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

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A R T I C L E   I N F O

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

A B S T R A C T

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 significantly reduced initial microbial populations by 0.5 log cfu g−1, including AMB and Y&M. However, microbial populations rebounded after day 7.

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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 x-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...
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 (CHCl3), 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 tocopherol (87.4 mg/100g FW) (Xiao et al., 2012), which is an ability and high price. Daikon radish (R. sativus var. longipinnatus) is one of the most commonly-grown commercial microgreens. It has an extraordinarily high concentration of 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 optimum 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. Un-washed 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 O2 and CO2 contents in the headspace of packages were analyzed using an O2/CO2 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 Auerset 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:
Total chlorophyll (µg/g FW) = \[ ((A_{646} - A_{710}) \times 0.01732 + (A_{663} - A_{710}) \times 0.00718) \times \text{dilution volume (mL)} \times 1000 / \text{fresh weight (g)} \]

2.3.2. Electrolyte leakage analysis
Tissue electrolyte leakage was measured following a modified procedure from Allende, Luo, McEvoy, Artes, & Wang (2004). Radish microgreens (5 g) were submerged in 150 mL deionized water at 20 °C and shaken for 30 min. The electrolyte of the solution was measured using a Model 135A Thermo Orion conductivity meter (Beverly City, MA, USA). Total electrolytes were obtained after freezing the samples at −20 °C for 24 h and subsequent thawing. Tissue electrolyte leakage was expressed as a percentage of the total electrolyte.

2.3.3. Overall quality and off-odor evaluation
Overall visual quality and off-odor were evaluated following the procedure of Luo, McEvoy, Wachtel, Kim, and Huang (2004) and Meilgaard, Civille, and Carr (1991). Briefly, the visual quality was evaluated on a 9-point hedonic scale, where 9, 8, 7 and 6 = like extremely, strongly, moderately and slightly, respectively, 5 = neither like nor dislike and 1, 2, 3 and 4 = dislike extremely, strongly, moderately and slightly, respectively. A score of 6 was considered the limit of salability (Kim, Luo, & Gross, 2004). Off-odor score was based on a 0 to 4 scale where 0 = no off-odor, 1 = slight off-odor, 2 = moderate off-odor, 3 = strong off-odor, and 4 = extremely strong off-odor. All visual quality and off-odor evaluation were carried out by three trained evaluators (1 male and 2 female, aged 28 to 43 years old). The evaluators have had over five-year of research experience with fresh produce, especially performing sensory evaluation of leafy greens. Prior to the start of this experiment, additional trainings specific to the organoleptic properties of radish microgreens were provided to the evaluators.

3. Results and discussion
3.1. Effect of different temperatures on quality and shelf life of radish microgreens
The changes in headspace atmospheres of packaged radish microgreens were significantly (P < 0.05) affected by storage temperature (Fig. 1A and B). Packages stored at 10 °C experienced a rapid depletion of O2 and accumulation of CO2, with the low O2 (9.1 kPa) and high CO2 (2.5 kPa) levels within the packages at the end of 14-day storage. Packages stored at 5 °C maintained higher levels of O2 (21.7 kPa) and CO2 (2.5 kPa) respectively, and a lower concentration of CO2 (1.3 and 1.6 kPa, respectively) than the packages stored at higher temperature 10 °C. This is likely due to the lower respiration rate of the samples stored at lower temperatures.

Decrease in chlorophyll content is associated with cellular degradation and/or senescence, which is often used to estimate quality loss of green vegetables (Hodges, Forney, & Wismer, 2000). No information has been found specifically on total chlorophyll content of microgreens. In this study, the initial chlorophyll content of radish microgreen leaves was around 754 µg/g fresh weight (FW). As shown in Fig. 1C, total chlorophyll content decreased in all samples through 14-day storage except for those held at 1 °C at which temperature samples maintained the highest chlorophyll content (691.1 µg/g fresh weight), and no apparent yellowing phenomenon was observed at the end of the storage period. In contrast, samples stored at 10 °C were first to show signs of yellowing on day 7, with a rapid decline in chlorophyll content with a final value of 171.8 µg/g fresh weight. Decrease in chlorophyll content is clearly temperature-dependant with lower temperature resulting in greater chlorophyll retention. It is probably due to the reduction of metabolic activity on chlorophyll degradation under low temperature (Pogson & Morris, 1997).

Tissue electrolyte leakage is an indicator of cell membrane damage (Fan & Sokorai, 2005) and has been closely related to quality loss in fresh-cut produce during storage (Kim, Luo, Saftner, & Gross, 2005; Luo et al., 2004). During this study, there was no significant difference found in three temperature treatments (1, 5, and 10 °C) (Fig. 1D). All the samples showed minimal increase (0.3–0.9%) in electrical conductivity during the entire 14-day storage, indicating that the samples stored at low temperature did not lose cell membrane integrity. It was also suggested that diakon radish microgreen is not susceptible to chilling injury (Chandra et al., 2012).

Overall visual quality and off-odor are important factors influencing the marketability of a food product. In this experiment, storage temperature significantly affected visual quality deterioration and off-odor development (Fig. 1E and F). Throughout the whole 14-day storage period, radish microgreens stored at 1 °C were rated highest in overall quality, followed by samples at 5 °C, with the final score of 7.9 and 6.5 on day 14, respectively. Samples stored at 10 °C maintained acceptable visual quality (a score of 7.6) until day 7, however, after day 7, yellowing was observed and all these samples experienced a sharp decline in overall quality which became unacceptable (scored 4.8) within 10 days of storage, indicating that temperature abuse is severely detrimental for the delicate radish microgreens. No off-odor was detected on radish microgreens before day 7 for all treatments (Fig. 1F). On day 10, all the three treatments displayed slight to moderate off-odor and the
higher the storage temperature was, the higher the intensity of off-odor was detected. At the end of 14-day storage, only slight off-odors were detected (scored 0.5 and 1.0, respectively) in the samples stored at 1 and 5 °C and moderate off-odor (scored 1.6) was detected in 10 °C treatment. The development of off-odors had a positive correlation with the decrease of O₂ and the increase of electrolyte leakage, suggesting that tissue senescence and deterioration resulted in cell membrane damage and undesirable fermentative volatiles, such as ethanol and acetaldehyde (Kim et al., 2005).

Changes in aerobic mesophilic bacteria (AMB) and yeast and mold (Y&M) populations on radish microgreens stored at different temperatures were shown in Fig. 1G and H. Storage temperatures significantly (P < 0.05) affected microbial growth rate. During the 14-day storage, AMB populations on radish microgreens stored at 10 °C increased more rapidly than those stored at 1 and 5 °C. AMB populations at 10 °C increased by a total of 0.8 log cfu g⁻¹, compared to 0.1 and 0.2 log for 1 and 5 °C, respectively. Y&M growth followed a similar trend. Low temperature significantly (P < 0.05) inhibited the growth of AMB and Y&M and samples stored at 1 °C maintained a relatively lower bacterial population than samples stored at 5 °C.

Storage temperature significantly affected the quality attributes and microbial growth of daikon radish microgreens. Samples stored at 1 °C maintained the best quality during the 14-day storage; therefore, 1 °C was considered to be the optimal storage temperature for daikon radish microgreens and was selected for the following packaging film and chlorine wash experiments.

Fig. 1. Effect of temperature on the changes in O₂ (A) and CO₂ (B) partial pressures within packages, chlorophyll content (C), electrolyte leakage (D), overall quality (E), off-odor (F), aerobic mesophilic bacteria (AMB) (G) and yeast & mold (Y&M) (H) populations of packaged daikon radish microgreens using 16.6 pmol s⁻¹ m⁻² Pa⁻¹ OTR film during storage (n = 4). Vertical bar represents ± standard error. — 1 °C, — 5 °C, and — 10 °C.
3.2. Effect of packaging atmospheric conditions on quality and shelf life of radish microgreens stored at 1 °C

Packaging film OTR significantly (P < 0.05) affected the headspace O₂ and CO₂ concentrations of radish microgreens packages at 1 °C (Fig. 2A and B). Atmospheres in the packages prepared with higher OTR films (21.4 and 29.5 pmol s⁻¹ m⁻² Pa⁻¹) equilibrated at higher levels of O₂ (15.0–16.0 kPa) and lower levels of CO₂ (1.2–1.3 kPa). This finding is in accordance with a previous report on fresh-cut salad savory (Kim et al., 2004). Packages prepared with 8.0 pmol s⁻¹ m⁻² Pa⁻¹ film OTR exhibited a relatively more rapid depletion of O₂ and accumulation of CO₂, than those occurred in all other treatments. However, the headspace O₂ concentrations were as high as 8.8 kPa and CO₂ concentrations were relatively low (3.0 kPa) on day 28, indicating that the tissues had not experienced anaerobic respiration.

After the 28-day storage at 1 °C, the content of total chlorophyll had declined slightly to a final range of 656–678 µg/g FW. Among all packaging film treatments, the total chlorophyll contents did not vary significantly over the entire storage time (Fig. 2C). Compared to 8.0 and 11.6 pmol s⁻¹ m⁻² Pa⁻¹ film OTR treatments, total chlorophyll loss of samples in 21.4 and 29.5 pmol s⁻¹ m⁻² Pa⁻¹ OTR film packages were slightly greater at the end of storage, however, the difference was not statistically significant (P < 0.05).

There was no significant difference on the tissue electrolyte leakage of radish microgreens among different packaging films.

Fig. 2. Effect of packaging film OTR on the changes in O₂ (A) and CO₂ (B) partial pressures within packages, chlorophyll content (C), electrolyte leakage (D), overall quality (E), off-odor (F), aerobic mesophilic bacteria (AMB) (G) and yeast & mold (Y&M) (H) populations of packaged daikon radish microgreens during 1 °C storage (n = 4). Vertical bar represents ± standard error. — 8.0, — 11.6, — 16.6, — 21.4, and — 29.5 (pmol s⁻¹ m⁻² Pa⁻¹).
Interestingly, it was noted that there was a sharp decrease in tissue electrolyte leakage for all treatments from day 0 to day 7, and also a slight decrease in the following seven days (from day 7 to day 14). This phenomenon was also observed in fresh-cut cilantro leaves during the early stages of storage at 0°C by Luo et al., (2004). This decrease in electrolyte leakage on day 7 suggested that a cell membrane damage recovery process may exist in plants/produce in the early stages of cold storage (Luo et al., 2004). During subsequent storage, increased electrolyte leakage was recorded for all packaging treatments. At the end of the 28-day storage period, samples packaged in 29.5 pmol s\(^{-1}\) m\(^{-2}\) Pa\(^{-1}\) OTR film had the lowest electrolyte leakage percentage (0.9%), whereas, the highest value (1.3%) was found in the lowest (8.0 pmol s\(^{-1}\) m\(^{-2}\) Pa\(^{-1}\)) OTR film package.

There was no noticeable quality loss among all treatments from day 0 to day 7 (Fig. 2E). Starting on day 14, tiny black spots were observed on the leaves of radish microgreens, resulting in reduced quality scores. At the end of storage, the overall quality scores of radish microgreens in all treatments had declined to 7.3–7.5, which was above the acceptable level.

Slight off-odor (a score of 0.7–1.3) developed in all samples at the end of storage (Fig. 2F). Samples from 29.5 pmol s\(^{-1}\) m\(^{-2}\) Pa\(^{-1}\) OTR film packages developed the least off-odor, followed by 21.4 pmol s\(^{-1}\) m\(^{-2}\) Pa\(^{-1}\) OTR film packages. This trend of increasing

**Fig. 3.** Effect of chlorine wash treatment on the changes in O\(_2\) (A) and CO\(_2\) (B) partial pressures within packages, chlorophyll content (C), electrolyte leakage (D), overall quality (E), off-odor (F), aerobic mesophilic bacteria (AMB) (G) and yeast & mold (Y&M) (H) populations of daikon radish microgreens during 1°C storage using 29.5 pmol s\(^{-1}\) m\(^{-2}\) Pa\(^{-1}\) OTR film (n = 4). Control represents unwashed sample. Vertical bar represents ± standard error. •—Non-washed, ——tap water, ——50 mg/L free chlorine, and ——100 mg/L free chlorine.

(Fig. 2D).
values with decrease in film OTR was in accordance with that found for electrolyte leakage, indicating that the development of off-odor was associated with loss of cell membrane integrity (Wang, Feng, & Luo, 2004). In addition, it is noted that no off-odor (a score of 0) was detected in samples packaged in 11.6 pmol s⁻¹ m⁻² Pa⁻¹ OTR film bags; instead, a pleasant but incongruent smell was present on all sampling days. The same experiments were repeated in another 1 °C chamber, and the same results were obtained. No satisfactory explanation was found.

The initial microbial load on radish microgreens was relatively high (7.1 log cfu g⁻¹ of both AMB and Y&M), similar to that found in baby spinach leaves (Allende et al., 2004). The result is also consistent with the finding recently reported by Chandra et al. (2012) for unwashed ‘Tah Tasai’ Chinese cabbage microgreens. It was also hypothesized by Chandra et al. (2012) that the delicate microgreen stalks may be more vulnerable to microbial attachment and growth than mature ones. From day 7 to day 21, AMB and Y&M populations (Fig. 2G and H) on radish microgreens remained stable at 1 °C. After day 21, the growth of AMB and Y&M increased slowly with the final count of 7.5–7.8 log cfu g⁻¹. Although gas compositions were significantly affected by different packaging treatments, there was no significant difference in the growth of AMB and Y&M among treatments (P > 0.05), suggesting that gas composition did not influence the overall growth of AMB and Y&M of radish microgreens under 1 °C storage. Luo et al. (2004) found similar results for fresh-cut cilantro leaves. Therefore, it may be deduced from these results that temperature is the predominant factor influencing growth for most microorganisms (Koseki & Itoh, 2002).

Among all the OTR film treatments, no significant difference was found on maintaining the quality and prolonging the shelf life of radish microgreens. Overall, samples packaged in 29.5 pmol s⁻¹ m⁻² Pa⁻¹ OTR film maintained relatively better quality during 28-day storage under 1 °C, demonstrating lowest tissue electrolyte leakage, AMB and Y&M counts, and off-odor score (except the suspicious off-odor score of 11.6 pmol s⁻¹ m⁻² Pa⁻¹ OTR film treatment); thus, the film with 29.5 pmol s⁻¹ m⁻² Pa⁻¹ OTR was chosen to be used in the subsequent wash study of daikon radish microgreens.

3.3. Effect of wash treatment on quality and shelf life of radish microgreens packaged in polyethylene bags and stored at 1 °C

During the entire 28-day storage period, no significant difference (P > 0.05) was found in the changes of O2 and CO2 composition in packages among all wash treatments (Fig. 3A and B). In the first seven days, the headspace O2 concentration of all bags dropped rapidly, nearly reaching equilibrium by day 7. All treatments maintained a constant high level of O2 (14.0–16.0 kPa) until the end of storage. Meanwhile, the CO2 level increased rapidly during the first 7 days followed by a slight decline. This result suggests that wash treatment had no significant (P > 0.05) effect on O2 reduction and CO2 evolution rates of radish microgreens packaged in the same permeable polyethylene bags (OTR = 29.5 pmol s⁻¹ m⁻² Pa⁻¹) and stored at low temperature (1 °C).

During the 28-day storage at 1 °C, the total chlorophyll content did not vary significantly (P > 0.05) (Fig. 3C). There was no direct relationship between wash treatment and total chlorophyll content. This lack of discernable effect due to wash treatment may be the result of large sample variation obscuring the variation attributable to wash treatment.

On day 0, unwashed samples (control) showed higher tissue electrolyte leakage than all other washed samples, probably due to tissue fluids exuded from cut ends. Meanwhile, water-washed samples exhibited lowest electrolyte leakage (0.8%) of all wash treatments, which is the same result reported for a recent study on ‘Tah Tasai’ Chinese cabbage microgreens (Chandra et al., 2012). After day 14, tissue electrolyte leakage increased rapidly for 100 mg/L chlorine treated samples and the values were significantly (P < 0.05) higher than those of other treatments on day 21 and day 28. On the contrary, no significant difference was observed in the changes of electrolyte leakage during subsequent storage among other treatments (Fig. 3D).

All samples subjected to different wash treatments maintained the highest possible visual score of 9.0 during storage at 1 °C until day 14 (Fig. 3E). After day 14, the visual quality of 100 mg/L chlorine treated samples declined rapidly, receiving the lowest overall score (a score of 7.2) at the end of the 28-day storage. However, no significant difference was found for overall quality of all other treatments (unwashed, water, 50 mg/L chlorine), which maintained good visual quality (scores of 7.8–8.0) at the end of storage. This suggests that the 100 mg/L chlorine treatment may have caused tissue damage during wash, which led to the quality loss during storage. However, the wash treatment with 50 mg/L free chlorine did not appear to have a detrimental effect on quality.

The results for off-odor development followed the same trends as those for visual quality (Fig. 3F). Only trace amount of off-odor (scored 0.2–0.8) was detected for each treatment on day 14. At the end of storage, a slight to moderate level of off-odor (scored 2.2–1.5) was detected from all samples except for 100 mg/L chlorine treated samples, which developed the strongest off-odor with a moderate to strong score of 2.5. The sensory results agreed well with those from tissue electrolyte leakage, suggesting that the loss of freshness and development of off-odor was related to tissue damage and senescence.

A wash treatment with 100 mg/L free chlorine significantly reduced microbial population on day 0, while no difference was found among all other treatments (Fig. 3G and H). Microbial populations increased after day 7 of storage. However, samples that received the 100 mg/L chlorine treatment had a more significant increase in microbial populations than the other treatments. AMB and Y&M growth in samples treated with 100 mg/L chlorine overtook that of all other treatments on day 14 and continued to outgrow others until the end of storage. This is in agreement with the more rapid quality loss observed in this treatment, probably due to tissue damage incurred during washing. A similar result was reported for ‘tah tasai’ Chinese cabbage microgreens treated with chlorinated water (Lee, Kim, & Park, 2009). Water washed samples experienced slightly less microbial growth after day 14 than did 50 mg/L chlorine washed samples. Among all treatments, unwashed samples maintained lowest microbial growth after the 14th day of storage, which is in accordance with the finding in a recent study of Kou et al. (2013). This result is probably due to the lower moisture content in these packages. Excess moisture remaining on washed leaf surfaces, and the possible damaged incurred from agitation during washing and drying may have promoted microbial growth in those packages. Radish microgreens have young and delicate leaf tissues that can be easily damaged during preparation. Since removal of excess water without tissue injury is often closely related to the maintenance of quality and shelf life of fresh or fresh-cut produce, future studies may need to optimize the washing, and drying processes.

4. Conclusions

The quality and shelf life of radish microgreens as impacted by three major postharvest treatment factors, i.e. storage temperature, packaging film OTR, and chlorine wash treatment were evaluated in this study. Storage temperature had a significant impact on package atmosphere, product visual quality, microbial growth and membrane integrity. A storage temperature of 1 °C was rated as the best
treatment followed by 5 °C storage. Samples stored at 1 °C maintained the highest overall visual quality with minimum off-odor development, lowest AMB and Y&M counts. This treatment also maintained the highest tissue integrity with minimum chlorophyll degradation, whereas those stored at 10 °C lost quality more rapidly.

Packaging film OTR significantly affected headspace gas composition during 1 °C storage; however, it did not have a significant effect (P < 0.05) on the quality and shelf life of the product, probably due to the presence of high level O2 and low level CO2 within the packages over time and low respiration rate of microgreens stored at 1 °C. In our study, microgreens packaged in all OTR film bags stored at 1 °C maintained good quality and shelf life throughout 28 days.

Among all wash treatments and control (no wash), 100 mg/L free chlorine wash treatment had a significant impact on the reduction of microbial population initially. However, microbial growth on these samples exceeded those of all other treatments after 7 days. In this study, the use of chlorine washing solutions did not achieve the goal of producing ready-to-eat radish microgreens with low microbial load and long shelf life, therefore, some alternative treatments need to be further investigated in the future study.

Acknowledgment

The authors thank Ms. Ellen Turner for providing valuable feedback on our manuscript, and Mr. Ernest W. Paroczy for assisting with radish microgreens planting.

References


