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Postharvest Biology and Technology 20 (2000) 53–61

Postharvest Biology and Technology

www.elsevier.com/locate/postharvbio

Use of controlled atmospheres and heat treatment to maintain quality of intact and minimally processed green onions

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Received 3 December 1999; accepted 1 May 2000

Abstract

To maintain high quality and to extend the shelf life of intact and minimally processed (removal of roots and compressed stem) green onions (*Allium cepa* × *A. fistulosum*), the potential benefits of controlled atmospheres (CA) and heat treatment were evaluated. Atmospheres of 0.1–0.2% O_2 or 0.1–0.2% O_2 containing 7.5–9% CO_2 were the CA conditions that best maintained the visual appearance and prolonged shelf life to more than 2 weeks at 5°C in both intact and cut onions. No CA treatment completely controlled extension, growth or 'telescoping' of the inner white leaf bases of the minimally processed onions at 5°C. Heat treatment (55°C water for 2 min) of the white leaf bases effectively controlled 'telescoping' of cut onions stored at 5°C. Total soluble sugars generally decreased in intact and minimally processed green onions, but were maintained in heat-treated cut onions. Heat treatment did not affect thiosulfinate concentrations during 14 days at 5°C, except for treated cut onions not stored under CA.

Keywords: White leaf base; Leaf extension; Heat treatment; Soluble sugars; Thiosulfinates

1. Introduction

There has been great interest in marketing value-added, fresh-cut or minimally processed vegetables (Cantwell, 1998). However, there are many limitations to post-cutting shelf life of these products due to undesirable physiological changes caused by the minimal processing (Ohlsson, 1994). Green onions provide an interesting challenge as a minimally processed product. Green onions are comprised of roots, a compressed stem (sometimes called stem plate), and leaves which consist of a lower white leaf sheath and the hollow upper green tissues. Minimal processing includes the trimming of the leaves, the cutting of the roots, and the removal of all or part of the compressed stem. Although this results in a convenient fresh-cut product, cutting damage, discoloration, dehydration, and decay are common defects of the cut

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0925-5214/00/$ - see front matter
PII: S0925-5214(00)00112-5

surfaces. These defects are similar to those reported for other minimally processed vegetables (Ahvenainen, 1996).

For fresh-cut green onions there are important additional defects. Due to lack of precision in the cutting process and frequent complete removal of the compressed stem, growth or extension of the white inner leaf bases may occur. This is also referred to as 'telescoping', and can cause a rapid loss in the overall market quality of the product. Another defect particular to green onions is leaf curvature due to negative geotropism, which occurs when the product is placed horizontally.

Hruschka (1974) reported that a CA of 1% O_2 + 5% CO_2 extended the shelf life of intact green onions at 0°C. The atmosphere reduced yellowing but did not affect curvature or decay incidence. Currently, commercial green onions may be packaged in films resulting in $<1\%$ O_2 and 8–10% CO_2 atmospheres at 5°C (Cantwell, unpublished). Heat treatments have been used to reduce growth phenomena, including sprout development in potatoes (Ranganna et al., 1998) and geotropic curvature in asparagus (Paull and Chen, 1999).

This study was undertaken to determine the potential benefits of CAs and heat treatment to maintain the quality of intact and minimally processed onions. For the minimally processed onions, a treatment to effectively control extension growth or 'telescoping' is required.

2. Materials and methods

2.1. Plant material

Green onions (*Allium cepa* × *A. fistulosum*) were produced in the Salinas Valley of California under usual production practices (Voss and Mayberry, 1999), harvested by pulling the plants within 2 h of undercutting the beds, and brought to the laboratory by placing in coolers in a water-ice slurry. At the laboratory they were trimmed (leaf tips and roots cut) and washed with clean chlorinated water (50 ppm NaOCl, pH 7.0) before use. In some experiments, commercially prepared onions were harvested into plastic crates in Mexicali, Baja California, shipped overnight in refrigerated trucks to Salinas, trimmed, washed with cold chlorinated water and packed in plastic film bags in 0.908 kg units. The bags were placed in polystyrene-lined carton boxes with gel ice and transported overnight to the laboratory where they were kept at 0°C until used.

2.2. Pre-storage treatments

Onions were prepared in three ways before storage; (1) intact onions were trimmed and had the roots cut off, but the compressed stem was intact; (2) cut onions had all roots and 5 mm of the stem plate removed by a razor blade; and (3) heat-treated cut onions had the lower 5 cm of the white stems dipped into 55°C water for 2 min which was followed by the same cutting treatment received by the second group. We have recently shown that this is one of several heat treatments effective enough to control 'telescoping' of cut onions (Cantwell and Hong, unpublished).

2.3. Storage conditions

Two CA experiments were conducted. For the first CA experiment, freshly harvested trimmed onions with intact stem plates (pre-storage treatment group 1) (ten onions per replication) were placed in glass containers in flow systems with air, air + 9% CO_2, 0.1% O_2, or 0.1% O_2 + 9% CO_2 for up to 21 days at 0, 5, and 10°C. The atmospheres were selected based on the analyses of commercially packaged green onions. The atmospheres were prepared as humidified mixtures from gases in cylinders and then distributed to the individual storage containers by manifolds. Atmosphere compositions were monitored periodically by an electrochemical oxygen analyzer and an infrared CO_2 gas analyzer, and maintained within $\pm 5\%$ of the indicated concentrations.

In the second CA experiment, green onions from the three pre-storage treatment groups were stored up to 21 days at 5°C in glass containers through which the following humidified atmospheres flowed; air, 2% O_2, and 0.2% O_2, alone or in combination with 7.5% CO_2, and air + 15% CO_2. Product quality was evaluated periodically during storage.

2.4. Quality evaluations

Overall visual quality was scored on a 9–1 scale, with reference points of 9, excellent; 7, good; 5, fair; 3, poor; and 1, unusable. A score of 6 was regarded as the limit of marketability. The visual quality assessment included discoloration and curvature defects but did not include extension or 'telescoping' defects in the minimally processed onions. Leaf discoloration was scored separately on a 1–5 scale, where 1, none; 2, slight; 3, moderate; 4, moderately severe; and 5, severe. Discoloration or loss of fresh green color was evaluated on the oldest leaf. For curvature, a score of 1–5 was used, where 1, none; 2, curvature of stem or leaf up to 15° from the horizontal; 3, 15–30°, 4, 30–45° and 5, $>45°$ from the horizontal. Inner leaf extension ('telescoping') was measured with a vernier caliper as the length to the nearest 0.1 mm from the cut surface of the white leaf base to the end of the most extended portion. Root re-growth was measured with a vernier caliper in intact green onions previously trimmed of roots.

2.5. Compositional changes

For analysis of total soluble sugars in the white stem bases (including any extension growth), 5 g of chopped tissue was homogenized with 195 ml 95% ethanol for 2 min. After centrifugation at 3000 rpm for 5 min to precipitate ethanol-insoluble material, 1 ml of the supernatant was diluted 20 times with distilled water. For the assay (Dubois et al., 1956) the reaction mixture consisted of 1 ml diluted extract, 0.1 ml of 80% phenol solution and 5 ml concentrated sulfuric acid. Tubes were vortex agitated, let to stand for 10 min, remixed and then held in a water bath at 30°C for 20 min. Absorbance was measured on a Perkin–Elmer UV–Vis spectrophotometer at a wavelength of 490 nm, and calculations were based on a glucose standard curve.

Thiosulfinate concentrations in white stem portions of the green onions were also measured spectrophotometrically (Riddles et al., 1979; Han et al., 1995). Samples (5 g) were homogenized in 10 ml distilled water. After centrifugation at 3000 rpm for 5 min, 375 μl of supernatant was pipetted into a test tube on ice. An aliquot of 375 μl, distilled water was added to another test tube for reference. Aliquots of 625 μl 0.8 mM cysteine solution were added to both the sample and reference test tubes. After shaking, they were held for 10 min at room temperature. Other test tubes at ambient temperature contained 0.8 ml of 200 μM DTNB (5,5′-dithio-bis-(2-nitrobenzoic acid). The 200 μM DTNB solution was prepared with 50mM HEPES buffer, pH 7.5. An aliquot of 200 μl of sample/cysteine solution or water/cysteine solution was added to the DTNB test tubes. For blank, only 200 μl of pure water was added to the DTNB tube. After shaking, test tubes stood for 10 min for color development. Absorbance was measured at 412 nm, and thiosulfinate concentrations were calculated according to Han et al. (1995).

2.6. Experimental design and statistical analysis

Experiments were conducted as completely randomized designs with three replicates of eight to ten green onions each per treatment. Data were analyzed as averages $\pm$ S.D. or by two-way analysis of variance (ANOVA) with mean separation by Duncan's multiple range test.

3. Results

Freshly harvested trimmed but intact green onions were stored for 21 days at 0, 5 or 10°C under 4 atmospheres (Fig. 1). These atmospheres were chosen based on conditions found in commercially packaged trimmed green onions for foodservice outlets, in which concentrations of O_2 range from 0.1 to 0.3% and CO_2 vary from 6 to 10%, depending on the temperature. Quality was best maintained at 0°C. The CAs at 5°C provided substantial benefit, but were not as effective as storage at 0°C. Visual quality of all the groups declined rapidly at 10°C and it appeared that at this temperature, shelf life of green onion was limited to 7 days regardless of storage atmosphere.

The main causes of loss of visual quality in intact green onions were the deterioration (discoloration) of the outer oldest leaf and leaf curvature (Fig. 1). At 0°C, curvature was completely controlled. Discoloration of the oldest leaf was completely controlled in CA, but was noticed in air-stored onions at 21 days. The high CO_2 atmospheres were most effective in controlling leaf discoloration at 5°C. At 5 and 10°C, stem curvature was most effectively controlled by the low O_2 atmospheres. At 5°C, 9% CO_2 in air provided substantial reduction in curvature, whereas this treatment was ineffective at 10°C.

In the second CA experiment, intact, cut or heat-treated cut onions were stored under a broader range of atmospheres at 5°C. For the intact onions, the combination of 0.2% O_2 and 7.5% CO_2 resulted in the highest visual quality scores after 21 days (Fig. 2). Other atmospheres also provided substantial benefits for the overall visual quality of the intact onions. The air + 15% CO_2 did not cause any visible injury to green or white portions of the leaves. Overall visual quality scores of cut green onions were lower than scores of the intact onions after 14 days. All atmospheres with CO_2 and the 0.2% O_2 atmosphere provided marketable product for at least 14 days, but no atmosphere was able to completely control the deterioration due to cutting. Heat treatment + cutting resulted in visual quality scores

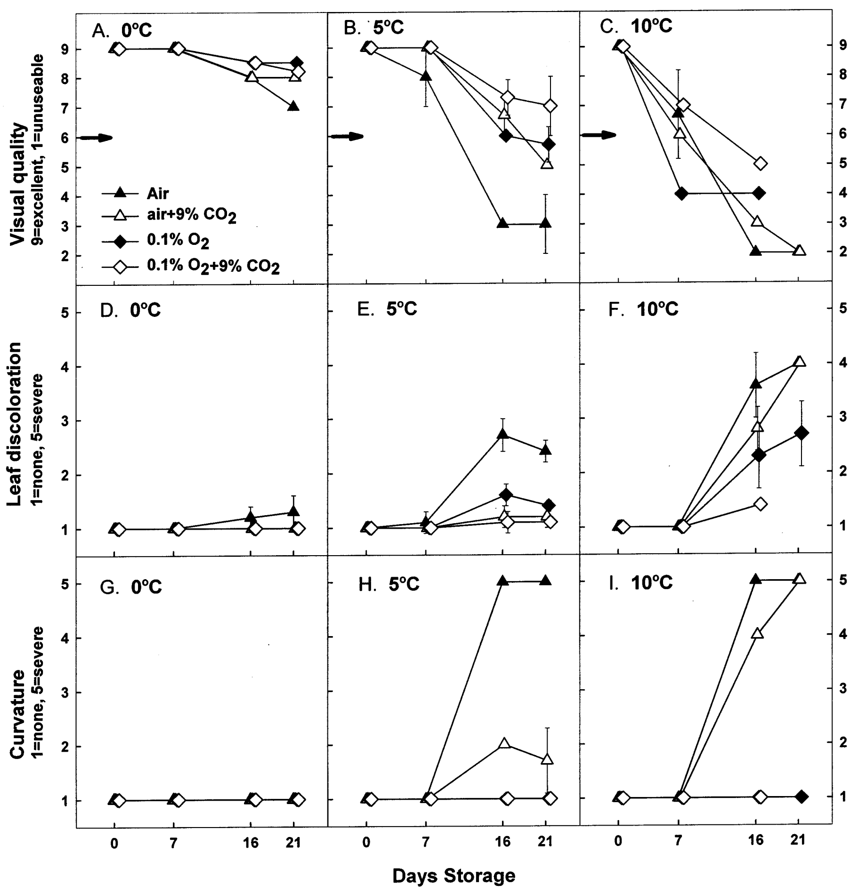

Fig. 1. Visual quality (A, B, and C), green leaf discoloration (D, E, and F) and curvature (G, H, and I) scores of trimmed green onions (with intact stem plates) stored in air or controlled atmospheres at 0, 5 and 10°C for 21 days. For visual quality, the arrows at score six indicate limit of marketability. The visual quality score was an overall assessment and included the discoloration and curvature defects. Data are averages of 3 replicates ± S.D.

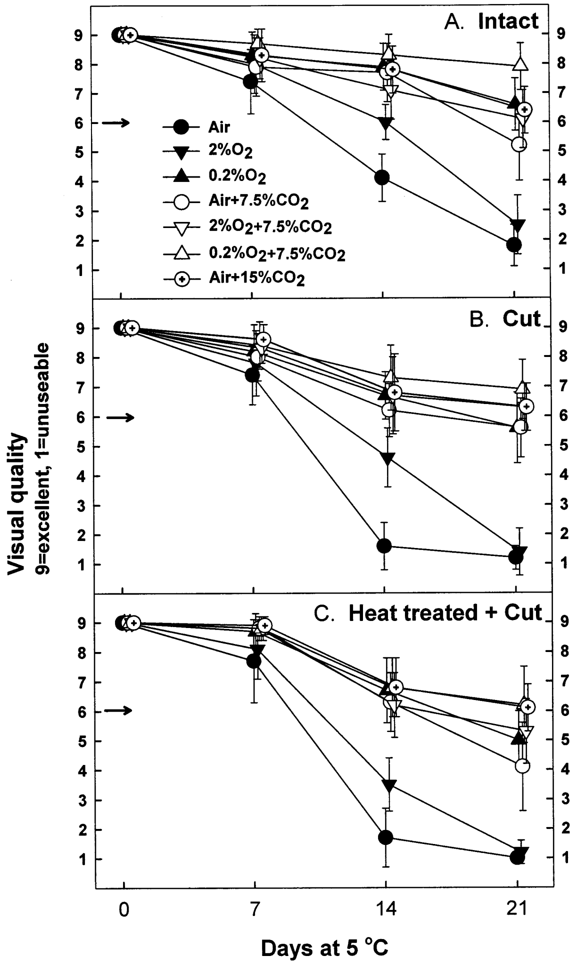

Fig. 2. Visual quality scores of intact (A) and minimally processed green onions (complete removal of roots and compressed stem) (B and C) stored in air or controlled atmospheres at 5°C for 21 days. The arrows at score 6 indicate limit of marketability. The visual quality score did not include 'telescoping' defects. Data are averages of 3 replicates + S.D.

slightly lower than those for cut onions. This was especially noticeable after 21 days. For cut and the heat-treated cut onions stored at 5°C, the highest visual quality was achieved with atmospheres of 0.2% O_2 + 7.5% CO_2 or air + 15% CO_2.

Inner leaf extension of cut or heat-treated cut green onions was affected by the heat treatment and storage atmospheres at 5°C (Fig. 3). The 0.2% O_2 atmosphere significantly delayed inner leaf extension, but 'telescoping' in 2% O_2 was similar to that in air. Generally, control of inner leaf extension was best in 0.2% O_2, 0.2% O_2 + 7.5% CO_2, and air + 15% CO_2. None of the atmosphere treatments, however, were as effective as the hot water dip. The heat treatment almost completely controlled the inner leaf extension regardless of storage atmosphere.

The re-growth of trimmed roots was highly variable at 5°C and was favored by atmospheres with 2% or more O_2 (Fig. 4). The 0.2% O_2 atmosphere alone or in combination with 7.5% CO_2 provided near complete control of root re-growth. High CO_2 atmospheres combined with low O_2 had no inhibitory effect on root growth, but rather appeared to stimulate root development. Although the differences were not significant in this test with green onions, a 5% CO_2 atmosphere notably increased rooting of fresh peeled garlic cloves compared with air storage at 10°C (Cantwell and Hong, unpublished).

Soluble sugar concentrations were variable but similar in white stem bases of intact or cut green onions stored in air and controlled atmospheres (Table 1). In air storage, soluble sugar content decreased in intact and cut green onions (84–59 and 65 g kg^{-1}, respectively, after 7 days), whereas there was no decrease in the sugar content of air-stored heat-treated cut onions. Storage atmospheres did not affect sugar concentrations of the green onions.

Thiosulfinate concentrations were determined to estimate changes in pungent flavor of the green onions (Block et al., 1992; Yoo and Pike, 1998). Thiosulfinate concentrations of the intact onions did not vary much during 14 days at 5°C. However, air-stored heat-treated cut onions had lower thiosulfinate concentrations than the corresponding stored control or cut onions (Table 1). Heat-treated cut onions stored in CA had thiosulfinate concentrations similar to the control or cut onions.

4. Discussion

The benefit of low temperature to extend shelf life of green onions has been well described. Hruschka (1974) reported a shelf life of at least 4 weeks at 0°C with or without top icing. The main factors that affected the visual quality of the stored intact green onions in our study were geotropic curvature and green leaf discoloration. High visual quality was maintained at 0°C for 2–3 weeks. After 3 weeks at 0°C, air-stored onions were still marketable but of lower quality than the CA-stored onions. At 5°C, modified atmospheres were needed to mitigate the detrimental effect of increased storage temperature on intact green onions. Shelf life was limited to about 2 weeks at 5°C except in the 0.1% O_2 + 9% CO_2 treatment in which the product was saleable after 3 weeks. High CO_2 atmospheres were more effective in controlling leaf discoloration while curvature was best controlled by the low O_2 atmospheres. Not surprisingly, the combinations of low O_2 + high CO_2 concentrations provided the best overall visual quality. Hruschka (1974) also reported that low O_2 and high CO_2 atmospheres

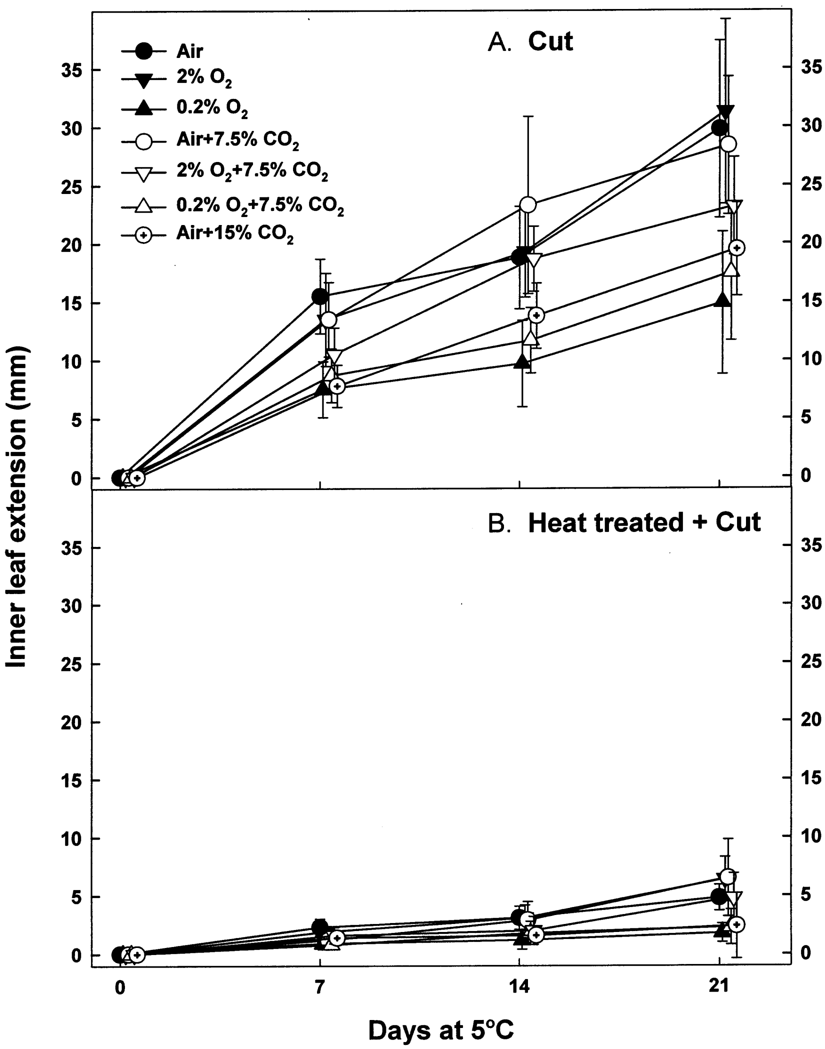

Fig. 3. Inner leaf extension ('telescoping') of white stem bases of minimally processed green onions stored in air or controlled atmospheres at 5°C for 21 days. Onions were cut (complete removal of roots and compressed stem) (A) or heat-treated (55°C water for 2 min) and cut (B). Data are averages of 3 replicates ± S.D.

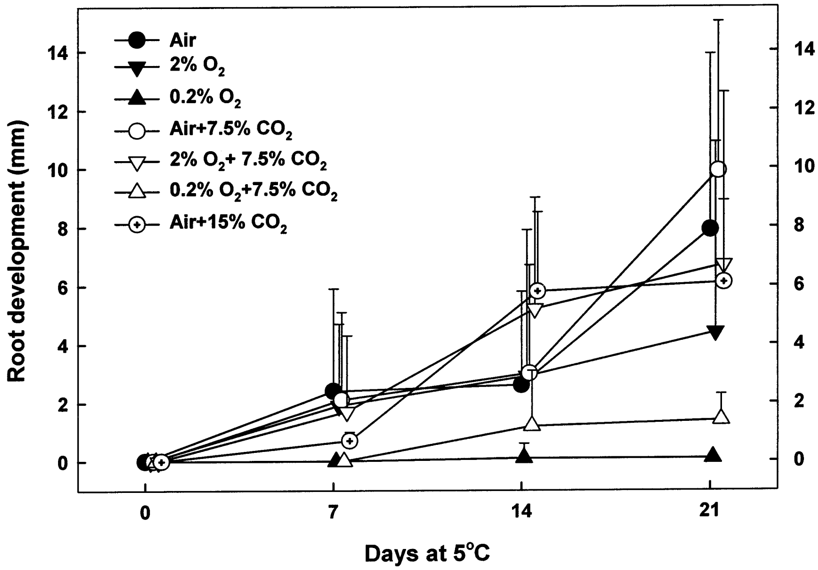

Fig. 4. Root development on trimmed green onions stored in air or controlled atmospheres at 5°C for 21 days. Roots were trimmed on day 0. Data are averages of 3 replicates ± S.D.

Table 1
Changes in total soluble sugars and thiosulfinates of the white stem bases of green onions during air and CA storage at 5°C for 7 and 14 days

Treatment	Atmosphere	Total soluble sugars ($g \cdot kg^{-1}$)*		Total thiosulfinates ($mmol \cdot kg^{-1}$)†	
		7 days	14 days	7 days	14 days
Intact	Air	58.6c‡	70.2c	1.43ab	1.43ab
	2% O_2+7.5% CO_2	76.1abc	78.0c	1.41abc	1.45ab
	0.2% O_2+7.5% CO_2	68.5bc	79.5bc	1.42ab	1.47a
Cut	Air	64.9bc	72.7c	1.40bc	1.38c
	2% O_2+7.5% CO_2	79.7ab	70.5c	1.44a	1.46a
	0.2% O_2+7.5% CO_2	69.0bc	88.9ab	1.43ab	1.46a
Heat-treated	Air	81.3ab	89.4ab	1.36d	1.32d
+Cut	2% O_2+7.5% CO_2	94.3a	75.9c	1.42ab	1.44ab
	0.2% O_2+7.5% CO_2	78.6abc	91.2a	1.38cd	1.47a

* Soluble sugars concentration at day 0 = 84.0 $g \cdot kg^{-1}$.
† Thiosulfinate concentration at day 0 = 1.44 $mmol \cdot kg^{-1}$.
‡ Mean separation within columns by Duncan's multiple range test, $P \leq 0.05$.

were beneficial to green onion shelf life, although they evaluated a more limited range of concentrations than evaluated in the present study.

Controlled atmospheres can regulate several growth phenomena in green onions. Geotropic curvature was best controlled by low temperature (0°C) or intermediate temperature (5°C) with low O_2 (0.1%) atmospheres. Extension growth of the cut onions was retarded, but not completely controlled, by 0.2% O_2 atmospheres at 5°C. The same CA conditions effectively controlled the root development of intact onions at 5°C. All the results demonstrate the determinant role of oxygen concentrations on the growth processes. Growth phenomena such as sprouting of onions and potatoes, root development on bulb onions, and periderm formation of potatoes are inhibited by low O_2 and/or high CO_2 atmospheres (Kader, 1986). The CA effect on growth phenomena may be due to the reduction of normal respiratory activities by CA, which in term may limit energy supply for growth related events (Kays, 1991). Additionally, some enzymatic steps in the growth process may be specifically inhibited by the CA conditions.

The heat treatment (55°C water for 2 min) effectively controlled extension of the cut onions. This treatment also reduced the rate of curvature of the green onions (Cantwell and Hong, unpublished results). The heat treatment, however, has to be considered a stressful treatment since visual quality scores were not as high as those of cut and untreated onions after 14-days storage. Various metabolic reactions (Klein and Lurie, 1992; Loaiza-Velarde et al., 1997) and growth phenomena can be controlled by short-term heat shock treatments. Ranganna et al. (1998) reported that hot water treatments retarded sprout development in potatoes. Paull and Chen (1999) demonstrated that geotropic curvature in green asparagus spears can be prevented by a 47.5°C, 2–5 min hot water dip.

In some cut and heat-treated cut onions, a yellow discoloration occurred at the cut base after about 15 days. It also occurred in the intact onions (although less frequently) and was perhaps due to microbial growth. For the minimally processed green onions, the heat treatment followed by high CO_2 atmospheres was the most effective combination in maintaining quality (i.e. good visual quality + reduced 'telescoping'), and retarding any appearance of yellowing at the cut surface. Blanchard et al. (1996) also reported that yellowing was a defect of minimally processed yellow bulb onions. Controlled atmospheres (2% O_2 with 5, 10 and 15% CO_2) reduced but did not completely control these color changes at 4°C. CA storage also reduced color changes of intact onions during storage (Leshuk and Saltveit, 1990).

Thiosulfinate concentrations of the intact or cut onions were higher than those of the heat-treated cut onions. Block et al. (1992) reported that the thiosulfinates responsible for the characteristic flavor of green onions were 1-propanesulfonothioic acid *S*-(*Z*)-propenyl ester, 1-propanesulfinothioic acid S-1-propyl ester, and methanesulfinothioic acid *S*-(*Z*)-propenyl ester. Yoo and Pike (1998) found that microwave treatment inactivated enzymes involved in the generation of alk(en)yl cysteine sulfoxide flavor precursors. Our results, although using much less drastic heating conditions, are consistent because air-stored heat-treated cut onions had the lowest thiosulfinate concentrations. The CA conditions negated the effect of the heat treatment on thiosulfinate loss.

5. Conclusions

Atmospheres of 0.1–0.2% O_2 or 0.1–0.2% $O_2 + 7.5$–9% CO_2 at 5°C were adequate storage conditions to maintain high visual quality of intact and minimally processed green onions. However, CA retarded but did not control extension growth or 'telescoping' of the cut ends of the minimally processed onions. A pre-storage heat treatment (55°C 2 min) effectively controlled 'telescoping' of the cut onions, and in combination with CA, provided a shelf life of more than 2 weeks at 5°C. The heat treatment plus CA did not reduce the soluble sugar and thiosulfinate concentrations of the minimally processed green onions.

Acknowledgements

This work was partially supported by a Korea Science and Engineering Foundation scholarship to the first author and a donation from NewStar Fresh Foods, Salinas CA.

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