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Modified atmosphere packaging affects the incidence of cold storage disorders and keeps 'flat' peach quality

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Firm-breaker and firm-mature flat peaches (*Prunus persica* L. Bastch cultivar 'Paraguayo') were stored in air for 10 days at 20°C, or precooled and sealed in either one of two unperforated or one macroperforated polypropylene film for 14 or 21 days at 2°C. The atmosphere inside the macroperforated film bags remained close to the composition of air during storage. In unperforated bags, steady state atmospheres were reached within 6 and 9 days: firm-breaker fruit (12% CO_2 and 4% O_2 in standard type polypropylene, 23% CO_2 and 2% O_2 in oriented type polypropylene); firm-mature fruit (22% CO_2 and 3% O_2 in standard polypropylene and 21% CO_2 and 2% O_2 in oriented polypropylene). After 14 days storage plus a 3-day shelf-life test, woolliness and slight internal browning developed in fruit stored in macroperforated polypropylene. Ethanol and acetaldehyde accumulated to higher levels in oriented polypropylene bags for both firm-breaker and firm-mature fruit. Modified atmospheres in both unperforated bags were associated with lower weight loss, less senescence and chilling injury, absence of decay, and delayed ripening changes of the fruit after a shelf-life period. © 1999 Canadian Institute of Food Science and Technology. Published by Elsevier Science Ltd. All rights reserved

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INTRODUCTION

Storage of peaches at low, non-freezing, temperatures is limited due to the development of chilling injuries (CI) such as internal and external browning, flesh breakdown, woolliness, reddish discoloration, loss of ability to ripen and increased incidence of decay (Lurie, 1993; Crisosto *et al*., 1995; Artés *et al*., 1996; Fernández-Trujillo and Artés, 1997*a*,*b*). In 'Paraguavo' peaches, lower susceptibility to Cl has been associated with storage of fruit more advanced in maturity (Fernández-Trujillo and Artés, 1997*b*).

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The tolerance range of gas concentrations has not been completely established for different peach cultivars. Low O_2 concentrations in absence of high CO_2 have limited or no benefit in reducing fungal growth in stone fruits, while levels of 10% CO_2 or more are required to significantly suppress fungal growth (El-Goorani and Sommer, 1981). In peaches and nectarines, a CO_2 concentration of 5% or more during storage at around 1°C is required to delay the onset of Cl (Lill *et al*., 1989; Zoffoli *et al*., 1997).

At any temperature and storage duration, the tolerance to high CO_2 increases when O_2 concentration increases (Kader *et al*., 1989). For some commodities, susceptibility to low O_2 and/or high CO_2 stress is influenced both by maturity stage and storage temperature (Kader *et al*., 1989; Ke *et al*., 1991*a*, 1994). Mature peaches are more susceptible to low O_2 atmospheres than immature ones (Ke *et al*., 1994). Thus, low storage

temperatures (0 to 2°C) combined with high CO_2/low O_2, atmospheres can delay normal ripening (Fernández-Trujillo and Artés, 1997*a*, 1998*a*) potentially enhancing Cl. Intolerance to these conditions is associated with accumulation of anaerobic volatiles, development of off-flavors and in some cases internal browning (Ke *et al*., 1994; Folchi *et al*., 1995; Zoffoli et al., 1997; Lurie and Aharoni, 1998).

There is a renewed interest in application of modified atmosphere packaging (MAP) for storage of stone fruits (Chambroy and Souty, 1995). Injurious levels of CO_2 and O_2 under MAP conditions have been established as greater than 10% for CO_2 and/or less than 1–2% for O_2 particularly if these levels are reached within 14 days of cold storage (Lill *et al*., 1989; Lurie and Aharoni. 1998). High CO_2 concentrations (5–20%) with or without low O_2 levels reduce the severity of Cl symptoms either in controlled atmospheres and MAP (Lurie, 1993; Zoffoli *et al*., 1997; Lurie and Aharoni, 1998). Macroperforated and unperforated polypropylene films maintain high quality of firm-breaker 'Paraguavo' peaches stored at 0.5 °C (Fernández-Trujillo and Artés, 1997*a*, 1998*a*). CI can be controlled when stored in macroperforated films at this temperature (Fernández-Trujillo and Artés, 1998*b*). An added benefit of storing peaches under high CO_2 and low O_2 in unperforated films is the suppression of fungal growth (Fernández-Trujillo *et al*., 1997).

Despite chilling sensitivity, peaches are often stored at 2°C or less during storage and transport to minimize the rate of perishability (Lill *et al*., 1989; Crisosto *et al*., 1995). Gradients within cold rooms impose a risk of fruit freezing injury in areas close to evaporators that are below 0°C. This risk partly explains why temperatures near 2°C are preferred by shipping cooperatives in Spain. Additionally, fruit of advanced maturity are preferred for immediate consumption (Fernández-Trujillo and Artés, 1997*b*). Thus, our objective was to study the effect of polymeric films with different gas permeabilities on peaches harvested at two maturity stages and stored at 2°C in order to improve fruit quality on a commercial scale.

MATERIALS AND METHODS

Plant material and experimental design

Mid-season flat peaches (*Prunus persica* L. Batsch cultivar 'Paraguayo') were harvested from a commercial orchard in Cieza (Murcia) and transported by ventilated car 5 km to a packinghouse, where they were sorted and selected for uniform size, appearance and freedom from defects. According to flesh firmness and peel ground color at harvest (mean ± SE. $n = 1,5$), peaches were classified as firm-breaker (FB: 95 ± 4 N and hue angle of 100.4 ± 1.2°) and firm-mature (FM: 53 ± 3 N and hue angle of 94.9 ± 2.5°). Both fruit types were preclimacteric (Fernández-Trujillo and Artés, 1997*b*).

Sound fruits were immediately transported by car to the laboratory in Murcia (35 km from Cieza). Six units of 20 fruits (three for analysis of quality parameters and hedonic testing and three for disorder inspection) were kept at 20°C (normal postharvest ripening). The remaining fruit were forced-air cooled to reach stone temperatures of 5 °C within 5 h and 2°C with 12 h. The following morning, the peaches of both maturity stages were randomly divided into experimental units of six fruits each (approximately 0.5 kg per bag of dimensions 33×15 cm). and scaled in polymeric film bags. Three polymeric films were used: PPP (non-oriented macroperforated polypropylene; 33 holes of 2 mm diameter per square dm., 40 μm thickness), SPP (non-oriented standard polypropylene; 40 μm thickness), and OPP (biaxially oriented polypropylene; 42.5 ± 3.8 μm thickness). SPP is a non-oriented film obtained by coextrusion from cast system with polypropylene as raw material and was supplied by Plásticos del Segura (Murcia, Spain). Water vapor transmission (mean ± SD) specifications were the following: (all in nmol $m^{-2} s^{-1}$) 2186 ± 60 for SPP and 57.9 ± 0.6 for OPP. For SPP gas permeabilities were (all in pmol $s^{-1} m^{-2} Pa^{-1}$):37.3 for CO_2 18.2 for O_2 (at 23°C). The specifications of the OPP film gas permeabilities as provided by the supplier (Derprosa, Spain). were: (all in pmol $s^{-2} m^{-1} Pa^{-1}$) 5.5 ± 0.11 for CO_2 and 1.4 ± 0.07 for O_2 (at 5°C). Storage conditions were 2.0 ± 0.5°C, 90–95% relative humidity (RH). Fruit samples were inspected (destructive assays) after 14 or 21 days of storage either before or after additional shelf-life testing of 3 days at 20°C and 70–75% RH, when the bags were opened. Six bags were used for quality analysis of every maturity stage×storage time×polymer film treatment 6 (120 bags in total). O_2, CO_2 and other gases, in five bags used only for this purpose, were measured for every maturity stage×polymer film treatment during 14 days of storage (30 bags in total).

Gas analysis

O_2 and CO_2 were monitored for 14 days by gas chromatography using 1-ml samples taken from each maturity×bag. Because of the known co-elution of argon and O_2 during gas chromatography, analysis, O_2 concentrations were reduced by 0.9% (the concentration of argon previously calculated in air). After 14 days, ethanol, acetaldehyde (1-ml samples) and ethylene (5-ml samples) concentrations were also assessed. For gas chromatography, a Perkin–Elmer Autosystem gas chromatograph, equipped with thermal conductivity (TCD) and flame ionization (FID) detectors with their respective Porapak QS 80/100 columns (1.2 m×3.18 i.d.), coupled to a Pe1020 recorder integrator (Norwalk, USA), was used. The system used a 10-port valve (Supelco Inc., PA). The sample was injected onto column 1 and held 0.5 min, to allow the composite peak of

air to pass onto column 2 (one position of the valve). Then the valve was switched back to its second position and the column sequence was reversed to allow CO_2 to pass to the detector (peak around 1 min), followed by O_2 (peak around 2.7 min.) and N_2. Oven, injector and FID temperatures for O_2 and CO_2 were 35, 115 and 150°C, respectively, 50, 115 and 175°C, respectively, for ethylene and 150, 175 and 250°C for ethanol and acetaldehyde. Gas flows were 18.4 ml min^{-1} for He, 80 ml min^{-1} for H_2 and 300 ml min^{-1} for air. Analysis was calibrated by chromatography of vapor samples prepared by injection of 1 ml of standard solutions of ethanol and acetaldehyde at 2°C into a 0.62-1 jar. For CO_2, O_2 and C_2H_4, gases of known standards in cylinders were used.

Quality attributes analysis

After 14 days and after subsequent shelf-life testing, total soluble solids (TSS). titratable acidity (TA), pH, flesh firmness, ground color of the skin and flesh color (CIE illuminant D65 conditions, $L^*a^*b^*$ coordinates) were measured on fruit in three different bags as replicates per treatment according to Fernández-Trujillo and Artés (1997*b*). Flesh firmness was also assessed after 21 days storage and after subsequent shelf-life testing. Color indices were lightness (L^*), hue angle [$H* = \tan^{-1}(b^* \times a^* - 1)$] and chroma [$C^* = (a^2 + b^2)^{-1/2}$].

The identification and isolation of species involved in fungal decay was conducted according to conventional methodology (Fernández-Trujillo *et al.*, 1997). Losses due to dehydration, fungal attack, senescence and CI were recorded after storage and after shelf-life tests. Losses were expressed as percent of fresh weight basis relative to harvest weight. Cl was divided into four classes (very slight, slight, moderate and severe injury). Only moderate and severe levels of Cl were considered as commercially significant losses (Fernández-Trujillo and Artés, 1997*a*). Woolliness was assessed on a scale where 0 = sound, 1 = very slight (VS), 2 = slight (S); 3 = moderate (M); 4 = severe (E), and expressed as an index $[(1 * N_{vs} + 2 * N_S + 3 * N_M + 4 * N_E) \times 100/(4^* N)]$ where N = total number of fruits examined and N_{VS}, N_S, N_M and N_E were the number of fruits showing the different degrees of woolliness. These indices represented the extent of the disorder on a 0 to 100 scale, while losses due to woolliness represented the severity of woolliness.

Statistical analysis

Experiments were performed using a completely randomized design. A three-way analysis of variance (ANOVA) was performed to determine the effect of the maturity stage at harvest (FB and FM), type of films (SPP, OPP, PPP) and shelf-life test (at end of storage and end of shelf-life) on quality factors. The effect of storage time (14 or 21 days) was also investigated for weight loss and analyzed by regression analysis for each plastic film because normal probability plot revealed the presence of two populations (unperforated and macroperforated films) for this variable. Disorder and decay incidences were transformed to their respective arcsin for statistical analysis. LSD values were used to compare treatments means. Values of quality attributes at harvest or after normal postharvest ripening were used for comparison purposes and for calculation of pooled LSD values (Table 3).

RESULTS AND DISCUSSION

Atmosphere composition in peaches stored in unperforated films

CO_2 levels reached a steady state between the sixth and ninth day of storage using both OPP and SPP films (Fig. 1). However, CO_2 accumulation in SPP bags was higher in FM than FB fruit in OPP bags, whereas it was slightly higher in OPP bags (Fig. 1). O_2 levels were close to the critical point of 1–2% defined by Mitchell and Kader (1989), particularly in fruit stored in OPP (Fig. 1). The atmosphere inside PPP bags was close to air (data not shown).

After 14 days of storage. both ethanol and acetaldehyde accumulated in the unperforated bags and ethylene concentrations were similar (Table 1). Ethanol accumulated at higher levels under OPP compared to SPP bags ($p \leq 0.001$, respectively). For acetaldehyde the differences between both film types were only significant in FB fruit (UP×M significant at $p \leq 0.05$, Table 1; LSD ($p = 0.05$) = 3 for this interaction). According to Ke *et al.* (1991*a*), a TSS value higher than 12.5° Brix may increase the threshold for ethanol to cause off-flavor. Ethanol and acetaldehyde volatiles are usually generated by a greater activity of the enzyme pyruvate decarboxylase, which converts pyruvic acid to acetaldehyde, the latter being converted in turn by the enzyme alcohol dehydrogenase to ethanol.

Storage disorders and weight loss

Physiological disorders

After 14 days of storage plus shelf-life testing, Cl (woolliness plus internal flesh browning) was observed only in FM–PPP fruit (24% CI loss, 13 on the 0–100 woolliness index) and in FB–SPP fruit (0% CI loss, but woolliness index was 8) (data not shown). After 21 days of storage, only FM fruit showed chilling injury symptoms: the woolliness index was 12% in PPP compared with 8% in both other films. After the shelf-life period, chilling injury and woolliness index were higher in PPP in fruit of both maturity stages (Table 2). The alleviation of CI by high CO_2 atmospheres resulting in an

extension of storage life confirmed previous findings in other peach cultivars (Lurie, 1993; Zoffoli *et al.*, 1997). No CO_2 damage was apparent.

Woolliness has been associated with altered pectic polymer breakdown (Dawson *et al.*, 1992; Lurie *et al.*, 1994). CO_2 slows the onset of CI by reducing PME activity (Ben-Arie *et al.*, 1993). At harvest, FM peaches has been shown to contain 28% greater pectin methylesterase (PME) activity than FB fruits (Fernández-Trujillo *et al.*, 1998). The lower steady state CO_2 levels in FB fruit stored in SPP (Fig. 1), could result in less inhibition of PME activity, thereby is consistent with the earlier woolliness development (only in this treatment the woolliness index was 8 after 14 days of storage plus shelf-life).

Ethanol and acetaldehyde accumulation under unperforated films may be related to the alleviation of CI. In white peaches stored at 4°C for 20 days using 1 to 21% O_2 plus 3 days of shelf-life, ethanol content compared to control in air was about 50% more at 1 or 3% O_2, and only 12% more at 5% O_2 (Kajiura and Iwata, 1971). Ke *et al.* (1991*b*) reported that ethanol and acetaldehyde accumulated in peaches kept in 0.02% O_2 at 0 or 5°C, or in 0.25% O_2 at 5°C, and in general low O_2 delayed incidence and reduced severity of chilling injury.

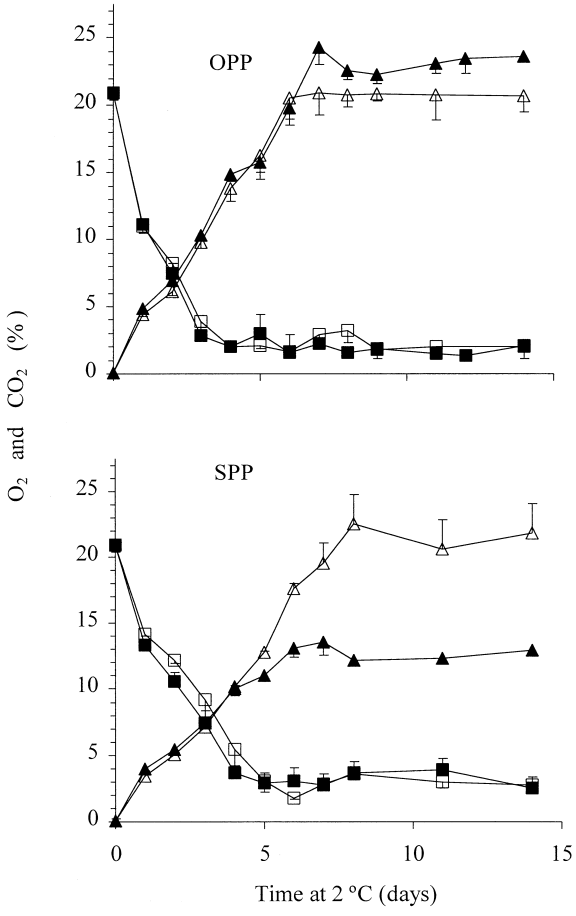

Fig. 1. CO_2 and O_2 composition within the bags of 'Paraguayo' peaches at firm-breaker (solid symbols) and firm-mature (hollow symbols) stages of maturity. Storage at 2°C in 40 μm thickness standard polypropylene (SPP) and 42.5 μm thickness oriented polypropylene (OPP) films (six fruits per bag). Bars are SE (n = five bags per treatment). CO_2 (Δ, ▲) O_2 (□, ■).

Decay

Addition reduction of storage life occurs in PPP fruit because of *Alternaria* spp. infection on woolly fruit (10% FB fruit stored in PPP for 21 days plus shelf-life). No decay was observed in SPP- or OPP-stored fruit. In other experiments (Fernández-Trujillo *et al.*, 1997), the fungistatic effect of high CO_2 MAP in FB late 'Paraguayo' peaches remained after 21 days at 0.5°C plus a shelf-life test. After normal postharvest ripening, decay reached 30% fruits in FM (17% *Rhizopus nigricans*, 3% *Monilinia* spp., 8% *Cladosporium* spp., 2% *Alternaria* spp.) and 37% in FB fruit (18% *Rhizopus nigricans*, 15% *Cladosporium* spp, 4% *Monilinia* spp.).

Senescence symptoms

After normal postharvest ripening. senescence losses (shriveling and/or overripeness) were 22% (w/w) and 2% for FB and FM fruit, respectively. After 14 days of storage plus the shelf-life test, symptoms of overripeness were evident in FM fruit (16% in PPP, 3% in SPP and 13% in OPP), reaching similar percentages after 21 days except in the case of FM–OPP fruit (Table 2). In both FB and FM fruit stored in unperforated films, senescence losses appeared after 21 days of storage plus a shelf-life duration without significant differences between treatments (Table 2).

Weight loss

Normal postharvest ripening resulted in 1.3 ± 0.1 and 2.1 ± 0.1% weight losses after 4 or 8 days at 20°C and 95% RH, without significant differences between FM and FB fruit. The same occurred during storage, where weight loss per week was approximately 0.57% in PPP films compared with 0.08 and 0.05% in SPP and OPP films. All linear regressions showed $r^2 > 0.90$ ($p \leq 0.05$). During the shelf-life period, total weight losses were 2.6, 3.1 and 1.6% in PPP, SPP and OPP films, respectively. The residual effect of the previous cold storage conditions on the reduction of weight losses in fruit kept in OPP bags may be related to slower ripening in fruit with high acetaldehyde and ethanol accumulation during storage (Table 1). Relative humidity is probably responsible for these differences among unperforated films and the other two treatments, because after ripening at 20°C at 70–75% RH weight losses increased 6.5-fold and severe shriveling developed in all fruits (data not shown).

Quality parameters

Flesh firmness

Flesh firmness of FM fruit decreased during cold storage but not that of FB fruit (Fig. 2). After 21 days of

Table 1. Effects[a] of maturity stage and unperforated film type on acetaldehyde, ethanol and ethylene content within the bags of 'Paraguayo' peaches after 14 days of storage at 2°C (mean ± SE, $n = 5$)

Maturity stage	Unperforated film[b]	Acetaldehyde	Ethanol ($\mu l\,l^{-1}$)	Ethylene	T^b (days)
Firm breaker	SPP	2.6 ± 1.3	480 ± 140	2.2 ± 0.8	24
	OPP	12.8 ± 2.5	5350 ± 590	1.3 ± 1.0	2
Firm-mature	SSP	5.1 ± 0.20	1790 ± 570	2.0 ± 0.7	25
	OPP	9.0 ± 2.6	4820 ± 880	1.5 ± 1.0	4
Source of variation[d] and df[e]					
Unperforated films (UP)	1	5.9***	65.8****		
UP × Maturity	16	10.6*	3.6n.s.		
Residual	19	30.7	29.9		

[a]In percentage of the total sum of squares and probability. n.s., not significant; *, ***,**** significant at $p = 0.05$, 0.001 or 0.0001, respectively.
[b]OPP = 42.5 μm thickness oriented polypropylene. SPP = 40 μm thickness standard polypropylene.
[c]Tolerance limit predicted (number of days to cause slight off-flavour) following the formulae: $T = (10^{0.288 \times \text{total soluble solids}})$/Average ethanol accumulation rate per day) (Ke *et al*., 1991*a*).
[d]Maturity effect n.s. for any variable. Any significant effect for ethylene.
[e]Degrees of freedom.

Table 2. Percentage of chilling injury and senescence losses (based on fresh weight at harvest) and woolliness index (0–100 scale) of firm-breaker (FB) and firm-mature (FM) 'Paraguayo' peaches stored for 21 days at 2°C plus a shelf-life test (3 days at 20°C) ($n = 36$)

Maturity stage and losses	Polymeric films[a]		
	PPP	SPP	OPP
FB			
Chilling injury	51[b]b[c]	3a	0a
Senescence	13b	3a	6a
Woolliness index	37[d]b	8a	5a
FM			
Chilling injury	55b	3a	5a
Sensescence	13b	3a	0a
Woolliness index	45b	10a	15a

[a]OPP = oriented polypropylene, 42.5 μm thickness. SPP = standard polypropylene, 40 μm thickness. PPP = macroperforated PP (33 holes of 2 mm diameter per square dm, 40 μm thickness) polypropylene.
[b]10% (w/w) colonized by *Alternaria* spp.
[c]Means separation within rows by LSD test ($p = 0.05$).
[d]This value is lower due to the onset of dryness plus browning of the cortical tissue of the fruit (not included in this index), affecting exclusively this treatment (scald index = 14).

storage, lower flesh firmness was obtained in FM fruit stored in PPP and SPP films (Fig. 2). After 21 days of storage plus 3 days of shelf-life, the reduced ability to soften in PPP fruit was abnormal compared to the trends during normal postharvest ripening at 20°C or in 14 days PPP shelf-life, very probably due to CI (Fig. 2, Table 2). FB fruit was affected by the dryness plus browning (corky texture) in the cortical tissue near the skin (Table 2) also known as flesh scald (Fernández-Trujillo *et al*., 1998). Any FB fruit subjected storage under unperforated films softened to similar flesh firmness obtained in fruit ripened after harvest at 20°C (Fig. 2), indicating a delay of ripening confirming previous results with 'Paraguavo' peaches stored in OPP at 0.5°C (Fernández-Trujillo and Artés, 1997*a*). Ritenour *et al*. (1997) showed that exposure to ethanol vapors at less than 6 ml kg^{-1} fruit for up to 6 h, a treatment that inhibited the ripening of mature-green tomatoes by 7 days, failed to inhibit the ripening of peaches. Assuming a maximum headspace of 0.5 l per bag, ethanol concentrations within the bags ranged from 0.96 to 10.7 ml kg^{-1} fruit after 14 days (Table 1). Thus, some delayed ripening effects in 'Paraguayo' peach could be mediated by ethanol vapors alone.

Titratable acidity (TA), total soluble solids (TSS) and pH

When comparing FM fruit subjected to normal postharvest ripening at 20°C and fruit stored in unperforated films for 14 days, the lower acidity in fruit kept in unperforated films (20.9 ± 2 and 23.9 ± 1 mMol $H^+ I^{-1}$ in SPP and OPP films, respectively) suggested that at 2°C organic acids became the substrate for respiration (Wankier *et al*., 1970; Lurie, 1992). The depletion in malic acid reserve (the main organic acid in peaches) has been attributed to the possible inhibition of the succinic

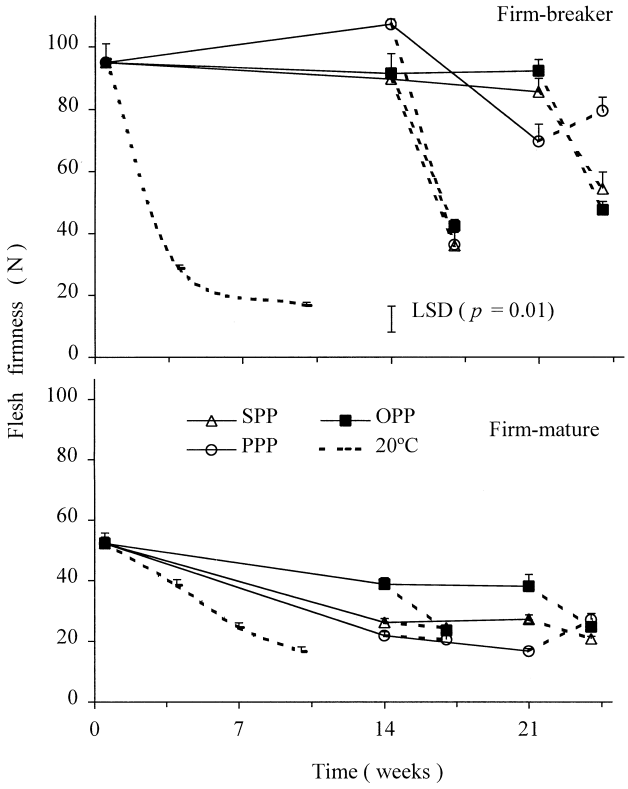

Fig. 2. Mean flesh firmness during storage at 2°C or after additional shelf-life test (3 days at 20°C; bags opened) in 'Paraguayo' peaches at firm-breaker (FB) and firm-mature (FM) stages of maturity stored under 40 μm thickness standard polypropylene (SPP), 42.5 μm oriented polypropylene (OPP), and 40 μm macroperforated polypropylene (PPP). Bars are SE ($n = 18$).

dehydrogenase of the Krebs cycle by elevated CO_2 concentrations (Wankier *et al.*, 1970). Lower acidity compared to control and a general decrease in TSS over time has been reported in peaches at 5–10% O_2 and 15–25% CO_2 during storage at 5°C (Deily and Rizvi, 1981). These authors found that these conditions resulted in the better retention of acids and provided the best textural and hedonic quality attributes. In other cases, acidity of peaches stored in low O_2 atmospheres and no more than 5% CO_2 or even in low O_2 and/or high CO_2 atmospheres, remained higher or similar than in air-stored fruit (Kajiura and Iwata, 1971; Ke *et al.*, 1991*b*; Lurie, 1993).

The Pearson product–moment correlation in FB and FM for pH and titratable acidity (both negatives) were −0.32 ($p = 0.04$) and −0.73 ($p = 0.001$), respectively. Only the OPP film induced a small but clear pH difference between FM and FB fruit after storage (0.1 units higher in FB–OPP fruit) or after the shelf-life test (M×F significant, LSD at $p \leq 0.05$, Tables 3 and 4). The shift in pH as a result in part of low titratable acidity was also more remarkable in SPP (5.06 ± 0.11 and 5.23 ± 0.15 units for FB and FM fruit, respectively) compared with OPP bags (4.88 ± 0.03 and 4.78 ± 0.03) units in FB and FM fruit, respectively) (M×F significant at $p \leq 0.05$). This fact was concomitant with faster softening in the SPP bags (Fig. 2), indicating a different tolerance to storage conditions for both types of fruit. The shift in pH and reduction in titratable acidity induced by high CO_2 was concomitant with softening in FM fruit (Fig. 2). In snap beans this phenomena has been associated with increased degradation of pectic substances by transelimination (Buescher and Adams, 1983).

Table 3. Quality parameters ($n = 3$) and ground and flesh color indices ($n = 18$) in firm-breaker (FB) and firm-mature (FM) 'Paraguayo' peaches under several treatments[a]

Quality parameters	Maturity stage[b]	At harvest	20°C 10 days	PPP 14 days + shelf-life	SPP 14 days + shelf-life	OPP 14 days + shelf-life	Polled LSD[c] ($p = 0.01$)
Titratable acidity	FB	42.3	37.3	28.9	28.9	33.3	4.4
(mMol H^+ I^{-1})	FM	33.9	28.4	23.6	27.4	31.8	6.9
pH	FB	4.82	4.61	4.86	4.92	4.85	0.11
	FM	4.64	4.74	4.86	4.95	4.60	0.15
L^* ground	FB	63.0	73.7	69.7	68.2	67.0	1.6
	FM	66.5	71.5	70.1	68.6	67.9	4.1
C^* ground	FB	34.5	41.2	39.0	37.7	38.2	2.0
	FM	34.0	39.1	36.6	35.4	36.9	2.6
H^* ground (°)	FB	100.4	98.7	94.6	94.9	101.5	4.9
	FM	94.9	83.4	83.0	75.8	81.8	12.4
C^* flesh	FB	27.8	23.1	19.1	22.3	24.9	2.7
	FM	22.3	21.7	16.9	18.6	15.4	3.0
H^* flesh (°)	FB	112.1	100.9	101.9	103.8	108.7	2.0
	FM	108.7	98.7	98.3	99.5	97.2	4.5

[a]OPP = oriented polypropylene, 42.5 μm thickness. SPP = standard polypropylene, 40 μm thickness. PPP = macroperforated PP (33 holes of Ø 2 mm per square dm, 40 μm thickness) polypropylene.
[b]Overall mean of each maturity stage during the experiment were always significant at $p < 0.05$ for all quality parameters.
[c]Pooled LSD calculations included data at harvest and after normal postharvest ripening.

However, after 14 days of storage plus a shelf-life test, both PPP fruit presented a decrease in titratable acidity without a significant increase in pH either compared to values after storage (F×SL significant. LSD at $p \leq 0.01$, Table 3 and Table 4). After 3 weeks of storage with or without the shelf-life test, low titratable acidity was only detected in FM–PPP fruit (20.9 ± 1 or $22.4 \pm 1\,\text{mMol}\,H^+\,I^{-1}$), probably as a result of a CI effect in FM 'Paraguavo' peach (Fernández-Trujillo and Artés, 1997*b*). pH in the same period was not associated to CI in the present experiment (data not shown), probably because pH responses usually are strongly storage time dependent (Fernández-Trujillo and Artéds, 1997*a*, 1998*b*).

TSS values were higher in FM fruit compared to FB fruit (14.2 and 13.2° Brix, respectively. LSD at $p \leq 0.0001$) with only 46.2% of the total variance explained and no other significant effects (data not shown).

Table 4. Analysis of variance of the significance in quality parameters of firm-mature (FM) and firm-breaker (FB) peaches stored in three plastic film bags (PPP, SPP, OPP) at 2°C for 2 weeks, with or without 3 days of shelf-life test (bags opened) at 20°C

Source	df[a]	Titratable acidity		pH	
		SS[b]	p[c]	SS	p
Maturity stage (M)	1	43.1	****	6.3	*
Polymer film (F)[d]	2	7.1	*	46.2	****
Shelf-life test (SL)	1	1.0	n.s.	4.5	*
M×F	2	0.1	n.s.	8.6	*
M×SL	1	16.4	****	0.0	n.s.
F×SL	2	9.4	**	10.7	**
M×F×SL	2	3.6	n.s.	4.2	n.s.
Residual	24	18.8		19.5	
% explained	35	81.2			

[a]Degrees of freedom.
[b]Sum of squares in percentage of the total.
[c]Probability: n.s. not significant. *, **, ***, **** significant at $p = 0.05$, 0.01, 0.001, 0.0001, respectively.

Ground and flesh color

In both kinds of fruit, the values of L^* and C^* skin indices and C^* and H^* flesh indices were positively correlated (Pearson product-moment correlation higher than 0.80 in all cases, $p \leq 0.0001$). Other correlations were lower than ± 0.42 ($p \leq 0.05$) (in the flesh) or non significant (in the skin). After storage and/or shelf-life of both kind of fruit in PPP and FM fruit in OPP, the decrease in flesh C^* index when compared to their respective control ripened after postharvest at 20°C (M×F×SL significant at $p \leq 0.0001$, Tables 2 and 5; data not shown), could be a sign of a slight internal browning. Intermittent warming storage reduced CI and also diminished flesh C^* values during storage (Fernández-Trujillo and Artés, 1998*a*,*b*).

During shelf-life test, normal color development was slow in FB fruit stored in OPP bags probably as a result of a residual effect of high CO_2 storage (Tables 1, 3 and 5). This effect was remarkable in L^* ground parameter (F×SL significant at $p \leq 0.01$), H^* flesh index (M×F×SL significant at $p \leq 0.001$), and to a lesser extent H^* ground index (M×F×SL significant at $p = 0.06$).

L^* and C^* ground values were maintained close to those found at harvest (Table 3) during storage in SPP and OPP films ($p \leq 0.01$; Table 5; data not shown). Because of the normal changes in L^* and C^* during the shelf-life test $p \leq 0.01$), only L^*'s of PPP and OPP fruit presented significant differences after this period as indicated the interaction F×SL (LSD at $p \leq 0.05$). This was well related to reduced senescence symptoms in fruit kept in unperforated films (Table 2) and particularly during storage (only 3% in SPP-FM fruit after 21

Table 5. Analysis of variance of the significance in flesh and ground color parameters of firm-mature (FM) and firm-breaker (FB) peaches stored in three plastic film bags (PPP, SPP, OPP) at 2°C for 2 weeks, with or without 3 days of shelf-life test (bags opened) at 20°C

Source	df[a]	Ground color (skin)						Flesh color					
		L^* SS[b]	p[c]	C^* SS	p	$H^{*\circ}$ SS	p	L^* SS	p	C^* SS	p	$H^*(^\circ)$ SS	p
Maturity (M)	1	3.9	**	25.4	****	74.9	****	0.0	n.s.	54.9	****	40.0	****
Polymer film (F)[d]	2	41.2	****	13.2	***	3.3	*	5.5	*	1.0	n.s.	2.5	*
Shelf-life (SL)	1	33.9	****	37.7	****	7.0	***	31.3	****	18.7	****	31.8	****
M×F	2	0.5	n.s.	0.6	n.s.	0.9	n.s.	2.0	n.s.	1.3	n.s.	0.5	n.s.
M×SL	1	0.9	n.s.	0.0	n.s.	0.2	n.s.	11.0	****	2.2	**	0.3	n.s.
F×SL	2	6.2	**	10.3	***	2.8	n.s.	0.3	n.s.	2.5	**	0.3	n.s.
M×F×SL	2	1.4	n.s.	12.5	n.s.	0.7	n.s.	1.1	n.s.	6.3	****	6.4	***
Residual	24[d]	11.9				10.2		48.8		13.2		18.3	
% explained	35[d]	88.1		87.5		89.8		51.2		86.8		81.7	

[a]Degrees of freedom.
[b]Sum of squares in percentage of the total.
[c]Probability: n.s. not significant. *, **, ***, **** significant at $p = 0.05$, 0.01, 0.001, 0.0001, respectively.
[d]For flesh color parameters residual ant total df were 60 and 71, respectively.

days at 2°C). In this cultivar, an increase in L^* values close to 73 (skin) or 80 (flesh) and a slight decrease thereafter are associated to ripening and senescence, respectively (Fernández-Trujillo and Artés, 1998*a*).

CONCLUSION

Storage of both FM and FB peaches in unperforated films resulted in high CO_2 and low O_2 levels, and this was associated with the reduction of CI, decay, and weight loss, while perforated film resulted in air-like atmospheres and did not show any benefits on fruit quality. High CO_2/low O_2 atmospheres delayed the changes associated with normal ripening for 3 days, especially in FB peaches.

It can be concluded that storing fruit at 2°C in an intermediate maturity stage in SPP films will preserve the freshness and quality of 'Paraguayo' peaches for 14 days without excessive loss of quality, and without risks of woolliness, senescence and decay development. Shelf-life periods should be reduced to a minimum particularly in more mature fruit due to excessive weight losses and senescence.

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