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Time of day for harvest and delay before processing affect the quality of minimally processed baby spinach

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ABSTRACT

The objective of this study was to evaluate if time of day for harvest and delay before processing affected the quality of baby spinach. Three times of the day for harvest (8:30, 13:00 and 17:30 h as H1, H2 and H3, respectively) and three times of delay before processing (DP) (3, 24 and 48 h as DP3, DP24 and DP48, respectively) were studied. Two trials were conducted, one in January and another in April corresponding with winter and spring seasons. Photosynthetic and transpiration rates of baby spinach just before harvest were the highest at midday (H2), coincident with the highest solar radiation and vapor pressure deficit. In winter, the leaf water content was the highest in H1 and H3, while in spring leaves harvested early in the morning (H1) showed the highest leaf water content and more vivid color measured as Chroma. The differences observed were maintained during storage only in spring. Respiration rates did not show differences among harvest times in winter while in spring, respiration rate increased with the progress of harvest time (HT), particularly with shorter DP (DP3 and DP24). Moreover, visual quality of minimally processed baby spinach did not show significant differences among HT in winter, while in spring, the visual quality decreased when HT was advanced. The DP did not affect most of the parameters evaluated during storage, except the decrease in the respiration rate and the increase in the microbiological counts, psycrotrophs and Pseudomonas, when DP was increased. Results showed the same tendency for the leaf water content, color, respiration rate and visual quality of baby spinach after storage. Therefore, the best visual quality obtained in H1 corresponded with higher leaf water content and color saturation and a lower respiration rate. According to these results, minimally processed baby spinach could be harvested any time of the day in winter, while it is recommended to harvest it early in the morning in spring. Minimally processed baby spinach can tolerate a delay to processing of at least 48 h without evident symptoms of quality loss.

1. Introduction

Minimally processed baby spinach is a very perishable leafy vegetable rich in health promoting compounds such as vitamins, minerals, amino acid and antioxidants (Gil et al., 1999; Pandrangi and LaBorde, 2004). Baby leaves have become a popular and profitable product due to the high demand for healthy and convenient food in addition to softer textures and attractive presentation (Cantwell et al., 1998; Martínez-Sánchez et al., 2012). Baby leaves are generally characterized as very perishable products with high respiration and water loss (Wang, 2003). The quality and postharvest shelf life of baby spinach can be affected by a range of pre-harvest factors such as genotype, maturity stage, growing conditions and proper harvesting time (Howard et al., 2002; Clarkson et al., 2005; Pandjaitan et al., 2005; Conte et al., 2008; Chang et al., 2013). In particular, the time of day for harvest has been reported to influence quality and the composition of bioactive compounds of fresh products (Khalid et al., 2009; Moghaddam et al., 2013; Hasperué et al., 2013, 2014). In baby leaves, significant improvements to postharvest shelf life have been described as being achieved by rescheduling the time of day for harvest to end-of-day harvest (Clarkson et al., 2005). These authors attributed this to biophysical characteristics of the cell walls, with increased cell wall extensibility and the accumulation of carbohydrates at the end of the day (Clarkson et al., 2005). These changes in leaf status can be due to the diurnal variation of environmental factors like temperature, light intensity and water supply (Veit et al., 1996; Fan et al., 2014). In spinach, some changes appeared to be related to variations in temperature and light intensity. Thus, several heat shock proteins, nitrate and ascorbic acid concentrations varied significantly over the 24 h period (Li et al., 2000; Gent, 2012; Chang

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et al., 2013). Ascorbic acid decreased to the lowest level around 6 h after the light intensity initially increased (Chang et al., 2013) while nitrate increased during a dark period but decreased in light (Gent et al., 2012; Chang et al., 2013). Hence, to reduce the nitrate content of spinach, leaves should be harvested after light levels initially increase (Chang et al., 2013). Several heat shock proteins (Hsp70s) in spinach exhibit a cyclic diurnal pattern that is consistent with a cyclic demand for molecular chaperone activity in leaf tissue (Guy and Li, 1998; Li et al., 1999), and they could prepare the plant for the stress associated with the normal diurnal rise in temperature during the day (Li et al., 2000).

Generally, the recommendations related to time of harvest for leafy vegetables have been focused on temperature management of these perishable commodities. Recommendations for products sensitive to high temperature include not harvesting when temperatures are too warm (Thompson et al., 2002). In this regard, the product's temperature can be kept low by harvesting early in the morning or at night (Thompson, 1998; Thompson et al., 2008). However, specific reports for vegetables have described that time of day for harvest has a variable response depending on the crop. In broccoli, changes in the metabolism due to time of day for harvest influenced the expression of genes during the day and also caused different patterns of expression during postharvest (Hasperué et al., 2013). Harvesting at the end of day maintained the green color of the inflorescence and the sugar levels of broccoli during postharvest (Hasperué et al., 2014). In lettuce, Moccia et al. (1998) reported that the postharvest quality of several lettuce cultivars is affected by time of day for harvest and the best time appeared to be variable depending on the variety. In hydroponic lettuce, the greatest yield was obtained when lettuce was harvested at dawn (Gent, 2012). In baby leaves including lollo rosso, salad roquette and red chard, Clarkson et al. (2005) reported that the shelf life increased significantly when harvesting at the end of the day (22:00 h). However, these effects were dependent on the species evaluated and suggested an interaction between genotype and environment on postharvest quality (Clarkson et al., 2005). The objective of this study was to evaluate the effect of time of day for harvest and the delay to processing on the quality of minimally processed baby spinach. Physiological and quality characteristics were evaluated including photosynthetic and transpiration rates, leaf water content, color, respiration rate, microbiological counts and sensory evaluations. Two trials, one in winter and another in spring, were compared to understand if there was any seasonality influence to optimize the time of harvest and the delay before processing of minimally processed baby spinach.

2. Materials and methods

2.1. Plant material and growing conditions

Spinach (*Spinacia oleracea* L.) was cultivated under commercial conditions in fields near Pulpí (Almería, Spain) by Primaflor S.L. Sowing was performed directly on elevated beds using a plant density of 700 plants m^{-2}. Plant material (20 kg) was harvested mechanically at 08:30, 13:00 and 17:30 h (H1, H2 and H3, respectively) on January 14th, 2013 (winter variety) and April 8th, 2013 (spring variety). The growing cycle to reach commercial maturity was 54 and 35 d for winter and spring, respectively. Climatic data during the growing cycle (Table 1) including sunshine, rainfall, radiation, temperature and crop evapotranspiration (E_c) were obtained from the nearby sampled field climatic station “Pozohiguera” (37° 30′ 13, 86″ N, 1° 41′ 38, 07″ W) (SIAM, 2014). On the day of harvest, radiation, temperature and vapor pressure deficit (VPD) were also measured (Fig. 1). In both trials, the days of harvest were sunny without rainfall. The last day of irrigation was one day before harvest. After harvest, baby spinach without precooling was transported (150 km) under refrigerated conditions in polystyrene boxes (2.5 kg of leaves per box) to the CEBAS-CSIC laboratory (Murcia, Spain).

2.2. Photosynthetic and transpiration rates

The leaf gas exchange parameters were measured using a portable photosynthesis system (model LCA-4, ADC Bioscientific Ltd., Hoddesdon, U.K.) with a leaf chamber (PLC-4N of 11.35 cm^2), configured to an open system as described by Simón et al. (2013). Photosynthetic and transpiration rates were measured in 30 leaves just before harvest in the winter trial. However, these parameters were not able to be measured in spring due to a technical failure of the equipment.

2.3. Processing, packaging and storage conditions

Different delays to processing were evaluated: 24 and 48 h (DP24 and DP48, respectively) in winter, and 3, 24 and 48 h (DP3, DP24 and DP48, respectively) in spring. Baby spinach was stored at 4 °C and 85% RH during the different delays to processing. After that, baby leaves were processed in an isolated clean minimal processing room at 4 °C. Samples were washed for 30 s in a cold (4 °C) chlorine solution (NaOCl 100 mg L^{-1}) 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 7.3 s^{-1} in an automatic salad spinner (K-50, Kronen GmbH, Kehl am Rhein, Germany). Samples of 100 g were mechanically packed in a vertical packaging machine (Etna 280-X model, Ulma, Oñati, Spain) using a 35 μm polypropylene (PP) film (Amcor Flexibles, Bristol, UK) with O_2 permeance of 2.63 E^{-12} mol m^{-2} s^{-1} Pa^{-1}, CO_2 permeance of 9.84 E^{-12} mol m^{-2} s^{-1} Pa^{-1} and H_2O permeance of 5.41 E^{-6} mol m^{-2} d^{-1} at 7 °C and 97% RH. Package size was 230 mm × 310 mm. One macro-perforation per bag was carried out manually with a needle (0.5 mm diameter). Passive modified atmosphere packaging (MAP) was created by the respiration rate of the product and the film permeability characteristics, including the hole, as packages were sealed under air conditions. Packages were stored in darkness for 3 days at 4 °C plus 6 days at 7 °C.

2.4. Leaf relative water content

Leaf water content was determined as relative water content (RWC) as described by Viacava et al. (2010) with some modifications. Fifteen replicates were measured for each condition: at harvest and before processing in winter and also after storage in spring. For RWC determination, 3 leaves per replicate

Table 1
Climatic variables during the spinach growing cycles including sunshine, rainfall, radiation, temperature and crop evapotranspiration (E_c).

Season	Growing cycle (days)	Mean daily sunshine (h)	Mean rainfall (mm)	Mean radiation (W m^{-2})	Mean temperature (°C)	Mean E_c (mm)
Winter	54	7.2 ± 1.3	0.1 ± 1.4	105 ± 22	10.2 ± 2.5	1.7 ± 0.4
Spring	35	9.4 ± 1.8	1.1 ± 3.4	196 ± 67	13.4 ± 2.9	3.4 ± 1.0

Values are the mean ± standard deviation of the data considering the whole growing cycle.