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Hot water and ethanol treatments can effectively inhibit the discoloration of fresh-cut sunchoke (*Helianthus tuberosus* L.) tubers

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ABSTRACT

The main problem affecting the quality of fresh-cut sunchoke tubers is cut surface discoloration. Pre- and post-cutting hot water and ethanol treatments were evaluated for their potential to inhibit discoloration, color changes, and associated phenolic metabolism in tuber slices stored in air at 5 °C. Some of the treatments tested inhibited discoloration and changes in a^* and hue color values. Slices that were post-cut treated with hot water at 50 °C for 6–8 min or 55 °C for 3–4 min and pre-cut treated with water at 50 °C for 20–25 min maintained good color for 8–12 days at 5 °C. Post-cut ethanol fumigation (150–750 μL/L for 5 h at 5 °C) can prevent discoloration for 30 d at 5 °C. Post-cut dips with ethanol solutions (3, 5, 8 or 10% for 5 min) increased shelf-life twofold or longer compared to untreated slices. Ethanol fumigation retarded the onset of wound-induced respiration rates as well as reducing maximum rates. A post-cut 10% ethanol dip also reduced respiration rates and reduced PAL activity and total phenolics. Ethanol dips had no effect and hot water treatments had no persistent effect on microbial loads over 12 d.

1. Introduction

Sunchoke or Jerusalem artichoke (*Helianthus tuberosus* L.) is a plant native to North America and currently produced in Mexico, United States, and China (Kays and Nottingham, 2008). Sunchoke tubers have a light or dark brown skin with a white, crisp, sweet pulp and can be consumed raw or cooked. The tubers contain 14–19% inulins (Cummings et al., 1995), non-digestible oligosaccharides with numerous purported health benefits, including lowering blood glucose, maintaining lipid homeostasis, and increasing mineral bioavailability (Niness, 1999).

Depending on cultivar and maturity, tubers can be stored at 0–2 °C for 6 months or longer (Kays and Nottingham, 2008). Besides dehydration, decay and sprouting defects, there is depolymerization of the inulins with storage time and an increase in simple sugars (Saengthongpinit and Sajjaanantakul, 2005).

Fresh-cut products aim to provide safe, fresh, and convenient produce items while requiring less transport and storage space than the intact commodity (Barrett et al., 2010; Francis et al., 2012; Watada et al., 1996). Innovations in fresh-cut product offerings can contribute to increased consumption of fruits and vegetables. Sunchoke tubers have the potential to be processed into fresh-cut products, but the main problem limiting shelf-life is a red discoloration of the cut surfaces (Wang and Cantwell, unpublished).

Inhibiting discoloration of fresh cut products has been studied for a wide variety of fruit and vegetables. Many approaches to resolve this problem have been taken including choice of cultivar, low temperature, low oxygen, high carbon dioxide atmospheres (Aquino-Bolaños et al., 2000) or super high oxygen (Jacxsens et al., 2001), and chemical and controlled atmosphere combinations (Gorny et al., 2002; Lu et al., 2006; Ma et al., 2010; Oms-Oliu et al., 2006). However, many of these treatments may cause off-odors and off-flavors or the compounds may not be generally recognized as safe (FDA, 2014). As a safe method, 45–55 °C heat-shock treatments have been shown to prevent browning reactions and maintain texture in various vegetables and fruits (Loaiza-Velarde et al., 1997; López-López et al., 2013; Tsouvaltzis et al., 2011). Heat treatment protected fresh-cut lettuce against browning, helped retain greenness, and decreased production of phenolics when applied either before or after cutting (Loaiza-Velarde and Saltveit, 2001).

Ethanol treatment is another method that has been used to inhibit browning of fresh-cut produce. Exposing lettuce mid-ribs to vapors or aqueous solutions of *n*-alcohols inhibited wound-induced tissue browning (Choi et al., 2005). Control of superficial scald (skin browning) in Red Delicious apples was achieved by treating the fruit with ethanol, butan-1-ol, or propan-1-ol (Ghahramani et al.,

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2000). Fresh-cut broccoli treated with ethanol maintained better storage quality (Han et al., 2006). Ethanol treated apples slices maintained appearance longer and had lower respiration rates than untreated slices (Bai et al., 2004). Ethanol was also found to extend the storage life of fresh-cut mango (Plotto et al., 2006) and fresh-cut eggplant (Hu et al., 2010).

Biosynthesis, oxidation and polymerization of phenolic compounds are often associated with discoloration and other color changes (Hisaminato et al., 2001; Rhodes and Wooltorton, 1978). In some products, PAL is considered the first committed enzyme in the phenylpropanoid pathway that regulates its overall activity (Dixon and Paiva, 1995). López-Gálvez et al. (1996) demonstrated a high correlation between the activity of phenylalanine ammonia lyase (PAL, EC 4.3.1.5.) and the discoloration on intact and cut lettuce leaves. Aquino-Bolaños et al. (2000) also demonstrated a close relationship between phenolic metabolism and browning of cut jicama tissue. However in other roots crops such as potato, there were no clear relationships between PAL, phenolic metabolism and cut tissue browning (Cantos et al., 2002; Luna et al., 2012; Ma et al., 2010). For some products such as apples and potatoes, polyphenol oxidase (PPO, EC1.10.3.1) activity is considered rate limiting. In general the most important factors that determine the rate of enzymatic browning of many fruit and vegetables are the concentrations of phenolic compounds in the tissue, tissue pH, temperature, and oxygen availability (Martinez and Whitaker, 1995; Rhodes and Wooltorton, 1978).

Although hot water and ethanol treatment have been effectively used to extend the shelf-life of some fresh-cut products, their effects on the phenolic metabolism and discoloration of fresh-cut sunchoke are unknown. The objectives of this study were to investigate potential treatments to control the discoloration of fresh-cut sunchoke tubers. Hot water and ethanol treatments applied before and after cutting were studied for their impact on visual quality, discoloration, respiration rates, phenolic metabolism and microbiology of the fresh-cut slices.

2. Materials and methods

2.1. Plant material and preparation

Medium size (60–90 g) sunchoke tubers (cultivars unknown) were purchased periodically from a local wholesaler in Sacramento, CA from product grown in Washington and California. Tubers were packaged in bulk in unsealed polyethylene bags in carton boxes and stored at 5 °C at the Mann Lab until used. Tubers were sorted and very small or defective (damage, decay) tubers were discarded. The tubers were scrub-washed with potable water and then rinsed in 200 μL L^{-1} sodium hypochlorite solution for 5 min, drained and air-dried.

Cleaned tubers were placed into clean LDPE (low density polyethylene) bags and returned to 5 °C until cut the following day. The terminal ends and protuberances (daughter tubers) were removed and tubers were cut into 4–5 mm thick slices on a V-Slicer PRIMA Mandoline (Borner, Germany) at 5 °C.

2.2. Hot water treatments

Four experiments were conducted to evaluate hot water temperature and dip times. After preliminary testing, two experiments evaluated potentially useful hot water treatments applied before and after slicing. Tubers were brought to room temperature and treated in a mass of water to mass of tuber ratio of 20–1. Water temperatures were raised to 1–2 °C above target temperature, tubers or slices immersed and water temperature was kept within ±1 °C of the target temperature.

2.2.1. Post-cut hot water treatment

Prepared slices were immediately placed in the hot water bath for the designated temperature and time. The first experiment evaluated untreated slices (control), and slices treated at 50 °C for 5 or 10 min, 55 °C for 2.5 or 5 min, or 60 °C for 1 or 2 min. Slices were evaluated after 0, 2, 4, 6 and 8 d at 5 °C with 3 replicates per treatment. In the second experiment treatments were control, 50 °C for 6, 8 or 10 min, and 55 °C for 3, 4 or 5 min. After hot water treatment, slices were immediately rinsed in 50 μL L^{-1} sodium hypochlorite water (pH 7.0) at 5 °C, blot dried with a paper towel to remove excess moisture and placed into unsealed small LDPE bags (8–9 pieces per bag). The ends were folded over and bags were placed on plastic trays inside unsealed large polyethylene bags, slices were evaluated after 0, 4, 8 and 12 d at 5 °C with 3 replicates per treatment. Control slices were also rinsed in cold chlorinated water.

2.2.2. Pre-cut hot water treatment

Two experiments were conducted in which the tubers were treated with hot water before slicing. The tubers were warmed 4–6 h at room temperature and daughter tubers were removed before treatment. The first experiment included the control, hot water at 45 °C for 15 or 30 min, 50 °C for 7.5 or 15 min, or 55 °C for 5 or 10 min. In the second experiment longer treatment times were used with 50 °C water for 15, 20 or 25 min and 55 °C water for 10, 15 or 20 min. The center of the tubers heated to 1–3 °C below the target temperature as measured by HI145 T-shaped thermometer (Hanna Instrument). After treatment, tubers were blotted dry, immediately cut into slices, placed in the unsealed LDPE bags and stored at 5 °C. Slices were evaluated after 0, 4, 8, and 12 d with 3 replicates per treatment.

2.3. Ethanol treatment

Three experiments were conducted in which ethanol vapor was applied before or after slicing or as a post-cutting dip solution.

2.3.1. Post-cut ethanol fumigation treatment

Sunchoke slices (about 70 at 7 g each) were placed without overlap on 2 lower layers of a plastic mesh grid in a closed 26 L polycarbonate chamber. A small fan for circulation and one absorbent gauze with different amounts of ethanol (0, 150, 300, 450, 600, 750 or 900 μL/L) were placed on the upper layer of the plastic grid. After fumigation for 5 h at 5 °C, the slices were then removed and directly placed in small unsealed LDPE bags and 3 replicates per treatment were evaluated after 0, 2, 4, 6, 8, 30, and 34 d at 5 °C.

2.3.2. Pre-cut ethanol fumigation treatment

The intact tubers were fumigated in the same way as described for post-cut ethanol treatment with 0, 300, or 600 μL/L ethanol for 5, 10, or 15 h at 5 °C. The slices were then prepared as previously described, packaged and 3 replicates per treatment were evaluated after 0, 4, 8, and 12 days at 5 °C.

2.3.3. Post-cut ethanol dipping treatment

Sunchoke slices were immersed in 0, 3, 5, 8, or 10% ethanol solutions for 5 min, blotted dry, placed in plastic bags and stored at 5 °C. Visual quality and color values were measured every 3 d until the ethanol treated slices began to redden.

2.4. Quality and shelf-life evaluation

The rating scales were developed by all three authors, but usually applied solely by the first author. Overall visual quality was evaluated by an experienced operator on a 9–1 scale, where 9 = excellent, fresh cut, no defects, 7 = good, minor defects, 5 = fair, moderate defects, 3 = poor, major defects, 1 = unusable. A