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Preharvest and postharvest factors related to off-odours of fresh-cut iceberg lettuce

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ABSTRACT

The influence of different preharvest and postharvest factors affecting off-odour development of fresh-cut iceberg lettuce in low-O_2 modified atmospheres (MA) was investigated. Fresh-cut iceberg lettuce developed undesirable off-odours under low O_2 and elevated CO_2 atmospheres. A strong relationship between CO_2 concentration and off-odour development was observed. Significant differences in off-odour development existed among different cultivars in two harvests in consecutive years. The influence of maturity stage was evaluated, comparing fresh-cut product from immature and over-mature heads with commercial ones. Higher CO_2 concentrations and higher accumulation of ethanol and acetaldehyde were detected in the headspace of MA-packed lettuce from immature heads. Differences in respiration rate of the fresh-cut product from heads cultivated during the winter–spring seasons were around 30%. Respiration rate of fresh-cut iceberg lettuce increased when medium temperature during cultivation increased. Changes in the product weight generated different CO_2 levels which correlated with the production of ethanol and acetaldehyde and other off-odour metabolites related with the lipoxygenase (LOX) pathway such as hexanal, 1-hexanol, and cis-3-hexen-1-ol. Volatile compounds such as cis-3-hexen-1-ol, β-elemene, ethyl acetate and dimethyl sulphide increased their content more than 10 times compared with other volatiles. Moreover, differences in the initial flushed gas-mixture with or without CO_2 showed higher CO_2 concentrations and the development of stronger off-odours when samples were flushed with an enriched CO_2 gas-mixture. In summary, visual quality of fresh-cut iceberg lettuce is important but so are odour and flavour. MAP currently used for fresh-cut lettuce may need some modification to inhibit off-odours and achieve better aroma and flavour qualities for preserving "freshness" of the cut product. Screening for cultivars with low browning potential and fermentation, harvested at optimum maturity stage and with an adequate package design are recommended.

1. Introduction

Iceberg lettuce has become the most popular lettuce (*Lactuca sativa* L.) type in terms of production, consumption and exports (FAOSTAT, 2010), and has also captured the most significant portion of the fresh-cut market. In an effort to meet this expanding demand, processors need a year-round supply of good quality product, sourcing lettuce from different regions throughout the year.

During processing of fresh-cut lettuce, mechanical wounding causes disruption of cells, which induces physiological responses such as an increase in respiration rate and enzyme pathways, many of which are associated with generation of phenolic compounds and volatiles (Rolle and Chism, 1987; Saltveit, 2000). Browning has been suggested as the main factor that limits shelf-life of fresh-cut lettuce (Heimdal et al., 1995). Active modified atmosphere packaging (MAP) of fresh-cut lettuce has become a successful technique for the control of browning (Ballantyne et al., 1998). Commonly, before sealing, bags are flushed with N_2 to generate an atmosphere sufficiently low in O_2 concentration. It is almost impossible to control browning without the risk of anaerobic respiration because the O_2 concentration at the steady-state that preserves lettuce quality is very low (0.2–0.5 kPa O_2) (Martínez-Sánchez et al., 2011). Because of that, accumulation of off-odours occurs. Off-odours have been recognized as a limiting factor for the quality and marketability of fresh-cut iceberg lettuce (Cameron, 2003). Low O_2 is usually manifested by fermentation, off-odour development and production of ethanol (Cameron et al., 1993; Smyth et al., 1998). The fermentation threshold is not always the lower O_2 limit in commercial practice. However, benefits due to O_2 levels near or below the fermentation threshold outweigh the loss in flavour or other quality parameters, as in particular is the situation for fresh-cut lettuce (Beaudry, 2000).

In general, processors must adjust film permeability for O_2 and CO_2 to the respiration rate of the packaged fresh-cut commodity

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to establish a beneficial MA inside the package (McDonald et al., 1990; Jacxsens et al., 1999; Kim et al., 2005). However, respiration rates change as a consequence of pre- and postharvest factors. Consequently, most of the time, the film permeability is not appropriately matched to the produce respiration rate and O_2 may become depleted and CO_2 enriched within the package, leading to anaerobic respiration and consequently, to fermentative volatile accumulation and off-odour development (Lopez-Galvez et al., 1997; Smyth et al., 1998). The primary limitation of MAP for fresh-cut lettuce is the lack of consistent control of O_2 concentration in the package, which caused the problem of off-odours. Several volatile compounds have been reported as contributing to off-odours after cutting iceberg lettuce, such as alcohols, aldehydes, terpenes, esters and acids (Belitz et al., 2004; Lonchamp et al., 2009). Some of them are more specific to mechanical injury, such as cis-3-hexenol and trans-2-hexenal, key aroma compounds of iceberg lettuce from lipoxygenase (LOX) activity (Arey et al., 1991). Terpenes, even in very low concentration, have also been identified as important aroma compounds of iceberg lettuce (Nielsen and Poll, 2006). Smyth et al. (1998) suggested that the presence of dimethyl sulfide in 10 day-old fresh-cut lettuce was responsible for the development of a putrid aroma.

The type and concentration of off-odours compounds may be influenced by pre- and postharvest factors such as genetics and maturity at harvest among others (Kader, 2002). Cultivar selection is of great importance in achieving quality of the fresh-cut product (Simonne et al., 2002; Hayes and Liu, 2008; Bunning et al., 2010). In general, growers and producers of fresh-cut lettuce obtain information regarding adequate cultivars from seed company representatives that often schedule different cultivars per season. This information is based on yield and other lettuce characteristics of the whole head without any reference to their suitability for fresh-cut. In the case of fresh-cut iceberg lettuce, selection of the most appropriate cultivars is one of the most important decisions lettuce processors must make each season (Rogers et al., 2006). Growers know that they must make frequent plantings and combine planting dates and cultivars with different growth rates. Climatic and environment conditions also influence the consistency of fresh-cut product. Substantial variation in the degree of off-odours development may also be attributed to postharvest factors. An initial package flushing with N_2 or a low O_2/high CO_2 atmosphere can be used to establish steady-state MA more rapidly to control tissue browning (Mateos et al., 1993; Heimdal et al., 1995), but these conditions can accelerate fermentation. The weight of the plant can be varied in order to generate a range of O_2 atmospheres low enough to preserve freshness by the control of browning (Beaudry, 2000). With this background, the objectives of this work were to evaluate the impact of some pre and postharvest factors on the development of off-odours, mainly related to anaerobic metabolism, of fresh-cut iceberg lettuce. The studied preharvest factors were genotype, maturity at harvest and season and the postharvest factors were those related to package design such as different weights and the initial gas-mixture composition.

2. Materials and methods

2.1. Plant material

Iceberg lettuce used in these experiments corresponded to different cultivars of the crisphead type, grown in the experimental field of Syngenta Seeds S.A. located in Torre Pacheco (Murcia, Spain), during the winter–spring seasons. The field trials were set up as a completely randomized block design with 3 replicate plots per block and each block on a separate bed. Each plot comprised 7 m lengths of bed, including a buffer of unused plants. In all trials the commercially recommended plant spacing was used, and the crop was grown using standard lettuce production conditions. Except for the study regarding the influence of maturity stage, all lettuces were harvested the same day when lettuce heads reached commercial maturity based on minimum head weight (350 g) (Gil et al., 2012) and optimal compactness (4–6). A trained person evaluated lettuce head compactness after cutting the lettuce by half longitudinally. The rating scores were assessed comparing with a visual scale of 8 lettuce photographs classifying as (1 = without compactness, 4 = minimum acceptable compactness, 5 = optimal compactness, 6 = maximum acceptable compactness and 8 = full compactness).

At each harvest, 10 heads per cultivar were sampled from each of the three blocks, up to a total of 30 heads per cultivar. Outer leaves were removed to duplicate the trimming in a commercial harvesting operation. After harvest, lettuces were transported (max. 140 km) to the CEBAS-CSIC laboratory (Murcia, Spain). Lettuce heads were stored for 24 h at 4 °C in darkness. The next day, lettuces were processed as described by Luna et al. (2012). Whole head measurements such as trimmed head weight, compactness and dry matter were taken from 10 heads before processing. Dry matter content was determined in 15 g of commercial tissue by drying the samples in a forced air oven at 65 °C until constant weight.

2.2. Processing, packaging and storage conditions

Iceberg heads were cut into 30 mm pieces, mixed to obtain a homogeneous sample and then washed for 30 s in 100 mg L^{-1} chlorine solution (NaOCl) adjusted to pH 6.5 with citric acid and rinsed with tap water for 30 s. Excess water was removed in an automatic salad spinner (K-50, Kronen GmbH, Kehl am Rhein, Germany). Fresh-cut lettuce was mechanically packed in a vertical packaging machine (Etna 280-X model, Ulma, Oñati, Spain) using a polypropylene (PP) film (Amcor Flexibles, Bristol, UK), 35 μm with O_2 permeance of 529 mL O_2 m^{-2} d^{-1} atm^{-1} and CO_2 permeance of 1981 mL CO_2 m^{-2} d^{-1} atm^{-1} at 7 °C and 97% RH. Package size was 230 mm × 280 mm. Fresh-cut samples of 250 g were stored under active MAP where nitrogen gas (N_2) was injected to achieve an initial concentration of approximately 0.5–2 kPa O_2. We also studied the influence of different CO_2 concentrations by using the same package size but only increasing the product weight from 180 g to 280 g to generate a wide range of CO_2 concentrations. We studied the influence of different levels of CO_2 by flushing the bags with N_2 enriched with CO_2. Packages were stored in darkness for 3 d at 4 °C and then transferred at 7 °C for the rest of the storage.

Quality measurements of fresh-cut lettuces were evaluated just after processing and during storage. Three to 5 packages were evaluated every sampling day, depending on the evaluation parameter.

2.3. Respiration rate and headspace gas composition

The respiration rate of fresh-cut iceberg lettuce was measured during storage with a 12 h photoperiod at 7 °C by means of the closed system (Fonseca et al., 2002). These storage conditions simulated distribution and retail sale conditions. A mass of 150 g of fresh-cut lettuce was placed in air-tight glass jars of 1.5 L. The containers were closed with 5 kPa $O_2 + N_2$ as initial gas atmosphere. At regular time intervals the O_2 concentration in the head space of each jar was measured until it reached below 0.5 kPa. These O_2 levels were fitted to a second order polynomial function to develop a respiration rate function as described in Gong and Corey (1994). The respiration rate was determined when O_2 level reached 0.5 kPa (approximately between 4 and 6 days after closing the jars) and data for each month represent the mean of at least 6 replicates.

The respiration rate and the changes in the headspace gas composition (O_2 and CO_2 kPa) of individual packages were monitored by an O_2 analyser (CG-1000, Ametek, Thermox Instruments Co.,