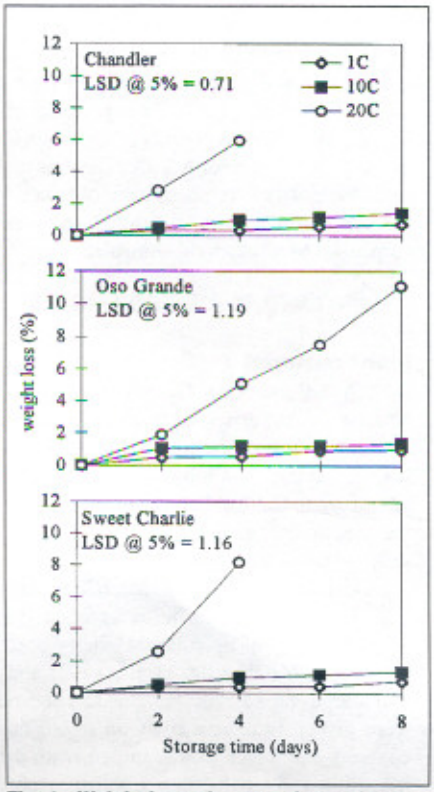

Fig. 1—Weight loss of wrapped strawberries stored at 1, 10 or 20°C.

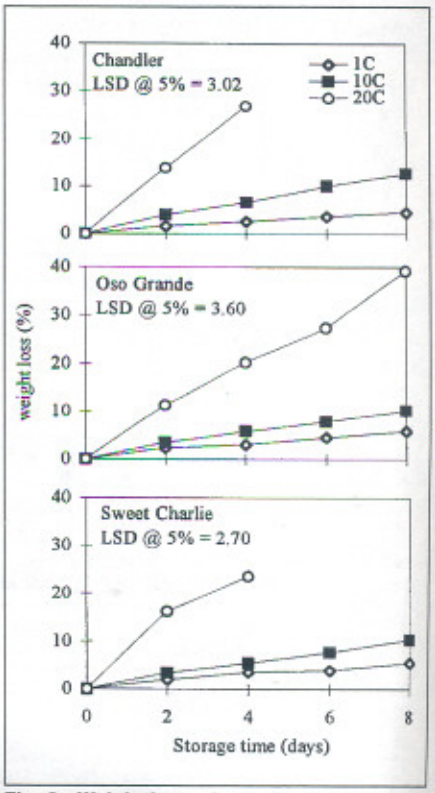

Fig. 2—Weight loss of unwrapped strawberries stored at 1, 10 or 20°C.

after freezing corn, and after certain periods during storage. Watada (1987) indicated that AA may continue to be synthesized during ripening of detached tomatoes. It has been suggested that increases in total AA content during storage of fruits and vegetables might be attributed to synthesis of AA from monosaccharides, since in plants most synthesis starts with preformed D-glucose (Liao and Seib, 1988; Loewus and Loewus, 1987; Seib and Tolbert, 1982). A noninversion pathway for AA synthesis from D-glucose in higher plants has been suggested, in which the C1 of glucose becomes the C1 of AA. The process involves oxidation of C1 and C2 from glucose and epimerization of C5, while the hydroxymethyl group at C6 is conserved. In a study of detached strawberries fed L-galactone-1,4-lactone, it was found that this compound was partially converted into AA (Baig et al., 1970). However, L-galactone-1,4-lactone is not a normal constituent of plants (Loewus and Loewus, 1987).

Several studies have suggested that AA might increase after harvest due to putative synthesis, but our results did not support this. The high level of water loss during storage of the strawberries tended to mask total losses of AA when expressed on a fresh weight basis, in some cases appearing to show no difference from initial values or, in other cases, higher levels after storage (data not shown). In a previous study using 'Chandler', 'Oso Grande' and 'Sweet Charlie' strawberries, Nunes et al. (1995) observed that apparent increases in total AA content on a fresh weight basis during storage were due to water loss during storage rather than to actual increases. Although compositional values expressed on a fresh weight basis may better represent the actual concentrations that would be experienced by a consumer, we expressed total AA content on a dry weight basis in order to determine the true effects on AA levels imposed by water loss. In published reports, AA contents were expressed on a fresh weight basis and thus may have been influenced by water loss. Therefore, we suggest that, when the water loss during storage of fruits and vegetables is very high, AA content should be expressed in terms of dry weight to make evaluation of the real effects of storage more reliable.

Correlation coefficients for linear regressions relating weight loss to total AA indicated an influence of water loss on AA content, particularly for strawberries stored at 20°C (Table 1). Correlation coefficients were generally highest for unwrapped fruit and wrapped fruit at 20°C, treatments that lost notable weight during storage.

Soft berries may lose AA rapidly as a consequence of tissue damage and bruising, which lead to increased water loss and allow exposure of AA to oxidation. Also, ascorbate oxidase, normally bound to the cell walls, might be released following tissue damage or water loss (Klein, 1987; Loewus and Loewus, 1987; Nobile and Woodhill, 1981). Strawberry fruit have a higher content of total AA in the cortex tissue than in the medulla tissue (110 mg 100g fresh weight^{-1} vs 70 mg 100g fresh weight^{-1}, respectively) (Bender, 1978). Since the strawberry surface is more affected by water loss than the interior tissues, AA degradation might be accentuated in unwrapped samples that are more subject to water loss. Alternatively, water stress may promote AA oxidation by affecting free radical scavenging systems in the plant tissue (Lesham, 1988; Thompson et al., 1987).

Table 1—Coefficients of linear correlation ('r') for weight loss and total ascorbic acid content during storage of 'Chandler', 'Oso Grande' and 'Sweet Charlie' strawberries[a]

Treatment	Temp. (°C)	Cultivar: Chandler	Oso Grande	Sweet Charlie
Wrapped	1	0.42ns[b]	0.39ns	0.55*
	10	0.59**	0.38ns	0.80***
	20	0.91***	0.87***	0.87***
Unwrapped	1	0.71***	0.79***	0.93***
	10	0.89***	0.85***	0.44*
	20	0.99***	0.86***	0.95***

[a]All fruit at 1 and 10°C were stored for 8 days; 'Oso Grande' fruit were stored for 8 days, and 'Chandler' and 'Sweet Charlie' for 4 days at 20°C.
[b]ns, *, **, and *** represent nonsignificant 'r' values or those that are significant at P<0.05, 0.01 and 0.001, respectively, for 18 df, except for 'Chandler' and 'Sweet Charlie' at 20°C, which were 10 df.

It has long been accepted that in broccoli, spinach and lettuce, refrigeration with high humidity causes greater retention of total AA compared to low humidity storage. Nelson et al. (1977) suggested that high moisture content in asparagus might protect the AA. Barth et al. (1990) studied the effects of misting on AA retention in broccoli during cabinet display at 18°C and reported that misted samples retained more AA than non-misted samples. They also observed that broccoli incurred AA losses with increased storage time. Barth et al. (1993), in a subsequent study with broccoli using modified atmosphere packaging, found that moisture retention was greater in packaged broccoli than in nonpackaged broccoli.

The gas concentrations inside wrapped baskets changed during storage (Fig. 5). The steady state concentrations were 19 and 16% for O_2, and 0.8 and 2% for CO_2 at 1 and 10°C, respectively. These O_2 and CO_2 levels would be expected to have little effect on fruit metabolism (Kader, 1980), and specifically ascorbate oxidase, which has been reported to have a KmO_2 of <10% (Liao and Seib, 1988; Seib and Tolbert, 1982; Mohr, 1980). Wrapped strawberries stored at 20°C began to decay between 4 and 6 days of storage, before the atmosphere composition within the packages reached steady state, but O_2 and CO_2 levels were 6 and 12%, respectively, after 4 days. The values published as optimum conditions for strawberries under modified atmosphere range from 5 to 10% O_2 and 15 and 20% CO_2 (Kader, 1993). Although Aharoni and Barkai-Golan (1987) attributed the fresher appearance and delay in desicca-

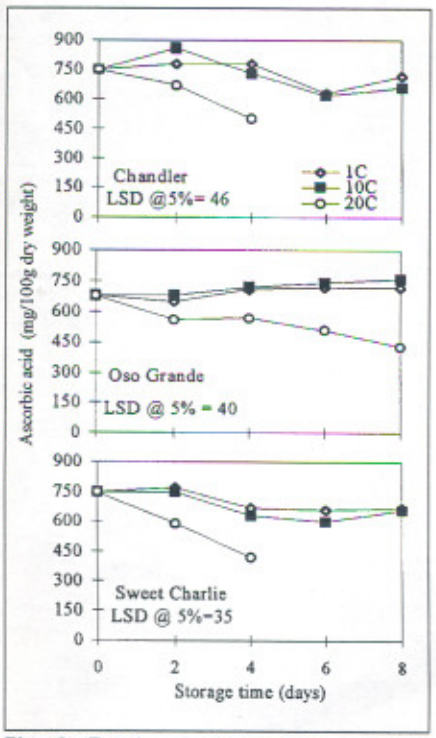

Fig. 3—Total ascorbic acid content in wrapped strawberries stored at 1, 10 or 20°C.

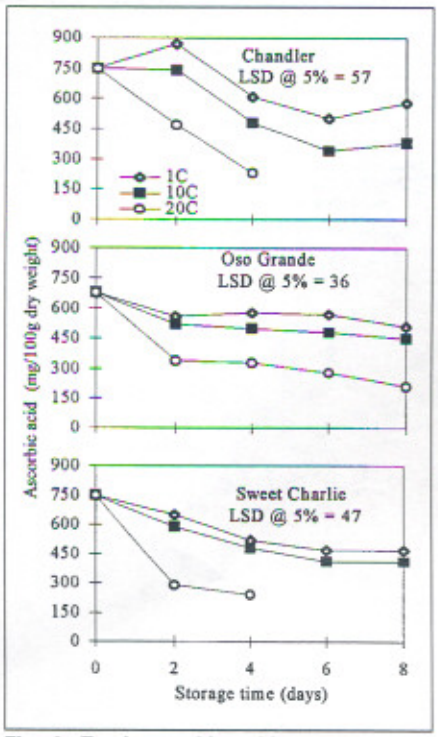

Fig. 4—Total ascorbic acid content in unwrapped strawberries stored at 1, 10 or 20°C.

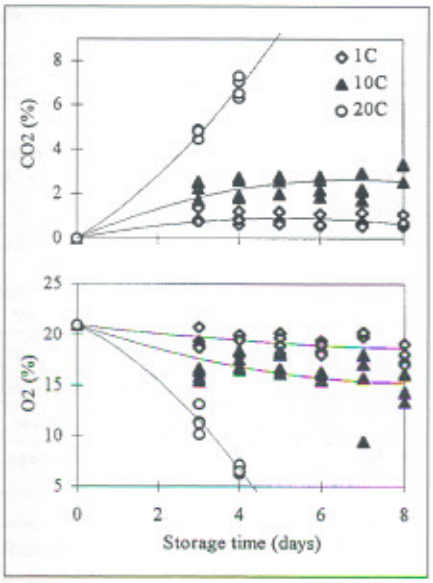

Fig. 5—Atmosphere composition (O_2 and CO_2) inside strawberry baskets wrapped with PVC film and stored at 1, 10 or 20°C.

tion of the calyx in PVC packages to atmosphere modification around the fruit, the CO_2 level was only 0.7% and the O_2 level 19.2% after 10 days storage at 2°C. It is more likely that the beneficial effects were due to inhibition of water loss. Since the O_2 levels at 1 and 10°C in our study were around 19 to 16%, it seems likely that total AA retention in the wrapped samples was due to moisture retention rather than reduced O_2 levels.

CONCLUSIONS

LOSSES OF TOTAL AA IN STRAWBERRY fruit were reduced an average of 7.5-fold by controlling moisture loss and maintaining refrigeration during the postharvest period (wrapped fruit at 1°C vs unwrapped fruit at 20°C). Thus, even short periods at ambient temperature without control of water loss, either prior to precooling or during retail display, could result in considerable losses of total AA in strawberries. At moderately low temperatures (from 1 to 10°C), control of water loss appeared to be more important than temperature control for maintenance of total AA levels in strawberries.

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