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Table of Contents

QUALITY OF STRAWBERRIES AFTER STORAGE IS REDUCED BY A SHORT DELAY TO COOLING

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ABSTRACT

The effects of delay to cooling and storage were evaluated on postharvest quality and decay of fresh harvested strawberries. 'Chandler' strawberries were forced-air precooled after delays of 0 or 6 hours at 30°C to study the effect of delaying precooling on decay, and physical and chemical characteristics of strawberries. For decay experiments the fruits were previously inoculated with *Botrytis cinerea* and *Rhizopus stolonifer*. Fruit pulp temperature was equilibrated to 30°C prior to the start of each experiment to minimize water loss differences between treatments. Evaluations were made after storage for one week at 1°C plus one day at 20°C.

Delaying the start of precooling resulted in greater water loss than in control fruits. Tissue firmness values were also lower in fruit from the delay treatment. Fruits were darker, less bright and apparently less red. No significant differences in pH were observed, but titratable acidity was slightly lower with the delay to cooling. Delaying precooling also caused increased losses of ascorbic acid, soluble solids, fructose, glucose and sucrose compared to controls, and also resulted in more decayed fruits. This illustrates the importance of rapid precooling and subsequent storage at low temperature for maintenance of an acceptable appearance, texture, flavor and nutritive value of strawberries.

KEYWORDS: Forced air cooling, Color, Firmness, Acids, Sugars, Ascorbic acid, Decay.

RESUMEN

El objeto de estudio consiste en ver el efecto sobre las características cualitativas de las fresas al demorar el enfriamiento. Para ello se encauzó aire frio a través de la variedad de fresas 'Chandler' con retrasos diferentes de cero y de seis horas con temperatura ambiente de 30°C. Las fresas fueron previamente inoculadas con *Botrytis cinerea* y *Rhizopus stolonifer*. La temperatura de los frutos fue mantenida a 30°C antes del comienzo de cada experimento para minimizar la diferencia de perdida de agua. Se tomaron datos despues de almacenarlas durante una semana a 1°C y un dia más a 20°C.

El resultado del retraso en el comienzo del enfriamiento fue una pérdida media de agua mayor que en la fruta de control, lo cual se evidanciaba por el incremento de arrugamiento superficial. Los valores de firmeza de tejidos fueron menores en la fruta que sufrió retraso en el enfriamiento. También su color fue más oscuro, y menos rojo y el matiz de color fue menor. Aunque en este experimento no se encontraron diferencias significativas en el pH, la acidez titrativa fue menor en las muestras con un retraso en el enfriamiento. Este retraso también causó un incremento en la pérdida de ácido ascórbico, sólidos solubres, fructosa, glucosa y sacarosa con respecto a las muestras de control. El retraso en el enfriamiento produce tambien unos frutos más pudridos. Los resultados ilustran la importancia de un enfriamiento rápido y el almacenaje posterior a bajas temperaturas para mantener a niveles aceptables la apariencia, textura, sabor y valores nutritivos de las fresas.

TÓPICOS: Enfriamiento por aire, Color, Firmeza, Acidez, Azúcares, Ácido ascórbico, Deterioro.

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INTRODUCTION

The importance of temperature management in maintaining the quality of fresh fruits and vegetables is well recognized (Kader, 1992). Because of the beneficial effects of low storage temperature in extending storage life, rapid attainment of such temperatures may be assumed to always have a positive effect on produce quality. However, delays before cooling inevitably occur in commercial handling during field and transport operations, and little objective information is actually available that might help to determine the effects of these delays on decay, and physical and chemical quality characteristics, including the nutritional value of the crops. Most of the literature available on the effects of delay to cooling of fruits and vegetables report only subjective evaluations of marketability or quality (Mitchell et al., 1964), or report measurements of only objective aspects of quality such as color, weight loss or firmness (Collins and Perkins-Veazie, 1993).
Strawberry is one of the most delicate and perishable fruits, being very susceptible to mechanical injury, physiological deterioration, water loss and decay. Deterioration under inadequate conditions is often due to gray mold caused by *Botrytis cinerea* and leak caused by *Rhizopus stolonifer* the most important fruit rots of strawberry. Gray mold is an important fruit rot wherever strawberries are grown and *Botrytis cinerea* is generally most important in the field. However, much postharvest rot is attributable also to this fungus. Leak caused by *Rhizopus stolonifer* is primarily a postharvest or storage rot. Rapid cooling of harvested fruits to below 6°C inhibits the growth and sporulation of this pathogen (Maas, 1992). Therefore, prompt removal of field heat and adequate packaging can slow down undesirable quality changes and increase strawberry shelf-life (Talbot et al., 1991).

The objective of this work was to evaluate the effects of a short (6 hours) delay to cooling at 30°C, as may be encountered in normal commercial operations, on the weight loss, firmness, color, composition and development of decay on strawberry (cv. Chandler). Quality measurements were performed after storage for 1 week at 1°C plus a simulated retail display period of 1 day at 20°C in order to determine if differences would be apparent at the consumer level for strawberries handled identically except for the timing of precooling.

MATERIAL AND METHODS

Plant material

'Chandler' strawberries were obtained from an Agricultural Experiment Station, located in the north of Portugal, at Vairão, Vila do Conde for the decay experiments, and from a commercial operation near Floral City, Florida, for the study of quality characteristics. 'Chandler' is the leading variety grown in California (Chandler, 1990) and the Mediterranean countries of Europe (Rosati, 1990). The strawberries were grown in double rows on raised beds covered with black plastic mulch. A total of two harvest/experiments were conducted during the 1993 winter season in Florida for the quality study, and a total of four harvests/experiments were conducted during the 1993 summer season, in Portugal, for the decay study.

Treatment and storage conditions

Commercially harvested fruits were removed from the field with minimal delay after harvest and transported to the laboratory within approximately two hours (Florida) and one hour (Portugal). Forty berries were selected for uniformity of color development (three-quarter to full red) and freedom from defects. For decay study four replicates of 10 berries each were inoculated with *Botrytis cinerea* or *Rhizopus stolonifer* and the remaining berries were used as a

control (non inoculated). The berries were then placed in a controlled temperature room at 35°C and 70 to 80% RH. Fruit pulp temperature reached 30°C within 1 hour, at which time the strawberries were either immediately transferred to a 1°C room for forced air cooling or maintained at 30°C for 6 hours then transferred to 1°C for cooling. This procedure was followed in order to simulate field temperature. The strawberries were then maintained at 1°C and 90 to 95% RH for one week. After 1 week, fruits were transferred to room temperature at 20°C and 80 to 85% RH for one day. Decay evaluation, and physical and chemical properties were measured using four samples of ten berries per treatment.

Fruit inoculation and decay evaluation

Petri dishes containing Potato Dextrose Agar (PDA) were inoculated with pure cultures of *Botrytis cinerea* or *Rhizopus stolonifer* and incubated at 21°C aerobically for 5 days. The dishes with the developed fungus were then flood with water plus surfactant. The inoculum was prepared suspending the conidia in 0.1% Tween 20 in order to avoid conidia to float in clumps. The strawberries were then artificially inoculated by submerging the fruits in the conidial suspension and stored under the conditions described above.
A grading system, HB System was used to determine the diseased tissue. This system is based on a 50 percent as a midpoint. The grades differ by a factor of two in either directions. The higher grades indicate higher percentage of decay (Horsfall and Cowling, 1978).

Weight loss

Fruits were weighed one by one before and after storage, and water loss was determined (weigh percentage). Chemical constituents are expressed in terms of dry weight. The dry weight was determined by drying aliquot of homogenized fruit tissue at 70°C for 6 days and reweighing.

Color assessment

Fruit surface color intensity was measured with a hand-held tristimulus reflectance colorimeter (Minolta CR-200b). Color was recorded using the CIE - L* a* b* uniform color space (CIE-Lab), where L* indicates lightness, a* indicates chromaticity on a green (-) to red (+) axis, and b* chromaticity on a blue (-) to yellow (+) axis. Numerical values of a* and b* were converted into hue angle ($H^\circ = \tan^{-1} b^*/a^*$) and chroma ($Chroma = (a^{*2}+b^{*2})^{1/2}$).

Firmness measurements

Fruit firmness (3mm deformation) was measured with an Instron Universal Testing Instrument Model 1132 (Instron Corp., Canton, USA). A 50 kg load cell was used for the firmness determination of fruits. Crosshead speed was 10 cm/min. A 16 mm diameter probe was used and data was plotted using a strip recorder at 5 kg full scale. Results in kgf were converted to Newton (N).

Chemical measurements

Samples were ground in a laboratory blender at high speed for 2 minutes. Soluble solids content of the puree was determined at 20°C with an Abbe refractometer.
The pH of the puree was determined using a pH meter (140 Corning Medical and Scientific Instruments, Medfield, MA) which was standardized to pH 4 and pH 7.
Fruit were blend and the puree centrifuged at 2,000 rpm for 30 minutes. After filtered, aliquots (6.00 g) of juice were diluted with 100 ml distilled water. The titratable acidity was determined

by titration with 0.1 N NaOH to an end point of pH=8.1 with a Fisher titrimeter. The results were calculated as percent of citric acid [(ml 0.1 N NaOH * 0.064/6.00g of juice)*100.
For total ascorbic acid analysis, 5 g of blended fruit were combined with 100 ml of a mixture of 6% metaphosphoric and 2 N acetic acids. The fruit-acid mixture was centrifuged for 20 minutes at 5,000 rpm. The analysis was performed by the dinitrophenylhydrazine method of Terada *et al.* (1978). The concentration of total ascorbic acid was calculated per 100 g of dry weight tissue from absorbance measured at 540 nm using a standard curve.
Fructose, glucose and sucrose were determined by the analysis of their trimethylsylil derivatives, prepared using Pierce STOX-oxime reagent (Pierce, Rockford, Illionois, USA) and N-trimethylsilylimidizole. A Tractor 540 Gas Chromatograph (Tractor Instruments, Austin, Texas, USA) equipped with a flame ionization detector (FID) and connected to a 243.84 cm x 0.3175cm column packed with 3% OV 17, 80-100 mesh Chromosorb WP with a flow rate for helium (carrier gas) of 40 ml/min was used for separation of the silylated sugars. The temperature of the column oven was programmed for 140° C for 3 min and subsequently for 8° C/min to 250°C, and injector and detector temperatures were set at 285° C and 300° C, respectively. Results were expressed in terms of dry weight.

Statistical Analysis

The Statistical Analysis System computer package (SAS Institute, Inc., 1982) was used for analysis of the data in these experiments. Initial analysis of the data for the combined harvests by analysis of variance (ANOVA) indicated a significant harvest effect. Subsequently, data for the different harvests were analyzed separately. Significant differences among cultivars were detected using Duncan's multiple range test, and between 0 and 6 h delay treatments by F values.

RESULTS AND DISCUSSION

Decay

Delay to cooling seems to have a considerable influence on the development of decay since strawberries precooled with no delay showed a lower percentage of incidence as well as severity of decay in all harvests when compared to 6 hours delay to cooling (Table 1).
Takeda et al. (1990) noticed that development of *Botrytis cinerea* and *Rhizopus stolonifer* was inhibited during storage at 1°C. Strawberries inoculated with *Rhizopus stolonifer* precooled with no delay and stored at 1°C presented lower rot development than strawberries inoculated with *Botrytis cinerea* as expected because *Rhizopus* rot seems to be inhibited at temperatures below 6°C (Maas, 1992). The higher incidence and severity of decay observed after 1 week storage at 1°C plus 1 day at 20°C could have been influenced not only by the delay to cooling but also by the exposure of the berries to a high temperature before cooling, and during the period at room temperature. Non inoculated strawberries from the third and fourth harvest, showed a higher incidence and severity of decay than those from the first and second harvest, for the no delay. This could be a consequence of a field infection that generally increases through the season. Some studies developed on the influence of late harvests on strawberry rot also indicate that the incidence of *Botrytis cinerea* and *Rhizopus stolonifer* species could be greater on fruits harvested late in the season (Dennis and Davis, 1977).

Table 1. Effects of delay to cooling on the incidence and severity of decay in strawberries inoculated with *Rhizopus stolonifer*[1] and *Botrytis cinerea*[2] after storage for 1 week at 1°C plus one day at 20°C.

Treatment	Incidence[x] (%)		Severity[y] (%)	
Harvest 1[1]	*Non In.*	*In.*	*Non In.*	*In.*
No delay	1.5	37.5	45.0	80.0
6 h delay	18.5	81.0	75.0	100.0
Harvest 2[2]				
No delay	4.5	62.5	65.0	90.0
6 h delay	37.5	81.0	80.0	95.0
Harvest 3[1]				
No delay	4.5	18.5	60.0	90.0
6 h delay	18.5	81.0	95.0	100.0
Harvest 4[2]				
No delay	9.0	62.5	70.0	95.0
6 h delay	18.5	81.0	90.0	100.0

x = Average percent surface area of strawberry fruit affected by decay as scored using the Horsfall-Barratt scale. y = Percentage of strawberry fruit showing evidence of fungal growth. Non in. = Non inoculated. In. = Inoculated

Weight loss and firmness

Weight loss was greater for strawberries precooled after a 6h delay at 30°C (Table 2). After storage weight loss by strawberries precooled immediately after harvest ranged from 7.27% to 7.64% of the initial weight, while delaying precooling increased weight loss from 9.84% to 12.28%. Since the cooling and storage conditions were identical for the 0 and 6h delay treatments, the differences in weight loss noted here must be due primarily to water loss during the delay before cooling. The water loss had a negative effect on the strawberry fruit appearance, leading to shriveling and a dull appearance of the epidermis.

Firmness of strawberries cooled immediately after harvest was greater than those cooled after a 6h delay (Table 2). When firmness was initially measured as the bioyield point, the results suggested that the berries from the delay treatment were actually firmer that the berries immediately after harvest (data not shown), but this result appeared to be due to toughening of the epidermis as a consequence of water loss rather than retention of flesh firmness. When the firmness data were expressed as the force required to compress a berry by 3 mm, flesh firmness was shown to actually be lower in the berries from the delay treatment.

Table 2. Effects of delay to cooling on weight loss, firmness and color of strawberries from the first and second harvest after storage for 1 week at 1°C plus 1 day at 20°C[z].

Treatment	Wt. loss (%)	Firmness (N)	Color			
			L*	a*	Hue	Chroma
Harvest 1						
No delay	7.27b[y]	4.85a	35.13a	30.91a	25.54a	34.08a
6 h delay	9.84a	4.03b	35.98a	31.30a	26.38a	35.10a
Harvest 2						
No delay	7.64b	5.23a	36.69a	32.07a	28.57a	34.99a
6 h delay	12.28a	4.72b	35.05b	30.74b	26.95b	32.80b

z = Data are means of 40 individual fruit replicates. y = Mean separation in columns (within a given delay to cooling) by Duncan's multiple range test, P=0.05.

Color

In spite of the differences between harvest times, significantly lower L*, a*, hue and chroma values overall were noticed with delay to cooling for the second harvest (Table 2). The berries were darker (lower L* value), less red (lower a* value) and the color less bright (lower chroma) than promptly precooled fruit. These color changes resulted in less attractive fruit and may be a consequence of the great moisture loss and overipeness of the fruit from the delay treatment.

Chemical composition

Strawberry dry weight in these experiments averaged about 10 % of the initial fresh weight. Same values for strawberry dry weight were reported by the United States Department of Agriculture (1991). The higher levels of water loss in the starwberries from the 6 h delay to cooling treatment tended to mask real losses on a fresh weight basis of some constituints. Therefore, we have expressed the compositional changes on a dry basis in order to illustrate the actual losses that occured in certain constituints irrespective of the concentrating effect imposed by water loss.

Berry pH was little affected by the delay treatment, despite some indication that there were greater losses of titratable acidity (expressed as citric acid equivalents) in the berries with 6 h delay before cooling (Table 3). Strawberries had lower SSC in the delay treatment than with no delay to cooling. Sugar levels were substantially lower in berries from the delay treatment.

Table 3. Effects of delay to cooling on composition of strawberries from the first and second harvest after storage for 1 week at 1°C plus 1 day at 20°C[z].

Treatment	pH	Titr. acidity (%)	SSC (%)	Ascorbic acid ($mg \cdot 100g^{-1}$)	Sugars ($g \cdot 100g^{-1}$) Fructose	Glucose	Sucrose
Harvest 1							
No delay	3.50a[y]	6.48a	75.85a	531.5a	17.18a	13.33a	6.15a
6 h delay	3.47a	6.64a	66.66b	506.6b	14.83b	11.04b	4.07b
Harvest 2							
No delay	3.39a	6.79a	60.38a	453.5a	16.35a	10.79a	5.86a
6 h delay	3.39a	5.62b	49.04b	380.1b	4.71b	2.18b	2.69b

z = Data are means of 40 individual fruit replicates. y = Mean separation in columns (within a given delay to cooling) by Duncan's multiple range test, P=0.05.

Ascorbic acid content was modestly, but significantly, higher in berries from the no delay treatment. The fact that differences in ascorbic acid levels were not greater due to 6 h exposure to high temperature after harvest may be related to the observation made by some researchers that reduction in moisture content or water activity in plant tissue appears to result in less degradation of ascorbic acid (Fennema, 1985).

CONCLUSIONS

The physical and chemical quality characteristics of strawberries that were measured in this study showed variability between harvests as a result of the simulated handling scenarios that were imposed to them. When cooling was delayed for 6 hours at 30°C, the berries presented more incidence and severity of decay, were significantly softer, more shriveled, had less attractive color, and acidity, SSC, sugar and ascorbic acid levels were lower than in fruit that were more quickly cooled. These differences were all apparent after 7 days storage at 1°C plus 1 day at 20°C, conditions simulating normal transportation and marketing times and optimum temperatures for strawberries. This study seems to affirm the assumption that rapid cooling, in addition to proper storage and transport temperatures, is critical for maintaining strawberry quality.

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