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Sensory quality, bioactive constituents and microbiological quality of green and red fresh-cut lettuces (*Lactuca sativa* L.) are influenced by soil and soilless agricultural production systems

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ABSTRACT

Quality characteristics and shelf-life of fresh-cut lettuce cultivated in soil, as the traditional production system, and soilless, as an innovative production system, were investigated. Three lettuce genotypes, lollo rosso and red oak leaf as red-leafed genotypes, and butterhead as a green-leafed genotype, were studied. Lettuces from both production systems were grown in the same open field and at the same time in the winter season. A longer growing period was needed, to obtain the same maturity stage, in the soil than in the soilless (102 and 63 d after planting, respectively). After harvest, the visual quality of the fresh-cut produce from red-leafed lettuce cultivated in soilless was better than those in soil. In the case of green-leafed genotype, the soilless system gave a lower visual quality of the fresh-cut product. Lollo rosso cultivated in the soilless system had a higher content of phytochemicals, including vitamin C and individual and total phenolics, than that cultivated in soil. At the end of storage, fresh-cut lollo rosso and red oak leaf grown in the soilless system showed significantly higher content of vitamin C than those in soil. This high content of antioxidants was linked to a better maintenance of visual quality and the control of browning when compared with the fresh-cut product from lettuces cultivated in soil. The soilless system was more effective in controlling microbial contamination as lettuce cultivated in the soilless system had a lower initial microbial load and slower microbial growth during storage. At the end of shelf-life, differences in microbial counts between soil and soilless lettuce were 3 and 1.5 log units higher for lactic acid bacteria and total coliforms, respectively, in soil. This study shows that higher quality and microbiologically safer raw product can be provided by the soilless system as a new growing system although it depends on the genotype and the season.

1. Introduction

Leafy lettuce (*Lactuca sativa* L.) is one of the primary fresh-cut vegetables increasingly being marketed for fast food, catering and home consumption because of convenience as a ready-to-eat product. Superior raw materials are required to provide consistent, high-quality fresh-cut produce throughout the year, including specifically developed cultivars and consistent raw products. Maximum postharvest quality can be achieved only by understanding and managing the various roles that preharvest factors play in postharvest quality (Crisoto and Mitchell, 2002). However, preharvest factors often interact in complex ways that depend on specific cultivar characteristics.

Leafy lettuce is traditionally cultivated in soil but recently, alternative soilless cultivation techniques have been considered. There are numerous soilless culture systems in place around the world, such as New Growing System (NGS™), the Nutrient Film Technique (NFT™) system, pot and sacs systems, aeroponics and floatation systems (Johnson, 2008; Fallovo et al., 2009). There can be a wide variation between soil and soilless systems in terms of inputs, size, location, environmental conditions and productivity. Such variation from one production system to another may affect the quality and safety characteristics of the raw material as well as those of the processed product. Soilless systems are suited to produce with short culture cycles and high plant density. They are often used for the production of high-value-added crops such as baby leaves (Nicola et al., 2005). Plant nutrition can be better controlled in these systems and soil contamination is avoided (FAO/WHO, 2008). Although some studies have been carried out to evaluate the quality of lettuce grown in soilless production systems (Cuppett et al., 1999; Tittonell et al., 2001; Hoque et al., 2010), limited studies are

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available in the literature comparing the effects of soil and soilless systems on lettuce postharvest quality, particularly for fresh-cut produce.

The terms quality and shelf-life, as they apply to fresh-cut products, are not consistently defined or applied in the same way as those applied to the original raw product. Sensory, nutritional, and microbiological qualities have been described as useful criteria, needed for accurate determinations of the shelf-life of fresh-cut fruit and vegetables (Cantwell and Suslow, 2002). Phytochemicals are becoming increasingly important for growers and processors who want to satisfy the demand of consumers for products with a high content of bioactive constituents. Production practices have been identified as risk factors that may influence the contamination and exposure to the consumer by human pathogens (Suslow et al., 2003). For the most part, lettuces are grown outdoors, where animals, birds and insects can transmit human pathogens to produce prior to or during harvest (Harris et al., 2002). Another potential risk for the contamination of lettuce is the soil contaminated with foodborne pathogens. Because of the variation in production practices, it is critical to know if different agricultural practices influence the microbiological quality of the processed product. Fresh lettuce at harvest has a natural epiphytic microflora, much of which is non-pathogenic (FAO/WHO, 2008). However, fresh lettuce may be expected to harbour a wide variety of microorganisms, including occasional pathogens (Beuchat, 2006). Fresh-cut lettuce, including red-leafed genotypes, lollo rosso and red oak leaf, has been implicated as a vehicle for the transmission of microbial foodborne disease worldwide (Ackers et al., 1998; Hilborn et al., 1999; Doyle and Erickson, 2008). The variable quality and microbiological susceptibility of fresh-cut lettuce may be related to the cultivar characteristics. Tremendous differences in surface morphology, tissue composition and metabolic activities of leaves provide a wide range of diverse ecological niches for species or groups of microorganisms (Beuchat, 2002).

Knowing and understanding that agricultural production systems are critical, in this study we wanted to identify if different lettuce cultivars including green and red-leafed lettuce genotypes, grown in soil and soilless systems in the same location and at the same maturity stage varied in terms of quality characteristics and shelf-life of the processed product. The possible variability that exists between these two production systems for the same period within the season means that the quality and safety aspects can be affected. This study tries to identify these differences by the evaluation of the sensory and microbiological qualities as well as the content of bioactive constituents including vitamin C and total and individual phenolic compounds of three genotypes.

2. Materials and methods

2.1. Plant material and growing conditions

Lettuces (*L. sativa* L.) of three genotypes, two red (lollo rosso cv Evasion and red oak leaf cv Jamai) and one green (butterhead cv Daguan) were cultivated under soil and soilless agricultural growing systems in the same location. The field was located at the experimental farm of Ruralcaja at the east coast of Spain (Paiporta, Valencia, 39°3′N, 0°3′W).

The area dedicated to the soil growing system comprised of 600 m^2 of raised beds. Before transplanting, 50 kg ha^{-1} of H_3PO_4 and 150 kg ha^{-1} of K_2SO_4 were applied to the soil and a nutrient solution with Mg^{2+}, Na^+, K^+ and Ca^{2+} was used for fertigation (supplementary information). The soil had a particle size distribution of 59.3% sand, 18.0% silt and 22.7% clay, classifying this soil texture as sandy clay loam (USDA Textural Soil Classification, 1987). Soil colour was 7.5 yellow-red 4/6 in accordance with the standardized Munsell colour system (Soil Survey Division Staff, 1993). Soil characteristics are described in the supplementary information. The number of plants in the soil system was 10 heads/m^2 and there was 0.3 m of plant spacing, including a buffer of unused plants at each end. The area dedicated to each genotype was similar (supplementary information).

The area dedicated to the soilless system comprised 425 m^2. The nutrient solution concentration used for the soilless growing system is shown in the supplementary information section. The electrical conductivity (EC) of the nutrient solution was 1.9 dS m^{-1} and the pH was 6.5. Demineralised water was used for the preparation of all nutrient solutions. For the soilless system, the New Growing System S.L. (NGS™, Almería, Spain) developed the hydroponic installation (Patent no. 2.221.636/7). This system consisted of an elongated plastic bag (12 m long) that gives support to the crop and collects excess of irrigation water thanks to its bottom layer (supplementary information). The steel lattice supports and gives shape to the multilayer trough that was fixed to the lattice structure with plastic clips. The steel lattice was placed on telescopic legs, facilitating labour. To ensure that the water flows back to the recirculation tanks, there was a slope of around 2%. Plants were placed every 0.3 m. Each block consisted of six lines of 12 m long, containing 40 plants per line. The area dedicated to each genotype was the same.

A randomised complete block design with three replicates was used in both growing systems. Seedlings were produced in a greenhouse in plastic trays and were transplanted 30 d after sowing. Harvest was performed 63 d after transplanting for the soilless system and 102 d for the soil system to reach the minimum weight required for each cultivar (180 g for lollo rosso and red oak leaf and 300 g for butterhead, following commercial specification of raw material for fresh-cut). At each harvest, 30 heads per plot were sampled with a total of 90 heads per cultivar and growing condition. Outer leaves were removed to mimic the trimming in a commercial harvesting operation. After harvest, lettuces were transported (200 km) to the CEBAS-CSIC laboratory (Murcia, Spain) under refrigerated conditions and kept 24 h at 4 °C and 70% relative humidity (RH) in darkness. The next morning, different measurements were taken before processing on 25 heads, such as fresh head weight, head width and maturity index (core length divided by head length × 100).

2.2. Processing, packaging and storage conditions

Each lettuce genotype was independently processed in a processing room at 4 °C under sanitary conditions. Lettuce heads from the three blocks were mixed and wrapper leaves were hand removed. Then, heads were cut into 30 mm pieces using a sharp stainless steel knife. Shredded lettuce was well mixed to obtain a homogeneous sample and then washed for 30 s in 100 mg mL^{-1} chlorine solution (NaOCl) adjusted to pH 6.5 with citric acid, drained for 30 s and then rinsed with tap water for 30 s. Excess water was removed by spinning for 1 min at 440 rpm 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), with O_2 permeance of 2.63 pmol s^{-1} m^{-2} Pa^{-1} and CO_2 permeance of 9.84 pmol s^{-1} m^{-2} Pa^{-1} at 7 °C and 97% RH. Package size was 230 mm × 320 mm. Fresh-cut samples of lollo rosso (125 g) were stored under passive modified atmosphere packaging (MAP), following commercial packaging conditions. The passive MAP was created by the respiration rate of the product and film permeability characteristics when packages were sealed under air conditions. Fresh-cut samples of red oak leaf (125 g) and butterhead (200 g) were stored under active MAP where nitrogen gas (N_2) was injected