LWT - Food Science and Technology 55 (2014) 551–558

Contents lists available at ScienceDirect

LWT - Food Science and Technology

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

Postharvest quality and shelf life of radish microgreens as impacted by storage temperature, packaging film, and chlorine wash treatment

Zhenlei Xiao [a], Yaguang Luo [b], Gene E. Lester [b], Liping Kou [c], Tianbao Yang [b], Qin Wang [a, *]

[a] Department of Nutrition and Food Science, University of Maryland, College Park, MD 20742, United States
[b] Food Quality Laboratory, Beltsville Agricultural Research Center, USDA, ARS, 10300 Baltimore Avenue, Beltsville, MD 20705, United States
[c] College of Food Science and Engineering, Northwest A&F University, Yangling, Shaanxi 712100, China

ARTICLE INFO

Article history:
Received 23 February 2013
Received in revised form
6 September 2013
Accepted 9 September 2013

Keywords:
Radish microgreens
Storage temperature
MAP
Chlorine wash
Shelf life

ABSTRACT

Microgreens are new and emerging products, which are young seedlings of vegetables and herbs. A recent study showed that microgreens contain higher nutrients compared to their mature counterparts. However, they typically have a short shelf life (1–2 days) at ambient temperature. The objective of this study was to optimize postharvest handling conditions to reduce the quality loss and extend the shelf life of daikon radish (*Raphanus sativus* L. var. *longipinnatus*) microgreens. Storage temperature, packaging film, and wash treatment were investigated. Changes in headspace composition, quality index, chlorophyll concentration, tissue electrolyte leakage, and aerobic mesophilic bacteria (AMB) and yeast & mold (Y&M) counts were monitored periodically during storage. Results indicated that (1) storage temperature significantly ($P < 0.05$) affected package atmosphere, product quality and shelf life. One degree Celsius was the optimal temperature for storage of radish microgreens with no chilling injury observed; (2) film oxygen transmission rate (OTR) significantly ($P < 0.05$) affected O_2 and CO_2 composition, but OTR did not significantly affect quality attributes during 28 days of storage at 1 °C; (3) Chlorine wash treatment (100 mg/L) significantly reduced initial microbial populations by 0.5 log cfu g^{-1}, including AMB and Y&M. However, microbial populations rebounded after day 7.

1. Introduction

Microgreens have gained popularity as a new culinary trend appearing in upscale markets and restaurants over the past few years. They are tender cotyledonary-leaf plants having vivid colors, intense flavors and tender textures; therefore, they are usually served fresh as ingredients in salad, soups and sandwiches or used as an edible garnish (Treadwell, Hochmuth, Landrum, & Laughlin, 2010). In a recent study, we found that microgreens generally contain higher concentrations of phytonutrients (such as α-tocopherol, β-carotene and ascorbic acid) than their mature-leaf counterparts (Xiao, Lester, Luo, & Wang, 2012). However, microgreens are delicate and have a very short shelf life (1–2 days) at ambient temperature; and as such are categorized to be highly perishable products (Chandra, Kim, & Kim, 2012).

Storage temperature is one of the most important factors affecting the postharvest physiology and storage behavior of produce. In general, low temperature storage can reduce quality loss and extend shelf life by depressing rates of respiration, senescence, and growth of spoilage microorganisms (Manolopoulou, Lambrinos, Chatzis, Xanthopoulos, & Aravantinos, 2010; Spinardi & Ferrante, 2012). Optimum storage temperature varies depending on the fruit or vegetable. For some chilling sensitive fruits and vegetables, the use of low temperature storage adversely affects quality attributes and causes deterioration more rapidly (Galvez, Garcia, Corrales, Lopez, & Valenzuela, 2010; Paull, 1999). Thus, the selection of optimum storage temperature is crucial.

Modified atmosphere packaging (MAP) is an effective technology for maintaining freshness and prolonging shelf life of produce, which has been successfully applied in fresh and minimally processed produce, such as lettuce (*Lactuca sativa* L.), broccoli (*Brassica oleracea* L. cv. *Acadi*), spinach (*Spinacia oleracea* L.) and mushrooms (*Agaricus bisporus* cv. U3 Sylvan 381) (Sandhya, 2010). There are many factors influencing package atmosphere of products, including product respiration rate, packaging film oxygen transmission rate (OTR), product weight, package surface area, storage temperature and relative humidity (Sandhya, 2010). In food supply

* Corresponding author. Department of Nutrition and Food Science, 0112 Skinner Building, University of Maryland, College Park, MD 20742, United States. Tel.: +1 301 405 8421; fax: +1 301 314 3313.
E-mail address: wangqin@umd.edu (Q. Wang).

0023-6438/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.lwt.2013.09.009

chains, package size and product weight are often pre-determined. Selecting a packaging film with suitable OTR to match the product respiration rate is the best way to maintain quality and extend shelf life of produce.

Consumer demand for fresh, convenient and nutritional foods have spurred a recent rapid growth of the minimally processed fruit and vegetable (Kobori, Huber, Sarantopoulos, & Rodriguez-Amaya, 2011). In the fresh-cut processing chain, chlorine-based solutions are very potent and efficient sanitizers and have been widely used in the fresh-cut industry in the USA. However, the use of chlorinated sanitizers is banned in some European countries due to the potential risk of undesirable disinfection by-products (DBPs) upon reaction with organic matters, such as chloroform ($CHCl_3$), haloacetic acids or other trihalomethanes (THMs) (Artes, Gomez, Aguayo, Escalona, & Artes-Hernandez, 2009). In recent years, some alternatives have been proposed, e.g. irradiation, ozone, electrolyzed water, essential oils, and organic acids. However, none of them have gained widespread acceptance by the industry (Rico, Martin-Diana, Barat, & Barry-Ryan, 2007).

Currently, there is no ready-to-eat microgreens are commercially available in the food supply chains due to their perishability and high price. Daikon radish (*Raphanus sativus* L. var. *longipinnatus*) is one of the most commonly-grown commercial microgreens. It has an extraordinarily high concentration of α-tocopherol (87.4 mg/100 g FW) (Xiao et al., 2012), which is an important lipid-soluble antioxidant and can protect cell membranes from oxidative stress. Moreover, the potent spicy flavor, bright green color and tender texture of daikon radish microgreens are also favorable. However, little information is available on optimal storage temperature, packaging film and wash treatment configuration of daikon radish microgreens. Therefore, the objectives of this study were 1) to optimize storage temperature; 2) to evaluate the effect of packaging film OTR under optimum storage temperature; and 3) to investigate the effect of chlorine wash treatment under optimal storage temperature and packaging film OTR on maintaining quality and prolonging shelf life of daikon radish microgreens.

2. Materials and methods

2.1. Sample preparation and packaging

Daikon radish (*R. sativus* var. *longipinnatus*) seeds were purchased from Living Whole Foods, Inc. (Springville, UT, USA). Seeds were sown in 28 cm *W* × 54 cm *L* × 6 cm *D* culture trays (Vacuum-Formed Standard 1020 Open Flats without holes, Growers Supply, Dyersville, IA, USA). The media was Farfard 3B potting soil consisting of 45% peat moss, 15% vermiculite, 15% perlite and 25% bark (Griffin Greenhouse & Nursery Supplies, Bridgeton, NJ, USA). Seeds were grown in a temperature-controlled (25 °C) growth chamber. During the first three days, the trays were covered and seeds were germinated in the dark. For the next 4 days, the seedlings were exposed to light irradiance (42 μmol s^{-1} m^{-2}, determined by LI-1000 datalogger, LI-COR, Lincoln, NB, USA) for a 12-hr photoperiod. Seven-day-old radish microgreens were harvested by cutting stem ends with scissors sterilized with 75 mL/100 mL alcohol. After harvest, radish microgreens were inspected prior to any treatment and plants with defects were discarded.

2.1.1. Temperature treatments

Fifteen grams of radish microgreens were packaged in polyethylene bags (15 cm × 15 cm, Pacific Southwest Container Inc., Modesto, CA, USA) with film oxygen transmission rate (OTR) of 16.6 pmol s^{-1} m^{-2} Pa^{-1}. All the bags were sealed and stored at 1, 5, or 10 °C cold rooms under dark for 14 days. Evaluations were performed on day 0, 3, 7, 10 and 14. All treatments were conducted in four replicates.

2.1.2. Packaging treatments

Radish microgreens (15 g) were packaged in 15 cm × 15 cm bags prepared from polyethylene films with OTRs of 8.0, 11.6, 16.6, 21.4, or 29.5 pmol s^{-1} m^{-2} Pa^{-1}. The permeability of the films was tested by the manufacturer (Pacific Southwest Container Inc., Modesto, CA, USA) under conditions of 23 °C and 101.3 kPa using a MOCON apparatus according to ASTM F2714-08 and ASTM F2622-08 standards. Four replicates of each treatment were prepared for each evaluation day (day 0, 7, 14, 21 and 28). All samples were stored at 1 °C in a dark room for subsequent evaluation.

2.1.3. Wash treatments

The sodium hypochlorite (NaOCl) wash solutions (50, or 100 mg/L free chlorine, pH 6.5) were prepared using Clorox® (6 mL/100 mL sodium hypochlorite, Clorox Co., Oakland, CA) and the pH was adjusted with citric acid solution. All the free chlorine levels before treatments were measured with a chlorine photometer (CP-15, HF Scientific Inc., Fort Myers, FL, USA). Radish microgreen samples (350–400 g) were washed in pre-disinfected mesh bags with gentle agitation in 40 L wash solutions at 20 °C for 1 min, followed by rinsing with 20 °C tap water for 1 min. Washed samples were then centrifuged at 300 rpm for 3 min with a commercial T-304 salad centrifugal dryer (Garroute Spin Dryer, Meyer Machine Co., San Antonio, TX, USA) to remove excess surface water. Unwashed samples were used as controls. Portions (15 g) of washed and unwashed radish microgreens were placed into polyethylene bags (15 cm × 15 cm) with OTR of 29.5 pmol s^{-1} m^{-2} Pa^{-1} and stored at 1 °C for 28 days in the dark. Four bags were randomly selected on each sampling day (day 0, 7, 14, 21 and 28) for quality evaluations.

2.2. Headspace gas composition

The O_2 and CO_2 contents in the headspace of packages were analyzed using an O_2/CO_2 gas analyzer (CheckMate II, PBI-Dansensor A/S, Ringsted, Denmark) by inserting the needle of the measuring assembly through a septum adhered to the packaging film.

2.3. Quality index

2.3.1. Chlorophyll analysis

Total chlorophyll content was determined spectrophotometrically using the method of Auderset et al. (1986) with minor modifications. Excised radish cotyledonary leaves (1.0 g) were transferred into 50-mL centrifuge tubes. After homogenization in 10 mL 80 mL/100 mL acetone (HPLC-UV grade, Pharmco-Aaper, Brookfield, CT, USA) solution at the speed of 17,500 rpm for 30 s (Adaptable homogenizer, VDI 25, VWR International, West Chester, PA, USA), the mixture was filtered (Grade 413 Filter Paper, Qualitative, VWR International, West Chester, PA, USA) into a 25 mL amber volumetric flask and rinsed with 80 mL/100 mL acetone solution until filter cake became colorless. The filtrate was diluted with 80 mL/100 mL acetone solution to 25 mL and stored at −20 °C until ready to measure. Absorbance was read at 646, 663, and 710 nm (UV-1700 Spectrophotometer, Shimadzu, Kyoto, Japan) and total chlorophyll was calculated by the following formula: