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Research Article

Combined Addition of Citric Acid and Ascorbic Acid Significantly Inhibits Browning in Chinese Yam (*Dioscorea polystachya* Turczaninow) Processing

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Chinese yam (*Dioscorea polystachya* Turczaninow) is widely cultivated in East Asia, whose edible stem is a common vegetable and herb in traditional Chinese medicine. In fruit and vegetable processing, browning is estimated to be a major reason of waste. Browning lowers the nutrition value and brings undesired characteristics in food processing. To develop a secure and low-cost browning inhibiting protocol in yam processing, different thermal treatment conditions and color protectants were tested for their color-protecting ability. Color difference ΔE was calculated to evaluate the browning with a colorimeter. To ensure that the color-protecting treatment does not influence the quality of yam, texture properties and nutrition compositions were quantified. The optimal treatment is as follows: deactivate yam in water bath of 60°C for 10 min and then incubate in 2 g/L citric acid and 1 g/L ascorbic acid for 1 hour. The treatment led to significant decrease of the color difference, with no obvious changes in the texture properties and nutrition value. To summarize, this research provides an ideal color-protecting solution in yam processing.

1. Introduction

Chinese yam is the edible stem of *Dioscorea polystachya* Turczaninow, which is native to China and cultivated in China, Japan, and Korea [1]. Yam is also used in traditional Chinese medicine. Modern food processing and packaging technology, especially the rapid development of precooked food industry in China, bring up various yam products, including salted yam, yam chips (a resemblance of potato chips), yam oatmeal, and yam biscuit. Inhibition or minimizing uncontrolled enzymatic and nonenzymatic browning should be one of top priorities in fruit and vegetable processing industry because browning leads to unfavourable changes in the sensory properties and lowers nutritional value [2–4]. In yam processing, browning's negative effect is especially significant: the peeled yam represents a pleasant and appetizing snow-white appearance and browning largely darkens the surface and softens the texture. Therefore, browned yam intermediate in the processing should be discarded or catalogued into the secondary product. A low-cost, stable, repeatable, and secure method to inhibit browning in yam processing should be developed.

In food industry, browning refers to all biological and chemical reactions which darken products and/or intermediates. Polyphenol oxidase (PPO) and peroxidase (POD) contribute to most enzymatic activities in food browning [2]. PPO (1,2-benzenediol:oxygen oxidoreductase; EC 1.10.3.1) contains copper ions in the active site. PPO can catalyze two reactions: (1) adding a hydroxy group to the *o*-position of the benzene ring of a phenol molecule, forming a diphenol; (2) oxidizing a diphenol, producing an *o*-benzoquinone. The two reactions require oxygen. *O*-Benzoquinone can undergo a series of nonenzymatic reactions, forming melanin. Melanin is an insoluble and black pigment, which renders food the undesired and unfavourable appearance. POD (peroxidase; EC 1.11.1.7) can oxidize phenol compounds with hydrogen peroxide as the cosubstrate. Some studies reported that PPO from

strawberry and mango harboured more enzymatic activities than POD after thermal treatment [5, 6].

Nonenzymatic browning normally is the result of Maillard reaction and/or caramelization [7]. Maillard reaction is an extreme complex reaction network, whose substrates are a reducing sugar, like glucose, and a compound with a free amino group. The amino group can be the R-group of an amino acid, e.g., lysine or the N-terminal end of a peptide [8, 9]. Maillard reaction is a mixed blessing: it can give food characteristic aroma, flavor, color/appearance, and texture properties. But it also has negative effects. As Maillard reaction starts from the condensation of a reducing sugar and a free amino group, it lowers the nutrition value of products. Moreover, acrylamide is an early product of Maillard reaction, whose correlation with cancer is still in debate [10–13]. It must be noticed that, in most cases, expected Maillard reaction takes place in the backing process, e.g., cake, bread, coco, coffee, and tea, while unexpected Maillard reactions normally take place inside the package or in the processing progress, e.g., on the shelf and in the transportation process, and lead to disgusting flavors and textures. Caramelization is widely used in food preparation since ancient times. It requires high temperature (>120°C) and starts from hydrolysis of sugar. Products of caramelization provide food special aroma and flavor. But inappropriate caramelization renders food undesired "burnt like" aroma and flavor, which in many cases result from overcooking or excessive thermal treatment [14, 15].

Various methods have been developed and applied in food industry to inhibit and minimize unexpected browning. Low temperature can inhibit activities of PPO and POD and lower rates of Maillard reactions. Fridge and cold chain logistics are quite common in food supply chain, supermarkets, and retailers. Dadali et al. found that microwave treatment is effective in reducing browning of lily bulbs. They suggest that the reduction in the browning should be results of decreased enzymatic activities of PPO and POD [16, 17]. Modified and controlled atmosphere package technology has been widely used in fruit and vegetable products. This technology controls the composition of the atmosphere around the product. At low O_2 or high idle gas (N_2, CO_2) condition, the respiration of cells slow down, leading to decreased PPO and POD activities and less browning. Moreover, lower O_2 content could inhibit degradation of oxygen-sensitive compounds [18]. Color protectants have important roles in inhibiting browning in research literature [6, 19]. To find out a low-cost color protectant suitable for yam processing, this research studies the browning inhibiting effect of sodium chloride, L-cysteine, citric acid, sodium erythorbate, and ascorbic acid on yam. Also, the influence of thermal treatment on yam browning was investigated.

2. Materials and Methods

2.1. Materials. Yam (length 0.5–1.0 m, diameter 8–12 cm) was purchased from local supermarkets in Yibin City, Sichuan Province, China, and stored at 4°C overnight for further research. Deionized water was provided by the water purification system (Milli-Q EQ 700, Merk, US). Unless otherwise stated, all chemicals are of analytical purity and supplied by Kelong Chemical Co. Ltd., Chengdu, China.

2.2. Methods

2.2.1. Pretreatment. Yam with similar size was screened, trimmed, and peeled with porcelain knife (to avoid oxidation caused by metal ions). Peeled yam was cleaned with deionized water, cut into 2-3 mm thick slices, incubated in water bath (time: 4–12 min, temperature: 40–80°C, and volume/weight = 20 : 1) to deactivate enzymes.

2.2.2. Color Protectant Treatment. Deactivated yam slice was cooled to room temperature in the air and then soaked in color protectant solution (sodium chloride: 4 g/L, 6 g/L, 8 g/L, 10 g/L, and 12 g/L; L-cysteine: 0.5 g/L, 1.0 g/L, 1.5 g/L, 2.0 g/L, and 2.5 g/L; citric acid: 0.5 g/L, 1.0 g/L, 1.5 g/L, 2.0 g/L, and 2.5 g/L; sodium erythorbate: 0.2 g/L, 0.4 g/L, 0.6 g/L, 0.8 g/L, and 1.0 g/L; ascorbic acid of 0.2 g/L, 0.4 g/L, 0.6 g/L, 0.8 g/L, and 1.0 g/L; combination: citric acid of 2 g/L and ascorbic acid of 1 g/L) for 1 h. Afterwards, yam slice was washed with deionized water, drained with tissue, and stored in the beaker at room temperature on the lab bench. To observe long-term effects of color protectant treatment, yam slice after color protectant treatment was washed with deionized water, drained with tissue, packaged via a vacuum pump, and stored on the lab bench for 1 month. The color difference ΔE was measured regularly.

2.2.3. Color Difference Measurement. Color difference was measured with the method described elsewhere [17]. Briefly, lightness (L), redness (a), and yellowness (b) of yam slice were measured with a colorimeter (UltraScan VIS, Hunterlab, US). The freshly sliced yam without any treatment was used as the blank. The color difference ΔE was calculated using the following equation:

$$\Delta \mathbf{E} = \sqrt{(\mathbf{L_s} - \mathbf{L_0})^2 + (\mathbf{a_s} - \mathbf{a_0})^2 + (\mathbf{b_s} - \mathbf{b_0})^2}. \quad (1)$$

In the formula, L_s, a_s, and b_s represent the lightness, redness, and yellowness of the treated yam. L_0, a_0, and b_0 represent the lightness, redness, and yellowness of the blank.

2.2.4. Texture Property Measurement. Texture properties of yam slices were measured with a texture analyzer (TA-XT Plus, Ronghua Instruments Co. Ltd., Changzhou, China). P/36 type flat bottom probe was used. The sample was condensed two times with the interval being 1s. Parameters: pretest speed, 1.0 mm/s; test speed, 3.0 mm/s; posttest speed, 3.0 mm/s; pressure level, 50%; force, 5 g; pressure height, 30 mm. The hardness was defined as the maximum force in the force-deformation curve. Number of peaks (Np) and the slope of the first peak (Sp) were used to quantify the brittleness.

2.2.5. Sensory Analysis. Sensory analysis of yam slices was performed according to China National Standard GB/T 29605-2013 (Sensory analysis-Guide for food sensory quality

control). The taste panel was composed of 5 male and 5 female undergraduate students in Sichuan University of Science and Engineering. The yam slice after water bath (60°C, 10 min, and volume/weight = 20 : 1) without color protectant treatment was used as the reference. The panel was asked to grade the odor and taste differences between test samples and the reference. A five-point grading format was used. 5 meant no difference or slight difference; 4 meant slight to intermediate difference; 3 meant intermediate difference; 2 meant intermediate to relatively huge difference; 1 meant relatively huge to huge difference.

2.2.6. Nutrient Quantification. Starch and protein were quantified according to methods described by Smith and Zeeman [20] and Jung et al. [21], respectively. Yam slices to be analyzed were freeze-dried and homogenized, and dry weight was recorded. For starch content measurement, soluble interferences were washed away with 80% ethanol three times (3000 × g, 10 min, Eppendorf 5804 R). Starch granules were gelatinized at 100°C for 10 min. Starch was converted to glucose in digestion buffer (200 mM sodium acetate, 6 units of amyloglucosidase (Roche Life Science, Germany), and 0.5 units of α-amylase (Sigma-Aldrich, Germany)) at 37°C for 4 hours. Glucose was enzymatically quantified, in which hexokinase and glucose 6-phosphate dehydrogenase were used to convert glucose to 6-phosphogluconate with concomitant reduction of NAD to NADH [22]. NADH was quantified with a spectrophotometer (UV-1800, Shimadzu, Japan), and starch content was calculated. Protein was quantified with the Kjeldahl method. Briefly, samples were digested in concentrated sulfuric acid with cupric selenite and potassium sulfate as the catalysts. 40% sodium hydroxide was used to release ammonia, which was then captured by 4% boric acid. The titration was performed with standardized 0.1 N hydrochloric acid, with 0.12% methyl red and 0.08% methylene blue as the indicator.

Allantoin and dioscin contents were measured according to Wu's work [23]. Allantoin was extracted with 80% ethanol two times and then separated on Agilent 1260 HPLC system. HPLC colum: Waters PAH C18 column, particle size 5 μm, diameter 4.6 mm, length 250 mm. Flow rate: 0.5 ml/min. Mobile phase: 10% of methanol and 90% of water. Detection wavelength: 224 nm. Allantoin was identified by comparing the retention time of the sample to the standard (National Institutes for Food and Drug Control, China) and then quantified *via* a standard curve.

Dioscin was extracted with 95% methanol two times, dried at 60°C, and then dissolved in methanol for further analysis on Agilent 1260 HPLC system. HPLC colum: Waters PAH C18 column, particle size 5 μm, diameter 4.6 mm, length 250 mm. Flow rate: 1.0 ml/min. Mobile phase: 88% of methanol and 12% of water. Detection wavelength: 210 nm. Dioscin was identified by comparing the retention time of the sample to the standard (National Institutes for Food and Drug Control, China) and then quantified via a standard curve.

2.2.7. Data Processing. Values in bar charts are means of three biological replicates. Error bars are standard deviations. $^{*}p < 0.05$; $^{**}p < 0.01$. Raw data were recorded with Microsoft Office Excel. Curves, bar charts, and significance analysis were produced and performed with Microsoft Office Excel.

3. Results

As shown in Figure 1(a), temperature has significant influence on the color difference ΔE. When temperature increases from 40°C to 50°C, color difference increases almost two times (from 5.33 ± 0.46 to 9.17 ± 0.38). When temperature reaches 60°C, the color difference dramatically drops to 2.74 ± 0.44, which is the lowest in this experiment. At temperatures higher than 60°C, the color difference and temperature are basically in lineal correlation, with the color difference at 80°C being 12.26 ± 0.56. This demonstrates that the optimal thermal treatment temperature of yam slices is 60°C.

Figure 1(b) shows that water bath time also has significant influence on the color difference. Insufficient water bath time (shorter than 10 min) leads to significant increase of color difference. In other words, when water bath time increases from 4 min to 10 min, the color difference drops from 4.21 ± 0.2 to 3.06 ± 0.17. However, longer water bath time (12 min) leads to an increase of color difference, compared with 10 min treatment. This might be attributed to nonenzymatic browning. Therefore, 10 min is the optimal treatment time.

Sodium chloride has the poorest color protecting effect in this study (Figure 2(a)). Even worse, sodium chloride of 10 g/L and 12 g/L treatment increases the color difference compared with the control; this indicates that inappropriate sodium chloride treatment can intensify browning. Sodium chloride of 4, 6, and 18 g/L can lower the color difference to about 60% of the control.

The color protection ability of L-cysteine varies with concentration (Figure 2(b)). L-cysteine of 1.5 g/L can lower the color difference to ~50% of the control. Higher or lower concentrations than 1.5 g/L intensify browning, but the color difference is still lower than the control. Similar phenomenon could be also observed in citric acid (Figure 2(c)) and sodium erythorbate (Figure 2(d)). Citric acid has very nice color protection ability, which also varies with concentration (Figure 2(c)). The optimal concentration of citric acid is 2.0 g/L, which can decrease the color difference to ~25%–50% of the control. It is noteworthy that after 25 hours, the color difference of 2.0 g/L treatment is about one quarter of the control; this indicates that citric acid is especially effective in long time. Sodium erythorbate and ascorbic acid are edible and extensively used antioxidants in food industry. Browning inhibiting effect of ascorbic acid increases with concentration (0.2 g/L–1.0 g/L). However, at low concentrations, the color difference of ascorbic acid is higher than 60% of the control at 5 h and 10 h (Figure 2(e)). This implies that the browning inhibiting effect of L-ascorbic acid is relatively lower than other antioxidants in the early stage (Figure 2(d)).

According to the above results, citric acid and ascorbic acid were combined and used as the color protectant in yam processing. The browning inhibiting effect of combination solution was compared with single antioxidant (citric acid

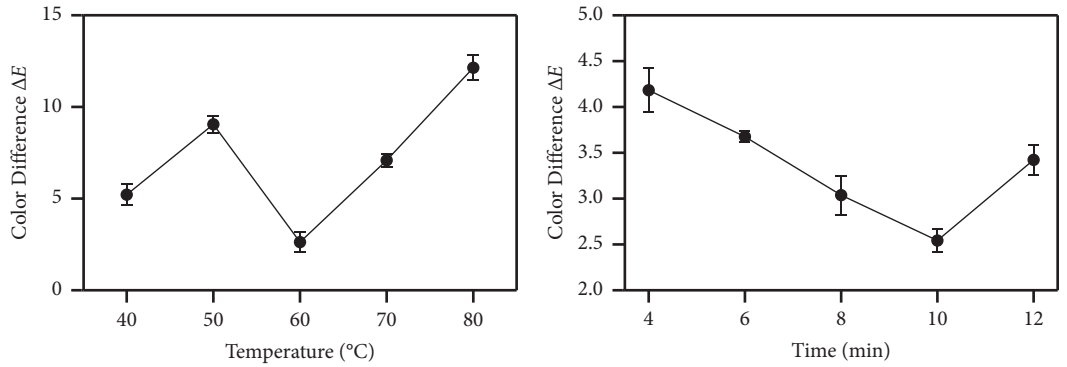


Figure 1: Influence of thermal treatment on the color difference ΔE of yam slices. (a) Temperature. (b) Water bath duration.

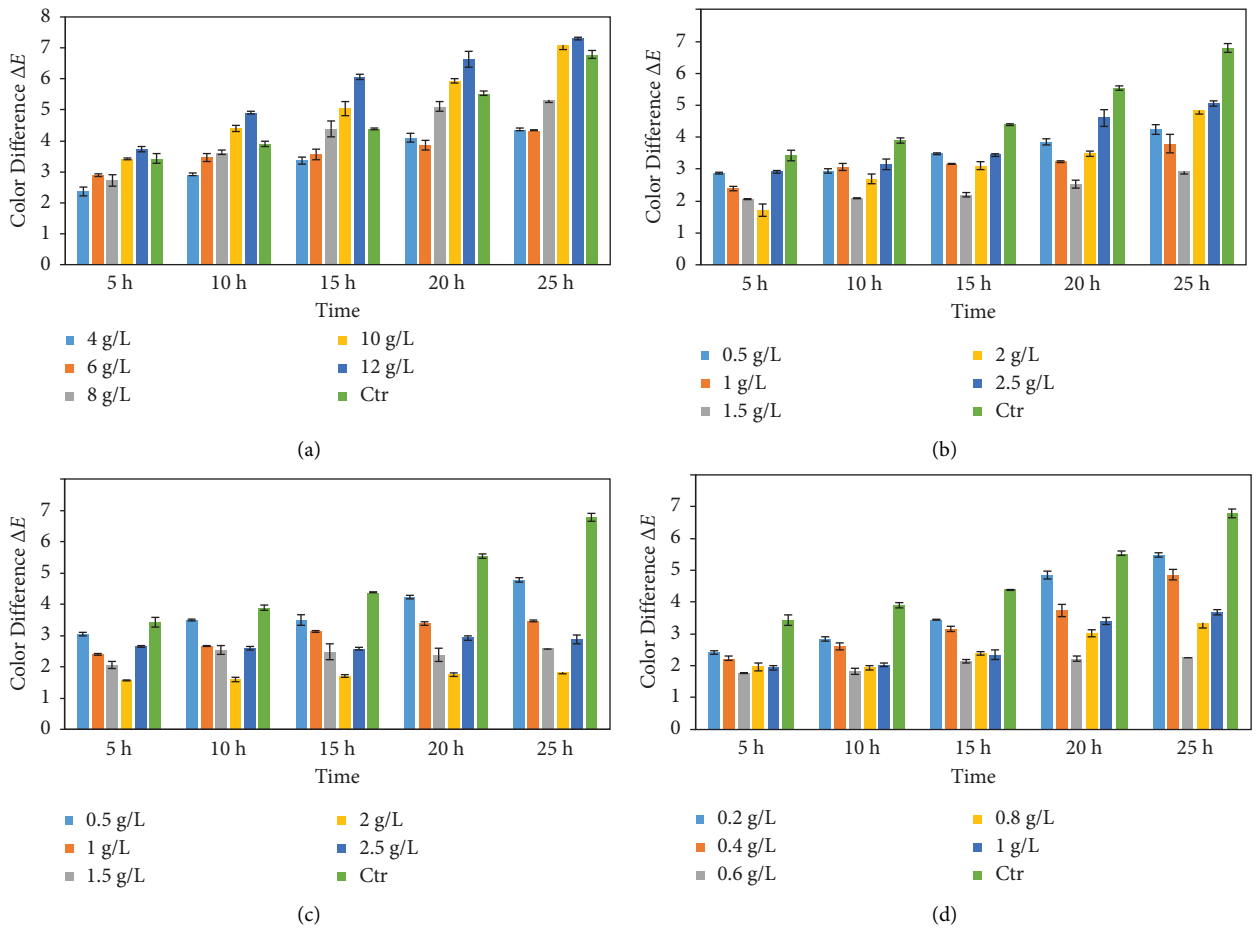
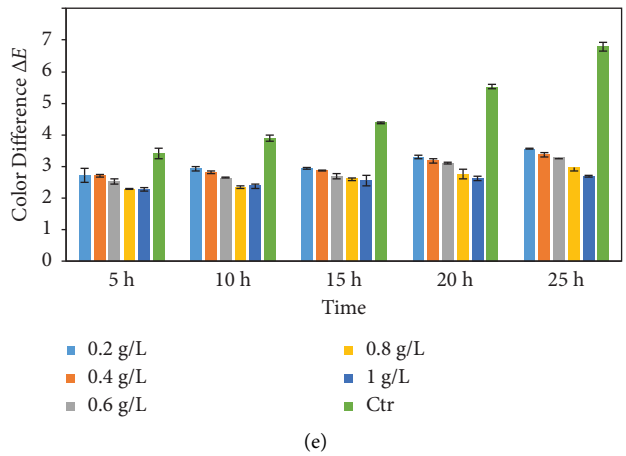


Figure 2: Continued.



(e)

Figure 2: Browning inhibiting effects of color protectants on deactivated yam slices. (a) Sodium chloride. (b) L-cysteine. (c) Citric acid. (d) Sodium erythorbate. (e) Ascorbic acid.

and ascorbic acid). In line with Figures 2(c) and 2(e), citric acid and ascorbic acid both have very strong browning inhibiting effect (Figure 3(a)). Moreover, combination of ascorbic and citric acid even provides better color protecting effect. The color difference in the combination is significantly lower than ascorbic acid and citric acid, reaching only about 10% of the control. This demonstrates that combination of ascorbic acid and citric acid provides the best browning inhibiting effect in this study. Furthermore, the sensory properties of yam slices were analyzed instrumentally and subjectively separately to ensure that citric acid plus ascorbic acid treatment does not lead to undesired flavor and texture changes. The brittleness and hardness of yam, measured by texture analyzer, did not change in the next 25 hours after treatment (Figures 3(b)–3(d)). This phenomenon can also be observed in the sensory analysis performed with panelists (Table 1). Furthermore, nutrition components (starch, protein, allantoin, and dioscin) were measured. As shown in Figures 3(e) and 3(f), nutrients were stable after color protectant treatment. These results suggest that citric acid plus ascorbic acid treatment could effectively protect color, with no influence on the texture, flavor, and nutrient contents.

Browning happens in processing, also inside the package. To explore whether citric acid plus ascorbic treatment could inhibit browning inside the package, yam slices after color protectant treatment were sealed with airtight plastic membrane, and then the color difference ΔE, texture properties, and nutrition composition were recorded in 30 days. Also, the texture and flavor properties were measured. As shown in Table 2, above parameters have few changes in the first 30 days, which is a typical shelf life for many yam products. Therefore, citric acid plus ascorbic treatment not only inhibits browning in yam processing but also helps to minimize browning in the storage and retail stage.

Table 1: Sensory analysis.

	Odor	Taste
24 h	5[a]	4.8 ± 0.4
30 d	5[a]	4.7 ± 0.5

[a]All 10 panelists gave a grade of 5; therefore, SD = 0 and not labelled.

4. Discussion

Browning is an important negative effect in food and vegetable processing industry; it leads to lower sensory quality, less nutrients, and disgusting off-flavors [2, 3]. In fact, browning is estimated to be the second major reason of food waste, with the biggest reason being spoilage caused by microorganism. The causes of food browning include enzymatic reactions, which require polyphenol oxidase (PPO) and peroxidase (POD), and nonenzymatic reactions, which normally refer to Maillard reaction and caramelization. Solutions to control food browning include thermal treatment, low temperature storage, and color protectant. The aim of thermal treatment is to deactivate PPO and POD to inhibit enzymatic browning. However, it must be noticed that high temperature could destroy thermolabile nutrients, such as vitamin C and E. Also, thermal treatment could lead to undesired characteristics in texture. Low temperature storage is normally applied in the transportation and storage stage. The aim of this study is to find a solution to inhibit and/or minimize browning in the processing stage. So, the optimal thermal treatment condition was explored. As shown in Figure 1(a), yam slices after 60°C water bath have the lowest color difference, indicating 60°C is the optimal temperature to minimize browning. 40 and 50°C water bath treatments have higher color difference. This can be explained by the fact that PPO and POD are relatively thermal-stable enzymes [2, 6, 19, 24], while the high color difference in 70 and 80°C should be the result of nonenzymatic browning. There are studies reporting that the reaction rate of nonenzymatic browning increases 2–8 times as the temperature increases by 10°C [25].

Figure 1(b) shows that the optimal thermal treatment temperature for yam is 10 min. Insufficient deactivating time shorter than 10 min leads to higher color difference, while longer time (12 min) will accumulate products of nonenzymatic browning, causing higher color difference. The

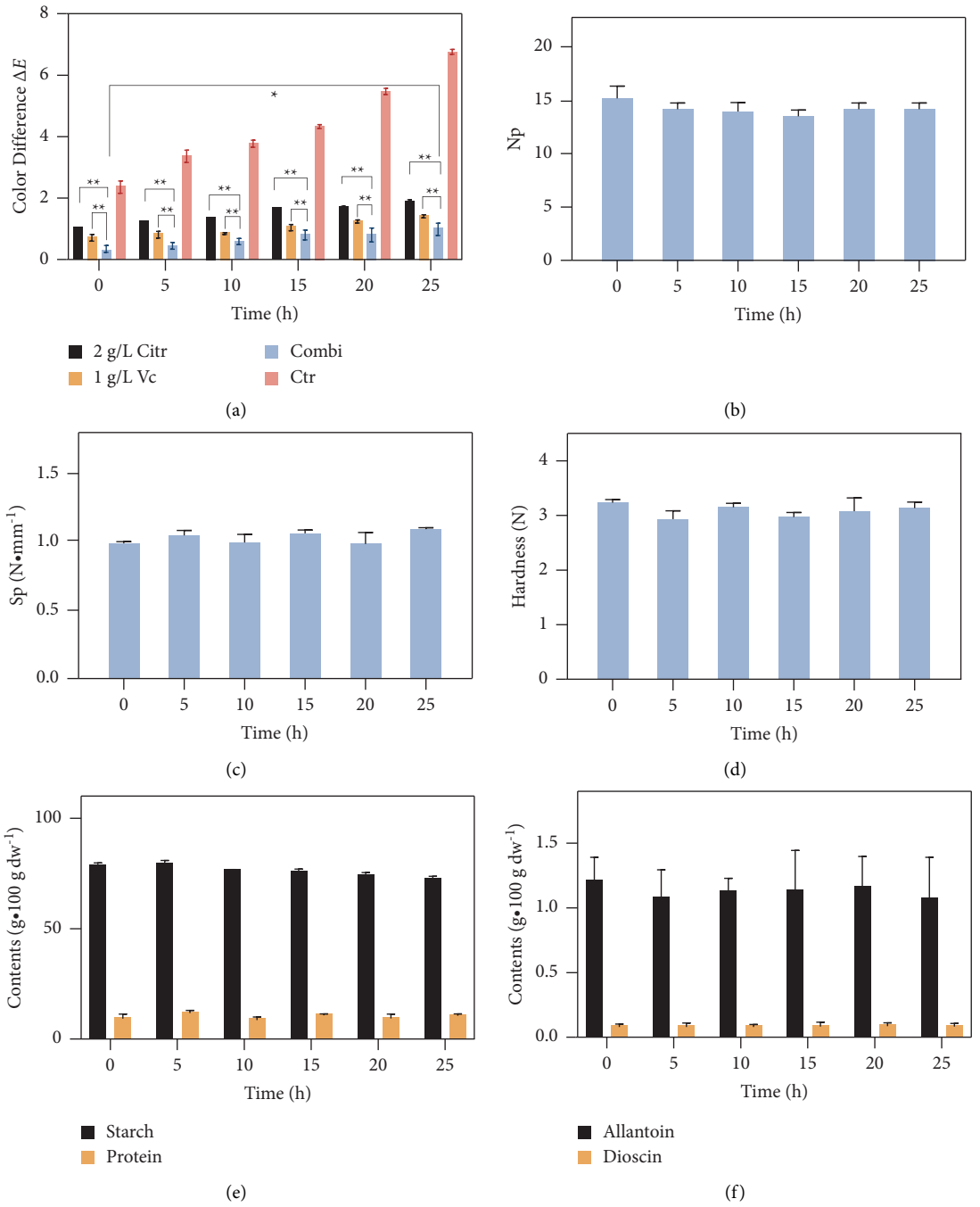


Figure 3: Color difference ΔE, texture properties, and nutrition compositions of yam after color protectant treatment. (a) Color difference ΔE. (b, c) Number of peaks (Np) and slope of the first peak (Sp) in the force-deformation curve were used to measure the brittleness. (d) The hardness was defined as the maximum force in the force-deformation curve. (e) Starch and protein contents. (f) Allantoin and dioscin contents. $^{*}p < 0.05$; $^{**}p < 0.01$.

Table 2: Color difference, texture properties, and nutrition composition of vacuum-packaged yam after color protectant treatment.

	0 d	5 d	10 d	15 d	20 d	25 d	30 d
ΔE	0.32 ± 0.02	0.32 ± 0.01	0.32 ± 0.02	0.31 ± 0.05	0.29 ± 0.02	0.32 ± 0.01	0.32 ± 0.01
Np	14.3 ± 0.58	11.3 ± 0.58	11.0 ± 0	12.67 ± 0.58	11.0 ± 0	11.0 ± 0	11.3 ± 0.58
Sp	1.1 ± 0.2	1.2 ± 0.1	1.1 ± 0.3	1.2 ± 0.1	1.3 ± 0.1	1.1 ± 0.1	1.1 ± 0.2
Hardness	3.42 ± 0.2	3.42 ± 0.3	3.42 ± 0.4	3.42 ± 0.5	3.42 ± 0.6	3.42 ± 0.7	3.42 ± 0.8
Starch	80.0 ± 3.1	80.4 ± 4.2	82. ± 3.9	79.4 ± 3.4	81.9 ± 3.9	78.9 ± 3.7	82.4 ± 3.8
Protein	10.4 ± 0.2	10.4 ± 0.3	11.4 ± 0.8	10.1 ± 0.5	10.9 ± 0.6	11.4 ± 0.3	11.1 ± 0.3
Allantoin	1.4 ± 0.2	1.42 ± 0.3	1.2 ± 0.1	1.0 ± 0.1	0.9 ± 0.1	0.8 ± 0.1	1.2 ± 0.3
Dioscin	0.12 ± 0.02	0.12 ± 0.03	0.13 ± 0.01	0.08 ± 0.01	0.09 ± 0.01	0.13 ± 0.01	0.12 ± 0.01

poorer color-protecting effect in shorter time must be due to residual enzymatic activities of PPO and POD. Therefore, in yam processing, the optimal thermal treatment condition is 60°C for 10 min.

Sodium chloride, L-cysteine, citric acid, sodium erythorbate, and ascorbic acid were tested for their color protecting effect in yam processing in this study. Sodium chloride is different from other color protectants in principle. High concentrations of sodium chloride can (1) denature proteins to deactivate PPO and POD and (2) decrease the solubility of oxygen in the solution to reduce the contact between substrate phenol and oxygen [26]. As shown in Figure 2(a), sodium chloride of 4 g/L, 6 g/L, and 8 g/L can inhibit browning. But the color difference of the treated yam is above 50% of the control, which is poorer than other color protectants and could be seen in the next figures. Even worse, 10 g/L and 12 g/L of sodium chloride lead to higher color difference compared with the control. This indicates that sodium chloride with concentration higher than the threshold can promote browning.

L-cysteine, citric acid, sodium erythorbate, and ascorbic acid are antioxidants [27–30]. Antioxidants can protect phenols and nutrients from oxygen's attack. It can be observed that the color difference of L-cysteine, citric acid, and sodium erythorbate does not always decrease with the concentration increase (Figures 2(b)–2(d)). When the concentration is higher than a threshold, the color difference starts to bounce. In L-cysteine-treated yam, the threshold is 1.5 g/L. Lower or higher concentration leads to the increase of the color difference. In citric acid, the threshold is 2 g/L, and in sodium erythorbate, the threshold is 0.6 g/L. It could be easily explained that the color difference in the low concentration is higher because of insufficient contact between the substrate and the antioxidant. The higher color difference in the high concentration might be due the pro-oxidation effect of antioxidant [31].

The browning inhibiting effect of citric acid is rather strong, as shown in Figure 2(c). It must be noticed that citric acid of 2 g/L and 2.5 g/L can keep color difference an almost constant, while in other concentrations, the color difference increases with time dramatically. Moreover, citric acid of 2 g/L has lower color difference than 2.5 g/L. 2 g/L citric acid's inhibiting effect can maintain the color difference down to ~30% of the control, which is the lowest among all antioxidants. It is noteworthy that after 25 hours, the color difference of 2.0 g/L treatment is about one quarter of the control; this indicates that citric acid is especially effective in long time. Therefore, citric acid has the best browning effect in some concentrations; this indicates that usage of citric acid should be careful to maintain the optimal concentration to avoid the pro-oxidation effect. So, citric acid was chosen to be one component in the further combination experiment.

Sodium erythorbate and ascorbic acid are a pair of isomers which share similar structures, with the only difference being the configuration of one carbon atom. In sodium erythorbate, the threshold concentration is 0.6 g/L. Lower and higher concentrations have much poorer inhibiting effects (Figure 2(d)). The reason of this concave curve should be similar with the phenomenon observed in L-cysteine, while in ascorbic acid, no pro-oxidation effects could be observed. Therefore, sodium erythorbate and ascorbic acid both work in minimizing the browning in yam processing. Considering (1) ascorbic is a beneficial vitamin, while sodium erythorbate has no physiological functions *in vivo*; (2) ascorbic acid's inhibiting effect does not fluctuate dramatically with concentration; and (3) sodium erythorbate and ascorbic acid of food grade have similar prices, ascorbic acid was chosen to be another component in the experiments.

According to the above results, citric acid, a strong but fluctuating color protectant, and ascorbic acid, a relatively weaker but stable color protectant, were combined to check whether their collaboration could provide better browning inhibiting effects. As shown in Figure 3(a), combination of citric acid and ascorbic acid significantly lowers the color difference, compared with citric acid and ascorbic acid. Moreover, after 25 hours at room temperature, the color difference of the combination is only 15% of the control, which is obviously better than any other treatment in this study. Although in combination treatment, there is a significant difference of color difference between 0 h (right after the color protectant treatment) and 25 h ($p < 0.05$, Figure 3(a)), the surfaces of yam slices are very similar, i.e., the change of color cannot be observed with naked eyes. This might be explained by the fact that the significant but small increase of color difference cannot lead to macroscopic changes in the appearance. The contents of starch and protein do not have significant changes after 25 hours; this indicates that the color difference should be products of reactions between amino acid and reducing sugar or phenol compounds and oxygen, while starch and protein do not contribute to the color difference.

It is necessary to prove that the color protecting methods described in this research bring very few or no negative influence on nutrients, flavor, and texture. Starch and protein are two main essential nutrients in yam, which in sum occupy ~90% of the dry weight. Allantoin and dioscin are secondary metabolites which are present in yam. Allantoin can decrease plasma glucose in streptozotocin-induced diabetic rats and inhibit the increase of total inflammatory cells in rats [32, 33]. Dioscin is a natural compound with therapeutic potential in metabolic diseases, cancer, inflammation, and infections [34]. To ensure that citric acid and ascorbic acid treatment is applicable for yam processing, hardness, brittleness, and contents of starch, protein, allantoin, and dioscin of treated yam slices were measured every 5 hours in 25 hours. As shown in Figures 3(b)–3(f), the hardness, brittleness, and nutrient contents of yam after color protectant treatment have very few changes over 25 hours. Furthermore, sensory evaluation was performed with panelists. It can be seen in Table 1 that there was no obvious sensory difference between the treated sample and the control. Therefore, citric acid plus ascorbic acid treatment does not influence sensory and nutrient quality of yam.

To explore whether citric acid plus ascorbic treatment could inhibit browning inside the package, yam slices after color protectant treatment were sealed with airtight plastic membrane, and then the color difference ΔE, texture

properties, and nutrition composition were recorded in 30 days. It is noteworthy that texture properties were measured subjectively and instrumentally, respectively. As shown in Tables 1 and 2, above parameters have few changes in the first 30 days, which is a typical shelf life for many yam products. Therefore, citric acid plus ascorbic treatment not only inhibits browning in yam processing but also helps to minimize browning in the storage and retail stage.

5. Conclusion

To summarize, 2 g/L citric acid plus 1 g/L ascorbic acid treatment gives very strong browning inhibiting effects and brings no negative influence on the sensory and nutrient quality, which is a very effective color protectant solution to minimize browning in yam processing.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

All persons who have made contributions to this work are listed as authors.

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