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Low oxygen levels and light exposure affect quality of fresh-cut Romaine lettuce

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ABSTRACT

Modified atmosphere packaging (MAP) has the potential to extend the shelf-life of fresh-cut lettuce mainly by limiting the oxidation processes. However, exposure to light conditions has been described as causing browning and quality loss. The influence of O_2 partial pressures (pO_2) and light exposure during storage on the shelf-life of fresh-cut Romaine lettuce was studied. Fresh-cut lettuce was exposed daily during storage to different light conditions: light (24 h), darkness (24 h) and photoperiod (12 h light + 12 h darkness). Changes in respiration rate, headspace gas composition, sensory quality, colour, electrolyte leakage, stomatal opening, water loss, texture and compositional constituents related to browning such as vitamin C and individual and total phenolic compounds were evaluated. Different weight samples (75–275 g), packaged with an initial pO_2 of 0.5–2.0 kPa balanced with N_2, reached pO_2 from 0.1 to 1.5 at the steady-state. Atmospheres with low pO_2 (0.2–0.5) at the steady-state preserved lettuce quality by the control of browning and the prevention of off-odours and off-flavours. Light exposure during storage positively influenced the number of open stomata (74% in light vs 24% in darkness) which contributed slightly to weight loss. Consumption of O_2 in samples exposed to light differed significantly from those stored in photoperiod or darkness (10.6 ± 7.0, 18.3 ± 3.5 and 25.8 ± 8.6 nmol O_2 kg^{-1} s^{-1}, respectively). Packages exposed to light showed higher pO_2 compared with packages stored in darkness while those exposed to photoperiod had intermediate values. Moreover, location of the packages in the shelves affected package headspace gas composition and thus, packages near the front of the shelves showed higher pO_2 than those at the back. The different light conditions did not influence the content of vitamin C or the individual and total phenolic compounds. This study shows that under light conditions respiration activity was compensated by photosynthesis resulting in a higher pO_2. Thus, browning of fresh-cut Romaine lettuce can be promoted by light exposure during storage as it increases headspace pO_2.

1. Introduction

Romaine lettuce is one of the lettuce types currently more demanded by consumers because of the crisp texture, good aroma and flavour as well as fresh appearance. In addition, it is one of the lettuce types richest in phytochemicals such as phenolic compounds (Llorach et al., 2008). The operations involved in the processing of fresh-cut lettuce such as cutting, drying and packaging cause tissue damage, increasing respiration and leading to a rapid quality deterioration and shelf-life reduction (Varoquaux and Wiley, 1994). One of the major causes of quality loss in fresh-cut lettuce is browning. In particular, the main problem of Romaine lettuce after cutting is browning of the midribs (López-Gálvez et al., 1996). This occurs faster and with less possibilities of control than in other types of lettuce such as Iceberg. Browning of fresh-cut lettuce has been extensively studied and different chemical treatments such as reducing agents, enzyme inhibitors, acidulants and complexing agents have been studied to control the phenolic metabolism that leads to browning. However, concerns about chemical toxicity preclude their use for fresh-cut products (Tomás-Barberán et al., 1997a; Peiser et al., 1998; Altunkaya and Gökmen, 2008). In this respect, the industry still needs a strategy to prevent browning and maintain quality and consumer acceptability without the use of chemical agents.

Modified atmosphere packaging (MAP) can extend the shelf-life of cut lettuce primarily by providing a sufficiently low O_2 partial pressure (pO_2) to retard browning (Smyth et al., 1998). Krahn (1977) reported that browning of cut lettuce could be prevented by MAP storage at $pO_2 < 2$ kPa whereas Ballantyne et al. (1988) reported that browning of shredded lettuce could be prevented by levels of 1–3 kPa pO_2. McDonald et al. (1990) reported that browning, particularly around the leaf edges, occurred at $pO_2 > 3$ kPa. Specially for Romaine lettuce, an initial pO_2 of 0.5–3.0 kPa has been recommended to prevent tissue browning (Gorny, 2001). Nevertheless, this range is very broad and when pO_2 is too low ($\leq$0.5 kPa) may lead to off-odours and off-flavours (McDonald et al., 1990) as well as green colour deterioration (Smyth et al., 1998) or browning

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when pO_2 is too high (≥3.0 kPa) (Ballantyne et al., 1988; Heimdal et al., 1995). MAP depends on the interaction between respiration rate of the commodity and the permeability characteristics of the film for a specific mass and package surface area (Kader et al., 1989; Majan et al., 2006). Several studies have focused on the influence of MAP on the sensory quality and compositional constituents related to browning of fresh-cut lettuce (Gil et al., 1998; Smyth et al., 1998; Beltrán et al., 2005) and the behaviour in the case of temperature abuse (Cantwell, 1996). However, no information about pO_2 related to browning and off-flavours is available in the literature for Romaine lettuce.

Additionally, light is one of the most important factors, among other environmental variables, affecting phytochemical content of vegetables (Li and Kubota, 2009; Zhou et al., 2009). In recent years, several studies have been focused on the influence of light exposure during storage on the quality of different vegetables. Lester and Makus (2010) reported that spinach leaves exposed to continuous light during storage were overall more nutritionally dense than leaves exposed to continuous darkness. Fluorescent light has been described as promoting weight loss but preserving vitamin C of Chinese kale during storage (Noichinda et al., 2007). However, a negative effect on the quality of fresh-cut asparagus has been observed during storage under light because of an increase in the physiological activity (Sanz et al., 2009). A few studies have suggested that exposure to light triggers a different physiological response depending on whether the vegetable is pigmented or not and therefore light exposure affects the atmosphere composition inside the packages (Sanz et al., 2007; Olarte et al., 2009). Some authors have reported that lighting causes increases in respiration rate by the photosynthetic activity of fresh-cut green vegetables which accelerates browning of the cut edges in leeks (Ayala et al., 2009), chlorophyll loss in broccoli and high transpiration and fermentation in cauliflower (Olarte et al., 2009). According to the information described above, exposure of the packages to uncontrolled light conditions during distribution and retail sale affects headspace pO_2 which can be responsible for the high variability in the quality characteristics of fresh-cut lettuce, mainly promoting browning and reducing shelf-life. For these reasons, the objectives of this study were to evaluate (1) the effect of low pO_2 and (2) the impact of light exposure on the shelf-life of fresh-cut Romaine lettuce by the evaluation of the respiration rate, headspace gas composition, sensory quality, colour, electrolyte leakage, stomatal opening, water loss, texture and the content of vitamin C and phenolic compounds.

2. Materials and methods

2.1. Plant material

Lettuces grown in Torre Pacheco (Murcia, Spain) under commercial growing conditions were harvested from December to May. After harvest, heads were transported in a ventilated vehicle to the CEBAS laboratory (Murcia, Spain) (40 min in the first study and 1.5 h in the second one) and stored in darkness overnight at 4 °C.

2.2. Processing, packaging and storage conditions

The next morning, the outer leaves were removed and the inner leaves cut into pieces (approx. 4 cm) using a sterile sharpened knife. Fresh-cut lettuce was washed in chlorinated water (100 mg/L at 6.5 pH adjusted with citric acid) at 4 °C, drained for 30 s and then rinsed with tap water for 30 s, following the procedure used by the fresh-cut industry. The excess of water was removed by an automatic salad spinner (K-50, Kronen GmbH, Kehl am Rhein, Germany) for 1 min. The processing was conducted under sanitary conditions in a processing room at 4 °C.

To study the effect of different pO_2 on the quality attributes of the packaged produce, a coextruded film (Amcor Flexibles, Bristol, UK) with O_2 permeability of $9.365E^{-17}$ mol m m^{-2} s^{-1} Pa^{-1} (504 mL O_2 25 μm/m^2 d atm) and CO_2 permeability of $3.166E^{-16}$ mol m m^{-2} s^{-1} Pa^{-1} (2507 mL CO_2 25 μm/m^2 d atm) at 7 °C and 95% HR and a package size of 230 mm × 280 mm was used. Different masses of fresh-cut lettuce from 75 to 275 g were mechanically packed in a vertical packaging machine (Etna 380 model, Ulma Packaging, Oñati, Spain). Active modified atmosphere was created by the injection of nitrogen (N_2) to reduce the initial pO_2, from 21 kPa in air to approximately 0.5–2 kPa O_2. Packages were exposed daily to a photoperiod consisting of cycles of 12 h of light and 12 h of darkness for 3 d at 4 °C and then transferred at 7 °C for the rest of the storage. These environmental conditions are very close to those during commercial distribution. Once the steady-state was established, the desired O_2 and CO_2 partial pressures were achieved inside the packages.

To study the effect of light exposure, approximately 175 g of cut lettuce were packed using the same film, package size and initial gas injection. Packages were randomly separated into three bunches depending on the light conditions: (1) dark for 24 h per day, (2) photoperiod, consisting of 12 h of light and 12 h of dark exposure per day, and (3) light for 24 h per day. The photosynthetical active radiation (PAR) on the shelves was 6 ± 1 μmol m^{-2} s^{-1} obtained from fluorescent lights (Philips Ibérica S.A., Madrid, Spain) of 58 W each, conditions similar to those of retail sale. Samples were stored for 3 d at 4 °C and then transferred at 7 °C for the rest of the storage.

2.3. Respiration rate and headspace analysis

The respiration rate of fresh-cut Romaine lettuce stored at different light conditions was measured by the closed method (Jacxsens et al., 1999). Romaine lettuce used for the respiration rate and headspace analysis was harvested and stored in darkness overnight at 4 °C before processing. After processing, fresh-cut lettuce (150 g) was placed in air-tight glass jars (1484 mL). The jars were flushed with N_2 to a pO_2 between 1 and 3 kPa by means of a gas mixing station (Witt-Gasetechnik, model KM 100-3M, Carburos Metálicos, S.A., Barcelona, Spain). By following the O_2 consumption and CO_2 production over time, the respiration rate of fresh-cut Romaine lettuce, expressed as nmol CO_2 kg^{-1} s^{-1}, was determined at 7 °C. Four jars were measured daily for up to 5 d.

Respiration rate and headspace gas composition (O_2 and CO_2) in individual packages were monitored daily using an O_2 analyzer with a ceramic oxide–zirconia electrochemical detection cell (CG-1000, Ametek, Thermox Instruments Co., Pittsburgh, PA, USA) and an infrared CO_2 detector (Via 510, Horiba Instruments Co., Irvine, CA, USA) until steady-state was attained. Samples of 0.25 mL of headspace gas were measured from each package with a calibrated syringe and two repetitions of each package were taken.

2.4. Sensory quality

Sensory quality was evaluated by a five member trained sensory panel. Experts were required to evaluate changes in visual quality, texture, flavour, off-odours and browning (leaf edge and leaf surface browning) of samples. Visual quality was evaluated considering the appearance features of gloss, freshness and colour uniformity and intensity. Samples were scored using a 1–9 hedonic scale where 9 = excellent, 5 = limit of marketability and 1 = inedible. Flavour and texture were evaluated in a 5-point scale where 5 = fully characteristic of the product, 3 = moderate and 1 = not characteristic. Defects such as off-odours and browning were evaluated as follows: 5 = severe, 3 = moderate and 1 = absence.