Control of red discoloration of fresh-cut sunchoke tubers

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Abstract

Sunchokes (*Helianthus tuberosus* L.) are inulin-accumulating tubers native to North America that are edible raw or cooked, and have good potential as a fresh-cut product. Sunchokes perform well as fresh-cut slices except for the development of a reddish discoloration on the cut surface. Dip treatments with ethanol (5%) provided effective control of discoloration. Untreated or ethanol-treated sliced tubers (5% for 3 min) were stored in air at 0 and 5°C, with best quality of untreated slices (visual, color values) maintained at 0°C. Ethanol treatment retarded discoloration effectively at both temperatures. Ethanol treatment suppressed respiration, and reduced wound-induced phenylalanine ammonia-lyase (PAL) activity and phenolic concentrations. Controlled atmospheres of 3% O_2 with 6 or 12% CO_2 at 5°C were less effective than ethanol dips, although high-CO_2 atmospheres also retarded PAL activity and increases in phenolics. Increased endogenous ethanol concentrations were developed by nitrogen-flushing of tubers at 10°C in closed containers, with accumulation of CO_2. These precutting atmosphere treatments were only partially effective in controlling slice discoloration. Pre-processing hot-water dips (50°C for 6 min plus 1 or 3 days at 20°C) or tuber-warming treatments (20°C for 7 or 14 days) were also partially effective in controlling red discoloration of sliced tubers.

Keywords: discoloration, respiration, phenolic metabolism, temperature conditioning, ethanol, CO_2 atmospheres

INTRODUCTION

Helianthus tuberosus L. (sunchoke or Jerusalem artichoke) is an adaptable and highly productive plant in temperate climatic zones, with the vegetation and tuber being used for human and animal food (Kays and Nottingham, 2008). More recently, the tuber has garnered renewed interest as a human food because of its complex carbohydrate composition. Sunchoke tubers are knobby structures with light- or dark-brown skin and a white, crisp, sweet-nutty pulp that can be consumed raw or cooked (Bach et al., 2013). The tubers contain inulin, a non-digestible fructose polymer with numerous reported health benefits (Kays and Nottingham, 2008).

Fresh-cut products provide convenient cut, washed and packaged items in ready-to-use portions (Brecht et al., 2004). Sunchoke tubers have potential as fresh-cut products to be consumed raw or cooked. A significant problem that limits shelf-life is discoloration of the cut surfaces (Wang and Cantwell, 2015). Discoloration is often associated with the synthesis and polymerization of phenolic compounds (Toivonen and Brummell, 2008). Phenylalanine ammonia-lyase (PAL) and polyphenol oxidase (PPO) are two key enzymes, activities of which are often closely associated with phenolic metabolism and browning (Adams and Brown, 2007). Wang et al. (2014) showed that red discoloration of fresh-cut sunchoke is associated with increased PAL activity and phenolic concentrations. Hot-water and ethanol treatments applied before or after cutting that reduced discoloration also reduced PAL activity and respiration rates.

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In this study, the following treatments were evaluated for their potential to control discoloration and extend the shelf-life of sunchoke slices: 1) post-cutting storage at 0°C was compared to storage at 5°C with and without ethanol treatment, 2) post-cutting controlled atmosphere, 3) pre-cutting atmospheres to induce high endogenous ethanol, 4) pre-cutting hot-water dip treatment plus conditioning, and 5) pre-cutting warming of tubers. The treatments were tested for their impact on slice discoloration, color values, respiration rates, and phenolic metabolism.

MATERIALS AND METHODS

Medium-sized tubers of a commonly grown sunchoke (light-skinned, knobby with white flesh, cultivar unknown) were produced in California and purchased through a local wholesaler. Tubers were stored in bulk at 0°C until used. Tubers were sorted, scrub-washed with water and rinsed in 200 ppm sodium hypochlorite for 5 min, drained and air-dried. Tubers were trimmed and manually cut into 4-mm thick slices using a V-Slicer Prima Mandoline (Borner, Germany). The slices were rinsed in 50 ppm sodium hypochlorite (pH 7.0), drained, blotted dry, and placed into small, unsealed low-density polypropylene (LDPE) bags. The bags were placed in unsealed larger plastic bags on trays at 5°C. Slices were evaluated after 0, 4, 8 and 12 days, with three replicates per evaluation.

For pre-cutting hot-water dips, tubers were brought to room temperature and treated in an agitated hot-water bath with water to a tuber mass ratio of 20 to 1. Tubers were held at 20°C for 1 or 3 days until prepared. For the warming treatment, tubers were transferred to 20°C in unsealed plastic bags and held for 7 and 14 days before preparation. Post-cutting ethanol dips were done after slicing by immersing pieces in 5% ethanol solutions at 5°C for 5 min. Slices were blotted dry, placed in plastic bags and stored at 5°C. Controlled atmospheres were obtained by mixing appropriate volumes of nitrogen, air and CO_2, humidifying and passing atmospheres through the storage chambers. The O_2 and CO_2 concentrations were monitored periodically.

Red discoloration was evaluated on a scale of 1 to 5, where 1 = none, 2 = slight, 3 = moderate, 4 = severe, and 5 = extreme discoloration. CIE L*a* b* values were determined on the slice surface midpoint from peel to the center with a Minolta Chroma Meter (Model CR-300, Minolta, Ramsey, USA) with illuminant A and a 10° viewing angle and calibrated on a white reference tile. For this study, a* color values were reported. Respiration rates of tuber slices were measured at 0 and 5°C using about 100 g slices in flow-through chambers and measuring CO_2 concentrations on an infrared analyzer. Calculations were based on the difference between inlet and outlet concentrations and were expressed as $\mu L\ CO_2\ g^{-1}\ h^{-1}$.

Total phenolics were determined on fresh samples by the Folin-Ciocalteu method modified from Singleton and Rossi (1965). PAL activity determination was based on the method of Ke and Saltveit (1986). The activity of PPO was measured by the method of Siriphanich and Kader (1985). Ethanol and acetaldehyde concentrations were determined by GC headspace analysis of frozen and heated chopped sunchoke samples, as described by Mateos et al. (1993).

Experiments were conducted in a completely randomized design with a minimum of three replicates per treatment (one replicate = 8 or 10 pieces, depending on the experiment). Data were calculated as means ± standard deviations or analyzed by ANOVA with mean separation by LSD.05.

RESULTS AND DISCUSSION

Untreated and ethanol-treated slices at 0 and 5°C

Untreated slices stored at 0°C had little discoloration up to 12 days, while discoloration was observed by 8 days in slices held at 5°C (Figure 1A-C). The 5% ethanol dip effectively retarded the development of discoloration in slices stored at both 0 and 5°C. Quality of ethanol-treated slices at 5°C was higher than untreated slices stored at 0°C by day 8. The ethanol dip reduced respiration rates at 0 and 5°C (Figure 1D). The ethanol dip reduced PAL activity (Figure 1E), but not PPO activity (data not shown) at 5°C and reduced

total phenolics (Figure 1F). While temperature had a significant impact on respiration, the ethanol treatment further reduced respiration rates. These results are similar to those reported by Wang et al. (2014), but included here are data from 0°C. The role of ethanol may be through its effect on respiration and reduced ATP production (Kern et al., 2009). With reduced respiration, less energy would be available for de novo PAL protein synthesis and activity (Plaxton and Podestá, 2006).

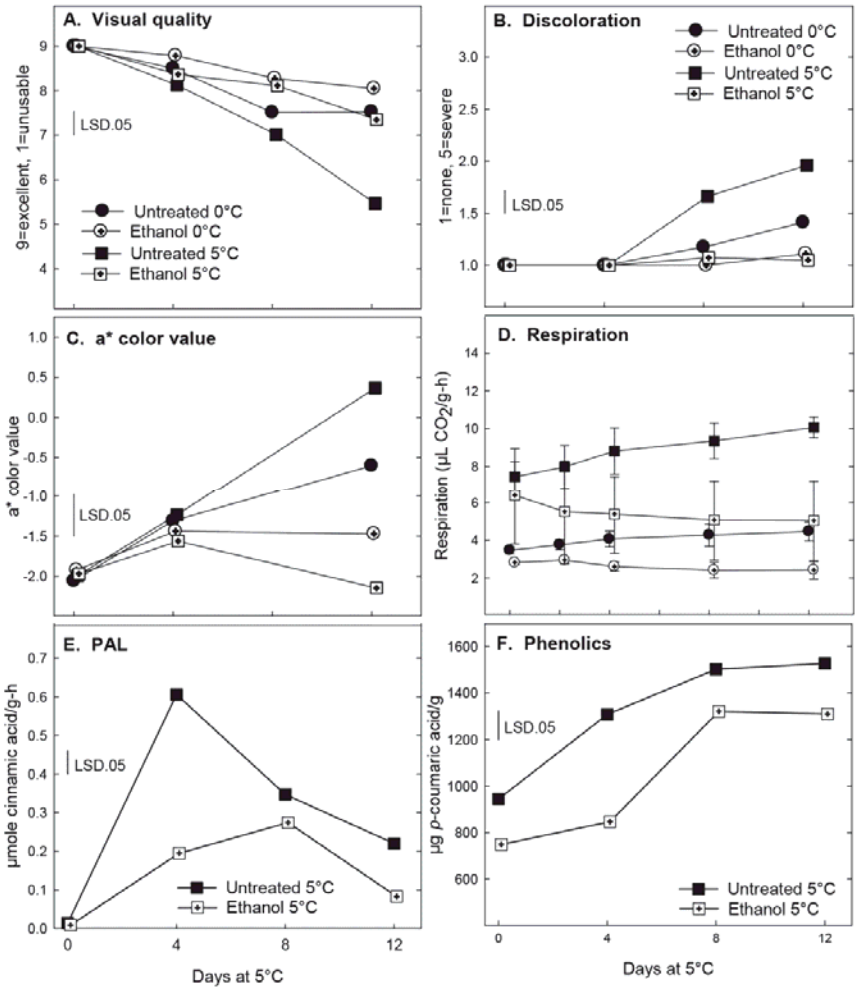

Figure 1. Visual quality (A), discoloration (B), a* color value (C), and respiration rates (D) of sunchoke slices stored at 0 or 5°C, and PAL (E) and total phenolics (F) of slices at 5°C. Slices were untreated or treated with 5% ethanol for 3 min. Data are means of three replicates with mean separation by LSD 0.05. Respiration data are means of three replicates ± standard deviation.

Post-cutting high-CO_2 atmospheres and ethanol

This experiment simulated commercial packaging by using controlled atmospheres of 3% O_2 + 6 or 12% CO_2 and comparing their effectiveness to an ethanol dip treatment. Between day 4 and 8, the untreated control showed notable red discoloration and increased a* color values (Figure 2A, B). The 3% O_2 + 6 or 12% CO_2 atmospheres retarded discoloration, but were less effective than the ethanol dip. The taste of ethanol could be detected in slices up to 2 days after treatment, but not afterwards. Increased PAL activity (Figure 2C) clearly preceded the increase in discoloration. The untreated tissue had high PAL

activity on day 4, whereas changes in a* value and discoloration scores were not noted until day 8. Both the ethanol dip and the 12% CO_2 treatment delayed the increase in PAL activity. Total phenolics increased from day 4 to 8 (Figure 2D). Both the ethanol dip and 12% CO_2 atmosphere maintained low total phenolic concentrations, although the latter treatment did not effectively retard discoloration. Similar modified atmospheres were effective in retarding discoloration in jicama roots (Aquino-Bolaños et al., 2000) but not potato tubers (Ma et al., 2010).

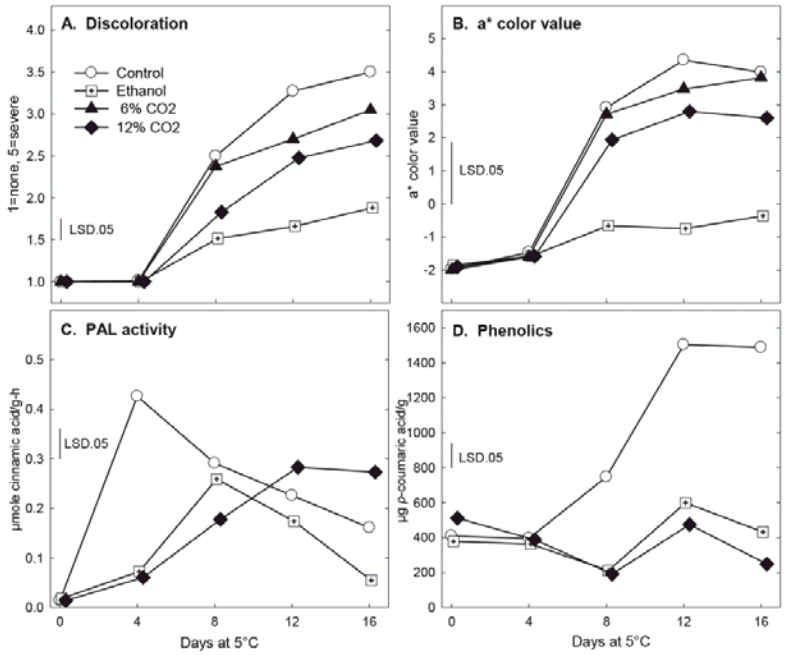

Figure 2. Red discoloration (A), a* color value (B), PAL activity (C), and total phenolic concentrations (D) of sunchoke slices untreated, ethanol-treated (5% 3min) or stored in 3% O_2 with 6 or 12% CO_2 at 5°C. Data are means of three replicates with mean separation by LSD 0.05.

Pre-cutting atmospheres: nitrogen flushing and CO_2 accumulation

Tubers were enclosed in chambers at 10°C, flushed with nitrogen gas, closed, and then held for 2, 4, and 8 days (test 1) or 6, 12, and 16 days (test 2). Corresponding O_2 concentrations were 0.5, 0.4, and 0.3% in test 1 and 0.4, 0.2, and 0.2% in test 2, with CO_2 concentrations reaching 10, 15, and 27% in test1 and 25, 25, and 35% in test 2. It was possible to increase endogenous fermentative volatile concentrations (Table 1). An 8-day treatment resulted in slices with 2725 µmol 100 g^{-1} FW ethanol, content which then decreased when slices were stored in air at 5°C (Table 1). However, neither an 8- nor 12-day enclosure was sufficient to significantly retard discoloration (Figure 3). A 16-day treatment resulted in an atmosphere of 0.2% O_2 and 35% CO_2 and did notably reduce discoloration of the slices (Figure 3).

Table 1. Acetaldehyde and ethanol concentrations of sunchoke tuber slices at 5°C. Before cutting, tubers were untreated or held in a closed container for 8 days at 10°C. The container was flushed with nitrogen gas and sealed, reaching 0.4% O_2 + 25% CO_2 after 8 days.

Treatment	Days at 5°C	Acetaldehyde (µmol 100 g^{-1} FW)	Ethanol (µmol 100 g^{-1} FW)
Control	0	4.9	45
	4	17.8	83
	8	19.1	189
Atmosphere	0	56.1	2725
	4	95.0	1261
	8	91.5	680
LSD.05		32.4	274

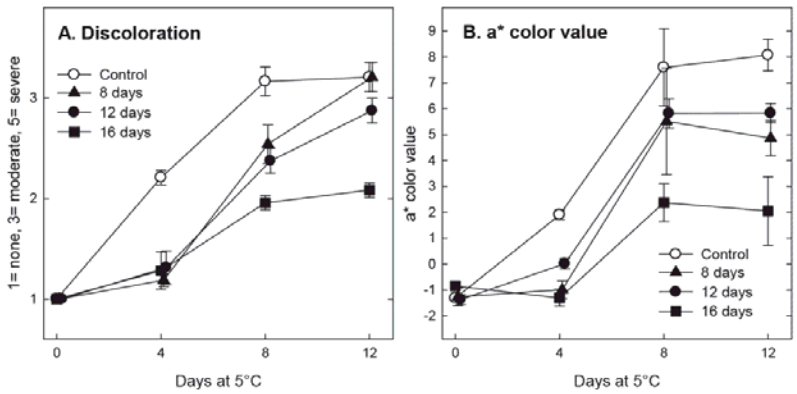

Figure 3. Effect of atmosphere pretreatments (nitrogen flush plus CO_2 build-up by respiration in a closed container) for 8, 12 or 16 days at 10°C on red discoloration and a* color values of sunchoke slices. Data are means of three replicates ± standard deviation.

Pre-cutting warming treatment

Tubers were held at 20°C for 7 or 14 days for a conditioning or warming treatment, with the goal of increasing metabolism and reducing wound-induced phenolic metabolism upon slicing. The 14-day treatment significantly reduced discoloration and associated increases in a* values (Figure 4). Both warming treatments reduced PAL activity and respiration rates (Figure 4C, D), but had no effect on PPO activity (data not shown) and reduced phenolic concentrations by only 15-25% (data not shown). The 14-day conditioning was partially effective.

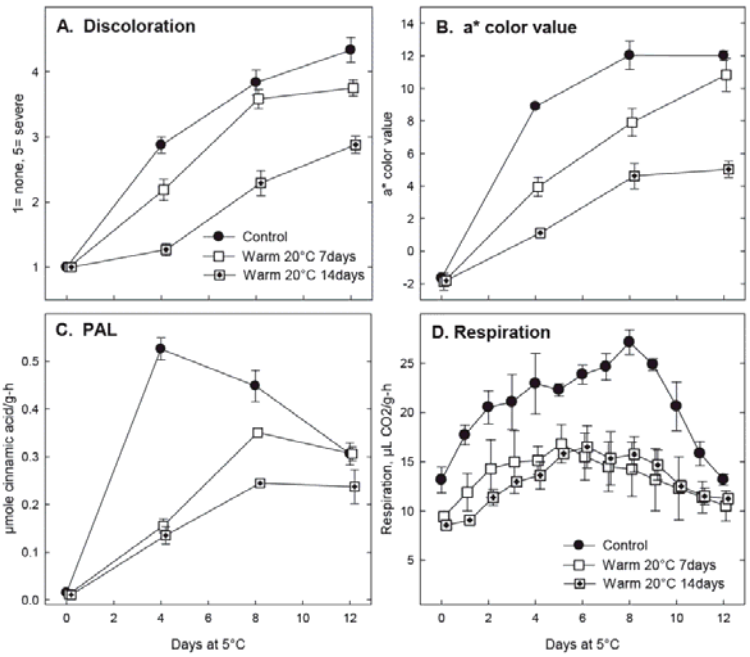

Figure 4. Effect of warming pretreatments at 20°C for 7 or 14 days on red discoloration (A), a* color values (B), PAL activity (C), and respiration rates (D) of sunchoke slices. Data are means of three replicates ± standard deviation.

Pre-cutting hot-water dips and warming treatments

The hot-water treatments were selected based on previous sunchoke research (Wang et al., 2014). Tsouvaltzis et al. (2011) also showed that preprocessing hot-water dips could partially reduce discoloration in fresh-cut potato. Heat treatment has been shown to be effective in controlling enzymatically induced discoloration by redirecting de novo protein synthesis from PAL to heat-shock proteins (Saltveit, 2000). In the present study, a pre-cutting 6-min dip at 50°C followed by 1 or 3 days at 20°C was partially effective in controlling red discoloration (Figure 5).

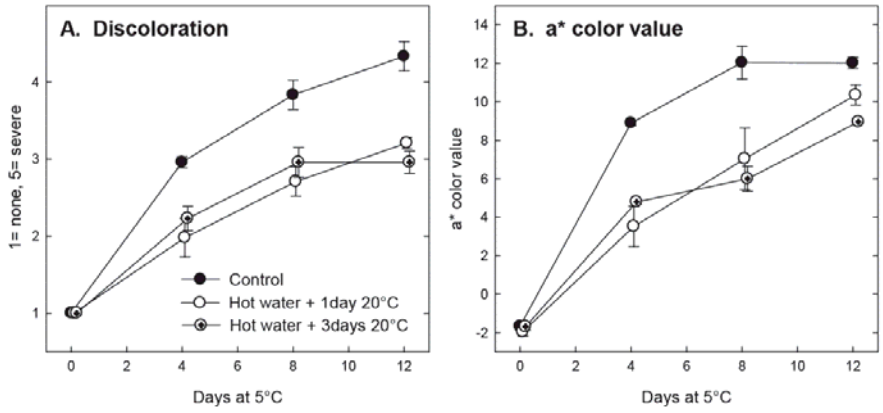

Figure 5. Effect of hot-water dip pretreatments (50°C for 6 min + 1 or 3 days at 20°C) on red discoloration (A) and a* color values (B) of sunchoke slices. Data are means of three replicates ± standard deviation.

CONCLUSIONS

Sunchoke tuber slices stored at 0°C had less discoloration than slices held at 5°C. Several treatments were effective in retarding red discoloration of fresh-cut sunchoke tubers at 5°C. These included ethanol dips, hot-water dips, short-term extreme atmospheres, and tuber warming. Ethanol dips were the most effective treatments. Effective treatments reduced respiration rates and PAL activity, and sometimes reduced phenolic content, but usually did not affect PPO activity.

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Literature cited

Adams, J.B., and Brown, H.M. (2007). Discoloration in raw and processed fruits and vegetables. Crit. Rev. Food Sci. Nutr. *47* (*3*), 319–333 http://dx.doi.org/10.1080/10408390600762647. PubMed

Aquino-Bolaños, E.N., Cantwell, M.I., Peiser, G., and Mercado-Silva, E. (2000). Changes in the quality of fresh-cut jicama in relation to storage temperatures and controlled atmospheres. J. Food Sci. *65* (*7*), 1238–1243 http://dx.doi.org/10.1111/j.1365-2621.2000.tb10271.x.

Bach, V., Kidmose, U., Thybo, A.K., and Edelenbos, M. (2013). Sensory quality and appropriateness of raw and boiled Jerusalem artichoke tubers (*Helianthus tuberosus* L.). J. Sci. Food Agric. *93* (*5*), 1211–1218 http://dx.doi.org/10.1002/jsfa.5878. PubMed

Brecht, J.K., Saltveit, M.E., Talcott, S.T., Schneider, K.R., Felkey, K., and Bartz, J.A. (2004). Fresh-cut vegetables and fruits. Hortic. Rev. (Am. Soc. Hortic. Sci.) *30*, 185–251 http://dx.doi.org/10.1002/9780470650837.ch6.

Kays, S.J., and Nottingham, S.F. (2008). Biology and Chemistry of Jerusalem Artichoke (*Helianthus tuberosus* L.). (New York, NY, USA: CRC Press, Taylor & Francis), pp.459.

Ke, D., and Saltveit, M.E. (1986). Effects of calcium and auxin on russet spotting and phenylalanine ammonia-lyase activity in Iceberg lettuce. HortScience *21*, 1169–1171.

Kern, K.A., Pergo, E.M., Kagami, F.L., Arraes, L.S., Sert, M.A., and Ishii-Iwamoto, E.L. (2009). The phytotoxic effect of exogenous ethanol on *Euphorbia heterophylla* L. Plant Physiol. Biochem. *47* (*11-12*), 1095–1101 http://dx.doi.org/10.1016/j.plaphy.2009.07.002. PubMed

Ma, Y., Wang, Q., Hong, G., and Cantwell, M. (2010). Reassessment of treatments to retard browning of fresh-cut Russet potato with emphasis on controlled atmospheres and low concentrations of bisulphite. Int. J. Food Sci. Technol. *45* (*7*), 1486–1494 http://dx.doi.org/10.1111/j.1365-2621.2010.02294.x.

Mateos, M., Ke, D., Cantwell, M., and Kader, A.A. (1993). Phenolic metabolism and ethanolic fermentation of intact and cut lettuce exposed to CO_2-enriched atmospheres. Postharvest Biol. Technol. *3* (*3*), 225–233 http://dx.doi.org/10.1016/0925-5214(93)90058-B.

Plaxton, W.C., and Podestá, F.E. (2006). The functional organization and control of plant respiration. Crit. Rev. Plant Sci. *25* (*2*), 159–198 http://dx.doi.org/10.1080/07352680600563876.

Saltveit, M.E. (2000). Wound induced changes in phenolic metabolism and tissue browning are altered by heat shock. Postharvest Biol. Technol. *21* (*1*), 61–69 http://dx.doi.org/10.1016/S0925-5214(00)00165-4.

Singleton, V.L., and Rossi, J.A., Jr. (1965). Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. Am. J. Enol. Vitic. *16*, 144–158.

Siriphanich, J., and Kader, A. (1985). Effects of CO_2 on total phenolics, phenylalanine ammonia lyase, and polyphenol oxidase in lettuce tissue. J. Am. Soc. Hortic. Sci. *110*, 249–253.

Toivonen, P.M.A., and Brummell, D.A. (2008). Biochemical bases of appearance and texture changes in fresh-cut fruit and vegetables. Postharvest Biol. Technol. *48* (*1*), 1–14 http://dx.doi.org/10.1016/j.postharvbio.2007.09.004.

Tsouvaltzis, P., Deltsidis, A., and Brecht, J.K. (2011). Hot water treatment and pre-processing storage reduce browning development in fresh-cut potato slices. HortScience *46*, 1282–1286.

Wang, Q., and Cantwell, M. (2015). Quality changes and respiration rates of fresh-cut sunchoke tubers (*Helianthus tuberosus* L.). J. Food Process. Preserv. *39* (*6*), 634–644 http://dx.doi.org/10.1111/jfpp.12271.

Wang, Q., Nie, X., and Cantwell, M. (2014). Hot water and ethanol treatments can effectively inhibit the discoloration of fresh-cut sunchoke (*Helianthus tuberosus* L.) tubers. Postharvest Biol. Technol. *94*, 49–57 http://dx.doi.org/10.1016/j.postharvbio.2014.03.003.