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Quality changes in fresh-cut 'Rocha' pear as affected by oxygen levels in modified atmosphere packaging and the pH of antibrowning additive

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ABSTRACT

Respiratory behavior of fresh-cut 'Rocha' pear suggests that optimization of O_2 concentration inside modified atmosphere packages (MAP) is of limited benefit. To test this hypothesis, packages were designed to achieve three equilibrium O_2 partial pressures. Fresh-cut 'Rocha' pear was treated with 250 mM calcium ascorbate solutions buffered at pH 3.0 and pH 7.0, packaged under the three MAP conditions, and stored at 5 °C for 20 d. Actual O_2 levels (mean ± confidence interval at 95%) during the experiment were 16.7 ± 0.2, 1.8 ± 0.2 and 0.25 ± 0.04 kPa with corresponding CO_2 levels of 1.3 ± 0.1, 4.3 ± 0.2 and 6.5 ± 0.4 kPa. Changes in quality attributes related to fruit metabolism, namely firmness, titratable acidity, pH, and soluble solids content were not affected by O_2 levels. Overall changes in water activity, levels of ascorbate, and microbial growth were also independent of O_2 levels. Oxygen partial pressure inside the packages affected browning, which was more intense at 16.7 kPa O_2. Sensory analyses performed after 8 d in storage confirmed that panelists perceived the differences in color but did not detect differences in firmness or taste among the samples under different O_2 levels. Browning was more intense at pH 3.0 than at pH 7.0 but the kinetics of other quality attributes were not affected by pH. No significant improvements of quality attributes dependent on the physiology of respiration of fresh-cut 'Rocha' pear can be obtained by reducing O_2 partial pressure inside the packages.

1. Introduction

Ready-to-eat fresh-cut fruit are a convenient means to foster fruit consumption by modern consumers. Packaging is required to prevent post-processing contamination and reduce water loss by fresh-cut fruit. A modification in the composition of the atmosphere surrounding the fruit occurs whenever plastic containers or films with various permeabilities to gases enclose respiring fruit pieces. Modified atmospheres with O_2 partial pressures lower than and CO_2 partial pressures higher than those in the normal atmosphere are reported as beneficial to extend the shelf-life of fresh-cut fruit, including 'Bartlett', 'd'Anjou' (Sapers and Miller, 1998), and 'Conference' pear (Soliva-Fortuny et al., 2002a,b). The beneficial modified atmospheres have initial O_2 levels of ca. 2.5 kPa (Soliva-Fortuny et al., 2007; Oms-Oliu et al., 2008), or even closer to 0 kPa (Soliva-Fortuny et al., 2002b, 2007).

Quality of fresh-cut produce is a multivariate attribute. Quality changes that determine the shelf-life of fresh-cut fruit include microbial growth, softening, browning, and water loss (Ahvenainen, 1996). These quality changes are differentially affected by processing, packaging, and storage factors and are likely to have different kinetics. Some quality attributes, e.g., firmness, electrolyte efflux, soluble solids content (SSC), juice pH or titratable acidity, depend, to a great extent, on the metabolic activity of the fresh-cut tissue. Other quality attributes, e.g., browning and the content of ascorbate used as antibrowning additive, are largely a result of biochemical reactions occurring in the cell-free environment of the cut surface. Water loss is regulated by plastic film characteristics and physical factors whereas microbial growth has its own metabolic regulation, interdependent on the metabolic rate of fresh-cut fruit. Therefore, the detailed examination of the effects of modified atmosphere packaging (MAP) on the kinetics of individual quality attributes in particular commodities is warranted, to assess the degree to which O_2 levels can modulate quality.

The systematic approach to MAP design involves the knowledge of respiration rate and film permeability to gases at the operating temperatures. Respiration rate is inversely correlated with shelf-life (Rolle and Chism, 1987; Fonseca et al., 2005), and can be reduced by low temperature and, in some instances, by modified

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Table 1
Respiration rate and characteristics of the packages used in the experiments.

O_2 level	Respiratory rate[a] (mmol h^{-1} kg^{-1})	Product mass (kg)	Films			Package surface (cm^2)
			Type[b]	Thickness (cm)	OTR[c] at 5 °C (mmol cm cm^{-2} h^{-1} kPa^{-1})	
HO	0.138	0.027	OPP	0.0040	9.048×10^{-09}	800
LO	0.125	0.110	OPP	0.0025	3.257×10^{-09}	800
VLO	0.095	0.116	OPP	0.0025	3.257×10^{-09}	450

[a] Estimate published in Gomes et al. (2010a).
[b] OPP: oriented polypropylene (Amcor Flexibles, Ledbury, UK).
[c] OTR: oxygen transmission rate; CO_2 permeability can be obtained multiplying OTR by 4.

atmosphere. The kinetics of respiration as a function of O_2 partial pressure has been established for fresh-cut 'Rocha' pear (Gomes et al., 2010a). At 5 °C, the shift from aerobic to anaerobic metabolism occurs at 0.25 kPa O_2 and the maximum reduction in respiration rate that can be achieved via the reduction of O_2 partial pressure is 49%. In contrast, a decrease in temperature from 5 to 0 °C results in a 64% decrease in respiration rate at atmospheric O_2 levels (Gomes et al., 2010a). Reductions in respiration rate lower than 50% are likely not sufficient for significant extension of quality attributes related to the metabolic activity of the tissue (Beaudry, 2000). Therefore, for all practical purposes, the physiological behavior of fresh-cut pear is likely to be similar at any O_2 concentration above the fermentation threshold. If this hypothesis is confirmed, no significant benefits on quality attributes dependent on the metabolic rate can be achieved via MAP in fresh-cut 'Rocha' pear. MAP, however, is likely to affect quality attributes unrelated to the metabolic activity of the tissue, such as microbial contamination and water loss.

In addition to packaging, fresh-cut pear requires the use of antibrowning additives (Gorny et al., 2002; Oms-Oliu et al., 2008). Calcium ascorbate is a commonly used antioxidant to prevent browning in fresh-cut produce. The effect of calcium ascorbate on color and firmness depends on the pH, which is a key explanatory variable for the quality effects of additives (Gomes et al., 2010b). Since MAP and calcium ascorbate are both expected to affect the quality of fresh-cut pear their combined effects must be examined in an integrated preservation system for fresh-cut pear including three hurdles: refrigeration, MAP, and calcium ascorbate additive.

This study was designed to test the hypothesis that quality attributes dependent on metabolic activity cannot be modulated via low O_2 MAP in fresh-cut 'Rocha' pear in the presence of calcium ascorbate. Kinetic data on the effect of O_2 partial pressure on respiratory activity were used to design packages to achieve three levels of reduction in respiration rate. The effect of O_2 partial pressure on the kinetics of changes was evaluated for several quality attributes that limit shelf-life of the product: physiological (firmness, electrolytes efflux, SSC, juice pH and titratable acidity), physical (water activity), microbiological (aerobic mesophilic and psychrophilic bacteria), and biochemical (color and ascorbate content). The effect of the pH of the antibrowning additive used to reduce undesirable discolorations was also assessed.

2. Materials and methods

2.1. Plant material and minimal processing

Pear (*Pyrus communis* L. 'Rocha') fruit used as raw material were harvested at commercial maturity and stored for 6 months at −0.5 °C, 90–95% RH, under controlled atmosphere with 2.0 kPa O_2 + 0.5 kPa CO_2 (balance N_2). Fruit were removed from storage and allowed to soften at 20 °C to a flesh firmness of 50 ± 1 N before processing. Whole fruit were cooled to a pulp temperature of 5 °C, surface sanitized with 2 mM sodium hypochlorite (pH 6.5), and rinsed with tap water before processing. Pears were cut by hand into longitudinal slices (ca. 10 mm thick) which were dipped for 1 min in cold solutions, drained, and placed inside the designed plastic bags (see Section 2.2). Dipping solutions contained calcium ascorbate (250 mM Ca^{2+}) and were buffered at pH 3.0 or pH 7.0. To assure the complete solubility of calcium ascorbate, the buffer solution at pH 3.0 was 100 mM citric acid–200 mM sodium phosphate and 100 mM Tris–100 mM HCl was used at pH 7.0 (Gomes et al., 2010b). All processing operations were performed in a cold room at 10 °C sanitized with sodium hypochlorite and fruit manipulations were made with gloved hands.

2.2. Active modified atmosphere packaging and storage conditions

Published data on the kinetics of respiration of fresh-cut 'Rocha' pear as affected by O_2 partial pressure (Gomes et al., 2010a) were used to design packages in which the predicted O_2 partial pressures would stabilize at ca. 18.2, 2.0, and 0.5 kPa, corresponding to 99, 89, and 68% of the maximal respiration rates at 5 °C, respectively. The change in gas composition was mathematically simulated and adjustment of packaging dimensions (A) and fruit weight (M), for given film permeability (P_{O_2}) and thickness (l), were manipulated to control the desirable levels of gases under steady-state conditions, according to Eq. (1) (Talasila and Cameron, 1997).

$$pO_{2pkg} = pO_{2atm} - \frac{(R_{O_2} \times M) \times l}{P_{O_2} \times A} \quad (1)$$

Estimates by the Michaelis–Menten model for pear slices at 5 °C (278.15 K) were $R_{O_2}^{max,T}$ = 0.139 mmol kg^{-1} h^{-1} and K_{m,O_2} = 0.240 kPa (Gomes et al., 2010a). Expected respiration rates at each O_2 level are given in Table 1.

Fruit slices were placed inside open plastic bags with the characteristics summarized in Table 1. The bags were flushed with a known gas mixture and sealed (Multivac A300/41/42, Germany). Gas mixtures with 18.2 kPa O_2 + 1.0 kPa CO_2, 2.0 kPa O_2 + 5.1 kPa CO_2, and 0.5 kPa O_2 + 5.1 kPa CO_2 (balance N_2) were obtained from Gasin (Barcelona, Spain). These active modified atmospheres are hereafter referred to as high oxygen (HO), low oxygen (LO), and very-low oxygen (VLO), respectively. Levels of O_2 ($pO_{2\ pkg}$) and CO_2 inside the packages were monitored throughout storage with a gas analyzer (CheckMate II, PBI Dansensor, Ringsted, Denmark). Packaged fresh-cut pear was stored at 5.0 ± 0.5 °C for 20 d.

2.3. Ethanol determination

Ethanol was measured in the headspace of two packages of each oxygen level and pH treatment. The package headspace was sampled manually using a Hamilton (Bonaduz, GR, Switzerland) 1.0 mL gas-tight syringe and ethanol quantified by GC-FID using a Varian CP-3800 system, equipped with a VF-624 ms column