Eating quality and ~~and nutritional quality~~health-promoting properties of two sweet cherry (*Prunus avium* L.) cultivars stored in passive modified atmosphere

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Abstract

Two sweet cherry cultivars ('New Star' and 'Sweet Heart') were chosen to explore the impact of passive modified atmosphere packaging (MAP) on the eating quality and ~~nutritional quality~~health-promoting properties of fruit. Packaged and unpackaged fruit were stored at 0 ºC for 15 or 30 days, followed by 0 or 3 days at 20 ºC, after which the analyses were undertaken. In most cases, MAP helped preserving higher firmness values and reducing the incidence of alterations and decay in both cultivars, but the effects on other physicochemical attributes were different for each cultivar. Partial least squares regression (PLSR) procedures were used to reveal relationships among the different variables assessed. Generally, fruit displaying higher antioxidant capacity were also characterised by higher values for firmness and titratable acidity, in turn related to better acceptability scores in both cultivars. However, the attributes contributing most to acceptability were different in each case. In 'New Star' fruit, acceptability was closely related to the perception of cherry flavour. In this cultivar, acetaldehyde content was related to the perception of off-flavours, while ethanol content was found to associate to soluble solids and to the perception of sweetness. In contrast, acceptability of 'Sweet Heart' fruit was related mainly to the perception of firmness and, to a lower extent, of sweetness.

Keywords

Antioxidant capacity, modified atmospheres, *Prunus avium*, sensory quality, storage potential, sweet cherry

INTRODUCTION

Non-climacteric sweet cherry (*Prunus avium* L.) fruit must be harvested fully ripe in order to achieve good eating quality. Surface colour and soluble solids content (SSC) are usually the main criteria used to determine harvest maturity of these fruit, and typical quality parameters such as SSC, titratable acidity (TA), SSC/TA ratios and firmness are generally used as indicators of the eating quality of produce (Serradilla et al., 2012). In turn, commercial quality also comprises aspects related to appearance, including colour of fruits and stems, and free from defects and infections (Romano et al., 2006). Standard and visual quality parameters, though, sometimes do not reflect completely the overall quality perceived by consumers. Aroma and flavour are also major attributes for the eating quality of the produce. Likewise, ~~nutritional quality~~health-promoting properties of produce ~~is~~ represent an additional commercial value for consumers, and these fruit are an excellent source of several ~~nutrients~~ bioactive compounds and phytochemicals such as phenolics, including anthocyanins (Serrano et al., 2005; Usenik et al., 2008; McCune et al., 2011; Pojer et al., 2013), which contribute to a healthy diet. Actually, the consumption of both sweet and sour cherries has been demonstrated to reduce the risk of a number of degenerative diseases (Jacob et al., 2003; Kang et al., 2003; Kim et al., 2005).

Because of high respiration and rapid softening rates, sweet cherries are highly perishable, with a very short shelf life. Modified atmosphere packaging (MAP), particularly at low temperatures, has proved an effective means for delaying fruit deterioration and reducing growth rate of decay-causing organisms, while preserving SSC, TA and green colour of stems (Meheriuk et al., 1995; Alique et al., 2003; Padilla-Zakour et al., 2004). Therefore, this technology has become a common practice in the commercialisation of sweet cherries for direct consumption. However, decreased

production of aroma volatiles arising from MAP may lead to deficient eating quality in spite of improved appearance. Additionally, enhanced fermentative metabolism at lower O_2 concentrations may also result in the development of off-flavours (Meheriuk et al., 1995; Remón et al., 2000; Kader, 2002; Golias and Bottcher, 2003). Sensory analysis can therefore be of help when assessing the suitability of postharvest procedures applied to fruit.

The potential benefits of MAP use are dependent upon a number of factors, including species, cultivar, physiological stage, atmosphere composition achieved, temperature or storage period. This means that MAP conditions must be optimised, and results assessed, on a case-by-case basis. The overall eating quality of produce should be taken into account to make recommendations as to the suitability of a given procedure. This is particularly true for sweet cherry, for which large variability in sensory and chemical attributes has been reported among cultivars (Usenik et al., 2008; Serradilla et al., 2012; Ballistreri et al., 2013). Additionally, to our best knowledge only a few ~~papers~~ reports ~~(Tian et al., 2004; Harb et al., 2006)~~ have reported the modifications induced by MAP on the content of health-promoting ~~compounds~~ properties in ~~cherry~~cherries (Tian et al., 2004; Harb et al., 2006; Khorsidi et al., 2011) and other stone fruit such as plums (*Prunus salicina* Lindl.) (Cantín et al., 2008; Guan and Dou, 2010; Díaz-Mula et al., 2011) or apricots (*Prunus armeniaca* L.) (Muftuoğlu et al., 2012). There is therefore ample opportunity for exploring the impact of this and other postharvest handling technologies on this aspect of fruit quality. The objective of this work was to study the impact of two commercially available MAP materials on a number of attributes potentially affecting the eating quality ~~and nutritional quality~~and health-promoting properties of sweet cherries. For this, 'New Star' and 'Sweet Heart' cultivars were chosen on the basis of their differences in commercial harvest date and standard quality attributes (i.e. early-season 'New Star' cherries show soft

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flesh at full ripening stage while late-season 'Sweet Heart' maintain high values of firmness throughout postharvest life).

MATERIALS AND METHODS

Plant material and postharvest handling

Sweet cherries (*Prunus avium* L.) from the cultivars 'New Star' and 'Sweet Heart' were picked from an orchard located in Corbins (Segrià, NE Spain) at commercial maturity on the basis of fruit colour, according to the usual standards in the producing area. Harvest dates were 4th and 25th June 2009, respectively. Defect-free, uniform colour fruit were harvested manually early in the morning, transported immediately thereafter to the ETSEA-UdL campus, and cooled at 0 ºC for 3 h. Fruit samples (2 kg) were then packaged in two types of polyethylene films (Film 1 and Film 2; hereafter, F1 and F2) currently available for commercial use on sweet cherries. Film thickness was 30 and 20 μm, respectively. Oxygen permeance was $1.5 \cdot 10^{-12}$ and $24 \cdot 10^{-14}$ mol s^{-1} m^{-2} Pa^{-1}, while water vapour permeance was $9.1 \cdot 10^{-12}$ and $6 \cdot 10^{-10}$ mol s^{-1} m^{-2} Pa^{-1}, correspondingly. The bags were folded over and sealed with tape, and the packages were stored thereafter at 0 ºC and 92% relative humidity under regular air. Unpackaged fruit stored under the same conditions served as controls. CO_2 and O_2 concentrations within the packages were determined at 20 ºC by means of a Checkpoint portable gas analyser (PBI Dansensor, Ringsted, Denmark). After cold storage for 15 or 30 days, packages were opened and samples were placed at 20 ºC. Analyses were carried out 0 (henceforth, 15+0 and 30+0

fruit) and 3 (henceforth, 15+3 and 30+3 fruit) days thereafter. Three replicates were used per treatment (packaging material × cold storage period × shelf life period) and cultivar.

Determination of standard quality parameters

Firmness was measured with a Durofel DFT 100 durometer (Agro-Technologie, Forges Les Eaux, France) fitted with a 5.64-mm tip. Two different measurements were performed on opposite sides of the equatorial zone of 30 tempered fruit, and results were expressed as Durofel units (1, no resistance - 100, maximum resistance). For the assessment of juiciness, three replicate samples (10 fruit each) per treatment were stoned and squeezed until no more juice was released. After filtration, the volume of juice recovered was measured, and expressed as mL 100 g^{-1} FW. SSC and TA were assessed in juice obtained as described above. SSC was determined with a hand-held refractometer (Atago, Tokyo, Japan), and results expressed as ºBrix. For TA determination, 10 mL of juice were diluted in 10 ml distilled water, and titrated with 0.1 M NaOH to pH 8.1; results were given as g malic acid L^{-1}. Skin colour was determined at two opposite equatorial points of 30 fruit using a portable tristimulus colorimeter (Chroma Meter CR-200, Minolta Corp., Osaka, Japan), with CIE D_{65} illuminant and 8 mm aperture diameter. Lightness (L^*) values were recorded, and hue angle was calculated from a^* and b^* parameters. Weight of individual packages was recorded on the day of harvesting and after the different sampling dates, and weight losses were expressed as percentage loss of original weight. The external appearance was assessed on 30 fruit per treatment in terms of stem browning and incidence of fungal decay (presence-absence); results were expressed as percentage of fruit affected.

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146 **Sensory evaluation**

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148 A total of 40 regular cherry consumers from the ETSEA-UdL campus participated in
149 sensory evaluation of fruit 0 and 3 days after cold storage. Cherries from the same batches
150 used to the determination of standard quality parameters were coded according to
151 packaging material, placed on white plates and presented immediately to each judge. The
152 code (a randomly assigned 3-digit number) used for each treatment was different for each
153 evaluating session, and the order in which fruit were presented to each panellist was
154 randomised. A total of six analysis sessions were conducted (three dates × two cultivars).
155 30+3 samples were not evaluated due to advanced decay and non-marketable overall state
156 of fruit (Tables 1 and 2). Participating judges were the same for all six sessions. Mineral
157 water was used as a palate cleanser between samples. The judges were asked to rate overall
158 fruit acceptability according to a 9-point hedonic test (1, dislike very much - 9, like very
159 much). Six additional sensory characteristics (perception of sourness, sweetness, firmness,
160 juiciness, cherry flavour and off-flavour) were also evaluated on a 5-point scale (1, no
161 perception - 5, strong perception).

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164 **Extraction and measurement of anthocyanins and total phenolic compounds**

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166 Batches of 30 fruit per replicate were stoned at each sampling date, frozen in liquid
167 nitrogen, freeze-dried, powdered, and kept at -80 ºC until processing. Lyophilised material
168 (50 mg) was homogenised in 10 mL methanol-HCl-water (50:1:49, v/v/v) and incubated
169 overnight at 4 ºC in the dark. After centrifugation at 4 ºC and 4000 × *g* for 5 min,

anthocyanin content in the supernatant was estimated spectrophotometrically at 532 nm (Jenway JW6715BO, Stone, Staffordshire, UK) as cyanidin-3-rutinoside, and expressed as mg cyanidin eq. g^{-1} DW.

For the assessment of total phenolics, samples (250 mg) of dry tissue were homogenised in 5 mL 80% (v/v) methanol and incubated at room temperature for 20 min. After centrifugation at 4 ºC and 4000 × *g* for 30 min, the pellet was re-extracted with 5 mL 80% (v/v) methanol and centrifuged again. Both supernatants were combined, recovered in a dark vial and placed at 4 ºC in the dark. Total phenolics were determined according to Luthria et al. (2006) in a 300 µL aliquot of the extract, mixed with 1.5 mL 20% (w/v) Na_2CO_3, 0.5 mL 2N Folin-Ciocalteau reagent and 7.7 mL ultra-pure water. The mixture remained 8 min at room temperature before an additional 1.5 mL 20% (w/v) Na_2CO_3 was added. The absorbance at 765 nm was recorded after 2 h at room temperature, and results were estimated as mg eq. gallic acid g^{-1} DW from the corresponding calibration curve.

Evaluation of antioxidant capacity

Total antioxidant capacity was measured in terms of radical scavenging activity (RSA) by the 2,2-diphenyl-1-picrylhydrazyl (DPPH) method as described elsewhere (Oms-Oliu et al., 2009). Dry material (200 mg) was mixed with 10 mL 100% (v/v) methanol, homogenised, and centrifuged at 4 ºC and 4000 × *g* for 20 min. An aliquot (200 µL) of the supernatant was mixed in 7.8 mL DPPH solution (63 µM in 100% (v/v) methanol) in a light-tight tube, and allowed to react during 2 h at room temperature. The absorbance of the reaction mixture was meaured at 515 nm against a methanol (100%, v/v) blank, and RSA was calculated according to the following equation:

RSA (%) = [1 - (Abs_{sample}/$Abs_{control}$)] × 100

where Abs_{sample} and $Abs_{control}$ are the absorbances of DPPH with and without sample, respectively.

Assessment of fermentative metabolism

Juice (5 mL) obtained from three replicate samples (10 fruit each) per treatment was put in 10-mL test tubes closed with elastic caps, and incubated at 65 ºC for 1 h for the analysis of ethanol and acetaldehyde content as described elsewhere (Ke et al., 1994). A 1-mL headspace gas sample was taken with a syringe and injected into a gas chromatograph (Agilent Technologies 6890, Wilmington, Germany), equipped with a column containing Carbowax (5%) on Carbopack (60/80, 2m×2mm i.d.) as the stationary phase, and a flame ionisation detector. Nitrogen was used as the carrier gas (24 cm s^{-1}), and operating conditions were as follows: oven temperature 110 ºC, injector temperature 180 ºC, detector temperature 220 ºC. Acetaldehyde and ethanol were identified and quantified by comparison with external standards, and results were expressed as µL L^{-1}.

One hundred milligrams of lyophilised powdered tissue was used for the determination of alcohol dehydrogenase (ADH; EC 1.1.1.1) and pyruvate decarboxylase (PDC; EC 4.1.1.1) activities on crude enzyme extracts, as previously described (Lara et al., 2003). Total protein content in the enzyme extract was determined with the Bradford (1976) method, using BSA as a standard. One activity unit (U) was defined as the decrease in one unit of A_{340} per minute. Each determination was done in triplicate, and results were expressed as specific activity (U mg $protein^{-1}$).

Statistical analysis

A multifactorial design with packaging material, storage period and shelf life period as factors was used to statistically analyse the results. All data were tested by analysis of variance (GLM-ANOVA procedure) with the SAS System 9.0 program package (SAS Institute, Cary, NC, 2002), and means were separated by the Fisher's LSD test at $p < 0.05$. Partial least squares regression (PLSR) was used as a predictive method to relate a matrix of dependent variables (*Y*) to a set of explanatory variables (*X*). Unscrambler version 9.1.2 software (CAMO ASA, 2004) was used for developing these models.

RESULTS AND DISCUSSION

The atmosphere composition within the packages was effectively modified (Table 3), F2 being considerably more restrictive regarding gas exchange, and thus resulting in significantly higher CO_2 and lower O_2 concentrations than inside F1 packages. Different parameters related to eating quality and ~~nutritional quality~~health-promoting properties of fruit were assessed in each case.

Standard quality and ~~nutritional quality~~health-promoting properties of MA-packaged sweet cherries

For 'New Star' cherries, the effects of MAP on firmness were dependent on the storage

period (Table 1). Whereas both packaging materials, and particularly F2, were generally helpful for firmness preservation upon removal from cold storage (15+0 and 30+0 fruit), for 15+3 cherries uniquely F1 allowed maintaining higher firmness levels in comparison with the controls, while packaging in F2 was detrimental for this attribute. Both packaging materials significantly lowered firmness in 30+3 ~~fruit~~'New Star' cherries. This dependency on the storage period was also observed for other parameters usually considered for assessing fruit quality, such as SSC and TA (Table 1). Lower TA levels than those in the controls were found for fruit stored within MAP upon removal from storage, while for 30+3 fruit the opposite was observed. Higher SSC content was observed for 15+0 samples packaged in F1, but both packaging materials led to lowered SSC in 30+0 cherries. Packaging under MAP preserved similar SSC to those in the controls at the end of the shelf life period at 20 ºC considered, with the only exception of F1-packaged fruit, which had significantly lower levels of this attribute during shelf-life following 15 days of cold storage. In general, both packaging materials decreased weight loss as well as the incidence of fungal decay and stem browning, though F2, more restrictive in term of gas exchange, was generally more effective.

'Sweet Heart' cherries were firmer, more acid, and contained higher SSC levels than 'New Star' fruit, both at harvest and after storage, but were generally less juicy (Table 2) and had lower contents of phenolic compounds (Table 4). The effects of MAP were more apparent for this cultivar (Table 2), with significantly better firmness retention for 15+0, 15+3 and 30+0 fruit, while 30+3 samples displayed similar firmness regardless of treatment. Yet previously, Kappel et al. (2002) and Remón et al. (2000) described a beneficial effect on cherry firmness preservation using MAP~~.~~, whereas Padilla-Zakour et al. (2004) reported no significant effect of MA-packaging in firmness values of both 'Lapins' and 'Hedelfingen' cultivars. SSC content was generally better preserved in MA-

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packaged fruit, but MAP led to higher TA levels uniquely after short-term (15 days) storage. Juiciness was lower in MA-packaged fruit, with the exception of 30+3 samples, for which the opposite was observed. Positive effects on the incidence of decay and stem browning were also observed in response to MAP, particularly for F2. The importance of maitaining green colour of stems during storage of cherries is remarkeable, as it has been suggested as a good indicator of postharvest freshness of sweet cherries (Linke et al., 2010). Thus MAP was in general effective in maintaining quality of fruit by slowing down the loss of soluble solids and by delaying softening.

Some indicators of ~~nutritional quality~~health-promoting properties were also assessed in MA-packaged fruit. These samples showed higher total antioxidant capacity in comparison with the controls, regardless of cultivar and storage period (Table 4). Similarly, the antioxidant activity of MA-packaged 'Siah-e Mashlad' sweet cherries stored up to 30 days at 3 °C was also higher than controls (Khorshidi et al., 2011); however, the gas composition did not affect the antioxidant capacity in the case of extended storage periods. In general, fruit with higher levels of antioxidant capacity had also higher firmness and TA levels (Tables 1 and 2), which were in turn related to better acceptance scores in both cultivars (Figures 1 and 2). This is interesting, as the upgrading in sensory quality, in terms of better flavour and overall acceptability, was also associated to this important ~~nutritional~~ health-promoting property. Regarding total phenolics and anthocyanin content, MAP effects were less clear, and were dependent upon cultivar and storage period. For 'New Star' fruit, no significant improvement in these ~~nutritional~~ properties was observed in response to MAP, with the exception of 15+0 samples, for which F2 resulted in higher levels of total phenolics, including anthocyanins (Table 4). Generally speaking, F1-stored fruit displayed lowered or similar levels of these attributes if compared to control, whereas F2 maintained similar values to those in control fruit, with the exception of 15+0 fruit,

295 which showed higher values of both total phenolics and anthocyanins content. However, to
296 keep fruit for and additional period (3 days) at 20 ºC helped enhancing the levels of both
297 attributes, and especially anthocyanin content. For 'Sweet Heart', packaging under passive
298 modified atmosphere was in general detrimental for the content of total phenolics and
299 anthocyanins after 15 days at 0 ºC (Table 4), while for fruit kept at 0 ºC during one month
300 the levels of these attributes were improved, particularly in samples packaged in F2.
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303 **Eating quality of MA-packaged sweet cherries**
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305 The standard parameters recurrently used by the fruit industry to evaluate commercial
306 quality of produce are not always indicative of overall eating quality and consumer
307 satisfaction. Therefore, we undertook a regression analysis applied to commercial quality
308 parameters potentially having some weight on sensory quality traits. Separate PLSR
309 models were developed for each cultivar, in which sensory characteristics (*Y* variables)
310 were related to a set of hypothetically explanatory variables (*X* variables), including
311 standard quality parameters as well as ethanol (etOH) and acetaldehyde (AA) contents as
312 indicators of the extent of fermentative metabolism induced in each case. Due to bad
313 overall condition and unmarketability of 30+3 fruit, these samples were not included in the
314 models.
315 For 'New Star' cherries, the *X* variables considered accounted together for 69% of
316 variability in sensory attributes perceived by the consumers (Figure 1). Samples distributed
317 along the first principal component (PC1) according mainly to storage period. 15+0
318 samples received the best acceptance scores, with 15+3 and 30+0 grouping progressively
319 leftwards, thus reflecting the rapid drop in the eating quality of these fruit as storage was

extended. The correlation loading plot shows which of the variables considered in the model were most rellevant for overall consumer satisfaction. As showin in Figure 1(b), acceptability scores were closely related to the perception of cherry flavour. Separation along PC1 was given mainly by sensory firmness (S firmness), perception of sourness and TA, which characterised 15+0 samples. There was a close relationship between TA and perceived sourness, between SSC and perceived sweetness and, to a lesser extent, between instrumental and sensory firmness. In contrast, sensory juiciness was poorly related to instrumental juiciness, which characterised 30+0 samples. Although fruit juiciness is generally regarded as desirable, high levels of this attribute might be also indicating over-ripening and tissue breakdown, which may explain the observation of an inverse relationship to overall acceptability and to instrumental and perceived firmness. Actually, the juiciest fruit were also characterised by higher incidence of fungal decay and stem browning, as observed in Figure 1(b). These samples also had higher contents of acetaldehyde, which has been shown to promote fruit softening in some fruits (Janes and Frenkel, 1978; Pesis, 2005; Botondi et al., 2012), and were associated to higher incidence of off-flavours. However, the fermentation induction point has been determined to be lower than 1 kPa at 0 ºC in 'Sams' sweet cherry (Petracek~~, Joles, Shirazi and Cameron,~~ et al., ~~2002~~), whereas O_2 concentrations within the packages were higher than 16 kPa (Table 3). Therefore, off-flavours detected were not likely to arise from the accumulation of fermentative metabolites, and may have been related rather to over-ripeness of these fruit.

Acetaldehyde has been also shown to enhance ripening-related gluconeogenesis from malate and other organic acids, suggested as an important pathway for sugar synthesis in non-climacteric fruit, where little or no starch reserves are usually found (Halinska and Frenkel, 1991). When O_2 availability decreases, acetaldehyde is increasingly reduced to ethanol (Fidler, 1968). Interestingly, ethanol content was associated to the perception of

345 fruit sweetness. Ethanol is one of the main volatiles in quantitative terms in 'Bing' cherries
346 (Mattheis et al., 1997), and its production is also required for the production of ethyl esters,
347 some of which contribute fruity and sweet notes to fruit aroma (reviewed in Pesis, 2005),
348 which might explain this observation. The emission of these and other flavour-contributing
349 volatiles is largely affected by storage conditions in 'Bing' as well as in 'Ambrunés' sweet
350 cherry (Serradilla et al., 2010). Furthermore, ethanol treatments reportedly increase
351 glucose, fructose and sucrose contents in melon (*Cucumis melo* L.), besides enhancing the
352 emission of ethyl esters and preserving firmness (Liu et al., 2012).

353 'Sweet Heart' cherries responded differently to MAP as shown by the corresponding
354 PLSR model (Figure 2). Up to 67% of variability in sensory attributes could be explained
355 by the model. These fruit quickly lost commercial quality during shelf life at 20 ºC: 15+3
356 samples had the worst values in terms of weight loss, incidence of fungal decay, stem
357 browning and off-flavour scores, as shown in Figure 2(b). For this cultivar, acceptability
358 was related mainly to the perception of firmness and, to a lower extent, of sweetness.
359 Contrarily to 'New Star' cherries, no close association was observed between sweetness
360 and SSC, maybe because of higher acidity levels (Tables 1 and 2) interfering with the
361 perception of the sweet components of taste. Similarly to 'New Star', sensory juiciness was
362 poorly related to instrumental juiciness. In contrast, no clear relationship to sensory
363 attributes was observed for ethanol or acetaldehyde levels, as displayed in Figure 2(b).
364 Acetaldehyde content had little weight on sample differentiation, as it was located close to
365 the center of the plot, while ethanol was neither associated to flavour nor to perception of
366 sweetness, contrarily to observations for 'New Star', and actually ethanol levels were
367 higher for those samples with lower acceptability scores. This may be indicative that the
368 composition of the aroma-related volatile profile is different in this cultivar. 'Sweet Heart'
369 fruit also had higher SSC values (Table 2), and therefore the contribution of ethanol to

sweetness perception may be not so relevant in this case. The induction of fermentative metabolism may also require different conditions in this cultivar: for instance, cold-storage under MAP generally inhibited the increase in PDC and, in some cases, in ADH activities during the subsequent shelf life period at 20 ºC (Table 5), contrarily to the observations for 'New Star'. The relationship between PDC and ADH activities and the concentrations of ethanol and acetaldehyde is not always clear, due to the use of both metabolites in different metabolic pathways, and also to the fact that ADH can catalyse the interconversion between acetaldehyde and ethanol in both directions, according to pH and to their relative concentrations within the cell (Botondi et al., 2012).

In summary, the results of this work confirm that MAP conditions during storage of 'New Star' and 'Sweet Heart' sweet cherries may extend marketability of produce. In general, MAP conditions storage contributed to firmness retention as well as to a reduction of the incidence of alterations and decay in both cultivars, when considering storage periods up to 30 days. Moreover, MA-packaged cherries displayed higher antioxidant capacity, which was indirectly related to better consumer's satisfaction scores. However, the attributes most influencing acceptability of scores were different for each cultivar which highlight the need to evaluate MAP effects on sweet cherries attributes case by case.

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DECLARATION OF CONFLICTING INTERESTS

The Authors declare that there is no conflict of interest.

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Con formato: Inglés (Estados Unidos)

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Table 1. Standard and commercial quality of 'New Star' sweet cherry fruit at harvest and after cold storage under MAP

Parameter		Packaging	Storage period at 0 ºC + days at 20 ºC			
	Harvest		15 + 0	15 + 3	30 + 0	30 + 3
Firmness	68.15	Control	61.93 Bb	66.33 Ba	52.87 Cc	53.62 Ac
(Durofel units)		Film 1	62.27 ABb	71.07 Aa	55.42 Bc	48.95 Bd
		Film 2	64.32 Aa	62.33 Ca	58.30 Ab	47.77 Bc
TA	9.74	Control	7.78 Aa	6.89 Ab	6.41 Ac	5.69 Bd
($g\ L^{-1}$)		Film 1	6.99 Ca	6.23 Bb	5.52 Cc	6.31 Ab
		Film 2	7.33 Ba	6.87 Ab	5.93 Bc	6.17 Ac
SSC	14.70	Control	13.70 Bc	15.40 Aa	15.40 Aa	14.27 Ab
(ºBrix)		Film 1	15.70 Aa	14.07 Bb	14.27 Bb	14.03 Ab
		Film 2	13.77 Bbc	15.57 Aa	13.70 Cc	14.27 Ab
Juiciness	45.30	Control	49.46 Cc	63.59 ABb	70.78 Aa	67.49 ABa
(mL 100 g^{-1} FW)		Film 1	61.31 Bc	60.97 Bc	65.35 Bb	69.24 Aa
		Film 2	68.46 Aa	66.06 Aa	61.91 Cb	65.08 Bab
Hue	13.10	Control	14.84 Ba	14.61 Ba	11.88 Ab	12.36 Ab
(º)		Film 1	13.78 Bb	16.21 Aa	11.69 Ac	12.62 Abc
		Film 2	16.28 Aa	14.48 Bb	11.81 Ac	12.45 Ac
Weight loss	-	Control	1.84 Ad	5.26 Ab	3.67 Ac	7.78 Aa
(%)		Film 1	0.24 Bb	3.99 Ba	1.79 Bb	4.44 Ba
		Film 2	0.49 Bb	4.60 ABa	0.71 Bb	4.13 Ba
Stem browning	-	Control	7.0 Ab	80.0 Aa	80.0 Aa	80.0 Aa
(% fruit affected)		Film 1	0.0 Bd	63.3 Bb	43.3 Bc	80.0 Aa
		Film 2	0.0 Bd	50.0 Cb	27.0 Cc	73.0 Aa
Decay	-	Control	10.0 Ab	16.6 Ab	13.0 Ab	33.3 Aa
(% fruit affected)		Film 1	0.0 Bb	6.6 Bb	10.0 Ab	23.3 Ba
		Film 2	0.0 Bb	0.0 Bb	6.6 Ab	10.0 Ca

Values represent means of 30 (firmness) or three (SSC, TA, juiciness, colour, weight loss) replicates. Means followed by different capital letters within a column for a given parameter are significantly different at $p < 0.05$ (LSD test). Means in the same row showing different lower-case letters are significantly different at $p < 0.05$ (LSD test).

Table 2. Standard and commercial quality of 'Sweet Heart' sweet cherry fruit at harvest and after cold storage under MAP

Parameter		Packaging	Storage period at 0 ºC + days at 20 ºC			
	Harvest		15 + 0	15 + 3	30 + 0	30 + 3
Firmness	81.15	Control	74.60 Cbc	73.22 Bc	76.90 Ca	76.40 Aab
(Durofel units)		Film 1	76.82 Bb	78.92 Aab	79.70 Ba	76.77 Ab
		Film 2	79.92 Ab	77.30 Ac	82.43 Aa	75.25 Ac
TA	11.02	Control	8.71 Ca	8.60 Ba	8.63 Aa	8.21 Ab
($g\ L^{-1}$)		Film 1	9.42 Ba	9.07 Ab	8.63 Ac	7.44 Bd
		Film 2	9.86 Aa	8.96 Ab	8.42 Ac	7.76 Bd
SSC	19.07	Control	17.13 Cb	18.33 Ba	17.33 Cb	18.13 Aa
(ºBrix)		Film 1	17.80 Bb	19.63 Aa	17.80 Bb	17.70 Bb
		Film 2	18.53 Ab	19.30 Aa	19.00 Aa	18.17 Ab
Juiciness	61.26	Control	61.87 Ab	63.22 Aab	65.72 Aa	56.28 Bc
(mL 100 g^{-1} FW)		Film 1	58.03 Bb	56.91 Cb	62.44 Ba	58.35 ABb
		Film 2	56.12 Bb	60.02 Ba	62.49 Ba	59.89 Aa
Hue	14.64	Control	15.56 Aa	11.20 Ab	15.46 Aa	15.42 Aa
(º)		Film 1	15.28 Aa	9.55 Bb	14.87 Aa	15.05 ABa
		Film 2	13.87 Ba	11.30 Ab	14.38 Aa	13.68 Ba
Weight loss	-	Control	1.05 Ac	6.93 Aa	1.80 Ac	5.10 Ab
(%)		Film 1	0.55 Ac	4.08 Ba	0.91 ABc	2.77 Bb
		Film 2	0.59 Ab	4.50 Ba	0.55 Bb	3.74 Ba
Stem browning	-	Control	60.0 Ac	80.0 Ab	76.6 Ab	90.0 Aa
(% fruit affected)		Film 1	40.0 Bc	83.3 Aa	67.8 Ab	80.0 Ba
		Film 2	13.3 Cc	66.7 Ba	43.3 Bb	66.7 Ca
Decay	-	Control	0.0 Ac	26.7 Ab	23.3 Ab	60.0 Aa
(% fruit affected)		Film 1	0.0 Ac	16.7 Bb	10.0 Bb	46.7 Ba
		Film 2	0.0 Ac	16.7 Bb	6.7 Bc	30.0 Ca

Values represent means of 30 (firmness) or three (SSC, TA, juiciness, colour, weight loss) replicates. Means followed by different capital letters within a column for a given parameter are significantly different at $p < 0.05$ (LSD test). Means in the same row showing different lower-case letters are significantly different at $p < 0.05$ (LSD test).

Table 3. CO_2 and O_2 concentrations (%) within bags of 'New Star' and 'Sweet Heart' sweet cherry fruit stored under MAP at 0 ºC

Cultivar	Packaging	Storage period + days at 20 ºC			
		15 + 0		30 + 0	
		O_2	CO_2	O_2	CO_2
'New Star'	Film 1	-	-	19.21 A	2.95 B
	Film 2	-	-	17.82 B	5.59 A
'Sweet Heart'	Film 1	20.00 Aa	0.81 Ba	19.62 Aa	0.94 Ba
	Film 2	17.40 Ba	4.20 Ab	16.11 Bb	4.64 Aa

Values are the means of three treatment replicates (-, not determined). Means followed by different capital letters within a column for a given cultivar are significantly different at $p < 0.05$ (LSD test). For each cultivar and gaseous compound, means in the same row showing different lower-case letters are significantly different at $p < 0.05$ (LSD test).

Table 4. Health-promoting properties in ‘New Star’ and ‘Sweet Heart’ sweet cherry fruit at harvest and after cold storage under MAP

Cultivar			Packaging	Storage period at 0 ºC + days at 20 ºC			
		Harvest		15 + 0	15 + 3	30 + 0	30 + 3
‘New Star’	Radical scavenging activity (%)	35.41	Control	30.62 Ba	25.29 Cb	19.55 Bc	20.10 Cc
			Film 1	32.95 Aa	33.51 Aa	28.90 Ab	24.44 Bc
			Film 2	32.17 Aa	31.11 Ba	28.21 Ab	27.24 Ab
	Total phenolics (mg g^{-1} DW)	11.19	Control	11.44 Bc	13.36 ABa	12.14 ABbc	12.44 Ab
			Film 1	10.95 Bb	12.58 Ba	11.35 Bb	11.08 Bb
			Film 2	12.53 Ab	13.50 Aa	12.27 Ab	12.56 Ab
	Anthocyanins (mg g^{-1} DW)	4.69	Control	5.66 Bc	6.93 Aa	5.83 Ac	6.28 Ab
			Film 1	5.14 CBc	6.72 Aa	5.22 Bc	5.73 Bb
			Film 2	5.99 Ab	6.33 Ba	5.97 Ab	6.56 Aa
‘Sweet Heart’	Radical scavenging activity (%)	37.33	Control	27.81 Ca	23.70 Cb	27.07 Ca	23.19 Bb
			Film 1	32.94 Aa	31.45 Aa	32.52 Aa	28.51 Ab
			Film 2	30.37 Ba	28.96 Ba	30.04 Ba	30.55 Aa
	Total phenolics (mg g^{-1} DW)	9.72	Control	11.62 Aa	10.48 Ab	10.39 Bb	9.33 Cc
			Film 1	10.08 Bab	9.81 Bb	10.47 Ba	10.25 Ba
			Film 2	9.16 Cc	10.13 ABb	10.97 Aa	10.88 Aa
	Anthocyanins (mg g^{-1} DW)	3.96	Control	5.27 Aa	5.19 Aa	3.52 Bc	4.12 Cb
			Film 1	4.57 Ba	3.69 Cc	4.18 Ab	4.34 Bb
			Film 2	3.80 Cd	4.48 Bb	4.23 Ac	4.99 Aa

Values represent means of three replicates. Means followed by different capital letters within a column for a given parameter and cultivar are significantly different at $p < 0.05$ (LSD test). Means in the same row showing different lower-case letters are significantly different at $p < 0.05$ (LSD test).

Table 5. Fermentative metabolism in 'New Star' and 'Sweet Heart' sweet cherry fruit at harvest and after cold storage under MAP

Cultivar			Packaging	Storage period at 0 ºC + days at 20 ºC			
		Harvest		15 + 0	15 + 3	30 + 0	30 + 3
'New Star'	PDC activity	7.15	Control	10.48 Bc	14.68 Cb	14.86 Ab	28.98 Aa
	(U mg^{-1} protein)		Film 1	14.12 Ac	18.47 Bb	7.71 Bd	25.68 Ba
			Film 2	10.26 Bc	20.31 Ab	8.59 Bd	23.88 Ca
	Acetaldehyde content	1.83	Control	1.23 Ab	2.17 Aa	2.24 Aa	1.40 Ab
	(μL L^{-1})		Film 1	1.47 Ab	1.57 Bb	2.48 Aa	0.88 Bc
			Film 2	1.20 Ab	1.39 Bb	1.72 Ba	1.38 Ab
	ADH activity	3.11	Control	7.82 Ac	16.29 Ab	8.56 Ac	23.94 Ba
	(U mg^{-1} protein)		Film 1	8.65 Ab	7.10 Bb	8.44 Ab	28.29 Aa
			Film 2	5.99 Bc	5.33 Cc	7.99 Ab	24.46 Ba
	Ethanol content	3.75	Control	3.87 Bc	12.87 Aa	5.79 Ab	6.17 Ab
	(μL L^{-1})		Film 1	5.50 Ab	7.90 Ba	5.23 Ab	3.53 Cc
			Film 2	3.04 Cc	8.12 Ba	3.00 Bc	5.05 Bb
'Sweet Heart'	PDC activity	4.93	Control	8.28 Ac	21.47 Aa	4.99 Ac	12.58 Ab
	(U mg^{-1} protein)		Film 1	11.61 Aab	12.84 Ba	6.29 Ac	8.88 Bbc
			Film 2	10.92 Aa	12.78 Ba	5.81 Ab	6.23 Bb
	Acetaldehyde content	1.52	Control	1.53 Bbc	1.43 Ac	2.10 Aa	1.67 Cb
	(μL L^{-1})		Film 1	1.70 Ac	1.51 Ad	1.94 Bb	2.34 Aa
			Film 2	1.33 Cd	1.42 Ac	1.63 Cb	1.91 Ba
	ADH activity	4.23	Control	12.07 Ab	13.70 Aa	10.24 Ac	14.36 Aa
	(U mg^{-1} protein)		Film 1	10.76 Bb	13.13 Aa	8.07 Bc	9.24 Bc
			Film 2	8.42 Cb	13.02 Aa	5.94 Bc	6.22 Cc
	Ethanol content	1.75	Control	6.59 Ab	8.01 Aa	5.78 Ab	8.04 Ba
	(μL L^{-1})		Film 1	6.10 Ab	4.26 Cc	5.32 Ab	12.30 Aa
			Film 2	4.87 Bb	7.04 Ba	3.55 Bc	6.83 Ca

Values represent means of three replicates. Means followed by different capital letters within a column for a given parameter and cultivar are significantly different at $p < 0.05$ (LSD test). Means in the same row showing different lower-case letters are significantly different at $p < 0.05$ (LSD test).

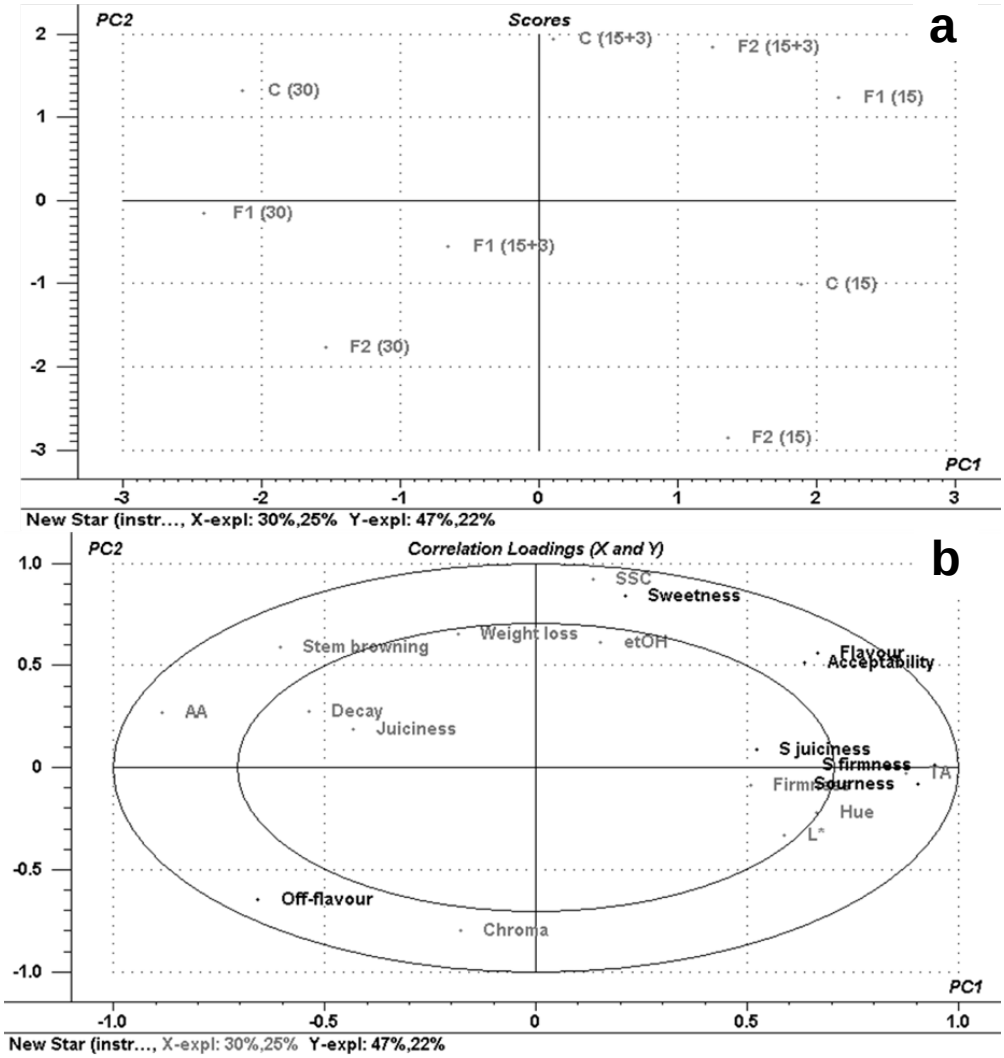

Figure 1. Scores (**a**) and correlation loadings (**b**) plots of PC1 *versus* PC2 corresponding to a PLSR model for sensory attributes (*Y* variables) versus standard quality and fermentative metabolites (*X* variables) in 'New Star' cherry fruit after cold storage under MAP.

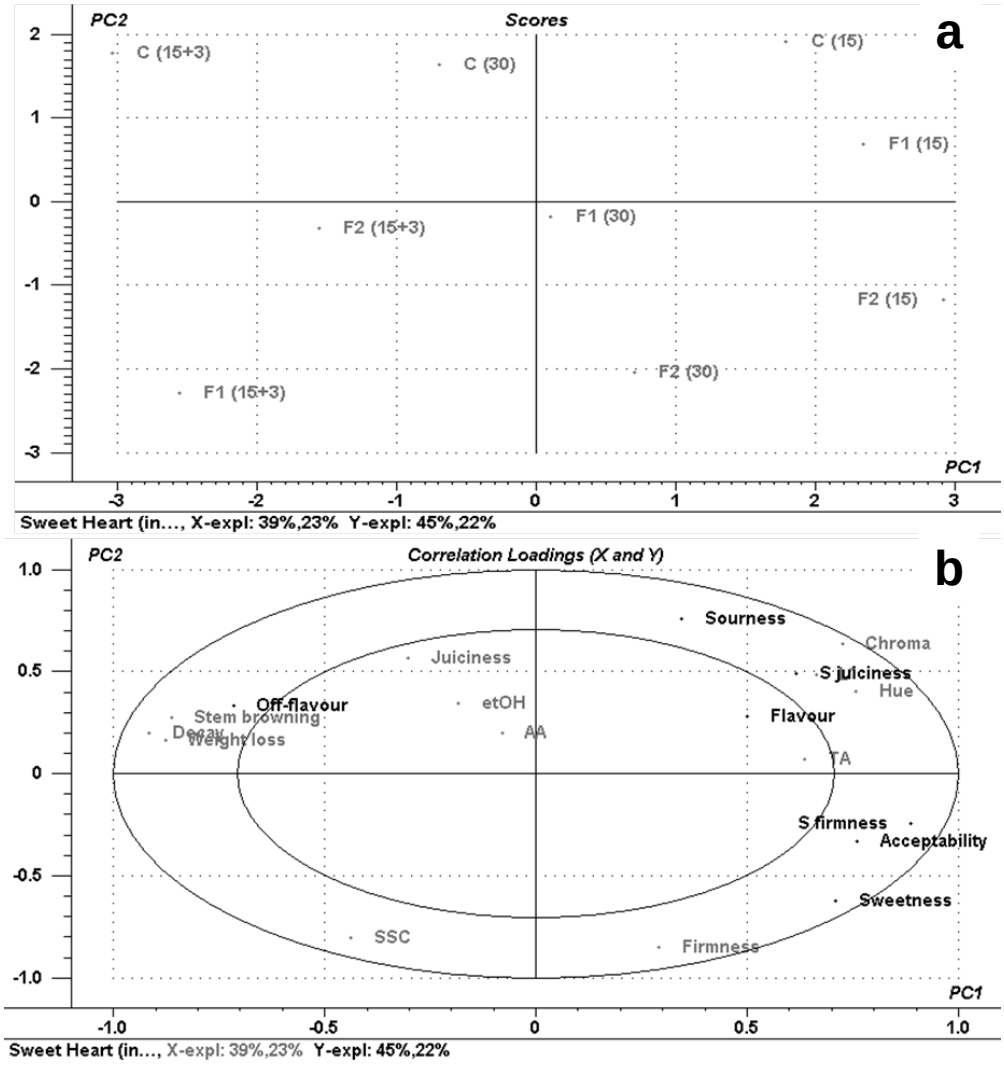

Figure 2. Scores (**a**) and correlation loadings (**b**) plots of PC1 *versus* PC2 corresponding to a PLSR model for sensory attributes (*Y* variables) versus standard quality and fermentative metabolites (*X* variables) in 'Sweet Heart' cherry fruit after cold storage under MAP.