Retention of quality and functional values of broccoli ‘Parthenon’ stored in modified atmosphere packaging

M.F. Fernández-León a, A.M. Fernández-León a, M. Lozano a, M.C. Ayuso b, M.L. Amodio c, G. Colelli c, D. González-Gómez a, *

a Technological Institute of Food and Agriculture (INTAEX), Junta de Extremadura, Ctra. Cáceres S/N, 06071 Badajoz, Spain
b Agriculture Engineering School, University of Extremadura, Ctra. Cáceres S/N, 06007 Badajoz, Spain
c Dept. PRIME, University of Foggia, Via Napoli 25, 71100 Foggia, Italy

A R T I C L E   I N F O
Article history:
Received 18 June 2012
Received in revised form 28 September 2012
Accepted 9 October 2012

Keywords:
Respiration rate
Health promoting compounds
Antioxidant activity
Quality parameters

A B S T R A C T
The aim of this research was to identify, quantify and compare the main quality parameters and functional compounds of ‘Parthenon’ broccoli florets stored at two different conditions. The first condition consisted in a modified atmosphere packaging (MAP) using microperforated polypropylene plastic. Then, the second one was in an unpackaged storage (Control). The main quality parameters assessed in this research were the overall appearance, odour, weight loss and colour. While, the functional compounds evaluated in this study were the chlorophyll and carotenoid pigments, vitamin C, total phenol content and intact glucosinolates, as well as the in vitro antioxidant activity. The results indicated that the loss of quality was lower in MAP than in Control samples when comparing with Fresh sample. In addition, the weight loss in MAP samples was 0.75% while in the Control samples was 3.36% at the end of storage. Besides, the losses of external attributes were also more pronounced in Control than in the MAP samples. Moreover, this degradation tendency was also observed for bioactive compounds, where their retention in the MAP was higher than in Control samples. In fact, the loss of total phenol content and intact glucosinolates content in MAP samples was about 20 and 23%, respectively, while in Control samples was about 48% and 57% correspondingly. This was also observed in the antioxidant activity (AA) values, since AA is correlated with these functional compounds.

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1. Introduction

Currently the interest in healthier diets has increased notoriously, consumers demand easy-to-cook and easy-to-eat products not only with relevant nutritious but also with healthy properties. In that sense, the demand on broccoli has increased particularly, and broad types of broccoli products are now available in the market: from fresh broccoli heads to new formats such as salads ready to eat or vegetable mixtures ready to cook (Schreiner, Peters, & Krumbein, 2007). From an economical point of view, Spain and Italy are the largest producers of broccoli and cauliflower in Europe. According to data from the Statistics Division of the Organization for Food and Agriculture of the United Nations (FAOSTAT, 2010), the broccoli production has risen steadily since 1997, peaking in 2010, when 511,100 t and 427,407 t were harvested in Spain and Italy, respectively.

A key factor of the increase of broccoli consumption is the abundance of health-promoting compounds observed in these cruciferous plants. Precisely, important amounts of glucosinolates, flavonoids and vitamins, together with antioxidant and free-radical scavenging properties were quantified in broccoli plants (Kris-Etherton et al., 2002; Page, Griffiths, & Buchanan-Wollaston, 2001; Vallejo, García-Viguera, & Tomás-Barberán, 2003). Different studies have demonstrated that these bioactive compounds have an important role in the prevention of different human diseases (Traka & Mithen, 2009). However, the abundance of these compounds decreases after harvest, together with a deterioration of the organoleptic quality attributes (Howard, Jeffery, Wallig, & Klein, 1997; Vallejo, García-Viguera et al., 2003).

A limiting factor that reduce broccoli consume is its perishable nature, characterized by its reduced shelf life after harvest. The main symptoms of quality loss are surface dehydration and loss of green colour, with floret yellowing as consequence of chlorophyll degradation together with a fastening of plant metabolism (Eason,
2.2. Experimental design

Experimental design.

Broccoli heads were cut into University of Foggia and selected, discarding damaged plants. Samples were rapidly transported to the Postharvest Laboratory of standard cultural practices. Plants were harvested during the last were grown in a commercial farm in Foggia, Italy, according to 30

2. Materials and methods

2.1. Plant material

Broccoli (Brassica oleracea L. var. italica cv. Parthenon) heads were grown in a commercial farm in Foggia, Italy, according to standard cultural practices. Plants were harvested during the last week of November 2010, at commercial maturity stage. The samples were rapidly transported to the Postharvest Laboratory of University of Foggia and selected, discarding damaged plants. Broccoli heads were cut into florets and prepared according to the experimental design.

2.2. Experimental design

Approximately 250 g of broccoli florets were packed in microperforated polypropylene bags of 25 cm × 25 cm with a thickness of 30 μm making a total of 54 bags of ready-to-use product. From them, 24 bags were sealed (Tecnovac T720, Tecnovac, Srl, Grassobbio, Italy) and placed at 5 °C in an active modified atmosphere (MAP). The MAP conditions were established according to our previous study (Fernández-León, Lozano, Ayuso, & González-Gómez, 2011). Thus, the experimental design was established in order to reach a final atmosphere composition of 5% of CO₂ and 10% of O₂ in each sealed sample bag. Thus, to get this final atmosphere composition, the equation proposed by Massey (2003) and González, Ferrer, Oría, and Salvador (2008) were applied:

\[
\text{GTR} = \frac{\text{RR} \times t \times W}{A \times (\text{GI} - \text{GF})}
\]

where:

\[
\text{GTR} = \text{Gas transmission rate (Film Permeability)}
\]

\[
\text{RR} = \text{Respiration rate}
\]

\[
t = \text{Film thickness}
\]

\[
W = \text{Product weight}
\]

\[
A = \text{Film surface area}
\]

\[
\text{GI} = \text{Initial gas composition}
\]

\[
\text{GF} = \text{Final gas composition}
\]

Therefore, considering the entire experimental factor, the proposed MAP was obtained by injecting 10% of CO₂ and 5% of O₂ (MAP samples).

The 30 remaining bags were not sealed and were divided into two groups: 6 bags were analysed on the same day of the experiment (Fresh samples) and the other 24 remaining bags were stored at 5 °C (Control samples). Both Control and MAP samples were analysed in each sampling day (3, 6, 9 and 12), so that 6 bags were available for each sampling date and treatment. When it was necessary samples were frozen at −80 °C until analysis. In all cases \( N = 6 \).

In order to know the permeability of microperforated polypropylene film, it was evaluated at 5 °C (1250 mL CO₂/m² × day) by a Lissy L100-5000 manometric gas permeability tester (M.Penati Strumenti, Srl, Piozzello, Italy).

2.3. Respiration rate

Respiration rate (ml CO₂/kg × h) was measured in triplicate using a dynamic system (Kader, 2002). Briefly, 0.1 mL of gas was collected from the inlet and from the outlet flows of each jar and injected into a gas chromatograph (model 17A; Shimadzu, Kyoto, Japan) equipped with a thermal conductivity detector (230 °C). Separation of carbon dioxide was achieved on a capillary column 19091J-413, HP-5 (30 m × 0.32 mm; 0.25 μm) from Agilent Technologies (Walldbronne, Germany), with a column flow of 7 mL/min, and oven temperature of 180 °C; the difference in concentration was then referred to the sample weight and to the air flow rate.

2.4. Gas analysis

The CO₂ and O₂ concentrations inside the packages were measured in triplicate by a gas analyzer MAPY 4.0 (Witt Italia Srl, Solza, Italy). A silicone septum was provided on the bag surface for sampling gas inside the package. Results were expressed as % of O₂ and CO₂ inside the bags.

2.5. Overall appearance and odour

In order to evaluate the effect of modified atmosphere packaging on fresh-cut broccoli, appearance and odour of broccoli florets were individually scored using a subjective scale of 5 to 1 as also described by Winkler, Faragher, Franz, Imsic, and Jones (2007) at each sampling day. In the case of appearance, a scale composed of pictures and a brief description for each score value was used, with 5 = excellent, no defects; 4 = very good, minor defects; 3 = fair, moderate defects; 2 = poor, major defects; and 1 = inedible. In the case of odour: 5 = typical odour, 4 = slightly off-odour, 3 = moderate off-odour, 2 = strong off-odour, 1 = odour of mouldiness. A score of 3 was considered as the limit of...
marketability and a score of 2 as the limit of edibility (Amodio, Cabezas-Serrano, Rinaldi, & Coletti, 2007).

2.6. Weight loss

Each bag was individually weighed the day of its preparation (Day 0) and at each sampling day and the weight loss was calculated as % of the initial fresh weight.

2.7. Colour

Colour parameters (L*, a* and b*) were measured in colour space CIELab by elaborating the images acquired by a Spectral scanner (DV Srl, Padova, Italy). Measurements were performed in each broccoli floret (la Zazzerà, Cornacchia, Amodio, & Coletti, 2010). The measure was made on top of each floret.

2.8. Chlorophyll pigments

Chlorophyll extraction was performed according to our previous work (García et al., 2005). Briefly, to extract chlorophyll pigments from plant tissue around 4 g from plant homogenate was accurately weighted and 15.0 mL of acetone was mixed into a centrifuge flask placed in an ice bath. After 1 min of homogenization using an Omni Mixer homogenizer (Omni International, GA, USA), samples were centrifuged for 15 min at 14,000 rpm at 4 °C. Samples were extracted three times and supernatants were then filtered into a 50.0 mL volumetric flask using acetone as solvent to complete the final volume. After pigment extraction plant homogenate was completely discoloured (colour changed from green to whitish). Before spectra measurement, samples were filtered by a 0.45 μm nylon filter. Photometric spectra were recorded between 600 nm and 700 nm in a UV-2459 UV–vis spectrophotometer (Shimadzu, Japan).

Chlorophyll a and b contents were determined using multivariate calibration by means of Partial Least Squares (PLS) (Fernández-León, Lozano, Ayuso, Fernández-León, & González-Gómez, 2010). The results were expressed as mg/100 g of fresh weight (FW).

2.9. Carotenoid pigments

The carotenoid composition was determined by HPLC (Mínguez-Mosquera & Hornero-Méndez, 1993). About 10 g of broccoli were extracted with acetone, saponified overnight to remove the chlorophylls, and the obtained extract was passed through a 0.45 μm nylon filter and injected in an Agilent 1100 liquid chromatograph (Agilent Technologies, Inc., Palo Alto, CA, USA) equipped with an Agilent Lichrosorb RP-18 column of 10 μm, 200 mm × 4.6 mm at 30 °C, and diode-array detector (460 nm). The initial mobile phase was acetone:water (75:25) for 5 min, raised to (95:5) over 10 min (García et al., 2007), and the flow rate was 1 mL/min. The pigments were quantified by external standard calibration, and results were expressed as mg of β-carotene and mg of lutein/100 g FW (González-Gómez, Lozano, Fernández-León, Fernández-León, & Cañada-Cañada, 2011).

2.10. Vitamin C

About 5 g of fresh broccoli were homogenized with 10 mL of methanol:water (5:95) plus citric acid (21 g/L) with EDTA (0.5 g/L). The homogenate was filtered through cheesecloth and a C18 Bakerbond SPE column (Waters, Milford, MA, USA). Ascorbic acid (AAc) and dehydroascorbic acid (DHAA) contents were determined as described by Zapata and Dufour (1992) with some modifications (Gil, Ferreres, & Tomás-Barberán, 1999). The HPLC analysis was achieved after derivatisation of DHAA into the fluorophore 3-(1,2-dihydroxyethyl) furou[3,4-b]quinoline-1-one (DFQ), with 1,2-phenylenediaminedihydrochloride (OPDA). Samples of 20 μL were analysed with an Agilent 1200 Series HPLC from Agilent Technologies (Waldbronn, Germany). Separations of DFQ and AAc were achieved on a Zorbax C18 column (250 mm × 4.6 mm; 5 μm particle size). The mobile phase was methanol:water (5:95 v/v) containing 5 mmol/L citrime and 50 mmol/L potassium dihydrogenphosphate at pH 4.5. The flow rate was 1 mL/min. Vitamin C was expressed as mg of ascorbic and dehydroascorbic acid/100 g FW.

2.11. Total phenol content and antioxidant activity

The same extraction was carried out for analyses of total phenols and antioxidant activity (AA). About 3 g of broccoli were homogenized in an Ultraturrax (IKA, T18 Basic; Wimington, NC, USA) for 1 min with 20 mL of extraction medium, 2 mM sodium fluoride methanol:water solution (80:20). The homogenate was centrifuged at 5 °C at 9000 rpm for 5 min. The pellet was discarded and the supernatant was retained and used as extract.

Total phenols were determined according to the method of Singleton and Rossi (1965). Each extract (100 μL) was mixed with 1.58 mL distilled water, 100 μL of Folin–Ciocalteu reagent and 300 μL of sodium carbonate solution (200 g/L). After 2 h standing in darkness, the absorbance was read at 725 nm against a blank using a spectrophotometer (UV-1700, Shimadzu, Jiangsu, China). Total phenol content (TPC) was calculated on the basis of the calibration curve of chlorogenic acid and was expressed as mg of chlorogenic acid equivalent/100 g FW.

The antioxidant assay was performed following the procedure described by Brand-Williams, Cuvelier, and Berset (1995) with minor modifications. The diluted sample, 50 μL, was pipetted into 0.95 mL of diphenylpyrindylhydrazyl (DPPH) solution to initiate the reaction. The absorbance was read, spectrophotometrically, after 30 min in darkness, at 515 nm. Trolox was used as the standard of the measurement and the antioxidant activity was reported in mg Trolox/100 g FW.

2.12. Intact glucosinolates

Intact glucosinolates (GS) were extracted following Kiddle and Vallejo slightly modified methods (Kiddle et al., 2001; Vallejo, Tomás-Barberán, González, & García-Viguera, 2003) were about 2 g of broccoli homogenate were extracted with 7 mL of methanol:ultrapure water (70:30) for 15 min at 70 °C with shaking. The extracts obtained were centrifuged or filtered, for sample purification, and further filtered by 0.45 μm nylon filter before to injection into the chromatograph. A high-performance liquid chromatography instrument coupled to an Ion Trap mass spectrometer (Varian 500-MS, Varian Ibérica S.L., Madrid, Spain) was used for the intact glucosinolates separation and determination from the broccoli extracts.

The chromatographic separation was performed on a 150 mm × 2.0 mm (3 μm) Pursuit C18 reversed-phase column with a Varian security filter as a guard column. The column oven temperature was set at 40 °C and the injected volume was 10 μL. The composition of the mobile phase varied linearly from 100% A (0.1 mL formic acid/100 mL) to 15% B (methanol MS–MS) in 15 min, to 40% B in 5 min, to 50% B in 5 min, and returned to 100% A in 5 min at a flow rate of 200 μL/min. The mass spectrometer was tuned by direct infusion of sinigrin standard solution producing maximum abundant precursor ion m/z 358 ([M–H]+) and fragment ion m/z 97 ([SO3H]+) signals during MS/MS (Tian, Rosselot, & Schwartz, 2005). The following transitions were used to assay 3 types of individual
glucosinolates: 1) Aliphatic GS: glucoraphanin (436 > 97), glucobi-
erin (422 > 97), glucoalyisin (450 > 97) and glucoeleuzin (420 > 97) 
(alkyl GS); sinigrin (358 > 97), gluconapin (372 > 97) and gluco-
brassicapin (386 > 97) (alkenyl GS); and progoitrin (388 > 97) 
(hidroxalkenyl GS); 2) Indole GS: glucobrassicin (447 > 97), 4-
methoxyglucobrassicin (477 > 97) and neoglucobrassicin 
(477 > 97); and 3) Aromatic GS: gluconasturtiin (422 > 97) and 
gluconasturtiin (408 > 97). These glucosinolates were quanti-
fied using the calibration curve of sinigrin (Sigma–Aldrich Spain, 
Madrid, Spain) as an external standard and expressed as mg of 
sinigrin equivalent/100 g FW (Fernández-León, Lozano et al., 2011).

2.13. Statistical analysis

For statistical studies SPSS 15.0 software was used (SPSS Inc., 
Chicago, IL, USA). Correlations were estimated with the Pearson test 
at p < 0.01 significance level. Data are expressed as 
means ± standard deviation of six independent replicates and were 
analysed using a one-way analysis of variance (ANOVA). When 
ANOVA detected significant differences between mean values, 
means were compared using Tukey’s HSD test.

3. Results and discussion

The experiment design of this research was established to 
obtain a gas concentration of 10% O2 and 5% CO2 in microperforated 
polypropylene bags for 12 days of storage at 5 °C. This design was 
aimed to assess the effect of the MAP in the quality and functional 
values of broccoli.

3.1. Respiration rate

Respiration rate is significantly affected by MAP treatment 
(Lange, 2000). Thus, the respiration rate at 5 °C decreased about 
13% in the sample treated with 10% of oxygen (52.36 ± 0.64 mL CO2/ 
kg × h) with respect to the Control sample (60.16 ± 0.48 mL CO2/ 
kg × h).

3.2. Gas composition

An active modified atmosphere was used by injecting 10% of CO2 
and 5% of O2. A decrease in CO2 and increase in O2 levels were 
observed (Fig. 1) for MAP in microperforated polypropylene bags in 
one day of storage at 5 °C, to reach the desired modified atmo-
sphere, 10% O2 and 5% CO2.

3.3. Overall appearance and odour

During cold storage at 5 °C, all samples from different treat-
ments (Control and MAP) showed a reduction in visual appearance 
and in odour score with respect to the Fresh sample (Table 1), this 
is in agreement with the results obtained for other authors (Cefola 
et al., 2010; Jia et al., 2009).

The reduction in the overall appearance begins to be statistically 
significant at Day 6 of cold storage for both samples (Control and 
MAP). However, the reduction in the odour score is statistically 
significant at Day 9 for MAP sample and, at Day 3 for Control 
sample. At the end of storage (Day 9 and Day 12) the MAP samples 
were above the limit of marketability (score 3), while Control 
samples were on the limit of edibility (score 2). Therefore, this MAP 
storage helps to maintain the organoleptic characteristics of broc-
coli florets.

3.4. Weight loss

One of the main problems during broccoli storage is the high 
weight loss, which affects its marketability. In fact, Control broccoli 
stored in air had lost 3.36% of its initial weight, while this value was 
significantly lower in MAP conditions (0.75% of weight loss, 
p < 0.05) at the end of storage at 5 °C (Table 1).

The effect of MAP on reducing weight loss is likely due to the 
limitation of water vapour diffusion by plastic films and, in turn, 
generating a water vapour pressure and higher relative humidity 
inside the package (Serrano, Martinez-Romero, Guillen, Castillo, & 
Valero, 2006). In that sense, a negative correlation was found 
between the weight loss and the appearance of broccoli florets 
(r = −0.811, p < 0.01), as it was reported before by Serrano et al. 

3.5. Colour

All individual colour parameters (L∗, a∗ and b∗) significantly 
increased at the end of storage in Control samples (p < 0.05). This 
fact was related to the yellowing process of broccoli florets. On the 
other hand, in MAP samples these colour parameters remained 
significantly similar to those obtained in the Fresh samples 
(p < 0.05).

Broccoli is a commodity that benefits from storage under 
increased CO2 and reduced O2 concentration atmospheres. The 
studied MAP storage conditions tested in this research work, 
positively affected the maintenance of the outer quality parameters 
of ‘Parthenon’ broccoli, as obtained by other authors (Cefola et al., 
2010; Izumi et al., 1996).

3.6. Chlorophyll pigments

The contents of chlorophyll pigments are summarized in Table 2. 
The results obtained were comparable to other reported values 
(Fernández-León, Fernández-León, Lozano Ruiz, Ayuso Yuste, & 
González-Gómez, 2012; Fernández-León et al., 2010; García et al., 

The results showed than both chlorophylls, a and b, remained 
without significant changes until Day 3 for the Control sample, 
while for the MAP sample no significant differences were observed 
during all cold storage period. At the end of storage the Control
Table 1: Appearance score, odour score, weight loss and colour levels of broccoli florets stored at 5 °C under modified atmosphere package (MAP) and its comparison with broccoli florets stored under atmospheric conditions (Control).

<table>
<thead>
<tr>
<th>Storage period (days)</th>
<th>Sample</th>
<th>Fresh Control MAP Control MAP Control MAP Control MAP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Appearance score</td>
<td>4.92 ± 0.13a</td>
</tr>
<tr>
<td></td>
<td>Odour score</td>
<td>4.92 ± 0.13a</td>
</tr>
<tr>
<td></td>
<td>Weight loss</td>
<td>4.50 ± 0.13a</td>
</tr>
<tr>
<td></td>
<td>Lightness (L*)</td>
<td>11.09 ± 0.36c</td>
</tr>
</tbody>
</table>

Values followed by the same letter in the same column are not significantly different (p > 0.05).

3.7. Carotenoid pigments

The influence of the storage conditions on these compounds is summarized in Table 2. The results obtained were comparable to other reported values (Fernández-León et al., 2012; Forney & Riji, 1991; García et al., 2005; Murkovic, Gams, Draxl, & Pfannhauser, 2000). The carotenoids content decreased along with the storage for both samples (Control and MAP) with respect to the Fresh samples. However, this decrease was higher and happened before (on Day 3) in the Control than in the MAP samples. At the end of cold storage the β-carotene and lutein concentrations were 0.71 and 0.53 mg/100 g FW in MAP samples, respectively, while in Control samples were 0.41 mg β-carotene/100 g FW and 0.31 mg lutein/100 g FW.

β-carotene and lutein are found in the lipid soluble fractions of biological systems. These pigments protect cellular membranes by scavenging/quenching free radicals (Singh, Upadhyay, Prasad, Bahadur, & Rai, 2007). Therefore, both compounds constitute the essential lipid-soluble antioxidants. Thus the amount of carotenoids has to be related to the AA, as we found in our results (r = 0.916, p < 0.01).

3.8. Vitamin C

The contents of vitamin C (ascorbic and dehydroascorbic acid) are summarized in Table 2 and the results obtained were comparable to other reported values (Bernalte et al., 2007; Fernández-León et al., 2012; Podsedek, 2007).

Vitamin C, which includes ascorbic acid and its oxidation product (dehydroascorbic acid) has many biological activities in human body, as a radial scavenger, that explains the high correlation observed between vitamin C content and AA value (r = 0.872, p < 0.01).

On the other hand, the amount of vitamin C decreased during the cold storage, but this decrease was higher and faster in Control samples than in MAP samples. Thus, at the end of storage the vitamin C content in MAP sample was 78.13 mg ascorbic and dehydroascorbic acid/100 g FW, while in Control sample was 54.73 mg ascorbic and dehydroascorbic acid/100 g FW.

3.9. Total phenol contents

Table 2 summarized the contents of total phenol (TP) for Fresh, Control and MAP broccoli samples during cold storage. The TP found in fresh broccoli (86.76 mg chlorogenic acid equivalent/100 g FW) was in accordance with the values reported in the literature (Koh, Wimalasiri, Chassy, & Mitchell, 2009; Sousa et al., 2008).

During the storage at 5 °C, TP significantly increased on Day 3 for both samples, Control and MAP (104.11 and 95.44 mg chlorogenic acid equivalent/100 g FW, respectively), with respect to the Fresh sample presented 5.72 and 1.96 mg chlorophyll a and b, respectively, per 100 g FW, while MAP sample presented 9.86 and 3.40 mg chlorophyll a and b, respectively, per 100 g FW. Therefore, broccoli florets from Control samples turn yellow faster, since the loss of green colour in florets has been attributed to chlorophyll degradation. In addition, this process is also related to respiration rate, ethylene production and lipid peroxidation processes (King & Morris, 1994; Zhuang et al., 1995). For this reason we found an inverse correlation (r = −0.621 and r = −0.720, p < 0.01) between the colour parameters (a* and b*) and chlorophylls contents, respectively. On the other hand, the chlorophylls content and antioxidant activity were highly correlated (r = 0.808, p < 0.01). Similar findings were reported before by Lai, Butler, and Matney (1980).
Aliphatic, indole and aromatic glucosinolates have been arranged according to their chemical structure, as storage for both samples, Control and MAP (52.95 and 51.17 mg)

Woodill, Flanagan, & Deemer, 2002; Podsedek, 2007; Wu et al., 2004). The in

However, for the rest of the storage period, there were no significant differences in the TP for MAP samples until Day 9, while for Control samples there was always a statistical decrease in TP for all dates of cold storage. This may be explained because in Control samples the membrane structures could have been damaged and the oxidation of phenolic compounds becomes the major trend and they decreased in cell (Toor & Savage, 2006; Yang et al., 2011). Additionally, the higher respiration of broccoli florets stored under air conditions (Control) might increase the metabolism of such synthesis is still unknown (Mithen, Dekker, Verkerk, Rabot, & Johnson, 2000; Xu, Guo, Yuan, Yuan, & Wang, 2006).

The degradation of glucosinolates is due to glucosinolates hydrolysis catalysed by endogenous thioglucosidases, namely the myrosinases (Mikkelsen, Petersen, Olsen, & Halkier, 2002; Schreiner et al., 2007).

Regarding the total contents of intact glucosinolates (Table 3) at the beginning of storage, no significant differences were observed between Fresh and Control samples (96.55 and 96.77 mg sinigrin equivalent/100 g FW, respectively), while for MAP samples intact glucosinolates content increased (100.87 mg sinigrin equivalent/100 g FW). This fact could be caused by biosynthesis in controlled and modified atmospheres, as a stress response (Bennett & Wallsgrove, 1994; Verkerk, Dekker, & Jongen, 2001). However, the total contents of intact glucosinolates decreased during the rest of cold storage, being this decrease higher in the Control samples than in the MAP samples.

Additionally, glucosinolates are characterized by their high antioxidant activity (Fernández-León et al., 2012; Moreno, Carvajal, López-Berenguer, & García-Viguera, 2006; Verkerk et al., 2009). Therefore, a strong correlation exists between the total content of glucosinolates and antioxidant activity (r = 0.951, p < 0.01).

### 3.10. Intact glucosinolates

The influence of storage conditions on intact glucosinolates (GS) concentration is summarized in Table 3, where these compounds have been arranged according to their chemical structure, as aliphatic, indole and aromatic glucosinolates.

According to the data showed in Table 3, aliphatic glucosinolates increases significantly their concentration at the beginning of storage for both samples, Control and MAP (52.95 and 51.17 mg sinigrin equivalent/100 g FW, respectively), with respect to the Fresh sample (44.50 mg sinigrin equivalent/100 g FW). This increase, as occur with phenolic compounds, is due to induction of the synthesis of glucosinolates in response to a stress, the mechanism of such synthesis is still unknown (Mithen, Dekker, Verkerk, Rabot, & Johnson, 2000; Xu, Guo, Yuan, Yuan, & Wang, 2006).

### 3.11. Antioxidant activity

The range of antioxidant activity (AA) levels was similar to other reported values for the same cultivar ‘Parthenon’ (Fernández-León et al., 2012; Fernández-León M.F., Fernández-León A.M. et al., 2011; Ou et al., 2002; Podsedek, 2007; Wu et al., 2004).

### Table 2

<table>
<thead>
<tr>
<th>Storage period in days</th>
<th>0</th>
<th>3</th>
<th>6</th>
<th>9</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td>Fresh</td>
<td>Control</td>
<td>MAP</td>
<td>Control</td>
<td>MAP</td>
</tr>
<tr>
<td>Chlorophyll a²</td>
<td>11.26 ± 0.84a</td>
<td>10.13 ± 1.29a</td>
<td>11.03 ± 1.57a</td>
<td>7.13 ± 0.71b</td>
<td>11.80 ± 0.45a</td>
</tr>
<tr>
<td>Chlorophyll b³</td>
<td>3.88 ± 0.29a</td>
<td>3.49 ± 0.45a</td>
<td>3.80 ± 0.54a</td>
<td>2.46 ± 0.25b</td>
<td>4.07 ± 0.15a</td>
</tr>
<tr>
<td>β-Carotene³</td>
<td>1.03 ± 0.04a</td>
<td>0.77 ± 0.03c</td>
<td>1.02 ± 0.04a</td>
<td>0.62 ± 0.02e</td>
<td>0.90 ± 0.04b</td>
</tr>
<tr>
<td>Lutein³</td>
<td>0.77 ± 0.03a</td>
<td>0.58 ± 0.02c</td>
<td>0.77 ± 0.03a</td>
<td>0.46 ± 0.02e</td>
<td>0.68 ± 0.03b</td>
</tr>
<tr>
<td>Vitamin C³</td>
<td>117.55 ± 1.47a</td>
<td>103.21 ± 2.79b</td>
<td>119.90 ± 1.18a</td>
<td>97.39 ± 3.66c</td>
<td>107.95 ± 4.54b</td>
</tr>
<tr>
<td>TPC⁵</td>
<td>86.76 ± 3.80c</td>
<td>104.11 ± 4.56a</td>
<td>95.44 ± 4.18b</td>
<td>65.07 ± 2.85d</td>
<td>84.16 ± 3.69c</td>
</tr>
<tr>
<td>AA⁴</td>
<td>121.91 ± 3.91a</td>
<td>117.77 ± 6.37a</td>
<td>121.68 ± 4.59a</td>
<td>86.29 ± 5.92cd</td>
<td>116.62 ± 2.70a</td>
</tr>
</tbody>
</table>

Values followed by the same letter in rows are not significantly different (p < 0.05).

### Table 3

<table>
<thead>
<tr>
<th>Storage period in days</th>
<th>0</th>
<th>3</th>
<th>6</th>
<th>9</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td>Fresh</td>
<td>Control</td>
<td>MAP</td>
<td>Control</td>
<td>MAP</td>
</tr>
<tr>
<td>Aliphatic GS²</td>
<td>4.45 ± 1.51b</td>
<td>52.95 ± 1.80a</td>
<td>51.17 ± 1.74a</td>
<td>33.37 ± 1.10d</td>
<td>42.27 ± 1.43b</td>
</tr>
<tr>
<td>Indole GS³</td>
<td>48.16 ± 0.61a</td>
<td>40.94 ± 0.52d</td>
<td>46.24 ± 0.59b</td>
<td>31.31 ± 0.40f</td>
<td>42.86 ± 0.54c</td>
</tr>
<tr>
<td>Aromatic GS³</td>
<td>3.89 ± 0.18a</td>
<td>2.88 ± 0.13cd</td>
<td>3.46 ± 0.16b</td>
<td>2.82 ± 0.13d</td>
<td>3.38 ± 0.16a</td>
</tr>
<tr>
<td>Total glucosinolates⁴</td>
<td>96.55 ± 1.77b</td>
<td>96.77 ± 1.95b</td>
<td>100.87 ± 1.97a</td>
<td>67.50 ± 1.30e</td>
<td>89.52 ± 1.66c</td>
</tr>
</tbody>
</table>

Values followed by the same letter in rows are not significantly different (p < 0.05).

mg/100 g fresh weight (FW).

mg ascorbic acid and dehydroascorbic acid/100 g FW.

mg chlorogenic acid equivalent/100 g FW.

Expressed as mg Trolox/100 g FW.
AA values were highly correlated with the biocompound contents, so that the evolution during storage was similar. No significant differences were observed in the values of AA for Control samples until Day 3 (117.77 mg Trolox/100 g FW), while for MAP samples until Day 6 (116.62 mg Trolox/100 g FW) of cold storage, with respect to the Fresh sample (121.91 mg Trolox/100 g FW). After, a decrease in these AA values were observed during the rest of cold storage, this decrease was higher for Control samples (69.05 mg Trolox/100 g FW) than for MAP samples (91.72 mg Trolox/100 g FW) at the end of storage (12 days).

4. Conclusions

The results presented in this research work indicate the importance of modified atmosphere packaging, using micro-perforated polypropylene bags, for fresh-cut broccoli ‘Parthenon’ stored at 5 °C in maintaining freshness and qualitative traits for a period of 12 days. The loss of quality parameters (overall appearance, odour, weight loss and colour) and the decrease of functional compounds contents (chlorophyll and carotenoid pigments, vitamin C, total phenol content and intact glucosinolates) were lower in samples stored in modified atmospheres than in samples stored in air at the end of storage (12 days). This was also observed in the antioxidant activity values at the end of cold storage. A decrease of AA values was higher in Control (43.36% less than the Fresh samples) than in MAP samples (24.76% less with respect to the Fresh sample).

Acknowledgements

D.G.-C. and M.F.F.-L. are grateful to the “Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria” (INIA) of Spain for his research contract (DOC-INIA) and for her doctoral scholarship. Part of this research has been funded by Junta de Extremadura and FEDER funds (Project GR10006) and Project “Red de Investigación Transfronteriza Extremadura-Centro-Alentejo” (RITECA-II).

References


