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Effects of aqueous chlorine dioxide treatment on browning of fresh-cut lotus root

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ABSTRACT

Effect of aqueous chlorine dioxide (ClO_2) treatment on browning of fresh-cut lotus root (FLR) was investigated to explore the feasibility to apply ClO_2 for browning inhibition of fresh-cut products. Cut lotus roots were treated in ClO_2 solutions at different concentrations (10, 50 and 100 mg/l) for different time (5, 10 and 15 min), followed by chilled storage for 8–10 days at 4 °C. Color parameters (L^*, a^* and b^*), polyphenol oxidase (PPO) activity and overall visual quality (OVQ) were measured at one-day interval during storage. Results showed that higher ClO_2 concentration and longer treatment time can provide better inhibitory effects on the browning of FLR. ClO_2 concentration, treatment time and storage time were three significant factors ($P < 0.05$) and some significant interactions were observed. PPO activities were largely inhibited by 100 mg/l ClO_2 treatment for 10 min. The 100 mg/l ClO_2 treatment maintained high OVQ scores during 10-day storage; while 50 mg/l ClO_2 treatment was acceptable for maintaining OVQ during 4-day storage. ClO_2 treatment was demonstrated to be a promising alternative approach to control browning and improve OVQ of FLR.

1. Introduction

Fresh-cut fruits and vegetables market shows a rapidly increasing rate influenced by consumers along with the new living profiles "rich in cash and poor in time" (An Bord Glas, 2004; Verlinden & Nicolai, 2000). However, the market of fresh-cut vegetables is usually limited by their short shelf-life and declining in post-processing quality. Browning is one of the major limitation factors that are detrimental for many fresh-cut products, such as apple, banana, potato, and lotus root. Polyphenol oxidase (PPO, EC 1.14.18.1) activity is known to be the main factor involved in browning (Walker & Ferrar, 1998). Extensive researches have been conducted for controlling the browning in fresh-cut fruits and vegetables. Several methods, such as thermal processing, exclusion of oxygen and anti-browning agents, have been studied to inhibit PPO-related enzymatic browning (Loaiza-Velarde, Mangrich, Campos-Vargas, & Saltveit, 2003). However, thermal processing can cause the loss of sensory and nutritional quality (Sun, Lee, & Song, 2002). Although exclusion of oxygen can inhibit PPO reaction, browning might restart when oxygen is reintroduced (Langdon, 1987). A common approach for preventing enzymatic browning is the use of anti-browning agents (Arslan & Dogan, 2005). Chemical additives, such as sulfites in any of their forms (sulfur dioxide, sodium or potassium metabisulfite, sodium or potassium bisulfite), acidifiers (citric, malic and phosphoric acids), chelators (EDTA), reducing agents (ascorbic acid, alone or in combination), calcium ascorbate, and cysteine, have been used for controlling browning in fruits and vegetables (Abbott, Saftner, Gross, Vinyard, & Janick, 2004; Bhagwat, Saftner, & Abbott, 2004; Fayad, Marchal, Billaud, & Nicolas, 1997; Karaibrahimoglu, Fan, Sapers, & Sokorai, 2004). Some new types of anti-browning agents have also been reported for the control of PPO activities in recent years, such as dipeptides (Girelli, Mattei, Messina, & Tarola, 2004), 2, 3-diaminopropionic acid (Arslan & Dogan, 2005), and glutamic acid (Dogan, Turan, Dogan, Alkan, & Arslan, 2007). However, using these agents is constrained by their high cost and/or low effectiveness. Therefore, research and development studies for finding effective substitutes are still ongoing (Rico, Martin-Diana, Barat, & Barry-Ryan, 2007).

Chlorine dioxide (ClO_2) has a broad and high biocidal activity and has been used to control microorganisms, including foodborne pathogens, in the produce industry (Du, Han, & Linton, 2002; Du, Han, & Linton, 2003; Han, Linton, Nielsen, & Nelson, 2000; Han, Linton, Nielsen, & Nelson, 2001; Han, Sherman, Linton, Nielsen, & Nelson, 2000; Roberts & Reymond, 1994). Aqueous ClO_2 as an anti-microbial has been approved by FDA to wash fruits and vegetables at a residual concentration of 3 mg/l (FDA, 1998). ClO_2 is a powerful oxidant that can react with many organic compounds, but produce much less toxic chlorinated by-products than chlorine

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and hypochlorite (White, 1992). ClO_2 also has a potential to inhibit browning of produce. Aqueous ClO_2 treatment has been reported to improve the quality of minimally processed lettuce by decreasing PPO activities (Youm, Lee, Jang, Kim, & Song, 2004). The previous studies in our laboratory showed that 4, 6, and 8 mg/l aqueous ClO_2 treatment exhibited anti-browning effects on Fuji apple juices (Fu & Du, 2004). Furthermore, we found that PPO activities could be inhibited by aqueous ClO_2 treatment at a broad temperature range and this effect was rapid (Fu, Zhang, Wang, & Du, 2007). Therefore, there is a need to further explore the anti-browning effects of aqueous ClO_2 treatment on fresh-cut produce.

Lotus Root is one of the most popular vegetables all over the world due to its crispness, attractive white color and abundant nutrients. However, fresh-cut lotus root (FLR) is usually challenged by the browning problems (Su, Jiang, Li, & Lin, 2003). Solution of 2% erythorbic acid + 1% citric acid and vacuum-packaging has been reported to be effective in inhibiting enzymatic browning in precut lotus roots (Lee & Eun, 1999). However, this approach would use high concentration of acids with special requirement of package. This study would provide some important information for controlling browning of FLR using an alternative approach.

2. Materials and methods

2.1. Plant materials

Lotus root (*Nelumbo nucifera* Gaertn cv. Bai Hua) materials were purchased from local wholesale market at Taian, PR China, transported to the laboratory and stored at 0–4 °C overnight before processing.

2.2. ClO_2 treatment

A stabilized ClO_2 powder product (Qi Lu, Shanghai Lanke Inc, Shanghai, China) was used in this research. After activated by tap water, ClO_2 solution (20,000 mg/l) was further diluted with tap water to specified concentrations. The ClO_2 concentration in sealed test bottles was measured over time at 360 nm wavelength using a UV-2100 spectrophotometer (Unico Inc, Shanghai, China) (Fu, Wang, & Du, 2005).

Lotus roots were washed with tap water to remove soil, peeled and cut into about 4 mm thick slices using a sharp knife. Then the FLR, about 1000 g, were immersed in ClO_2 solutions at different concentration (10, 50 and 100 mg/l) for different periods (5, 10 and 15 min) with a ratio of 1 kg:4 l (FLR:solution) at room temperature of 25 °C, respectively. After each treatment, the liquid was drained off. The samples packaged in polyethylene bags (35 cm × 25 cm) were closed by making a knot at the opening end of the bag and then stored at 4 °C, respectively. During storage, color, PPO activity and overall visual quality were measured at one-day interval. Samples treated with tap water were used as the control in order to simulate the commercial treatment conditions.

2.3. Color measurement

Color, expressed as L^*, a^* and b^* values, were determined using a CR-300 chroma meter equipped with a CR 300 measuring head (Minolta, Hong Kong), where L^*, a^* and b^* indicates luminosity, chromaticity on a green (−) to red (+) axis, and chromaticity on a blue (−) to yellow (+) axis, respectively. CIE illuminant C and 0° viewing angle geometry were used for color measurement. Measurement was carried out with 4 sites on the surface of each sample. The chroma meter was calibrated on a standard white tile ($L^* = 97.06$, $a^* = 0.04$ and $b^* = 2.01$) before each series of measurements.

2.4. Assay for PPO activity

PPO was extracted from samples using the similar procedures reported by Fu (Fu et al., 2007) and Rocha (Rocha & Morais, 2001) with some modifications. The samples were homogenized with extraction buffer (0.2 mol/l, pH 7.0, sodium phosphate buffer, stored at 4 °C) at the ratio of 2.0 ml:1.0 g (buffer:lotus root) in an external ice bath for 3 min including 20 g/kg polyvinylpolypyrrolidone (PVPP, insoluble). The homogenates were centrifuged at 12,000 × *g* for 10 min using a TGL-16G-A superspeed centrifuge (Anting Inc, Shanghai, China) at 4 °C. The supernatants were collected and measured for PPO activity.

The enzymatic activity was determined by measuring the increase of absorbance at 410 nm for catechol at 25 °C using a UV-2100 spectrophotometer (Unico Inc, Shanghai, China). The reaction mixture contained 2.8 ml substrate solution and 0.2 ml enzyme sample. The substrate solution was 0.02 mol/l catechol dissolved in 0.05 mol/l, pH 7.0 sodium phosphate buffer. The reference cuvette contained only the substrate solution. The linear section of the activity curve as a function of time was used to determine the enzyme activity [Units/(min ml enzyme)]. A unit of enzyme activity was defined as the change of 0.001 in the absorbance value per minute under the conditions of the assay. When a lag phase occurred, the reaction rate was measured after the lag phase.

2.5. Overall visual quality (OVQ) evaluation

Generally, OVQ is considered as the most important characteristic in determining shelf-life of fresh-cut products (Gómez-López et al., 2007). OVQ evaluation was performed by a semi-trained panel of six persons selected from College of Food Science and Engineering at Shandong Agricultural University. The panellists, who had previously participated in evaluating the sensory quality of fresh-cut vegetables, received two sessions of training before formal evaluation. Samples were transferred to closed plastic recipients coded with random numbers. Fresh appearance, browning and general acceptability of samples were scored ranging from 1 to 9 based on the following scale: 9 = excellent, just sliced; 7 = very good; 5 = good, limit of marketability; 3 = fair, limit of usability; and 1 = poor, inedible (Perez-Gago, Serra, & del Rio, 2006).

2.6. Statistical analysis

All the treatments and measurements were performed in triplicate. Excel 2003 and SPSS 12.0 softwares were used for data analysis. The mean values were calculated and reported with a 95% confidence interval. Analysis of variance (One-way ANOVA and three-factor ANOVA for three variables tested), followed by least significant difference (L.S.D.) and Student Newman Keuls' (SNK) Multiple Range Test with a significance level $P = 0.05$, was performed on the data to determine significant factors (variables) and their interactions among factors ClO_2 concentration, treatment time, and storage time.

3. Results

3.1. Effect of ClO_2 treatment on color of fresh-cut lotus root

3.1.1. Effect of ClO_2 treatment on L^* value

L^*, depending on reflectivity of determined surface, was used to express luminosity of sample surface. The higher L^* value of FLR, the brighter surface it has. The effect of ClO_2 treatment on L^* values of FLR is shown in Fig. 1. Generally, L^* tended to decrease with increasing storage time. Compared to the treated samples, L^* values