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Sodium chloride, a cost effective partial replacement of calcium ascorbate and ascorbic acid to inhibit surface browning on fresh-cut apple slices

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ABSTRACT

Ascorbic acid and calcium ascorbate are used commercially in dip solutions to inhibit the development of browning on the surface of fresh-cut apple slices. A sodium chloride dip has also been shown to inhibit browning and this study examined its interaction with various forms of ascorbate on the postharvest life of apple slices. Comparison of the effectiveness of ascorbate moieties showed that the concentration of ascorbic acid required to achieve any desired postharvest life was twice that of calcium ascorbate, but calcium, sodium and potassium ascorbates were equally effective in inhibiting browning. The inclusion of 0.1 mol/l sodium chloride into a dip requires only half the concentration of ascorbate to maintain the same postharvest life. The very low cost of sodium chloride means that materials in such a dip are about half the cost of an ascorbate-only solution. Since 0.1 mol/l sodium chloride does not affect the taste of apple slices and is an allowable food additive, it should be considered as a cost effective partial replacement of ascorbate in commercial dips. There also seems to be a cost advantage of sodium ascorbate over calcium ascorbate.

1. Introduction

Fresh-cut slices of apple are an important segment of the fresh fruit and vegetable market. However, in common with other fresh-cut produce, the act of cutting enhances a range of degradative changes that limit the useful postharvest life with browning on the cut surface a major factor in loss of quality. The browning is generally considered due to oxidation of endogenous polyphenolic compounds containing an *o*-dihydroxy group to the corresponding *o*-quinones in the presence of oxygen. The reaction is catalysed by an oxidising enzyme, in particular, polyphenoloxidase (PPO). Subsequent reactions generate a coloured polymer (Robards, Prenzler, Tucker, Swatsitang, & Glover, 1999).

Ascorbic acid has long been applied to fresh-cut produce as a dip (Ponting, Jackson, & Watters, 1972; Sapers & Ziolkowski, 1987) and it is claimed to be the most widely used agent to prevent browning (Oms-Oliu et al., 2010). However, the effect of applied ascorbic acid is temporary as it is irreversibly oxidised over time (Nicolas, Richard-Forget, Goupy, Amlot, & Aubert, 1994). An approach to enhance the action of ascorbic acid is the addition of calcium chloride (Luo & Barbosa-Canovas, 1996) and a patent filed by Chen, Trezza, Wong, Camir, and Pavlath (1999) claimed optimal inhibition of browning with a dip containing calcium ions and ascorbate ions in the ratio of 2:1. Subsequent studies have applied calcium ascorbate to inhibit browning in fresh-cut apple slices with effective treatments reported as a 60 g/l dip on Braeburn apples (Aguayo, Requejo-Jackman, Stanley, & Woolf, 2010) and a 50 g/l dip on Ambrosia apples (Tardelli, Guidi, Massai & Toivonen, 2103). Treatment with calcium ascorbate is now widely employed by the fresh-cut apple industry to inhibit browning and to maintain the

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quality of fresh-cut apples with a 50 g/l dip an industry standard in North America (Tardelli, Guidi, Massai, & Toivonen, 2013).

While sodium chloride is widely used as a food additive, few studies have examined it as a postharvest treatment to inhibit browning of fresh-cut produce. Tortoe, Orchard, and Beezer (2007) found a dip of 0.05 mol/l sodium chloride was as effective as calcium chloride in inhibiting browning of fresh-cut Golden Delicious apples during 14 days in 4 °C. Li, Wills, Golding, and Huque (2014) examined a range of salts and found that sodium chloride inhibited browning during storage at 5 °C in a concentration dependent manner with an 0.1 mol/l solution (equivalent to about 6 g/l) giving an extension in postharvest life of 2–3 times that of water-dipped slices but did not affect the taste of slices. Apart from its acceptability as a food additive, sodium chloride would seem to offer economic advantages due to its very low cost particularly in relation to ascorbate; sodium chloride can be commercially purchased at a price that is 10% that of ascorbic acid and 5% that of calcium ascorbate (commercial quotation from Chem Supply, Sydney). This study examined the inhibition in surface browning on Granny Smith apple slices achieved by sodium chloride in combination with ascorbic acid and calcium ascorbate. Comparison was also made of the relative effectiveness of the calcium, sodium and potassium ascorbate salts to inhibit browning. The objective was to retain a desired postharvest life of slices at 4 °C while minimising the amount of ascorbate in a dip solution.

2. Material and methods

2.1. Fruit treatment and browning assessment

Granny Smith apples (*Malus domestica* Borkh) were harvested from a commercial orchard at Orange, NSW, Australia, transported to the laboratory, and stored at 0 °C before small batches were periodically used in an experiment. For each experiment, apples were prepared, stored and assessed for browning by the method described by Pristijono, Wills, and Golding (2006). This involved cutting an apple longitudinally into six unpeeled slices with each slice distributed into a different treatment unit which contained eight slices. Slices in each treatment unit were dipped in a solution at 4 °C for 5 min, drained on paper then placed in a 4 l polyethylene container with a beaker of water (50 ml) to maintain a high humidity. Each container had two holes (1 cm diameter) in the lid to prevent changes in the concentration of the respiratory gases, carbon dioxide and oxygen, in the container. Daily measurement of the lightness (L-value) of the cut surface of each slice using a colorimeter (Minolta CR-300, Osaka) was made with the time for tissue browning to reduce the L-value to 76.5 taken as the postharvest life of an apple slice. The mean postharvest life of all eight slices in a treatment unit was expressed as the postharvest life for that treatment unit.

In all experiments, sodium chloride was added to the dipping solution at the optimal concentration of 0.1 mol/l (≡ 6 g/l) reported by Li et al. (2014). The concentration of ascorbic acid, calcium ascorbate, potassium ascorbate and sodium ascorbate in a dip ranged from 6.2 mmol/l to 0.2 mol/l, with respect to ascorbate concentration (≡ 1.2–40 g/l).

2.2. Measurement of PPO activity

PPO activity was assessed using the method of Rocha and Morais (2001) with some modification. A sample of tissue (1 g) taken half way from core to skin of an untreated apple slices and frozen at −20 °C for 30 min then ground to powder with polyvinylpyrrolidone (0.16 g) and 0.1 mol/l sodium phosphate buffer (pH 7) (8 ml) containing 0.25% Triton-100, centrifuged at 12000 g for 10 min at 4 °C. The supernatant was used as crude PPO. Supernatant solutions were obtained from three apples and utilized as replicate samples in analysis of PPO activity. PPO activity was determined using the method of Yingsanga, Srilaong, Kanlayanarat, Noichinda, and McGlasson (2008) with the supernatant (0.2 ml) added to a phosphate buffer containing 0.1 mol/l pyrocatechol in the presence of sodium chloride and/or ascorbate as free acid, calcium or sodium salt in a cuvette. A control cuvette did not contain anti-browning chemical. The change in absorbance was noted over 3 min. A standard curve was prepared of absorbance at 420 nm against concentration of 1,2-benzoquinone, the oxidation product of catechol and used to calculate PPO activity as μkat/g fresh weight of apple.

2.3. Analysis of polyphenols by HPLC

HPLC analysis of phenols was conducted on the juice of freshly blended apple flesh that was filtered through three layers of cheesecloth. Filtrate (5 ml) was placed into a test tube together with 5 ml sodium chloride and/or ascorbate as the acid, calcium or sodium salt solution. Distilled water (5 ml) was added into a control tube. All procedures were conducted at 4 °C with the tubes then held in a water bath at 20 °C for 30 min. The reaction was then terminated by the addition of methanol. The sample was filtered through a 0.45 μm syringe filter and the levels of chlorogenic acid and epicatechin, the major monomeric polyphenols in Granny Smith apple (Li et al., 2014), were analysed by HPLC using the method described by Golding, McGlasson, Wyllie, and Leach (2001) and modified by Li et al. (2014). This involved extraction of polyphenols from apple tissue with methanol, passing the supernatant through a syringe filter and a 20 μl sample injected into a reversed phase HPLC column (Hydro-RP, 250 × 4.6 mm, 4 μm). The mobile phases were Solution A 935 ml/l (phosphoric acid, (2 ml/l), 50 ml/l acetonitrile and 15 ml/l tetrahydrofuran and Solution B 485 ml/l phosphoric acid (2 ml/l), 500 ml/l acetonitrile and 15 ml/l tetrahydrofuran. The mobile phase sequence was 100% A for 5 min, increasing to 50% A and B from 5 to 45 min, then up to 100% B over 45–55 min and maintained to 60 min. The flow rate was 1 ml/min at a column temperature of 40 °C. The column effluent was analysed for absorbance at 280 nm. Chlorogenic acid and epicatechin were identified based on retention time and quantified against standard curves of the respective compounds.

2.4. Statistical analysis

Analysis of variance was performed using SPSS for Microsoft version 18.0 software package (SPSS Chicago, IL) and least significant differences (LSD) at $P = 0.05$ for means were calculated to determine significant differences between treatments. All studies were replicated by conducting experiments on at least two different occasions and for each batch of fruit there were three units of eight fruit slices for each treatment.

3. Results and discussion

The effect of a range of dipping solutions on browning development expressed as postharvest life, being the time for the surface flesh colour to decline to L-value of 76.5 Minolta colour units, was initially examined for ascorbic acid and calcium ascorbate in water and in the presence of sodium chloride. The concentration of calcium ascorbate solutions is expressed in terms of molarity of the ascorbate ion, that is, as $calcium_{0.5}$ ascorbate. Experiment 1 in Table 1 shows firstly, that dipping in 0.1 mol/l sodium chloride increased the postharvest life from about 3 days for water control slices to 7.5 days. Dipping in 0.2 mol/l ascorbate (calcium salt)

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