Scientia Horticulturae 201 (2016) 1–9

Contents lists available at ScienceDirect

Scientia Horticulturae

journal homepage: www.elsevier.com/locate/scihorti

Innovative harvest practices of Butterhead, Lollo rosso and Batavia green lettuce (*Lactuca sativa* L.) types grown in floating hydroponic system to maintain the quality and improve storability

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ARTICLE INFO

Article history:
Received 29 September 2015
Received in revised form
26 November 2015
Accepted 13 January 2016
Available online 29 January 2016

Keywords:
Leafy vegetables
Chlorophyll fluorescence
Self-life
Postharvest quality
Hydroponics
Nitrates

ABSTRACT

In series of trials, we evaluated the effects of different harvest practices and storage conditions in postharvest quality of lettuce (*Lactuca sativa* L.) types of Lollo rosso (cv 'Carmesi'), Butterhead (cv 'Gemmaverde') and Batavia green (cv 'Dragone') grown in floating hydroponic system (FHS). There was clear indication that harvest practice significantly affected storage life (SL), relative fresh weight (RFW) and visual appearance rating (VAR) of all lettuce types. SL of rooted plants increased by up to 20.8, 16.6 and 26 days for cvs 'Carmesi', 'Gemmaverde' and 'Dragone', respectively compared to the un-rooted controls (conventional harvest). Independently to cultivar tested, the RFW values of rooted plants, ranged from 96.86 to 113.77%, while those of the un-rooted controls from 79.06 to 87.51%. Leaf color and chlorophyll degradation was not affected or changed in rooted plants, even after 28 days at storage. We propose that rooted plants can be stored at temperatures of 4–5 °C for longer without any quality decline, thus giving practical advantages to commercial handling.

1. Introduction

Market sales of vegetables have increased as a result of changes in consumer attitudes and life styles (Brecht et al., 2004; FAOSTAT, 2010; Cook, 2012). However, fresh product consumption encounters several problems related to quality maintenance during storage (Paull, 1999). Post-harvest, wound-induced physiological and/or biochemical reactions play a key role in degradation that shortens storage life considerably (Wills et al., 2004). Shelf-life and quality of lettuce depends on type and cultivar (Lopez-Galvez et al., 1996), pre-harvest cultivation techniques (Fonseca, 2006; Konstantopoulou et al., 2010; Rodríguez-Hidalgo et al., 2010; Iacusso et al., 2011), temperature and relative humidity (RH) at storage (Paull, 1999; Moreira et al., 2006) and postharvest treatments (Salunkhe et al., 1991; Rodríguez-Hidalgo et al., 2010). Generally, cut lettuce has a very short postharvest life and may be stored for up to 15 days at 0 °C and >95% RH (Salunkhe and Kadam, 1998; Wills et al., 2004; Lin and Block, 2009; Agüero et al., 2011; Agüero et al., 2014). Nevertheless, extended storage at inappropriate temperatures and/or RHs may lead to extensive weight loss (Moreira et al., 2006; Agüero et al., 2014), oxidative loss of chlorophyll (Yamauchi and Watada, 1993; Yamauchi et al., 1997; Agüero et al., 2011) and vitamin C (Lee and Kader, 2000; Moreira et al., 2006), as well as increase in microbial contamination (Moreira et al., 2006; Agüero et al., 2011). All such processes intensify as temperature increases and RH levels drop. Postharvest deterioration symptoms may include bleaching and browning of green color, texture breakdown and reduction of flavour due to increase in respiration rate, water loss, enzymatic activity and microbiological contamination (Brecht, 1995; Ragaert et al., 2007; Atkinson et al., 2013). Storage of lettuce can be improved by the implementation of modified atmospheres (Lopez-Galvez et al., 1996; Escalona et al., 2006).

In many arid or semi-arid regions such as the Mediterranean traditional cultivation systems might be inappropriate due to high water cost and/or low quality (Brecht et al., 2004). In such cases, the protected hydroponic cultivation systems serve as solid alternatives (Frezza et al., 2005). Especially when using the closed-loop hydroponic systems, water and fertilization savings are significant (Frezza et al., 2005; Kader, 2008). In Greece, most lettuce types are traditionally cultivated in soil. However, in recent years, the implementation of soilless cultures is increasing mainly with aggregate systems such as rockwool, perlite and pumice or water culture systems such as NFT. Despite the relatively large market for minimally

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http://dx.doi.org/10.1016/j.scienta.2016.01.021
0304-4238/

processed leafy vegetables, alternative cultivation techniques such as the Floating Hydroponic System (FHS) have not been sufficiently tested (Lee et al., 2007; Fallovo et al., 2009). FHS is considered as important growing tool that helps growers obtain cleaner products, free of substrate traces. This, results in milder washing procedures and elimination of water wastage by consumers. In FHS the control of salinity helps the improvement of postharvest quality characteristics and even eliminate nitrate content in leafy vegetables (Mengel and Kikby, 1987; Frezza et al., 2005; Fallovo et al., 2009; Seo et al., 2009; Scuderi et al., 2011). When lettuce plants were grown in FHS nutrient solutions of 37 and 44 mequiv L^{-1} at spring and summer seasons, respectively, fresh weight and mineral content was significantly increased (Fallovo et al., 2009). Furthermore, lettuce plants grown in FHS at 3.8 and 4.8 mS cm^{-1} EC showed better firmness, higher dry matter content, less total color change and overall better shelf life compared to plants grown at lower EC of 2.8 mS cm^{-1} (Scuderi et al., 2011).

The present study was performed to evaluate different harvest and storage protocols for FHS grown lettuces and correlate them with postharvest quality. No published research was found on alternative harvest practices for lettuces grown in FHS. Storage at higher temperatures was also tested and alternatives were proposed as practical guides to commercial handling.

2. Materials and methods

2.1. Plant material

Lettuce seeds (*Lactuca sativa* L.) of Lollo rosso cv 'Carmesi' (Rijk Zwaan, Fijnaart, The Netherlands), Butterhead cv 'Gemmaverde' (Vilmorin, La Ménitré, France) and Batavia green cv 'Dragone' (Vilmorin, La Ménitré, France) were germinated in 60 × 20 cm plastic trays (INA plastics, Athens, Greece) filled with sterilized expanded perlite moistened with full strength nutrient solution. Plantlets remained in the trays from the emergence until they reached 3–4 true leaves (12–14 days). Then, the plantlets were transplanted to 4-cm diameter pre-cut holes made on 1.25 m long × 0.60 m wide and 0.05 m thick boards of extruded polystyrene (Styrofoam; Dow Hellas, Athens). The plantlets were supported by plastic net pots and were transplanted at 100 plants m^{-2} density. Two weeks later (7–8 leaf stage), the plants were transplanted to a final plant density of 20, 30 and 20 plants m^{-2} for cvs 'Carmesi', 'Gemmaverde' and 'Dragone', respectively.

2.2. Growing conditions-floating hydroponic system (FHS)

Lettuce plants of the cvs listed above were grown (in cycles) inside a non-heated, 200 m^2 productive greenhouse located in Kalamata, Peloponnese, GR (37° 2′ 20″ N/22° 6′ 51 ″E) from November 2014 to May 2015. Temperature and relative humidity (RH) inside the greenhouse were recorded by data loggers (Argos Electronics, Athens, Greece). Average, nutrient solution temperature ranged between 16–20 °C in winter (November–February) and between 20–23 °C in spring (March–May). Average minimum and average maximum air temperatures in the greenhouse ranged between 13.2 ± 2 °C and 24.2 ± 4 °C in winter, respectively and between 16.0 ± 2.0 °C and 27.0 ± 4 °C in spring, respectively. Average RH inside the greenhouse ranged between 70–80%.

Cultivation was carried out in a 10 m long × 4 m wide × 0.30 m deep FHS unit. The nutrient solution in FHS was prepared according to commercial nutrient recommendations and was adapted to local environmental conditions (Savvas and Adamidis, 1999). Its concentration (in meq L^{-1}) was Ca^{2+}: 7.47; Mg^{2+}: 3.23, K^+: 6.54, NH_4^+: 0.84; SO_4^{2-}: 5.19; NO_3^-: 9.62; $H_2PO_4^-$: 1.92 and (in μmol L^{-1}) Fe: 35; Mn: 8; Zn: 6; Cu; 0.75; B: 30 and Mo: 0.5 (Assimakopoulou et al., 2013). During cultivation, pH and EC was adjusted at 5.8–6.0 and 2.0–2.1 mS cm^{-1}, respectively. pH was adjusted using nitric acid and EC was stabilized by the addition of water or fresh nutrient solution depending on its level. pH and EC were measured daily using a portable pH/EC meter (Hanna HI9813-5, USA). Water loss by evapotranspiration from the FHS unit was automatically replaced by fresh nutrient solution (see above) keeping its 0.30 m depth constantly. Dissolved oxygen (DO) levels in the nutrient solution was maintained above 4.5 mg L^{-1} (Mathieu et al., 2006) using an air compressor and a pump continuously recirculating O_2 at the rate of 250 L min^{-1}. DO was measured using a portable oxygenometer (GMH 3630, Greisinger electronic GmbH, Wuerzburg, Germany).

2.3. Harvest practice and storage conditions

Rooted lettuce plants of cvs listed above were harvested at the commercial maturity stage, 2–3 weeks after final transplanting at 200–300 g FW depending on lettuce type. The harvested materials were immediately transported to the laboratory (i.e., approx. 20 min later) and placed at 4 °C. Four individual trials were carried out at different times of the year to test nine harvest treatments and three storage temperatures (Table 1). Full rooted plants (whole root) were placed on air or with their roots in nutrient solution and in tap water (held in glass containers) or were folded in water-soaked burlaps. One third rooted plants (1/3 of the root) were placed on air or with their roots nutrient solution, in tap water or were folded in water-soaked burlaps. Un-rooted plants (roots cut on the basal bottom – conventional harvest) were placed on air and were used as controls. All upper plant parts (i.e., leaves) were covered with plastic perforated, transparent bags (30 × 40 cm) and placed inside cold rooms at 0–1, 4–5 or 10–11 °C and 60–70% RH in the dark in a complete randomised design (CRD) or in randomised block design (RBD) as factorial arrangements depending on the experimental lay out (Table 1).

2.4. Assessments and quality parameters

2.4.1. Storage life (SL), relative fresh weight (RFW) and water uptake (WU)

SL was recorded as days from harvest (i.e., day-0). The end of SL was considered when RFW value dropped below 80% of the initial. Lettuce FW was measured by weighing lettuces every 2 days with a digital balance (Kern, & Sohn GmbH, Balingen, Germany) and RFW was calculated as percentage (%) of the initial value using the following equation $RFW = [(FW_i - FW_f/FW_i) \times 100] + 100$ where FW_i = initial fresh weight at day-0 and FW_f = final fresh weight at measurement day (Darras et al., 2010). WU was calculated as mL g FW^{-1} day and it was measured by weighing the glass containers (container + content) with a digital balance (Kern, & Sohn GmbH, Balingen, Germany).

2.4.2. Color

Color was measured on the outer surface of the leaves using a Minolta colorimeter (Model CR-300, Minolta Co., Ltd., Osaka, Japan). Before sampling, the instrument was calibrated on a Minolta standard white reflector plate. Assessments were carried out by placing the colorimeter sensor (8 mm aperture) on the outer leaf surface, midway between the apical and the basal ends. L^* (lightness index scale from black to white), a^* [degree of redness ($+a^*$) to greenness ($-a^*$)], b^* [degree of yellowness ($+b^*$) to blueness ($-b^*$)], H^* (Hue; arctan b^*/a^*), C^* [chroma; $(a^2+b^2)^{1/2}$] and total color difference (ΔE) were recorded. ΔE was also calculated using the following equation: $\Delta E = [(L_f - L_i)^2 + (a_f - a_i)^2 + (b_f - b_i)^2]^{1/2}$, where L_i = initial lightness (day-0), L_f = final lightness (day-14), $a_i = a^*$ value at ini-