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Strawberry quality as a function of the 'high pressure fast cooling' design

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Oso Grande strawberries were picked, wrapped with polyvinyl chloride film, and finally cooled by 'high pressure fast cooling' units with slight differences in design in terms of number of fans functioning and ventilation spacer widths. The effect on strawberry quality of these cooling cells was evaluated compared to room-cooled fruits, and when compared to quality parameter values at fruit gathering. Quality evaluations by means of determination of main sugars and organic acids, colour, firmness, total soluble solids, titrable acidity and pH assessments were carried out at different commercial stages, inmediately after cooling, after 3 days at 2°C simulating refrigerated transport, and after 4 days at 17°C storage (shelf-life). Reducing (by half) the ventilation spacer (V cell), resulted in a 20% higher air speed and a 20% faster cooling than control units (N cell), while units using half of the fans (F cell) showed a lower air speed (45%) and a 30% more time to cool down the product. These modifications also affected strawberry quality. Fruits from the fastest cooler cell, V cell, showed a different quality pattern compared to fruits from N and F cells, with a higher sucrose inversion and less glucose and fructose contents. V cell-cooled strawberries presented a lower content of citric, malic and ascorbic acids during shelf-life. However, fruits cooled by the V cell showed the highest marketable fruit percentage, although with a decrease in red colour compared to fruit at gathering, and fruit cooled by the N or F cells. In these cells, fruit colour remained practically unchanged along the different commercial stages including the long shelf-life period. © 1998 Elsevier Science Ltd. All rights reserved

INTRODUCTION

The strawberry is a major export of Spain, cultivated mainly in Huelva province (southwestern Spain); the primary market for fresh consumption extends across central Europe. Therefore, strawberry producers must take into account an extra 3-day period of refrigerated, surface transport before the fruit is retailed. Thus, effective strawberry handling procedures are required to prevent deterioration during packing and transport.

The strawberry is one of the most delicate and perishable fruits, being susceptible to mechanical injury, physiological deterioration, water loss and decay. At high temperatures, respiration increases markedly, leading to a depletion of nutrient reserves, so that fruit senescence is accelerated. Even under low temperature and high relative humidity conditions, storage life is usually only about 7 days. Prompt cooling of strawberries to near 0°C can slow down undesirable quality changes and increase the shelf-life of this fruit (Boyette *et al.*, 1989; Talbot and Chau, 1991). Therefore, the importance of temperature management in maintaining the quality of strawberry, as well as other fruits and vegetables, is well recognized (Kader, 1992). On the other hand, packaging of fruits with polymeric films is often used to protect against mechanical damage, and to prevent moisture loss, hence maintaining a better appearance overall (Hening and Gilbert, 1975). Robinson *et al.* (1975) observed a maximum permissible water loss of approximately 6% before the marketability of strawberries was impaired.

Recognition of the need for rapid product cooling has extended to all the strawberry handling processes in the Huelva strawberry region. This fruit is typically harvested, graded and packed into plastic punnets in the field by the picker. These combined operations reduce the delay between harvest and cooling (Mitchell *et al.*, 1964; Harvey and Harris, 1973). A new concept for cooling is now being rapidly introduced in Huelva packing houses; this is 'high pressure fast cooling' (HPFC). This cooling concept is derived from the forced-air cooling idea developed by Guillou (1960). In

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a typical HPFC cell, fans pull air from a false ceiling producing cooling as refrigerated air is pulled through the containers (pallets) of product. There are two zones in the HPFC cell, the suction and blow zones, only connected by the product. These cells have a capacity of 5–8 tons of strawberries (12–16 pallets) with a cooling time of 0.75–3 h depending on the manufacturer and user.

Installation of different HPFC cells in this strawberry-producing region is only in response to economic considerations, with little objective or subjective information on their effect on strawberry quality. This work was initiated with the objective of evaluating cooling performance of different designs of these HPFC cells, taking the traditionally used room cooling as control, and to investigate changes of strawberry quality parameters during cooling, transport and retail of this fruit.

MATERIALS AND METHODS

Plant material

Oso Grande strawberries (*Fragaria×ananassa* Duch.) were harvested by trained pickers, selecting for uniformity of size (22.8 ± 1.8 g/fruit) and colour development (three-quarters to full ripe), packed in polystyrene punnets with a capacity of 500 g strawberries, transported to the packing house facility (S.C.A. Costa de Huelva, Huelva, Spain), and wrapped manually with a polyvinyl chloride (PVC) plastic film. Ten punnets were located in each carton flat (60×40×9 cm), and pallets (120×80 cm) were formed by four columns of 23 stacked flats, oriented in the same direction, on a wooden pallet base. Every flat has a trapezoidal vent opening (39×35×4 cm) in each long side to allow air to pass through (28.11% vent opening). These are normal dimensions and practices for most strawberry producers in Huelva, except for the polymeric film used, where PVC and perforated polypropylene are used depending on the market destination.

HPFC cells

Three HPFC cells (Grenco Ibérica, S.A., Huelva, Spain) were compared in this work, using traditional room cooling as control. HPFC cell N (N cell) had a capacity of 8 tons strawberries with dimensions 10.4×3.8×3.6 m, 8 fans in line along the cell on a false ceiling, suction zone 1.40 μm wide, and ventilation spacers 40 cm wide (blow zones width). HPFC cell type F (F cell) has the same dimensions as the N cell but only 4 fans in line. HPFC cell type V (V cell) shares N cell characeristics but has ventilation spacers reduced by half (20 cm); this gives rise to a suction zone 1.80 m wide.

HPFC cells were loaded, in every cooling operation, with two rows of 8 tightly stacked pallets of strawberries, at around 15°C, along the cell (the central corridor created by the two pallet rows is the suction zone). Cooling was performed by refrigerated air at −3°C, and terminated when fruits reached an average temperature of 2°C in all cases.

Cooling performance

Strawberry pulp temperatures during cooling processes were measured every 8 s using 1 mm thermocouples and DeltaTrack data loggers (Modesto, Canada). Strawberry temperatures from four pallets were followed and, for each pallet tested, three layers of flats, top, mid height and bottom were instrumented with 15 thermocouples, strategically located and inserted approximately 1.5 cm into the fruit.

Air speed through the pallets was measured with an anemometer (Davis Instruments, Hayward, CA, USA) at the air exit of the pallet in the three layers of flats stated above.

Postharvest treatments

Strawberry pallets formed at the packing house in the different experiments were treated simulating normal postharvest conditions. Thus, strawberries were cooled with the HPFC cells or room cooled and, once fruits attained 2°C, they were immediately transferred to a refrigerated room at 2°C and stored for 3 days, simulating transport. After the transport period, fruits were moved to a 17°C room for 4 days to mimic retail conditions.

Quality evaluation

The following determinations were carried out with fruits at gathering, immediately after cooling by any of the different systems, after the 3 days at 2°C (transport), and after the retail period (shelf-life):

Firmness
Fifty fruits per treatment were taken for firmness. Firmness was measured as penetration force required to depress 2.4 mm into the fruit with a Zwick 3303 densimeter (Zwick Gmbh Co., Ulm, Germany), using a 5 mm plunger tip, and it is expressed as Newton (N)/cm^2.

Total soluble solids
Three replicates per treatment of ten berries each were homogenized in an Omni-mixer (Sorvall, Newton, USA) at high speed for 3 min. Homogenate was centrifuged at 27 000 g for 15 min, and the resulting supernatant vacuum-filtered through Whatman filter paper No. 1 (Maidstone, UK). This supernatant was used for determination of total soluble solids (TSS) by means of an Atago DBX-55 refractometer (Atago Co. Ltd, Tokyo, Japan).

Titrable acidity and pH
Titrable acidity (TA) was measured three times on 1 ml aliquots of the previous supernatant diluted with 25 ml

distilled water with a Crison automatic titrator (Crison Instruments, S.A., Barcelona, Spain) that measures the volume of 0.1 N NaOH required to reach pH 8.1. Results were expressed as per cent citric acid in terms of fresh weight. The pH was determined on the supernatant with a Crison 501 pH meter (Crison Instruments, S.A., Barcelona, Spain).

Marketable fruit loss

The incidence of postharvest losses was monitored by following the weight of 8 punnets per treatment along the commercial steps described above. After removing fruits with visible mycelial growth and/or at least one-third damaged surface, fruit were weighed and the marketable fruit percentage determined.

Colour assessment

Strawberry skin colour was evaluated with a Minolta CR-200 portable tristimulus colorimeter (Minolta, Ramsey Corp., NY, USA) using colour space L^*, a^*, b^*. Numerical values were converted into hue angle ($\tan^{-1}$ b^*/a^*) and chroma $[(a^{*2}+b^{*2})^{1/2}]$ (Francis, 1980). For this purpose two determinations at the strawberry equatorial zone were made on 30 fruits.

Sugars and organic acids determination

Major sugars and organic acids, including vitamin C, in the strawberries were determined in triplicate for each treatment according to Pérez *et al.* (1997). Ten strawberries were blended in the dark with 95% ethanol for 3 min at maximum speed with an Omni-mixer (Sorvall, Newtown, USA). The homogenate was vacuum-filtered through Whatman No. 1 filter paper and the residue washed twice with ethanol 80%. The filtrates were combined and adjusted to 5 ml/g FW with ethanol 80%. Ten millilitres of this ethanolic extract were evaporated in the dark to dryness at 50°C. The dry residue was redisolved in 1 ml of 0.2 N H_2SO_4 containing 0.05% EDTA, loaded onto a C_{18} Sep-Pak cartridge (Lida, Kenosha, USA), and eluted with up to 4 ml of the same solution. These extracts, containing sugars and organic acids, were filtered through 0.45 μm Nylon filters before HPLC analysis.

Sugars and organic acids were analyzed by HPLC in a Hewlett-Packard 1090 liquid chromatograph equipped with a photodiode array detector and a Waters 410 differential refractometer (Millipore) connected in series. Data were processed by means of a Hewlett-Packard 85-B computing system, and a Beckman Analogue Interface Module 406 and a Gold V.711 software, respectively. Isocratic separations of the compounds were made on a stainless steel Ion-300 (300 mm × 7.8 mm, 10 μm) column, containing a cation-exchange polymer in the ionic hydrogen form, with an IonGuard GC-801 guard column (Interaction, San Jose, USA), and thermostatized at 23°C. The mobile phase utilized for the elution consisted of a filtered (0.22 μm Nylon) and degassed solution of 0.0085 N H_2SO_4, and a flow rate of 0.4 ml/min. The UV detector was selected at 195 and 245 nm, and a refractive index detector was used at sensitivity 16×; the injection volume was 20 μl.

Atmosphere composition

Gas composition inside each basket was analysed during simulated transport and shelf-life. CO_2 and O_2 contents were analysed by a gas chromatograph, Hewlett-Packard 5890, equipped with a thermal conductivity detector, on a stainless steel Carbosieve S-II (3 m × 3 mm i.d.) column and helium as carrier gas.

Statistical analysis

A 5% level of least significant difference, calculated by Duncan's multiple range test, was employed to establish differences between means obtained for each quality parameter during the commercial stages.

RESULTS AND DISCUSSION

The results of the comparison of the three HPFC designs in terms of cooling speeds, and compared to room cooling, indicate that strawberries cool more rapidly in the V-type cell than in the other two HPFC designs, and, as was anticipated, than in room cooling (Fig. 1). Average times showed that, using the V-type cell, berries were cooled to 2°C in 1.75 h, 2.17 h with the N cell, and 3.17 h with the F cell, while it took 9 h to cool strawberries to 2°C by means of room cooling. These cooling speed differences among HPFC cells were a direct consequence of the air speed circulating through the product in each cell (Table 1). Thus, average air speed for the F cell was 0.50 m/s, less than half of that measured for the N cell (1.11 m/s), although that did not mean a half cooling time for the latter. The N cell took around 30% less time than the F cell to cool strawberries to 2°C. By the same token, berries cool slightly more rapidly in the V cell than in the N type. V cell air speed was around 20% higher than in the N cell, and it was able to cool the berries around 20% faster. These

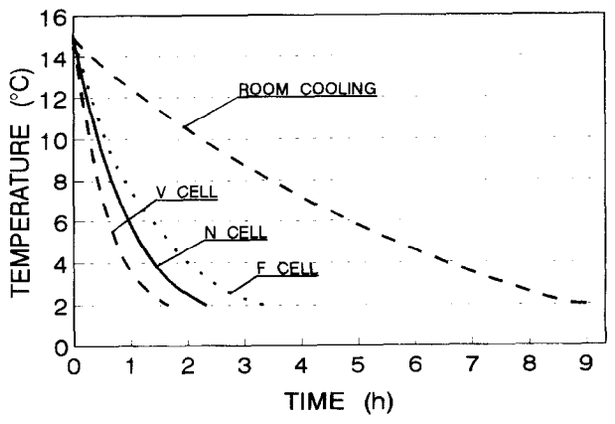

Fig. 1. Comparative cooling curves for HPFC cells and room-cooling with PVC-wrapped strawberries.

Table 1. Comparative air speeds through the product and along the pallet for the different HPFC cells

Position along the pallet	Air speed (m/s)		
	F cell	N cell	V cell
Top	0.50 ± 0.22	0.99 ± 0.24	1.30 ± 0.10
Centre	0.62 ± 0.15	1.28 ± 0.18	1.60 ± 0.10
Bottom	0.37 ± 0.17	1.06 ± 0.20	1.17 ± 0.15
Average	0.50 ± 0.19	1.11 ± 0.23	1.35 ± 0.22

results showed that reducing (by half) the ventilation spacer width results in an important decrease of cooling time within HPFC units, without affecting other cooling management parameters.

A study of the air speed through the product along the pallet showed that the centre of the pallets is favoured with a higher air pass in these HPFC units, and this is reflected in a slightly higher cooling speed in that zone (data not shown). On the other hand, data showed apparently less homogeneity for air speed, and cooling, along the pallet for the V cell than for the other two designs. Taking differences in air speed within the same cell as percentages of the average air speed, the V cell would be the most homogeneous with a maximum variation of 13.3%, against 15.3% and 26.0% for the N and F cells, respectively.

Berry temperatures throughout the pallet showed an increasing gradient in the air flow direction. Thermocouple readings, at the end of the cooling period, indicate a temperature difference between strawberries near the cooling air entrance and those near the cooling air exit of the pallet of 2.8 ± 1.0°C in the N cell, 4.2 ± 0.8°C for the F cell, and 3.4 ± 1.1°C in the case of the V cell. Although there were some differences among HPFC unit types, they were not significant so it can be assumed that there is an average temperature difference of 3.5°C between these two fruit positions. This is highly important from a cooling management point of view, since achievement of the end of cooling is usually determined manually at the hottest part of the pallet. Failure to consider this important management point will cause a high risk of freezing part of the fruit load.

Strawberries cooled by these HPFC units and by room cooling exhibited slight differences in quality after the cooling period itself, and during simulated transport and shelf-life. Figure 2 displays the changes of the major sugars, sucrose, glucose and fructose during these commercial stages. Sucrose content remained practically constant in those fruits cooled in N and F cells during transport, while those strawberries cooled in a V cell or room-cooled showed a slight decrease with respect to gathering values. This lowering in sucrose content was more evident after the 4-day shelf-life period, with a reduction of around 60% for fruits cooled in N and F cells, reaching 80% in fruits coming from a V cell or room-cooled. These data are consistent with our previous findings (Pérez *et al.*, 1996) showing that strawberry seems to continue its ripening process during shelf-life, in the same way as fruit still attached to the plant (Reyes *et al.*, 1982). In this sense, Ferreira *et al.* (1994) observed that anthocyanin synthesis continues after harvest in stored strawberries.

Concomitant with the decrease in sucrose content, an increase in glucose and fructose was observed in fruits cooled with the N and F cells, the inversion of sucrose into glucose and fructose being much clearer with the latter. Fruits coming from the N cell showed an increase in these monosaccharides after cooling and transport with, apparently, no decrease in sucrose levels. On the other hand, fruits cooled by a V cell or room-cooled presented a lower glucose and fructose content after transport and shelf-life, compared to gathering. This could indicate a net depletion of sugars in these fruits as a consequence of less retardation of ripening and senescence due to the cooler system used.

Changes in major organic acids, citric, malic, and ascorbic acids, during the commercial stages are shown in Fig. 3. Except for fruits cooled by the N cell, content of citric acid remained unchanged after cooling and simulated transport. Slight differences were noticed but they were not significant. Fruits from the N cell showed a reduction in the content of this acid that reached 30% after transport. At the end of shelf-life, fruits room-cooled or cooled by the N and F cells showed an increase in the citric acid content that, while not significant in room-cooled strawberries, is especially intense in fruits cooled by the F cell. On the other hand, fruits cooled by the V cell showed a decrease in the content of citric acid after the shelf-life period.

Generally speaking, malic acid content decreases sharply in overripe fruits whereas citric acid content decreases only slightly in fruits still attached to the plant. This is also true for strawberry, as was reported by Reyes *et al.* (1982), and it could give an idea of the degree of fruit ripeness. Malic acid content during the different commercial stages of this study showed this pattern but with some differences among coolers. Whereas in F cell fruits an increase in the content of malic acid was noticed after the cooling and transport periods, V cell strawberries remained almost unchanged, and fruits cooled by the N cell or room-cooled showed a decrease of around 30% in the content of this acid. The decrease in the content of malic acid is more evident during shelf-life in all cases, especially in fruits coming from a V cell whose content in this acid was almost completely depleted.

Ascorbic acid was included among the quality parameters evaluated for fruits and fruit products because of its nutritional value (Cano *et al.*, 1994; Gensler *et al.*, 1995). Ascorbic acid is quite unstable and is thus taken as an indication of fruit freshness. Oso Grande strawberries showed an average content of ascorbic acid at gathering of 36 mg/100 g. This low value is, however, in good agreement with those reported by Nunes *et al.* (1995) for this variety. Ascorbic acid content in

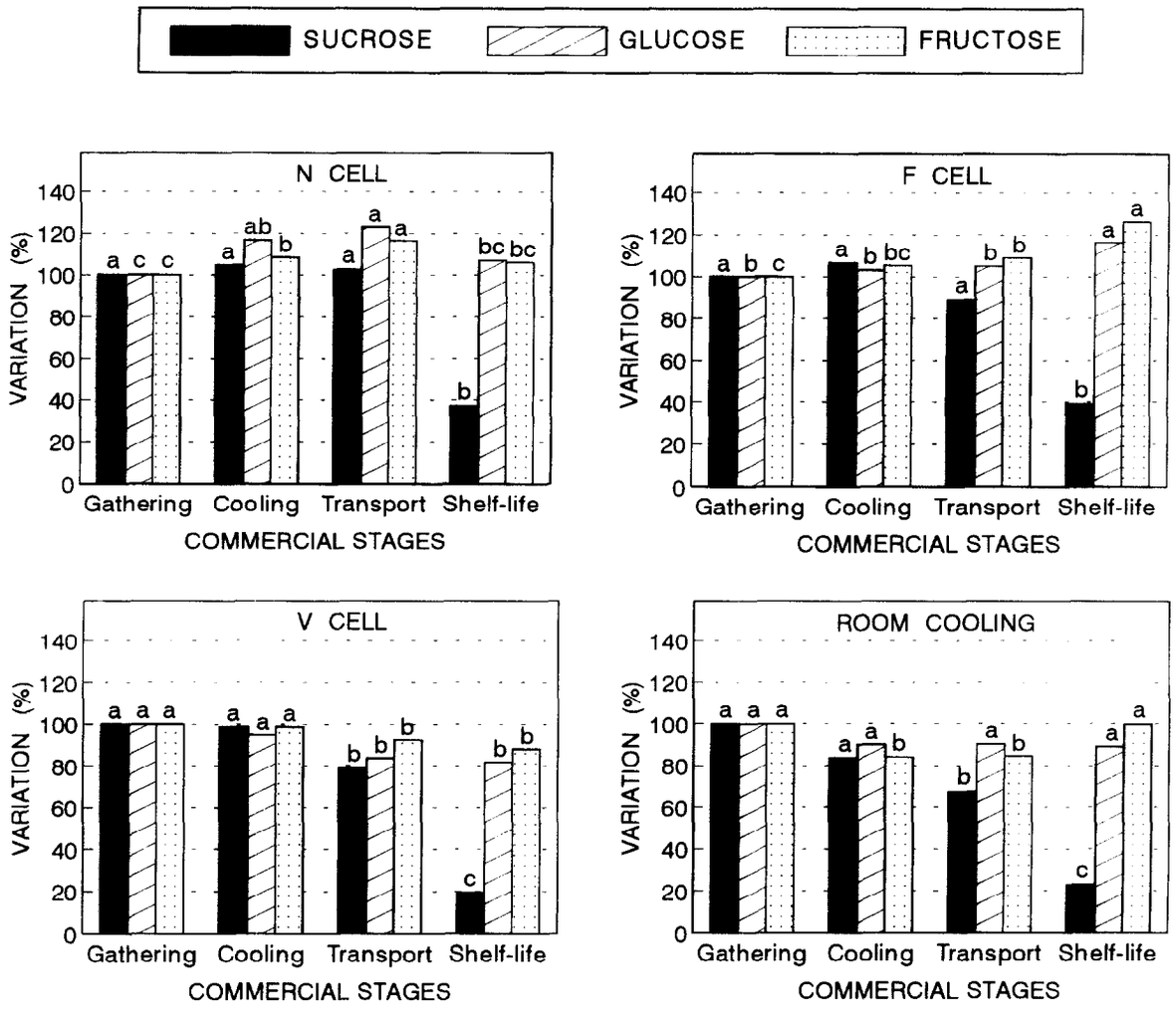

Fig. 2. Changes of major sugars in strawberries cooled by HPFC cells and room-cooling during the different commercial stages, compared to values at gathering (100%). Mean values at gathering were: sucrose 21.5 ± 2.58 mg/g FW, glucose 13.0 ± 1.40 mg/g FW, and fructose 13.6 ± 1.39 mg/g FW. For each parameter, bars with the same letter are not statistically different ($p < 0.05$).

strawberries cooled by the different HPFC cells or room-cooled showed a constant value with slight variations after cooling and simulated transport. However, after the shelf-life period, an increase in the content of this acid was observed in all cases except for V cell fruits, where a net degradation reaching 35% was detected. Conversely, N cell fruits showed an increase of more than 30% in the final content of ascorbic acid. Results obtained in this study were not due to water loss differences since fruits remained wrapped, so that the possible relationship between water activity and ascorbic acid degradation (Lee and Labuza, 1975; Fennema, 1985) does not apply in this case.

Measures of other quality parameters such as TA, TSS, pH and firmness showed no significant differences with the commercial stages and within the different strawberry coolers. Strawberry mean TA value at gathering was 0.95% citric acid and varied by 0.12% of this value during the study. Mean TSS content for Oso Grande strawberries at gathering was found to be 7.29°Brix, and this value varied by a maximum of ±0.53. Sugars and acids would be expected to constitute a major part of the TSS and TA, respectively. In this sense, very poor correlation values for TSS and total sugars ($r = 0.8$), and TA and organic acids ($r = 0.3$) were found (Pérez *et al.*, 1997). This had been previously observed by Shaw (1988), especially for total sugars and TSS, and may be explained by the different levels of soluble polyuronides depending on the degree of strawberry ripeness (Knee *et al.*, 1977; Huber, 1984).

As stated above, neither pH nor firmness showed any significant differences during this study. Average strawberry pH at gathering was 3.71, and values varied by ±0.29. Strawberry firmness exhibited a mean value of 17.26 N/cm^2 at gathering and it varied non-significantly by ±3.27 N/cm^2 during the commercial stages studied in all the coolers.

Strawberry colour changed with the cooling system used (HPFC or room-cooling) and even among the different HPFC units (Table 2). Colour of the fruits cooled by the N and F cells remained practically unchanged over the different commercial stages including the long period of shelf-life at 17°C. However, those strawberries cooled by means of a V cell displayed, after shelf-life, a

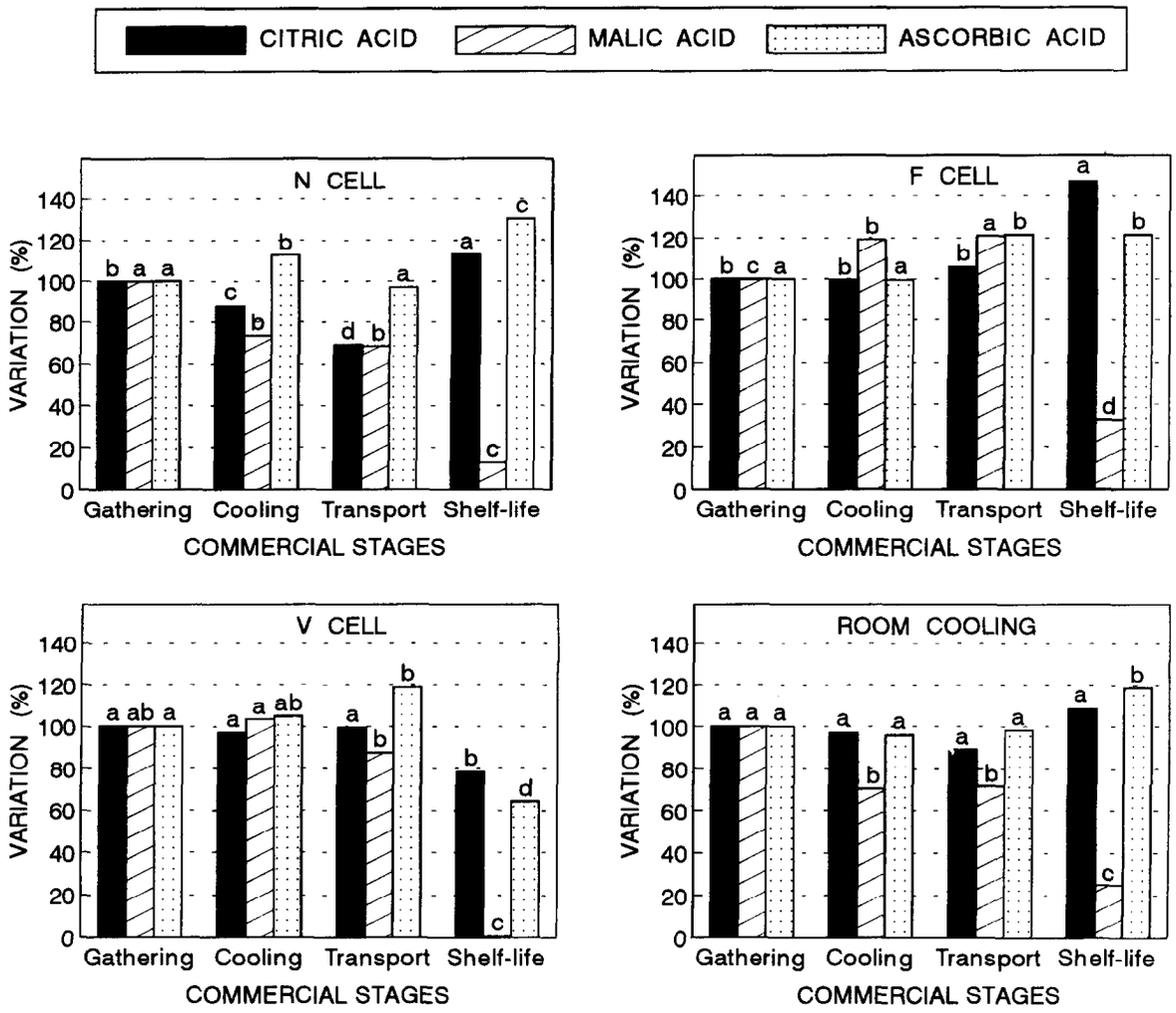

Fig. 3. Evolution of major organic acid contents in strawberries cooled by HPFC cells and room-cooling during the different commercial stages, and compared to values at gathering (100%). Mean values at gathering were: citric acid 7.42 ± 1.03 mg/g FW, malic acid 1.44 ± 0.17 mg/g FW, and ascorbic acid 0.36 ± 0.04 mg/g FW. For each parameter, bars with the same letter are not statistically different ($p < 0.05$).

lighter (higher L^* value), less red colour (higher hue value) with less redness (lower a^* value), than the same fruits at gathering before the cooling process. On the other hand, room-cooling of strawberries resulted in a reduced redness of fruits but with the apparent contradiction of a lower hue value (more red), which might be explained by the induction of oxidative browning in the fruits (Nunes *et al.*, 1995). Besides, these fruits presented a less intense colour (lower chroma value). Overall, room-cooling resulted in less attractive fruits that was manifest during the shelf-life period. Ke *et al.* (1991) reported a reduction in strawberry redness during storage at CO_2 concentrations higher than 20%, or very low O_2 levels (0.25%). These gas concentrations found in the internal atmosphere of the wrapped punnets during this work reached 3% CO_2 and 18% O_2 after simulated transport, and an average 15% and 8%, respectively, at the end of the shelf-life period. These percentages, clearly under the critical CO_2 concentration and above the minimum O_2 level found by Ke *et al.* (1991), allow us to conclude that no effect of the atmosphere composition was involved in colour development or chemical composition of strawberries in this study.

Finally, the unit used to cool strawberries seems to determine the fruit marketability percentage (Table 2). While there were no significant differences in marketable fruits between those strawberries cooled by the N or F cell, decreasing to around 37% at the end of the shelf-life period, V cell-cooled fruits suffered less wastage, with a final marketability value of 45%, but with a poorer fruit quality, as shown above. On the other hand, marketable fruits from room-cooling reached only an average of 15.37%. A correlation between strawberry cooling time and marketability is inferred from these results, which could be related to the same effect observed for precooling delays of strawberries (Mitchell *et al.*, 1964). It should be noted that our study was carried out under adverse climatic conditions, with heavy rainfall and fog, which gave rise to a high incidence of *Botrytis* rot (*Botrytis cinerea*) during shelf-life. This fungus was the main causative agent of the high spoilage found among fruits.

Table 2. Effects of different HPFC cell designs on strawberry colour and marketability and compared to room-cooled strawberries. Parameters were obtained at different commercial stages: fruit gathering at the facility, after cooling to 2°C, after 3 days at this temperature simulating transport, and after shelf-life for 4 days at 17°C

Cooling system	Stage	Marketable fruit (%)	Colour				
			*L**	*a**	*b**	Hue	Chroma
N cell	Gathering	100.0	33.05	31.41	19.94	32.41	37.20
	Cooling	100.0	32.10	29.83	17.83	30.87	34.75
	Transport	99.70	32.63	29.79	19.46	33.15	35.58
	Shelf-life	36.73	34.20	31.44	20.08	32.57	37.30
F cell	Gathering	100.00	32.55	31.07	21.82	35.08	37.96
	Cooling	100.00	33.85	31.45	20.91	33.62	37.96
	Transport	99.44	35.13	32.89	23.12	35.11	40.20
	Shelf-life	37.77	32.44	31.17	21.65	34.78	37.95
V cell	Gathering	100.00	32.87	30.92	21.07	34.27	37.42
	Cooling	100.00	31.32	30.60	20.31	33.57	36.73
	Transport	99.60	35.50	28.24	22.86	38.99	36.33
	Shelf-life	45.00	36.16	29.31	22.01	36.90	36.65
Room-cooling	Gathering	100.00	33.01	30.27	21.46	35.33	37.10
	Cooling	100.00	32.80	30.52	20.23	33.54	36.61
	Transport	99.70	33.88	30.38	21.65	35.48	37.30
	Shelf-life	15.37	32.14	23.04	15.40	33.76	27.71

Results from this research demonstrated, first that the new HPFC units that are being installed in south-western Spain, fulfil the short cooling time requirements needed by the strawberry facilities. It is important to note that the time factor is increasingly important in strawberry processing facilities due to the high volumes of produce that they manage each day. For a medium-sized packing house, this can reach a peak of 150 tons/day. This shortening in the strawberry cooling times seems to produce a better retention of quality chemical parameters, colour and marketability than fruits traditionally room-cooled. Contrary to what was expected, an excessive shortening of that cooling time gave rise to some quality problems, especially in terms of chemical composition, whilst maintaining comparatively high marketability. This effect could be due to a relatively high difference between skin and pulp temperatures that were not detected because the thermocouples were inserted 1.5 cm deep into the fruit. Problems related to freezing might be occurring in the strawberry surface that would explain the higher decrease in sucrose content in V cell-cooled fruits, in agreement with results reported by Skrede (1983) on sugar changes of frozen strawberries with thawing.

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REFERENCES

Boyette, M. D., Wilson, L. G. and Estes, E. A. (1989) Postharvest cooling and handling of strawberries. *N.C. Agric. Ext. Serv. Cir.* 413–412.

Cano, M. P., Torija, E., Marín, M. A. and Cámara, M. (1994) A simple ion-exchange chromatographic determination of non-volatile organic acids in some Spanish exotic fruits. *Z. Lebensm. Unter. Forsch.* **199**, 214–218.

Fennema, O. R. (Ed.) (1985) In *Food Chemistry*, 2nd edn, pp. 488–493. Marcel Dekker, New York, NY.

Ferreira, M. D., Brecht, J. K., Sargent, S. A. and Aracena, J. J. (1994) Physiological responses of strawberry to film wrapping and precooling methods. *Proc. Florida State Hort. Soc.* **107**, 265–269.

Francis, F. J. (1980) Colour quality evaluation of horticultural crops. *HortScience* **15**, 58–59.

Gensler, M., Rossman, A. and Schmidt, H. L. (1995) Detection of added L-ascorbic acid in fruit juices by isotope ratio mass spectrometry. *J. Agric. Food Chem.* **43**, 2662–2666.

Guillou, R. (1960) Coolers for fruits and vegetables. *Calif. Agr. Exp. Sta. Bull.* 773.

Harvey, J. M. and Harris C. M. (1973) Strawberry-market quality in relation to postharvest handling and shipping practices. In *ASHRAE Symp.* LO-73-7, pp. 5–9. Am. Soc. Heating Refrig. Air Condit., UK.

Hening, Y. S. and Gilbert, S. G. (1975) Computer analysis of the variables affecting respiration and quality of produce packaged in polymeric films. *J. Food Sci.* **40**, 1033–1035.

Huber, D. J. (1984) Strawberry fruit softening: the potential roles of polyuronides and hemicelluloses. *J. Food Sci.* **49**, 1310–1315.

Kader, A. A. (1992) Postharvest biology and technology: an overview. In *Postharvest Technology of Horticultural Crops*, ed. A. A. Kader, pp. 15–20. Univ. Calif., Div. Agric. Nat. Resour., Publ. 3311, Davis.

Ke, D., Goldstein, L., O'Mahony, M. and Kader, A. A. (1991) Effects of short-term exposure to low O_2 and high CO_2 atmospheres on quality attributes of strawberries. *J. Food Sci.* **56**, 50–54.

Knee, M., Sargent, J. A. and Osborne, D. J. (1977) Cell wall metabolism in developing strawberry fruits. *J. Exp. Bot.* **28**, 377–396.

Lee, S. H. and Labuza, T. P. (1975) Destruction of ascorbic acid as a function of water activity. *J. Food Sci.* **40**, 370–373.

Mitchell, F. G., Maxie, E. C. and Greathead, A. S. (1964) Handling strawberries for fresh market. *Univ. Calif. Agric. Exp. Sta. Cir.* 527.

Nunes, M. C. M., Brecht, J. K., Morais, A. M. M. B. and Sargent, S. A. (1995) Physical and chemical quality characteristics of strawberries after storage are reduced by a short delay to cooling. *Postharv. Biol. Technol.* **6**, 17–28.

Pérez, A. G., Olías, R., Espada, J., Olías, J. M. and Sanz, C. (1997) Rapid determination of sugars, nonvolatile acids, and ascorbic acid in strawberry and other fruits. *J. Agric. Food Chem.* **45**, 3545–3549.

Pérez, A. G., Olías, R., Olías, J. M. and Sanz, C. (1996) Furanones in strawberries: evolution during ripening and postharvest shelf life. *J. Agric. Food Chem.* **44**, 3620–3624.

Reyes, F. G. R., Wrolstad, R. E. and Cornwell, C. J. (1982) Comparison of enzymic, gas–liquid chromatographic, and high performance liquid chromatographic methods for determining sugars and organic acids in strawberries at three stages of maturity. *J. Assoc. Off. Anal. Chem.* **65**, 126–131.

Robinson, J. E., Browne, K. M. and Burton, W. G. (1975) Storage characteristics of some vegetables and soft fruits. *Ann. Appl. Biol.* **81**, 399–408.

Shaw, D. V. (1988) Genotypic variation and genotypic correlations for sugars and organic acids of strawberries. *J. Am. Soc. Hortic. Sci.* **113**, 770–774.

Skrede, G. (1983) Changes in sucrose, fructose, and glucose content of frozen strawberries with thawing. *J. Food Sci.* **48**, 1094–1096.

Talbot, M. T. and Chau, K. V. (1991). Precooling strawberries. *Florida Coop. Ext. Ser.-IFAS, Univ. Fla. Cir.* 942.