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Effects of precooling, packaging film, modified atmosphere and ethylene absorber on the quality of refrigerated Chandler and Douglas strawberries

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Cellophane and polyethylene packaging in conjunction with precooling, a modified atmosphere and an ethylene absorber were tested in order to obtain a more extended postharvest life of strawberry Chandler and Douglas cultivars. Treatment had a significant influence on all the physical and chemical characteristics investigated. Low density polyethylene bags with or without a CO_2 atmosphere resulted in the lowest weight losses, conductivity and degree of fruit decay, together with the highest firmness values. The use of an ethylene absorber constituted an additional cost without a proven benefit.

INTRODUCTION

Strawberries (*Fragaria ananassa*) are highly perishable fruits. Their short postharvest life is due to fungal infections caused by *Botrytis cinerea* and *Rhizopus* spp. (Maas, 1981) and to rapid fruit and calix desiccation (Aharoni & Barkai-Golan, 1987). The prevention of postharvest decay and quality losses would provide a more extended period for export and domestic consumption. The most prevalent method of maintaining quality and controlling decay of strawberries is by rapid cooling after harvest followed by storage at low temperatures, typically 1°C, with a high relative humidity (Browne *et al.*, 1984).

Strawberries tolerate the use of CO_2-enriched atmospheres in the control of decay (El-Kazzaz *et al.*, 1983). However, prolonged exposure to CO_2 may cause off-flavour development (Woodward & Topping, 1972).

Modified atmosphere packaging in conjunction with low temperature storage has been recognized as a promising and inexpensive technique for improving the shelf life of fresh fruits and vegetables while minimizing product quality impairment, weight losses and microbial spoilage (Zagory & Kader, 1988; Wills *et al.*, 1989).

There is a lack of information on postharvest changes in Chandler and Douglas strawberry cultivars under different storage conditions. The objective of our study was to evaluate the most adequate postharvest storage conditions required to maintain the quality of Chandler and Douglas strawberries for 11 days at 2°C.

MATERIALS AND METHODS

Fruit

Strawberries were Chandler and Douglas cultivars (cv.) obtained on the day of harvest from local producers at Alginet (Valencia, Spain). Fruits were collected in polystyrene baskets with a capacity of 500 g strawberries.

Packing films

Two different types of packaging films were used. Perforated cellophane sheets (CS) were placed on top of the baskets and fixed with elastic bands. Low density polyethylene bags (PB) were heat-sealed after introducing one or more baskets per bag.

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Ethylene absorber

Sachets containing a natural porous clay (1·5 g per sachet), coated with $KMnO_4$, were used as the ethylene absorber (EA). Volatile compounds absorbed by the clay react with $KMnO_4$, yielding CO_2 and water.

Postharvest treatments

Strawberries were subjected to the following treatments: for CS, baskets were covered with perforated cellophane sheets and stored in a cold room at 2°C; for CS + PC (precooling), baskets covered with perforated cellophane sheets were precooled by forced air at 2·5°C and 5 m/s, which lowered the temperature from 18 to 4°C in 1 h, and were stored at 2°C; PB, one basket was introduced into each polyethylene bag and stored at 2°C; for PB + CO_2, six baskets were introduced into each polyethylene bag, CO_2 was flushed until a 15% concentration measured with an Icare model Ducalix 31 201 Pl portable apparatus (Icare, Madrid, Spain) was reached, and baskets were stored at 2°C; for PB + EA, one basket was introduced to each polyethylene bag together with two ethylene absorber sachets and stored at 2°C; as control, untreated strawberry baskets were placed in a cold room at 2°C.

Quality evaluation

The following determinations were carried out for each treatment and variety.

Weight losses
They were estimated after storage by weighing 12 baskets with a 0·01 g accuracy.

Colour intensity
This was measured on 50 randomly chosen fruits with a Minolta portable colorimeter (Minolta, Madrid, Spain), using the 'a', 'b' and 'L' coordinates of the Hunter Lab system. Higher 'a' values indicate a more intense red colour.

Firmness
This was measured as the force (kg) needed to produce a deformation of 2 mm with an Instron universal testing machine model 4301 (Instron Corp., Canton, MA), using a 35 mm diameter plate (Del Río *et al.*, 1987) on 20 randomly chosen fruits.

Electrical conductivity
This was measured with a Crison 523 portable conductimeter (Crison, Barcelona, Spain) on 20 randomly chosen fruits in two opposite points per fruit.

Soluble solids content
This was measured (three replicates) with an Abbe refractometer (Pzo, Warsaw, Poland) on the supernatant (15 000 *g* for 15 min) of a purée made from sliced strawberries.

Titratable acidity and pH
Titratable acidity was determined on 5 ml of the previous supernatant,diluted in 145 ml of deionized water, by titration with 0·1 N NaOH to an end-point of pH 8·1, and expressed as g citric acid/100 g fruit. The pH was measured on the supernatant with a Crison digital 501 pH meter (Crison, Barcelona, Spain).

Anthocyanin content
This was determined after extraction with acidified ethanol from a 2 g aliquot of a fresh homogenate, according to the procedure of Morris *et al.* (1985).

Bruising and decay evaluation
This was performed on 100 randomly chosen fruits, which were examined and classified as healthy fruit (0); slightly injured (1), if less than 25% of the surface was affected; and injured (2), if more than 25% of the surface was affected. Strawberries were considered as putrefied if fungal mycelia and/or brown tonalities were found in the injured zones.

Gaseous composition
Carbon dioxide, O_2 and N_2 contents were analysed by injecting 1 ml headspace gas into a gas chromatograph (model 5830 A, Hewlett-Packard, Santa Clara, CA) equipped with a 120 mm, $^1/_8$ in (3·2 mm) diameter Poropack Qs 80 100 column and a thermal conductivity detector. Helium was the carrier gas. Injector, oven and detector temperatures were 115, 36 and 150°C, respectively. Ethylene was determined by injecting 1 ml of headspace gas into a gas chromatograph (model 8500, Hewlett-Packard, Santa Clara, CA) equipped with a flame ionization detector and an activated alumina column held at 80°C, with N_2 as carrier gas.

Ascorbic acid determination
Samples (three replicates per treatment) were prepared according to Ashoor *et al.* (1984). They were analysed by HPLC in a Hewlett-Packard chromatograph (model 1084 B) equipped with a spectrophotometric detector and a 200 mm RP-18 column held at 30°C, using 0·2 M $KHCO_3$ as the mobile phase. The retention time was 1·54 min. Results were expressed as mg/100 g fruit.

Statistical analysis

Data were subjected to analysis of variance. Least significant difference at the 1 or 5% level was used for comparison of means.

RESULTS AND DISCUSSION

Changes in physical characteristics

The effects of different treatments on the physical characteristics investigated are shown in Table 1. The highest weight losses were obtained in both cultivars for control strawberries. Berries packed in PB with or

Table 1. Changes in physical characteristics of strawberry Chandler and Douglas cultivars after storage for 11 days under different conditions.

Characteristic	Cultivar	0 days	11 days					
			CS	CS + PC	PB	PB + CO_2	PB + EA	Control
Weight losses (%)	Chandler	—	2·63[b]	2·62[b]	0·34[b]	0·31[b]	0·52[b]	4·11
	Douglas	—	2·83[b]	3·11[b]	0·31[b]	0·31[b]	0·57[b]	4·20
Colour ('a')	Chandler	27·93	28·05	27·24	29·79	28·32	29·01	28·08
	Douglas	28·12	28·35[b]	25·10[a]	28·93[b]	28·30[b]	26·52	25·88
Firmness (kg)	Chandler	0·216	0·225	0·240	0·251	0·268[a]	0·293[ab]	0·236
	Douglas	0·0221	0·170[a]	0·199	0·203	0·255[b]	0·216	0·203
Conductivity (mS)	Chandler	0·21	0·18[a]	0·15[ab]	0·14[ab]	0·15[ab]	0·16[a]	0·17[a]
	Douglas	0·18	0·23[a]	0·21[a]	0·18[b]	0·21[a]	0·23[a]	0·22[a]
Bruising	Chandler	—	1·33	1·18	0·75[b]	0·80[b]	0·80[b]	1·40
	Douglas	—	1·44	0·62[b]	0·79[b]	0·85[b]	1·14	1·29

CS, cellophane sheets; PC, precooling; PB, polyethylene bags; EA, ethylene absorber.
[a] Significantly (P<0·01) different from the initial (0 days) value.
[b] Significantly (P<0·01) different from 11 days control strawberries.

without CO_2 or EA exhibited minor weight losses. These results are in agreement with those obtained by Aharoni & Barkai-Golan (1987) and Guichard *et al.* (1992).

The 'a' value at 0 days was 27·93 for Chandler cv. and 28·12 for Douglas cv. No significant differences from the initial value were found after storage of Chandler cv. during 11 days for control strawberries or for any of the treatments. However, a significant increase during storage of Douglas cv. was observed for CS, PB and PB + CO_2 treatments. No treatment differed significantly from the control in Chandler cv. strawberries. Significantly higher 'a' values than the control were found for CS, PB and PB + CO_2 treatments in Douglas cv. The 'a' values previously obtained (Spayd & Morris, 1981; Morris *et al.*, 1985; Li & Kader, 1989; Ke *et al.*, 1991) were higher than ours, a fact which may be explained by the different cultivars investigated.

The firmest Chandler cv. strawberries after 11 days were obtained with treatment PB + EA. Their firmness was significantly higher than that of 0 day strawberries (0·216) and than firmness of control strawberries after 11 days. The highest firmness of Douglas cv. strawberries after 11 days was recorded for PB + CO_2 treatment, significantly higher than the initial value (0·221) and than that of control berries after storage. El-Kazzaz *et al.* (1983) obtained similar results with G-3 and G-4 berries stored under air + 15% CO_2 for 7 and 21 days. Ke *et al.* (1991) had more pronounced effects on retarding softening with berries stored under 20% CO_2. Aharoni & Barkai-Golan (1987) obtained the best firmness scores in sensorial evaluation for PB strawberries. Berries stored with EA were the most resistant to penetration, according to the results of De la Plaza & Merodio (1987).

All treatments resulted in conductivity values of Chandler cv. significantly lower than the initial value (0·21). Oppositely, Douglas berries' conductivity after 11 days was in most cases significantly higher than the initial value (0·18). In Chandler cv. CS + PC, PB, PB + CO_2 and PB + EA strawberries showed a lower conductivity than the control, whereas in Douglas cv. the only significant difference found was between PB strawberries and the control. Couture & Willemont (1989) found a minor increment in the conductivity of berries under modified atmosphere (10% CO_2 and 5% O_2) during the first days of storage, but after 10 days the value was similar to that of the control.

The best results regarding bruising and decay evaluation were obtained with PB, PB + CO_2 and PB + EA treatments for Chandler cv. and with CS + PC, PB and PB + CO_2 treatments for Douglas cv., scores being significantly lower than those of the control. These results are in agreement with data obtained by Aharoni & Barkai-Golan (1987) for Aliso berries wrapped in PVC and held for 10 days at 2°C plus 2 days at 20°C. Browne *et al.* (1984) also observed a slight decay in Cambridge Favourite berries wrapped in PB with 3, 5 and 10% CO_2 after 6 days at 2°C.

Putrefied berries were only found for Chandler cv. in control (1 out of 100) and CS (1 out of 100) and for Douglas cv. in CS (3 out of 100) and PB (1 out of 100). El-Kazzaz *et al.* (1983) did not find *B. cinerea* spoilage in air + 15% CO_2. Barkai-Golan *et al.* (1983) found considerably lower incidence of fungal spoilage after 8–10 days for berries wrapped in PB or PVC at 2°C under 7·5 to 12% CO_2, a result which could be explained by senescence delay.

Changes in chemical characteristics

The soluble solids content of both varieties (Table 2) decreased during storage for most postharvest treatments as compared to the respective initial values (10·08 for Chandler cv. and 9·58 for Douglas cv.), with the only exception being, PB + EA strawberries. The only significant difference between treatments and control after 11 days was that found for PB + EA berries in Douglas cv.

The acidity of Chandler cv. decreased significantly during storage from an initial value of 0·91 with treat-

Table 2. Changes in chemical characteristics of strawberry Chandler and Douglas varieties after storage for 11 days under different conditions

Characteristic	Cultivar	0 days	11 days					
			CS	CS+PC	PB	PB+CO_2	PB+EA	Control
Soluble solids (°Brix)	Chandler	10·08	9·30[b]	9·23[b]	9·30[b]	9·10[a]	9·55	9·80
	Douglas	9·58	8·10[a]	8·03[a]	8·47[a]	7·63[a]	9·57[c]	8·20[a]
Acidity	Chandler	0·91	0·86	0·85[b]	0·78[ac]	0·87	0·83[ad]	0·89
	Douglas	1·03	0·94[ac]	1·04	0·87[ac]	1·00[d]	0·96[ac]	1·06
pH	Chandler	3·19	2·98[a]	2·98[a]	2·98[a]	2·90[a]	3·01[a]	2·97[a]
	Douglas	3·30	3·00[a]	2·94[a]	3·03[a]	2·99[a]	3·01[a]	2·99[a]
Anthocyanins (UA/g)	Chandler	22·0	23·5[ac]	25·2[ac]	26·8[ac]	20·7[ac]	24·5[a]	24·3[a]
	Douglas	24·9	24·4[ac]	27·1[ac]	21·1[ac]	15·5[ac]	23·1[ac]	25·8[a]
Ascorbic acid (mg/100 g)	Chandler	n.d.	20·68	15·90	21·64	12·99	27·28	18·76
	Douglas	n.d.	17·33	12·06	20·06	19·88	18·55	15·32

CS, cellophane sheets; PC, precooling; PB, polyethylene bags; EA, ethylene absorber.
[a] Significantly ($P < 0·01$) different from the initial (0 days) value.
[b] Significantly ($P < 0·05$) different from the initial (0 days) value.
[c] Significantly ($P < 0·01$) different from 11 days control strawberries.
[d] Significantly ($P < 0·05$) different from 11 days control strawberries.
n.d. = not determined.

ments CS + PC, PB and PB + EA, whereas in Douglas cv. (initial value 1·03) significant decreases were recorded for CS, PB and PB + EA treatments. PB treatment resulted in the lowest acidity for both cultivars. A significant decline in pH during storage was recorded in both cultivars for all treatments and for the control, with significantly lower values than at 0 days (3·19 for Chandler cv. and 3·30 for Douglas cv.). Moulton (1947) did not obtain significant differences between Robinson berries wrapped in cellophane, pliofilm or cellulose acetate and held for 4 days at 4°C. Spayd & Morris (1981) found a decrease in acidity and an increase in pH value for Cardinal and A-5344 berries as they matured. Morris *et al.* (1985) found a pH increase in Cardinal and Sunrise berries held 4 days at 4°C and 4 days at 4°C plus 2 days at 21°C, whereas Li & Kader (1989) and Ke *et al.* (1991) did not find significant differences between Selva berries stored in various controlled atmospheres.

Anthocyanins increased during storage of Chandler cv. for most treatments, the only exception being PB + CO_2 berries which, after 11 days, had an anthocyanin content lower than the initial value (22·0). In Douglas cv. only CS+PC and the control resulted in a higher anthocyanin level than the initial value (24·9). PB + CO_2 treatment retarded colour development in both cultivars, in agreement with results previously obtained for other cultivars (Woodward & Topping, 1972; Li & Kader, 1989; Ke *et al.*, 1991; Guichard *et al.*, 1992). El-Kazzaz *et al.* (1983) pointed out the presence of off-flavours in strawberries stored at high CO_2 concentrations. No off-flavours were found in our trials.

No significant differences in ascorbic acid content between treatments were found after storage. Moulton (1947) and Hudson *et al.* (1985) obtained higher values than ours, maybe due to the method of analysis or to the cultivar investigated. Li & Kader (1989) did not find significant differences in ascorbic acid content between strawberries stored in various controlled atmospheres.

The concentrations of O_2, CO_2, N_2 and ethylene in the head space of strawberries after storage are shown in Table 3. Carbon dioxide content in PB + EA strawberries was similar to the level found for PB treatment, in disagreement with previously published results (De la Plaza & Merodio, 1987). Aharoni & Barkai-Golan (1987) found only 1·9% CO_2 for berries wrapped in 18 μm thick PVC during 10 days at 2°C. Ethylene traces were detected in our experiments for PB treatments with or without CO_2, but not for PB + EA berries.

Table 3. Gas composition (%) of the headspace of baskets of strawberry Chandler and Douglas cultivars after storage for 11 days under different conditions

Gas	Cultivar	PB	PB + CO_2	PB + EA
CO_2	Chandler	6·9	13·3	5·6
	Douglas	6·8	16·3	6·2
O_2	Chandler	14·0	11·2	16·0
	Douglas	13·9	8·9	14·6
N_2	Chandler	79·1	75·5	78·4
	Douglas	79·3	74·8	79·2
C_2H_4	Chandler	Trace	Trace	ND
	Douglas	Trace	Trace	ND

ND = not detected.

Optimum storage conditions for Chandler and Douglas cultivars

The significance of the main effects shown in Table 4 indicates that treatment had a considerable ($P<0·01$) influence on all characteristics investigated. Cultivar also had a significant influence on most characteristics. However, weight losses, bruising and pH behaved in a similar way for Chandler and Douglas cultivars.

Table 4. Significance determined by analysis of variance of the main effects (treatment and cultivar) and their interaction T × C on characteristics studied after storage of strawberry Chandler and Douglas cultivars for 11 days under different conditions.

Characteristic	Treatment	Cultivar	T × C
Weight losses	**	NS	NS
Colour	**	**	**
Firmness	**	**	NS
Conductivity	**	**	**
Bruising	**	NS	**
Soluble solids	**	**	**
Acidity	**	**	NS
pH	**	NS	NS
Anthocyanins	**	**	**
Ascorbic acid	**	*	*

$*P<0{\cdot}05$; $**P<0{\cdot}1$; NS = nonsignificant.

Significant interactions treatment × cultivar were recorded for some of the variables investigated.

It may be concluded from our data that PB treatments generally resulted in the lowest weight losses, conductivity and bruising score and the highest firmness value.

PB + CO_2 berries exhibited the lowest soluble solids value and anthocyanins content. The low soluble solids value, due to the fermentation process, was not related to the presence of off-flavour.

The use of the ethylene absorber gave rise, in PB + EA strawberries, to neither an improvement in the studied characteristics nor to an increase in CO_2 concentration. It constituted an additional cost without a proven benefit.

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