

Effect of low and superatmospheric O₂ modified atmosphere on the quality of fresh-cut pears

Zora Jandric¹, Robert Soliva-Fortuny², Gemma Oms-Oliu²,
Olga Martín-Belloso², Slavica Grujic¹

¹Faculty of Technology, University of Banjaluka, Bosnia and Herzegovina
²Department of Food Technology, UTPV-CeRTA, University of Lleida, Spain
e-mails: zora.jandric@yahoo.ca; rsoliva@tecal.udl.cat; goms@tecal.udl.cat;
omartin@tecal.udl.cat; grujicstavica@yahoo.com

The effect of low O₂ and superatmospheric O₂ atmospheres in combination with a dipping into N-acetyl-L-cysteine (NAC) and reduced glutathione (GSH) on fresh-like quality “Flor de Invierno” pears was studied. Changes in headspace gas composition, colour, firmness, acidity and soluble solids were examined. The fresh-cut pears were dipped into 0.75% (w/v) NAC and 0.75% (w/v) GSH aqueous solution and then packaged into polypropylene trays under low O₂, superatmospheric O₂ and traditional passive atmosphere (PA) conditions. Trays were stored at 4±0.5°C and analyzed periodically during 28 days. Superatmospheric O₂ atmosphere caused a stress in pears cells tissue leading to many contents of ethylene, acetaldehyde and ethanol and limiting shelf-life of pears up to 21 days. Because of complete inhibition of ethylene production, maintenance of initial colour, texture and acidity, a low O₂ atmosphere was the most effective for fresh-cut pears quality preserving during 28 days of refrigerated storage.

Keywords: Fresh-cut pears, modified atmosphere packaging, colour, quality changes.

Introduction

Interest for fresh-cut and ready-to-eat products is rising continuously in developed countries during the last few years. Fresh-cut or minimally processed fruits are important products on market in fast development because of their convenience and fresh-like quality (Oms-Oliu et al., 2008; Rojas-Grau et al., 2006).

Major changes during processing fresh-cut fruits are surface browning, tissue softening and dehydration. Browning has been studied in different fruits such as pears, apples, mango, pineapple, bananas, strawberry, peach or muskmelon (Gorny et al., 2000; Martínez-Ferrer et al., 2002; Oms-Oliu et al., 2008; Pesis et al., 2005; Rojas-Grau et al., 2007; Soliva-Fortuny et al., 2004) and different treatments were used to preserve their original fresh-like characteristics. In fresh-cut pears, operations such as peeling, coring, slicing and cutting are critical because they limit the shelf-life of fruit products due to browning and physiological stresses caused by physical damage or wounding (Rojas-Grau et al., 2006; Rojas-Grau et al., 2007; Soliva-Fortuny et al., 2003). Cut surface browning is caused in sliced pears by the action of polyphenol oxidase (PPO) on phenolic compounds (Amiot et al., 1995). PPO catalyses the hydroxylation of monophenols to o-diphenols (monophenolase activity) and the oxidation of o-diphenols to o-quinones (catecholase activity) in the presence of oxygen (Soliva-Fortuny et al., 2002). The quinones react

¹ Corresponding author: Zora Jandric, e-mail: zora.jandric@yahoo.ca

This work was supported by the Ministry of Science and Technology (AGL2003-09208-C03-01), the Project (CYTED-XI.22) of the Program of Science and Technology for the Development and by the Departament d'Universitats, Recerca i Societat de la Informació of the Generalitat de Catalunya (Spain) and TEMPUS18084 project.

nonenzymatically with amino acids and proteins leading to formation of brown (melanin), red or black pigments (Dong et al. 2000).

Numerous browning inhibitors have been used to protect cut surface browning of fresh-cut fruits. In fresh-cut pears, effective inhibitors such as N-acetyl-L-cysteine (NAC) and reduced glutathione (GSH) have been used (Dong et al., 2000; Gorny et al., 2002; Oms-Oliu et al., 2008; Rojas-Grau et al., 2007; Sapers et al., 1998). NAC and GSH can act to reduce o-quinones back to o-diphenols or react with o-quinones to yield colourless compounds (Rojas-Grau et al., 2006). Dipping treatments of NAC prevented fresh-cut pears or apples from browning whereas GSH avoided darkening (Dong et al., 2000; Sapers et al., 1998).

Packaging under modified atmosphere combined with browning inhibitors can extend shelf-life by slowing down browning reactions, reducing water loss and respiration rates and decreasing ethylene biosynthesis and activity. Wounding induces an increase in respiration and ethylene production, browning, texture breakdown, water loss, off-flavour production and microbiological spoilage. Production of ethanol, ethylene and acetaldehyde might be beneficial for postharvest fruit quality (Pesis et al., 2005). Modified atmosphere packaging (MAP) with low O₂ and elevated CO₂ can induce substantial changes in respiration rates, growth of microorganisms, enzymatic browning and transpiration. Excessive low O₂ atmosphere may trigger anaerobic metabolism in fruits, resulting in the production of acetaldehyde and ethanol (Oms-Oliu et al., 2008; Rojas-Grau et al., 2008; Soliva-Fortuny et al., 2002b). High CO₂ concentrations also inhibit several enzymes of the Krebs' cycle including dehydrogenase, which would either trigger anaerobic respiration or result in accumulation of succinic acid which is potentially toxic to the fruit (Martinez-Ferrer et al., 2002; Soliva-Fortuny et al., 2003). Superatmospheric O₂ atmosphere may affect the synthesis and accumulation of some volatile compounds associated with respiratory metabolism, including ethyl acetate, ethylene and acetaldehyde and for inhibiting enzymatic discoloration, preventing anaerobic fermentation reactions or undesirable moisture and odour losses (Sapers et al., 1998).

The objective of this work was to compare the effectiveness of low (2.5% O₂ and 7% CO₂, balance N₂) and superatmospheric oxygen (70% O₂, balance N₂) modified atmospheres combination with a dipping into 0.75% (w/v) NAC and 0.75% (w/v) GSH aqueous solution on the quality of fresh-cut "Flor de Invierno" pears during 28 days of storage at 4 °C.

Materials and methods

Fruit processing and storage conditions

Pears (*Pyrus communis* L.cv. Flor de Invierno) harvested in Lleida (Spain) at commercial maturity were stored at 4±1 °C prior processing. The pears were washed and dried. After that, the fruits were peeled, the core was completely removed and the tissue was cut into slices. To reduce browning of the cut fresh fruits due to exposure to the air and other wounding stresses, a maximum of four fruits were processed at the same time. Pear slices were dipped into an aqueous solution of NAC (Sigma-Aldrich Chemic, Steinheim, Germany) at 0.75% (w/v) and GSH (Sigma-Aldrich Chemic) at 0.75% (w/v) for 2 min and drained in a performed plastic container for 1 min. Then, 100g of fruit sample were placed in polypropylene trays (155 x 50 x 112 mm) (MCP Performance Plastic LTC, 2005) and wrapped with a plastic film. The O₂ and CO₂ permeability of the film were 100 cm³ m⁻² bar⁻¹ day⁻¹ at 38 °C and 0% relative humidity (RH) and 500 cm³ m⁻² bar⁻¹ day⁻¹ at 23 °C and 0% RH, respectively.

The trays were packaged in modified atmosphere (70% O₂ or 2.5% O₂ + 7% CO₂, balance N₂) and traditional passive atmosphere (PA). The packages were sealed with a MAP machine (ILPRA Food Pack Basic V/G, Ilpra S.C.P. Vigenovo, Italia) and immediately stored in darkness at 4±0.5 °C, RH=95%. Determinations were carried out during 28 days (every 3 days during the two first weeks and then weekly for 2 weeks) in duplicate for each treatment.

Determination of headspace gases

Headspace gases of fresh-cut pear packages were determined using a gas analyzer (Micro-GC CP 2002 gas analyzer, Chrompack International, Middleburg, The Netherlands) equipped with a thermal conductivity detector. Prior to measuring, an adhesive septum was pasted up to the plastic material of the package. A portion of 1.7 mL was automatically withdrawn from the headspace and injected into the instrument. Injection carried out through a pin-needle connected to the injection system through a septum stuck to the plastic material of the bag. A 0.25 µL sample was injected to CP-Molsieve 5Å packed column (Chrompack International, Middleburg, The Netherlands) (4 m x 0.32 mm, df = 10 µm) held at 80 °C and 100 kPa for O₂ determination. A 0.33 µL sample was injected to Pora - PLOT Q column (Chrompack International, Middleburg, The Netherlands) (10 m x 0.32 mm, df = 10 µm) at 70 °C and 200 kPa for CO₂ determination. The ethylene, acetaldehyde and ethanol concentrations were measured through the same column as CO₂ but at 100 °C and 200 kPa conditions.

Colour determination

Cut pear surface colour values were measured using a colorimeter (Minolta Chroma Meter Model CR - 400, Minolta, Tokyo, Japan). The instrument was calibrated with a standard white plate and set up for D65 illuminant and 10° observer angle. Readings were made by attaching colorimeter optical glass cell to the surface of pear tissue. Two readings were obtained for each replicate by changing the position of the pear slices in the optical glass cell to get uniform colour measurements. Colour was determined using a CIE L*a*b* colour system, where L* indicates lightness (L* = 0, black and L* = 100, white). a* is the chromatic coordinate that represents the proportion of redness and varies from green (-) to red (+) and b* is the chromatic coordinate that represents the proportion of yellowness and varies from blue (-) to yellow (+).

The h* is hue angle in a colour wheel of 360° (0° = red-purple, 90° = yellow, 180 = bluish-green and 270° = blue) and it was calculated by Equation 1 :

$$h^* = \arctan (b^* / a^*), \quad (1)$$

Where, h* - hue angle; a* - redness; b* - yellowness;

Total colour difference (ΔE^*) was obtained from the Euclidian distance between L*, a* and b* values at the time of analyses, using Equation 2 :

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{0.5}, \quad (2)$$

Where, ΔE^* - total colour difference; ΔL - lightness;

Firmness determination

Firmness of pear slices was determined using a TA-XT2 Texture Analyzer (Stable Micro Systems Ltd., England, UK). Pear wedges were cut in triangular shaped samples of 1.0 cm height and firmness was measured by the maximum penetration force for a 4 mm diameter probe. The downward distance was set at 10 mm at a rate of 5 mm/s and automatic return. Pear slices were held perpendicular to the probe and thus the rod penetrated the geometric centre of the sample. Four samples were analysed from each tray to obtain representative readings.

Determination of pH, total acidity and soluble solids

The pH was determined using a CRISON 2001 pH-meter (Crison, Barcelona, Spain) with a glass electrode that penetrated and measured the pH directly in crushed fruit. Total acidity (TA) was performed by diluting 25 g of crushed sample into 25 mL distilled water and titrating with 0.1 N NaOH up to pH 8.1.

The soluble solids content was measured at 20°C with a digital refractometer Atago RX-1000 (Atago Company Ltd., Tokyo, Japan). Four or five drops of crushed sample were added to the instrument lens. Two readings were carried out for each package.

Statistical analyses

Significance of the results was analyzed using the Statgraphics Plus V.5.1 software package (Statistical Graphics Co., Rockville, Md., U.S.A.). Analysis of covariance of the time data series was used to determine differences among treatments. Specific differences between means were determined by least significant difference (LSD). All comparisons were made with a level of significance of 95%.

Results and discussion

Changes in headspace gas composition of fresh-cut pears

The composition of the headspace atmosphere in fresh-cut pears packaging can indicate respiration rate and gas diffusivity through the fruit tissue. Modified atmosphere packaging can be effective in delaying the physico-chemical changes and prolonging the shelf life of fresh cut fruits (Gorny et al., 2002; Oms-Oliu et al., 2008; Rojas-Grau et al., 2007; Soliva-Fortuny et al., 2002). Physiological stress as a consequence of processing, led up to a significant modification of the package gas composition. Table 1 shows that oxygen, carbon dioxide, ethylene, acetaldehyde and ethanol concentrations in modified atmosphere packages with fresh-cut “Flor de Invierno” pears were significantly influenced by the packaging atmosphere and time ($p \leq 0.05$). Under low oxygen atmosphere (2.5% O₂ and 7% CO₂, balance N₂) oxygen concentrations slightly decreased up to 1.18%. Pear slices under superatmospheric O₂ (70% O₂, balance N₂) and PA (21% O₂) consumed more O₂ and showed higher respiration rate under these conditions. The decrease in O₂ concentrations was induced during 28 days up to 57.16% and 0.98%, respectively (Figure 1). Oms-Oliu et al., (2008) noticed for fresh-cut pears stored under high oxygen atmosphere that the O₂ concentrations remained >50 kPa throughout storage, while CO₂ increased up to levels >20 kPa, at the end of storage.

TABLE 1. ANALYSIS OF COVARIANCE OF THE STUDIED PARAMETERS

Parameters	F-ratio		
	Time	Atmosphere	Interaction Time-atmosphere
Head-space atmosphere			
O ₂	64.75*	8304.66*	16.18*
CO ₂	350.73*	14.07*	8.54*
C ₂ H ₄	205.78*	1138.33*	66.96*
Acetaldehyde	243.11*	70.08*	65.89*
Ethanol	227.88*	50.23*	6.31*
Colour			
L*	281.98*	359.50*	30.44*
a*	298.82*	122.62*	89.94*
b*	142.94*	62.15*	24.95*
h*	10842.56*	2543.66*	2636.60*
ΔE*	550.87*	245.93*	57.67*
Texture	88.98*	22.31*	7.84*
pH	32.38*	14.16*	4.06*
Acidity	24.42*	4.20 ^{n.s.}	3.56*
Soluble solids	5.48*	32.71*	1.60 ^{n.s.}

Note: Numeric values are the F-ratio of the variance explained by a factor compared with the unexplained variance. * Statistically significant correlations ($p \leq 0.05$). ^{n.s.} non-significant correlation.

FIGURE 1. PACKAGE HEADSPACE COMPOSITION OF FRESH-CUT "FLOR DE INVIERNO" PEARS DIPPED IN 0.75% (w/v) NAC AND 0.75% (w/v) GSH SOLUTION PRESERVED UNDER DIFFERENT MAP CONDITIONS. DATA SHOWN ARE THE MEANS (\pm STANDARD DEVIATION).

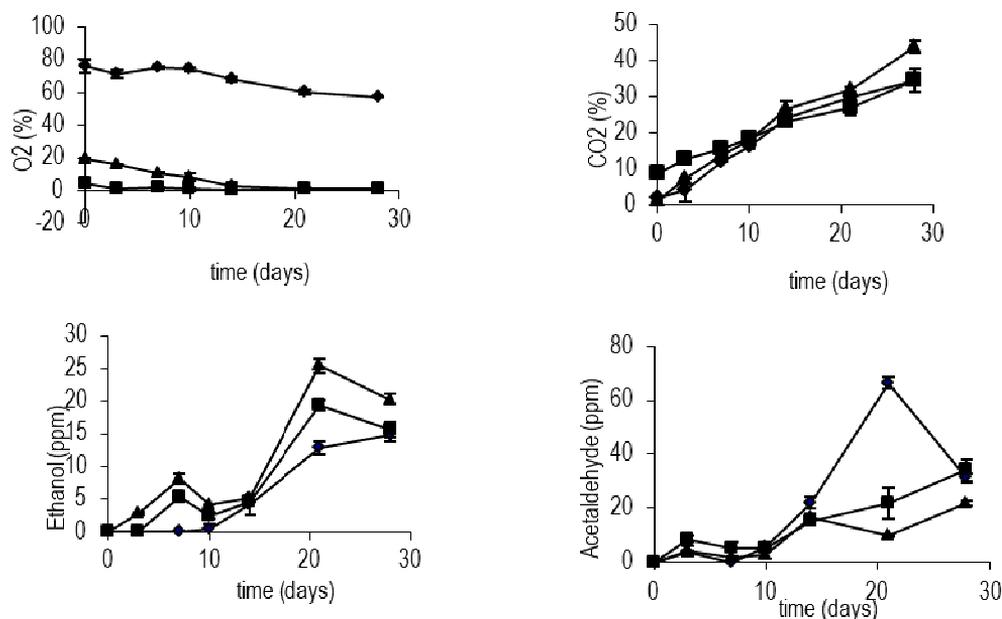
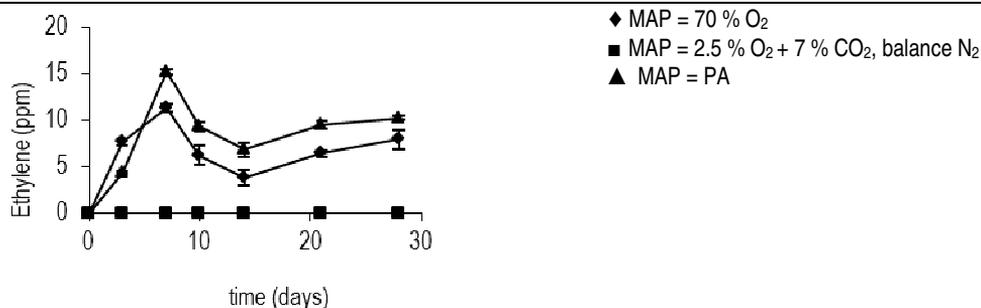


FIGURE 1 (continued). PACKAGE HEADSPACE COMPOSITION OF FRESH-CUT “FLOR DE INVIERNO” PEARS DIPPED IN 0.75% (w/v) NAC AND 0.75% (w/v) GSH SOLUTION PRESERVED UNDER DIFFERENT MAP CONDITIONS. DATA SHOWN ARE THE MEANS (\pm STANDARD DEVIATION).



CO₂ production increased continuously in packages with pears under all atmosphere conditions in our experiment (Figure 1). The increase of CO₂ levels under low O₂ atmospheres was lower than that observed under superatmospheric O₂ and PA conditions. It means that respiration rate is reduced in fresh-cut product packaged in low O₂ atmospheres. Rojas–Graü et al., (2007) reported that CO₂ production of fresh-cut “Fuji” apples was significantly lower in samples stored under a 2.5 kPa O₂ + 7 kPa CO₂ atmosphere than under PA packaging. Accumulation of CO₂ in pineapples packages stored under 10% CO₂, 4% O₂, 86% N₂ increased more after 10 days of storage at 5 °C (Martinez-Ferrer et al., 2002).

Ethylene is a growth-stimulating hormone produced by fruits and accumulates in the package speeding up product respiration. Ethylene has been shown to be noticeable induced within a few minutes of processing (Soliva-Fortuny et al., 2003). In our experiment production of ethylene in pear slices packaged under superatmospheric O₂ and PA rose to 11.28 ppm and 15.25 ppm after 7 days and later decreased to 7.94 ppm and 10.18 ppm respectively. On the other hand, ethylene production in pear slices packaged in low O₂ atmospheres was completely inhibited (Figure 1). These results are in agreement with results of other authors (Rojas-Grau et al., 2007; Soliva-Fortuny et al., 2004).

Acetaldehyde, a natural aroma component, formed from pyruvate by the enzyme pyruvate decarboxylase reacts with CO₂ to form ethanol. Acetaldehyde production differed among storage atmospheres, and continuously increases in pears packaged under low O₂ atmosphere and PA. Under superatmospheric O₂ levels, acetaldehyde reached values of 66.35 ppm after 21 days and then decreased to 31.29 ppm by the end of storage (Figure 1). This high acetaldehyde level in superatmospheric O₂ modified atmosphere may be a stress response when pears were exposed to very high O₂ concentrations. At super-atmospheric concentrations, O₂ could enhance production of reactive oxygen species, which can damage cytoplasm of cells and cause anaerobic respiration appearing. Acetaldehyde may be reduced to ethanol and react further to form ethylacetate. That reaction, together with acetaldehyde permeation through the package material, could explain the decrease of acetaldehyde values after 21 days of storage. Acetaldehyde accumulates during ripening even under aerobic conditions but in greater extent under partially or totally anaerobic conditions (Oms-Oliu et al., 2008). Golians and Botther (2002) noticed that apples stored under 8% CO₂ and 1% O₂ produced much more acetaldehyde than under an atmosphere of 1% O₂ without CO₂. In strawberry, the application of (40-100%) O₂ for 14 days caused an important increase in the contents of acetaldehyde and ethanol¹². Increase in acetaldehyde and ethanol content has been associated with changes in undesired colour, texture and nutritional quality (Oms-Oliu et al., 2008; Pesis et al. 2005; Soliva-Fortuny et al. 2002; Soliva-Fortuny et al., 2003).

Production of ethanol is an indicator of anaerobic fermentation and ethanol is responsible for development of un-pleasant off-flavours and odours in fresh-cut fruits. Content of ethanol, in the package headspace gas composition, reached the highest values after 3 weeks and then slightly decreased under all conditions (Figure 1). Ethanol concentrations for fresh-cut pears packaged under PA was higher (20.19 ppm) than under low and superatmospheric O₂ atmosphere (14.86 ppm and 15.89 ppm). Ethanol production was in correlation with CO₂ production. Lower and higher ethanol production was indicated by lower and higher CO₂ production under low relatively superatmospheric O₂ atmosphere and PA at the end of storage. Low values of ethanol under low O₂ atmospheres indicated less anaerobic respiration rate, a reduction of off-flavours and better consistency. These results agreed with those of Soliva-Fortuny et al. (2004) and Rojas-Grau et al. (2007).

Changes in colour

The effect of modified atmospheres on colour of fresh-cut “Flor de Invierno” pears were determined by measuring L*, a*, b*, h* and ΔE* parameters during storage. Analysis of variance showed that time and atmosphere had a significant effect ($p \leq 0.05$) on all these parameters (Table 1). The L* value is an indicator of darkening and decreased with storage time. Changes in L* values for fresh-cut products dipped in 0.75% NAC and 0.75% GSH mixture solution and packaged in low O₂ atmosphere were smaller (L* values decreased from 67.01 to 59.22) than those packaged in other conditions. Browning was the highest for fresh-cut pears under superatmospheric O₂ with L* values decreased from 65.38 to 53.69 due to enzyme reactions (Figure 2). The effectiveness of low O₂ atmospheres is in agreement with the results obtained by Rojas-Grau et al. (2007).

FIGURE 2. EVOLUTION OF COLOUR PARAMETERS (L*, a*, b*, h*, ΔE*) FOR FRESH-CUT “FLOR DE INVIERNO” PEARS DIPPED IN 0.75% (W/V) NAC AND 0.75% (W/V) GSH SOLUTION PRESERVED UNDER DIFFERENT MAP CONDITIONS. DATA SHOWN ARE THE MEANS (± STANDARD DEVIATION).

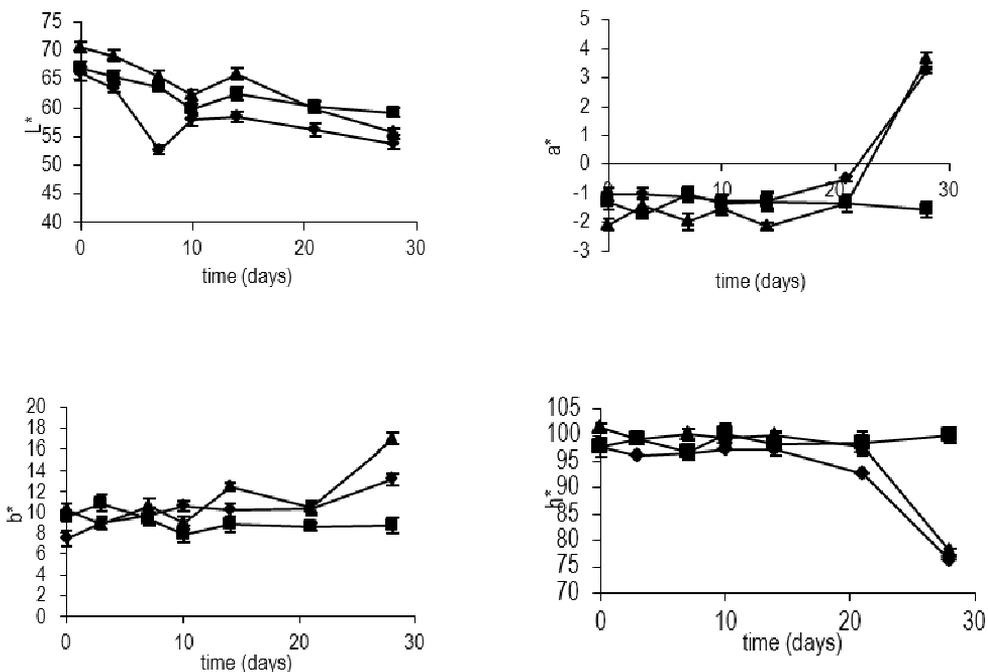
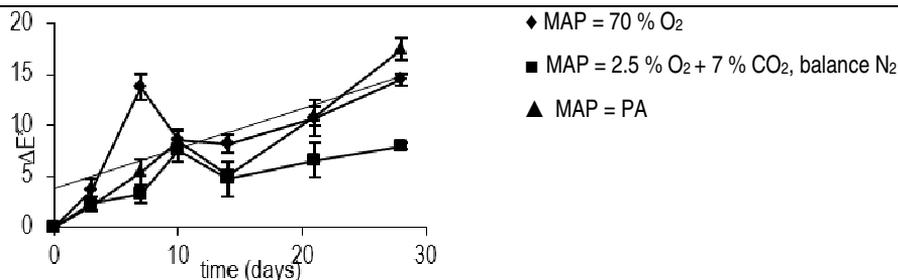


FIGURE 2 (continued). EVOLUTION OF COLOUR PARAMETERS (L^* , A^* , B^* , H^* , ΔE^*) FOR FRESH-CUT "FLOR DE INVIERNO" PEARS DIPPED IN 0.75% (W/V) NAC AND 0.75% (W/V) GSH SOLUTION PRESERVED UNDER DIFFERENT MAP CONDITIONS. DATA SHOWN ARE THE MEANS (\pm STANDARD DEVIATION).



The a^* values for fresh-cut pears packaged under low O₂ atmospheres did not increase significantly. In contrast, a^* values for fresh-cut products under superatmospheric O₂ and PA increased from negative to positive values throughout 3 weeks (Figure 2) showing colour changes from light green to red colour and lost of freshness. Similar results were found in Conference pears and shown as lightness depletion and a slight rise in a^* values (Soliva-Fortuny et al., 2004).

The b^* values were maintained relatively stability along the time without significant changes for pears stored under low O₂ atmospheres. Under superatmospheric O₂ and PA, values increased from 7.49 to 13.18 and from 10.22 to 16.96, respectively during storage showing colour changes from light yellow to darker shade, with lost of fresh colour (Figure 2). Martínez-Ferrer et al. (2002) noticed that fresh-cut mango packaged under 10% CO₂, 4% O₂, 86% N₂ was prevented from browning and resulted in the best maintenance of L^* and b^* values during 25 days of storage. On the other hand, Rojas-Grau et al. (2008) reported that b^* values did not seem to be related to browning in their experiment.

The h^* values represents real colour parameter and they are calculated through a^* and b^* values. The h^* values for fresh-cut pears stored under low O₂ atmosphere were kept constant. In contrast, h^* values for pears packaged under superatmospheric O₂ and PA conditions decreased from 21 to 28 days leading to browning on pear slices (Figure 3). This noticeable decrease in h^* values under superatmospheric O₂ and PA can be due to higher activity enzymes in presence of oxygen. Wsazalaki et al. (2000) find that fruit hue angle was significantly lower in strawberries stored in air, 60 and 80 kPa O₂ after 14 days of storage at 5 °C. Apple slices treated with 1% NAC solution maintained higher absolute h^* values (around 100) during 43 days storage, regardless of the ripeness state or package atmospheres (2.5 kPa O₂+7 kPa CO₂) (Rojas-Grau et al., 2007).

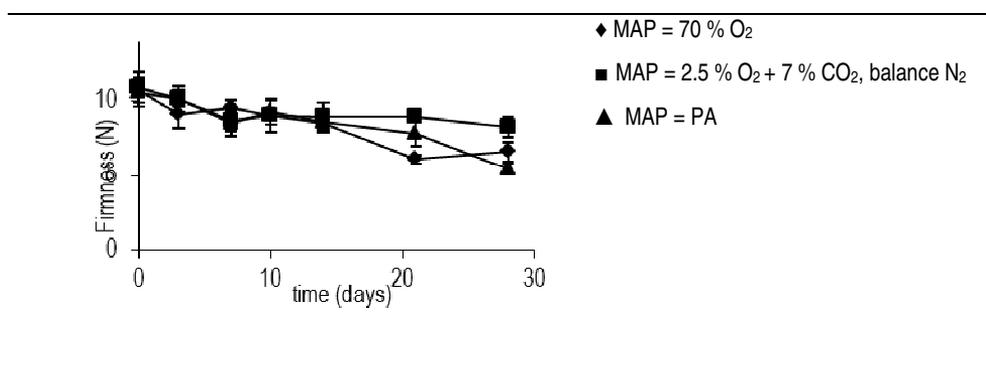
Our results showed that the ΔE^* values rose in fresh-cut pears stored under all conditions. ΔE^* values were higher for pears packaged under superatmospheric O₂ and PA (14.46 and 17.49) than under low O₂ (7.98) atmospheres after 4 weeks storage. Rojas-Grau et al. (2006) reported that ΔE^* values rose when storage time increased in apples dipped in different antibrowning solutions and packaged under PA.

Decrease in L^* and h^* values and increase in a^* , b^* and ΔE^* values indicated browning of fresh-cut "Flor de Invierno" pears. Low O₂ atmospheres reduced polyphenol oxidase activity and thus, browning. Fresh-cut pears packaged under this condition showed a more acceptable colour and visual appearance, than those stored under other atmosphere conditions. On the other hand, in fresh-cut pears stored under superatmospheric O₂ and PA, significantly lower h^* values (76.28 and 77.89) and positive a^* values (3.24 and 3.64) indicated undesirable browning with red-purple colour at the end of storage.

Changes in firmness

Slicing operations also result in dramatic losses of firmness of fruit tissues (Soliva-Fortuny et al., 2003). Fruit softening is a consequence of changes in physical and mechanical properties of the tissue based on changes in the chemical structure of the cell walls polysaccharides and other changes during ripening (Rojas-Grau et al., 2007). Table 1 show that in our experiment firmness was significantly influenced by time and packaging atmosphere ($p \leq 0.05$). Fresh-cut pears packaged under low O₂ (2.5% O₂ and 7% CO₂, balance N₂) atmospheres showed the highest values during 4 weeks storage (Figure 3).

FIGURE 3. EVOLUTION OF FIRMNESS (N) FOR FRESH-CUT "FLOR DE INVIERNO" PEARS DIPPED IN 0.75% (w/v) NAC AND 0.75% (w/v) GSH SOLUTION PRESERVED UNDER DIFFERENT MAP CONDITIONS. DATA SHOWN ARE THE MEANS (\pm STANDARD DEVIATION).



Firmness of the fresh cut-pears packaged under superatmospheric O₂ atmosphere and PA decreased from 10.79 N to 6.63 N and from 10.56 N to 5.47 N, respectively. Gorny et al. (2000) reported that low O₂ (0.25 kPa and 0.5 kPa) or superatmospheric (40, 60, 80 kPa) atmospheres alone did not effectively prevent loss of firmness in fresh-cut pears. Atmosphere modification (100% N₂) had not any significant effect on the evolution of pear firmness (Rojas-Grau et al., 2007; Soliva-Fortuny et al., 2004).

On the contrary, Martinez-Ferrer et al. (2002) reported that 10% CO₂, 4% O₂, 86% N₂ modified atmosphere maintained a better fresh like texture than superatmospheric oxygen atmosphere or vacuum conditions in mangoes and pineapples. Strawberries stored in 5% O₂ + 15% CO₂ lost less weight, maintained better firmness than those stored in 10% O₂ + 20% CO₂ (Brecht et al., 2002).

Determination of pH, total acidity and soluble solids

Acidity can act on processes respiration in fresh-cut fruits. Analysis of variance indicated that time and atmosphere had a significant affect ($p \leq 0.05$) on pH and total acidity (Table 1). The pH values decreased in the first 7 days and then increased at the end of storage under all conditions. But pH value, for fresh-cut pears under superatmospheric O₂ and PA, were greater (5.01 and 5.18 respectively) than in low O₂ atmospheres (4.60) by the end of storage.

This decrease could be correlated with water loss and organic acid degradation during storage when environment becomes more acid. Total acidity decreased during the storage under all conditions, but slightly declined under low O₂ atmosphere. pH values on the fifth day decreased for mangoes and pineapples and then pH increased throughout of 25

days of storage (Martinez-Ferrer et al., 2002). Soliva-Fortuny et al. (2004) found that the perception of acidity was not substantially modified throughout storage.

TABLE 2. DETERMINATION OF PH, TOTAL ACIDITY AND SOLUBLE SOLIDS FOR FRESH-CUT PEARS STORED UNDER DIFFERENT MODIFIED ATMOSPHERES. DATA SHOWN ARE THE MEANS (\pm STANDARD DEVIATION)

	Atmosphere	Time (days)						
		0	3	7	10	14	21	28
pH	70%O ₂	4.48 \pm 0.03	4.52 \pm 0.99	4.24 \pm 0.03	4.36 \pm 0.06	4.33 \pm 0.06	4.53 \pm 0.04	5.01 \pm 0.17
	2.5%O ₂ +7%CO ₂	4.46 \pm 0.11	4.46 \pm 0.11	4.29 \pm 0.01	4.33 \pm 0,01	4.43 \pm 0.08	4.47 \pm 0.02	4.48 \pm 0.06
	PA	4.66 \pm 0.04	4.41 \pm 0.01	4.46 \pm 0.01	4.48 \pm 0.01	4.44 \pm 0.04	4.61 \pm 0.03	5.18 \pm 0.22
Total acidity (g citric acid/10 Og)	70%O ₂	0.09 \pm 0.01	0.09 \pm 0.01	0.11 \pm 0.01	0.10 \pm 0.00	0.11 \pm 0.00	0.07 \pm 0.02	0.06 \pm 0.01
	2.5%O ₂ +7%CO ₂	0.09 \pm 0.01	0.09 \pm 0.01	0.10 \pm 0.00	0.10 \pm 0.00	0.09 \pm 0.01	0.08 \pm 0.00	0.08 \pm 0.01
	PA	0.09 \pm 0.00	0.10 \pm 0.00	0.08 \pm 0.01	0.08 \pm 0.01	0.09 \pm 0.02	0.07 \pm 0.00	0.05 \pm 0.01
Soluble solids ($^{\circ}$ Brix)	70%O ₂	14.05 \pm 0.21	14.30 \pm 0.4	14.10 \pm 0.4	14.05 \pm 0.0	14.30 \pm 0.42	13.95 \pm 0.35	13.60 \pm 0.42
	2.5%O ₂ +7%CO ₂	12.45 \pm 0.35	12.45 \pm 0.3	13.10 \pm 0.1	13.45 \pm 0.3	12.80 \pm 0.42	12.50 \pm 0.42	13.30 \pm 0.14
	PA	13.15 \pm 0.91	13.30 \pm 0.4	13.30 \pm 0.4	12.70 \pm 0.4	12.20 \pm 0.45	13.15 \pm 0.07	11.60 \pm 0.57
			2	2	7			
		5	4	5				
		9	2	2				

The soluble solids content in the fresh cut-pears treated during experiment did not vary throughout storage and were not significantly influenced by time and atmosphere. These results are in accordance with results found by Senesi et al. (1999) and Soliva-Fortuny et al. (2002b).

Conclusion

Results showed that different antioxidants used to preserve initial colour of fruits and applied in combination with MAP could improve fresh-like quality and acceptance of fresh-cut “Flor de Invierno” pears during of refrigerated storage. The application of a low O₂ and elevated CO₂ atmospheres with a dip in 0.75% (w/v) NAC and 0.75% (w/v) GSH aqueous solution preserved a quality colour and texture of fresh-cut pears, completely inhibited ethylene production, reduced CO₂ accumulation and can ensure a commercial shelf-life up to 28 days. On the other hand, superatmospheric O₂ levels induced higher content of ethylene and anaerobic volatile compounds, softer texture, lower acidity and had a negative effect on colour (a^* and h^* values). Storage atmosphere did not affect soluble solids content of fresh-cut pears.

References

- Amiot, M., Tacchini M., Aubert, S., Oleszek, W., 1995. “Influence of cultivar, maturity stage and storage conditions on phenolic compositions and enzymatic browning of pear fruits,” *J. Agric. Food Chem.*, Vol.43, pp.132-37.

- Brecht, J., Chau, K., Fonseca, S. et al., 2002. "Maintaining optimal atmosphere conditions for fruits and vegetables throughout the postharvest handling chain," *Postharvest Biol. Technol.* Vol.27, pp.87-101.
- Dong, X., Wrolstad, R.E., Sugar, D., 2000. "Extending shelf life of fresh-cut pears," *J. Food Sci.*, Vol.65, No1, pp.181-86.
- Golias, J., Botther, H., 2002. "Postharvest response of apple fruits after storage in extreme gas concentrations II. The occurrence of anaerobic metabolites," *Gartenbauwissenschaft*, Vol.67, pp.72-77.
- Gorny, J., Cifuentes, R., Hess-Pierce, B., Kader, A., 2000. "Quality change in fresh-cut pear slices as affected by cultivar, ripeness stage, fruit size, and storage regime," *J. Food Sci.*, Vol.65, No3, pp.541-544.
- Gorny, J., Hess-Pierce B., Cifuentes, R., Kader, A., 2002. "Quality changes in fresh-cut pear slices as affected by controlled atmospheres and chemical preservatives," *Postharvest Biol. Technol.*, Vol. 24, pp. 271-78.
- Martínez-Ferrer, M., Harper, C., Pérez-Muñoz, F., Chaparro, M., 2002. "Modified atmosphere packaging of minimally processed mango and pineapple fruits," *Food Engineering and Physical Properties*, Vol.67, No9, pp.3365-371.
- Oms-Oliu, G., Aguiló-Aguayo, I., Martín-Belloso, O., 2006. "Inhibition of browning of fresh-cut pear wedges by natural compounds," *J. Food Sci.*, Vol.71, No3, pp.216-24.
- Oms-Oliu, G., Soliva-Fortuny, R., Martín-Belloso, O., 2007. "Respiratory rate and quality changes in fresh-cut pears as affected by superatmospheric oxygen," *J. Food Sci.*, Vol.72, No8, pp.456-263.
- Oms-Oliu, G., Soliva-Fortuny, R., Martín-Belloso, O., 2008a. "Effect of natural antibrowning agents on color and related enzymes in fresh-cut fuji apples as an alternative to the use of ascorbic acid," *Postharvest Biol. Technol.*, Vol.48, pp. 295-301.
- Oms-Oliu, G., Soliva-Fortuny, R., Martín-Belloso, O., 2008b. "Edible coatings with antibrowning agents to maintain sensory quality and antioxidant properties of fresh-cut pears," *Postharvest Biol. Technol.*, Vol.50, pp.87-94.
- Pesis, E., 2005. "The role of the anaerobic metabolites, acetaldehyde and ethanol, in fruit ripening, enhancement of fruit quality and fruit deterioration," *Postharvest Biol. Technol.*, Vol.37, pp.1-19.
- Rojas-Graü M., Sobrino-López, A., Tapia, M., Martín-Belloso, O., 2006. "Browning inhibition in fresh-cut "Fuji" apple slices by natural antibrowning agents," *J. Food Sci.*, Vol.71, No1, pp.59-65.
- Rojas-Graü, M., Grasa-Guillem, R., Martín-Belloso, O., 2007. "Quality changes in fresh-cut Fuji apple as affected by ripeness stage, antibrowning agents and storage atmosphere," *J. Food Sci.*, Vol.72, No1, pp.36-42.
- Rojas-Graü, M., Soliva-Fortuny, R., Martín-Belloso, O., 2008. "Effect of natural antibrowning agents on color and related enzymes in fresh-cut fuji apples as an alternative to the use of ascorbic acid," *J. Food Sci.*, Vol.73, No. 6, pp. 267-72.
- Sapers, G., Miller, R., 1998. "Browning inhibition in fresh-cut pears," *J. Food Sci.*, Vol.63, No2, pp.342-34.
- Senesi, E., Galvis, A., Fumagalli, G., 1999. "Quality indexes and internal atmosphere of packaged fresh-cut pears," *J. Food Sci.*, Vol.2, pp.111-20.
- Soliva-Fortuny, R., Biosca-Biosca, M., Grigelmo-Miguel, N., Martín-Beloso, O., 2002. "Browning, polyphenol oxidase activity and headspace gas composition during storage of minimally processed pears using modified atmosphere packaging," *J. Sci. Food Agric.*, Vol.82, pp.1490-496.
- Soliva-Fortuny, R.C., Grigelmo-Miguel, N., Hernando, I. et al., 2002b. "Effect of minimal processing on the textural and structural properties of fresh-cut pears," *J. Sci. Food Agric.*, Vol.82, pp.1682-688.
- Soliva-Fortuny, R., Alòs-Saiz, N., Espachs-Barroso, A., Martín-Beloso, O., 2004. "Influence of maturity at processing on quality attributes of fresh-cut Conference pears," *J. Food Sci.*, Vol.69 No7, pp.290-94.
- Soliva-Fortuny, R., Martín-Beloso, O., 2003. "New advances in extending the shelf life of fresh-cut fruits: a review," *J. Food Sci.*, Vol.14, pp.341-53.
- Wszalaki, A., Mitcham, E., 2000. "Effects of superatmospheric oxygen on strawberry fruit quality and decay," *Postharvest Biol. Technol.*, Vol.20, pp.125-33.