Effect of exogenous γ -aminobutyric acid treatment on the enzymatic browning of fresh-cut potato during storage

Haiyan Gao^{1,2} · Qing Zeng^{1,2} · Zhengnan Ren^{1,2} · Peizhong Li^{1,2} · Xinxing Xu^{1,2}

Revised: 15 August 2018 / Accepted: 19 September 2018 / Published online: 10 October 2018
© Association of Food Scientists & Technologists (India) 2018

Abstract The aim of this study was to evaluate the effect of γ -aminobutyric acid (GABA) treatment on the enzymatic browning of fresh-cut potatoes. The browning index and activities of browning and defense-related enzymes were analyzed after 0, 1, 2, 3, 4, 5, and 6 days of storage at 4 °C. The results showed that the treatment with 20 g/L GABA for 10 min significantly retarded the browning of fresh-cut potatoes. GABA inhibited the browning of fresh-cut potatoes by enhancing the activities of catalase and superoxide dismutase, and decreasing the activities of polyphenol oxidase and reactive oxygen species. The results suggest that GABA plays an important role in reducing the browning of fresh-cut potatoes. Hence, GABA treatment is a promising approach for reducing the browning and maintaining the quality of fresh-cut potatoes.

Keywords γ -Aminobutyric acid · Fresh-cut · Potato · Enzymatic browning

Introduction

Owing to the freshness, convenience, and nutritional value of fresh-cut fruits and vegetables, consumer demand for fresh-cut products has continuously increased over the last 20 years (Derossi et al. 2016). However, fresh-cut products spoil easier than raw products, because peeling and cutting

can lead to water loss, damage, browning, and microbial spoilage (Soliva-Fortuny and Martin-Belloso 2003; Chen et al. 2016).

Browning is a major factor contributing to quality loss in fresh-cut potatoes (Cantos et al. 2002; Ma et al. 2010; Wang et al. 2015). It seriously affects the sensory quality of fresh-cut potatoes and damages their nutritional components (Ali et al. 2016; Mishra et al. 2013; Queiroz et al. 2011; Zambrano-Zaragoza et al. 2014). Various technologies, including ultrasound, controlled atmosphere, organic acid, sulfites, and curing, have been suggested to control the browning of fresh-cut products. However, technical drawbacks limit their application to extending the shelf-life of fresh-cut fruits and vegetables. Thus, the development of safe, healthy, and environment-friendly technologies is urgent for commercial use, to control the browning of fresh-cut potatoes.

Phenolic compounds are oxidized by polyphenol oxidase (PPO), leading to undesirable enzymatic browning on the surface of fresh-cut potatoes (Hou et al. 2014). Research has shown that senescent tissue and many abiotic stresses—such as chill stress, salt stress, and mechanical injury—contribute to the occurrence of enzymatic browning (Zhang et al. 2015a, b). Increased activity of phenylalanine ammonia lyase (PAL) leads to the accumulation of phenolic compounds (Saltveit 2000). Although a positive correlation between the PAL activities and a high browning potential was found (Thybo et al. 2006), PAL improved the antioxidant capacity of plant tissue by playing the important role of scavenging reactive oxygen species (ROS) (Rechner et al. 2001). Therefore, inhibiting the enzymes related to browning could be of great value in preventing the browning of fresh-cut potatoes.

γ -Aminobutyric acid (GABA) is a non-protein free amino acid conserved widely, from bacteria to plants and vertebrates. As a new functional factor, it has been approved for

✉ Haiyan Gao
hygao1111@126.com

¹ School of Life Sciences, Shanghai University,
Shanghai 200444, People's Republic of China

² Shanghai Key Laboratory of Bio-Energy Crops,
Shanghai 200444, People's Republic of China

use in food (Notice of the Ministry of Health of the People's Republic of China 2009). GABA-enriched foods have become increasingly popular in recent years (Mody et al. 1994). Experimental evidence shows that exogenous GABA can reduce the oxidative damage caused by metal ions in barley seedlings (Song et al. 2010) and alleviate chilling injury (CI) in peach fruit (Shang et al. 2011). Furthermore, it was found that treatment of pear fruit with 100–1000 µg/ml GABA induced strong resistance against blue mold rot caused by *Penicillium expansum* (Yu et al. 2014).

To our knowledge, there is few reports on the effect of exogenous GABA treatment on fresh-cut fruits and vegetables. The aim of this research was to evaluate the effects of exogenous GABA treatment on the browning of fresh-cut potatoes, and the possible mechanisms involved.

Materials and methods

Raw material

Potatoes (Netherlands VII) were purchased from the Shanghai wholesale market in China and quickly transported to the lab. A selected batch of undamaged and non-defective potatoes, with uniform size, color, and maturity were washed to remove the surface dirt and cooled (at 4 °C) immediately, prior to processing.

Effect of GABA concentration on inhibition of browning in fresh-cut potatoes

The potatoes were peeled and cut into 0.5–1 cm thick slices. The potato slices were immediately rinsed in different dipping solutions for 5 min. The dipping solutions were: (1) deionized water (control), (2) 10 g/L GABA, (3) 15 g/L GABA, (4) 20 g/L GABA, (5) 25 g/L GABA, and (6) 20 g/L citric acid (CA, positive control). The potato slices were then air-dried and dispensed into plastic trays with polyethylene plastic wraps and stored at 4 °C with 90% relative humidity (RH). Each sample, containing three replicates, was obtained from nine fruits after each treatment.

Effect of GABA treatment with different rinsing times on inhibition of browning in fresh-cut potatoes

The potatoes were peeled and cut into 0.5–1 cm thick slices. The potato slices were immediately rinsed in 20 g/L GABA or control (deionized water) solution for 5, 10, and 15 min. The slices were then air-dried and dispensed into plastic trays with PE plastic wraps and stored at 4 °C with 90% relative humidity (RH). Each sample, containing three replicates, was obtained from nine fruits after each treatment.

Browning index (BI)

During storage, potato browning was scored visually after 0, 1, 2, 3, 4, 5, and 6 days of storage by determining the extent of surface browning, using the following scores: 0 = No browning; 1 = Browning covering < 25% of the surface; 2 = Browning covering $\geq 25\%$ but < 50% of the surface; 3 = Browning covering $\geq 50\%$ of the surface.

The BI was calculated as follows (Zhang et al. 2015a):

$$\frac{\sum(\text{browning scale} \times \text{No. of corresponding fruits each class})}{4 \times \text{Total No. of fruits}}$$

Color measurement

The colors of the potato slices were analyzed using a tristimulus colorimeter (Chromameter-2 Reflectance, Minolta, Osaka, Japan) equipped with a CR-400 measuring head after 0, 1, 2, 3, 4, 5, and 6 days of storage. The instrument was standardized against a white tile before the measurements. The color was expressed using the Hunter scale parameters L^* , a^* , and b^* . The potato color changes were determined by following the changes in L^* , a^* , and b^* (Manzocco et al. 2011).

Sample treatment for enzyme activity

Tissue samples of the pulp from the 20 g/L GABA, 15 g/L CA, or control fruit treatments were collected after 0, 1, 2, 3, 4, 5, and 6 days of storage and immediately frozen in liquid N_2 . They were ground with a chilled FW-100 grinder until frozen and then stored at -80 °C for the subsequent analyses. Each sample, containing three replicates, was obtained from nine fruits after each treatment.

Enzyme assays

Frozen pericarp tissues were homogenized with different buffers to assay different enzymes: 0.5 mL of sodium acetate buffer (100 mM, pH 5.5) containing 1 mmol polyethylene glycol 6000 (PEG 6000), 4% polyvinylpyrrolidone (PVP), and 1% Triton X-100 for peroxidase (POD), and 3 mL for PPO; sodium borate buffer (100 mM, pH 8.8) containing 40 g/L PVP, 2 mM Ethylenediaminetetraacetic acid (EDTA), and 5 mM β -mercaptoethanol for PAL; and 2 mL of sodium phosphate buffer (100 mM, pH 7.5) containing 5 mM dithiothreitol (DTT) and 5% PVP for catalase (CAT). The homogenate was centrifuged at $12,000 \times g$ for 20 min at 4 °C. The supernatants were used as the crude enzyme sources to assay the enzymatic activities. Each sample, containing

three replicates, was obtained from nine fruits after each treatment, and the experiment was repeated twice.

POD activity was determined using guaiacol as the substrate (Cao et al. 2013). The reaction mixture consisted of 0.5 mL of crude enzyme extract and 3 mL of 25 mM guaiacol (in 50 mM sodium acetate buffer, pH 5.5). The increase in absorbance at 470 nm was measured after the addition of 200 μ L of 0.5 M hydrogen peroxide (H_2O_2) (in 50 mM sodium acetate buffer, pH 5.5). One unit of POD activity was defined as the amount of enzyme that caused an increase in absorbance of 0.01/min at 470 nm, and the activity was expressed as units per mg of protein.

PPO activity was assayed using the method of Cao et al. (2013). The reaction mixtures consisted of 4 mL sodium acetate buffer (50 mM, pH 5.5), 1 mL pyrocatechol, and 100 μ L of crude enzyme extract. One unit of PPO activity was defined as the amount of enzyme extract producing an increase in absorbance of 0.01/min at 420 nm, and the activity was expressed as units per mg of protein.

PAL activity was assayed using the method of Cao et al. (2013) with slight modifications. The assay mixture consisted of 3 mL sodium borate buffer (50 mM, pH 8.8) and 0.5 mL of 20 mM L-phenylalanine. After incubation at 37 °C for 10 min, 0.5 mL of crude enzyme extract was added. Optical density (OD_0) was immediately measured at 290 nm. After incubation at 37 °C for 1 h, OD_1 was immediately measured at 290 nm. One unit of PAL activity was defined as the amount of enzyme that caused an increase in absorbance of 0.01 in 1 h at 290 nm. The results were expressed as units per mg of protein.

CAT was assayed using the method of Cao et al. (2013) with slight modifications. The assay mixture consisted of 2.9 mL of 20 mM H_2O_2 and 100 μ L of crude enzyme extract. One unit of CAT activity was defined as the amount of enzyme extract producing an increase in absorbance of 0.01/min at 240 nm, and the activity was expressed as units per mg of protein.

The superoxide dismutase (SOD) activity was determined by measuring its ability to inhibit the photoreduction of nitro blue tetrazolium (NBT), as described by Toivonen and Sweeney (1998). One unit (U) of SOD activity was defined as the amount of enzyme that caused a 50% inhibition of NBT reduction at 560 nm.

Malondialdehyde (MDA) content assay

Frozen potatoes tissues (1.0 g) were homogenized in 5 mL of 100 g/L trichloroacetic acid. The homogenate was centrifuged for 20 min at 10,000 $\times g$. The supernatant was collected for the measurement of the MDA content.

The MDA concentration was measured in accordance with Cao et al. (2013) with a slight modification. The supernatant

phase (1 mL) was mixed with 2 mL 0.67% thiobarbituric acid. The solution was placed in a boiling water bath for 20 min, and then quickly cooled down and centrifuged at 10,000 $\times g$ for 20 min to clarify the solution. The absorbance was measured at 450, 532, and 600 nm. The MDA concentration was calculated according to the formula:

$$\text{MDA content } (\mu\text{mol/g}) = \frac{[6.45 \times (A_{532} - A_{600}) - 0.56 \times A_{450}] \times V}{V_s \times m \times 1000}$$

where V and V_s are the total volume of the extract solution and the volume of the extract solution contained in the reaction mixture, respectively. The content of MDA was expressed as $\mu\text{mol/g}$.

ROS assay

The superoxide radical (O_2^-) production rate was determined using the method of Elstner and Heupel (1976), with a slight modification. Frozen pericarp tissues were ground using a chilled FW-100 grinder, and 3 g of the powders was homogenized with 15 mL of 50 mM sodium phosphate buffer (pH 7.8) containing 1 mM EDTA, 2% (w/v) PVP and 0.3% Triton X-100. The homogenate was centrifuged at 12,000 $\times g$ for 20 min at 4 °C. A 1 mL sample of the supernatant was mixed with 1 mL of 50 mM sodium phosphate (pH 7.8) and 1 mL of 1 mM hydroxylamine hydrochloride. After incubation for 1 h at 25 °C, 1 mL of the above reaction mixture was added to 1 mL of 17 mM 4-aminobenzene sulfonic acid, and 1 mL of 7 mM α -naphthylamine was added to the mixture, which was incubated for a further 20 min at 25 °C. Then, 4 mL of n-butanol was added to the reaction mixture. The absorbance of the n-butanol phase was measured at 530 nm to determine the O_2^- concentration. The O_2^- production rate was expressed as $\text{nanomol}/(\text{min} \cdot \text{g})$ FW.

The H_2O_2 content was determined according to the method described by Prochazkova et al. (2001). Frozen pericarp tissue was ground using a chilled FW-100 grinder and 1 g of the powder was homogenized with acetone. The homogenate was centrifuged at 12,000 $\times g$ for 20 min at 4 °C. The precipitate was washed repeatedly with cold acetone and dissolved in 3 mL of 2 M H_2SO_4 . After centrifugation at 3000 $\times g$ for 10 min at 4 °C, the absorbance of the supernatant was measured at 412 nm. The H_2O_2 content was expressed as $\mu\text{mol/g}$ FW.

Statistical analysis

The data were analyzed using the one-way analysis of variance (ANOVA univariate, SPSS 17.0, SPSS Inc., Chicago IL, USA). Duncan's multiple range test was used

to compare the mean values of the data, and the statistical significance in this experiment was applied at the level $p \leq 0.05$.

Results and discussion

Effect of GABA treatments with different concentrations on BI and color of fresh-cut potatoes

The effect of different concentrations of GABA was evaluated by BI and color determinations, and visual observation of the fresh-cut potatoes. The values of the BI, colorimetric coordinates (L^* , a^* , and b^*), and colors of the potato slices are shown in Fig. 1 and Fig 6 of Appendix. With the extension of storage time, the BIs of all the samples gradually increased. Different GABA concentrations and the CA treatment significantly ($p \leq 0.05$) decreased the reaction of enzymatic browning in the fresh-cut potato slices (Fig. 1). Although browning still occurred on the potato surfaces, its degree was significantly lower than that in the control. The 20 g/L GABA treatment had the lowest BI among those of the four different GABA treatments.

Color parameters (L^* , a^* , and b^*) were used to measure the browning appearance of the fresh-cut products. L^* (brightness) clearly shows the browning degree of the samples: a higher L^* value indicates a brighter cut surface and a lower browning degree (Chen et al. 2015). The L^* values significantly declined in 2 days and then hardly changed during storage (Fig. 6 of Appendix). After 2 days, the L^* values of the GABA-treated and CA-treated samples were significantly higher than that of the control potatoes ($p < 0.05$). The a^* (green to red) value for all the fresh-cut potatoes increased throughout the storage period, but differences in the GABA-treated and control potatoes were significant from Day 3 to Day 6 (Fig. 6 of Appendix).

Fig. 1 BI of fresh-cut potatoes during storage for different concentrations of GABA in treatments

A significant difference was not found in the b^* (blue to yellow) values between the fresh-cut potatoes before the first day. However, the b^* value at Days 2–6 for the GABA-treated potatoes were significantly higher than that of the control ($p \leq 0.05$). These results indicated that the GABA treatment can improve the L^* , and thereby reduce the browning index.

The visual appearance of fresh-cut products strongly affects the consumers' decision to purchase. The visual appearances of the fresh-cut potatoes on Day 6 after different GABA treatments are shown in Fig. 6 of Appendix. Obviously, the visual appearances of the control on Day 6 were not acceptable to consumers. Combined with the above data, these results indicate that 20 g/L GABA is the most effective and economical treatment to retard the enzymatic browning of fresh-cut potatoes.

Effect of GABA treatments with different rinsing times on BI and color in fresh-cut potatoes

BI showed an increasing trend in the all samples throughout the storage period (Fig. 2). The GABA treatment for 10 min had the lowest BI among different rinsing times with GABA treatments.

The L^* value slightly decreased with the storage time and no significant differences were found for the different rinsing times with GABA. This indicated that the rinsing time in GABA treatments is not a key factor in the browning of fresh-cut potatoes. The GABA-treated potatoes had a significantly lower a^* value than that of the control potatoes, and the difference was significant only from 0 to 3 days of storage ($p \leq 0.05$). The b^* value slightly decreased during storage; the potato slices that were GABA-treated and CA-treated had significantly higher values than that of the control potato slices ($p \leq 0.05$). The visual appearances of the fresh-cut

Fig. 2 BI of fresh-cut potatoes during storage for different soaking times in GABA treatments

Fig. 3 Effect of GABA treatment on activities of PPO (a) and POD (b) in fresh-cut potatoes during storage at 4 °C

potatoes on Day 6 after GABA treatments with different rinsing times are shown in Fig. 7 of Appendix. Obviously, the visual appearance of the control on day 6 was significantly browning compared to the GABA treatment groups.

The present study showed that GABA was effective for decreasing BI. BI, which measures the purity of the brown color, is widely considered an essential index in

Fig. 4 Effect of GABA treatment on activities of PAL (a), CAT (b), and SOD (c) in fresh-cut potatoes during storage at 4 °C

the fresh-cut industry (Zambrano-Zaragoza et al. 2014). GABA can effectively decrease BI of fresh-cut potatoes (Figs. 1, 2). According to Figs. 6, 7 of Appendix, the L* of the GABA treatment was higher the control. It was proved that GABA can decrease the browning of fresh-cut potatoes again. At the same time, the visual appearance indicated that GABA can retard the enzymatic browning of fresh-cut potatoes (Figs. 6, 7 of Appendix). The combined BI, L*, a*, and b* values and visual appearance indicated that 20 g/L GABA for 10 min is the most

effective and economic treatment to retard the enzymatic browning of fresh-cut potatoes.

PPO and POD activities

Enzymatic browning occurs as a result of the oxidation of phenolic compounds by PPO to form quinones (Zhu et al. 2009; Yoruk and Marshall 2003). In general, browning does not occur because PPO, POD, and phenolic compounds are localized in different areas in a whole cell; i.e., the localization can prevent PPO and POD from interacting with the phenolic compounds, and thus, retard the occurrence of browning. However, cutting destroys this distribution. When subjected to mechanical damage, it was easy to cause PPO reactions which would lead to enzymatic browning (Duan et al. 2007). The PPO enzyme activities in the fresh-cut potatoes increased with storage time, but there was no significant difference between the GABA-treated and control samples at Days 0 and 1 (Fig. 3a). We deduced that GABA had not acted on Days 0 and 1. The control fresh-cut potatoes exhibited a significantly rapid increase in the PPO activities. The PPO activities reached the maximum on Day 6 in each treatment. After Day 1, the GABA-treated and CA-treated samples had significantly lower PPO activities than that in the control ($p \leq 0.05$). On Day 2, the PPO activity of the GABA-treated potatoes was 45.6% of that in the control potatoes. PPO plays an important role in enzymatic browning. Hence, the level of PPO activity may be associated with the browning rate. Studies indicated that the color of sliced potatoes was an indirect measure of the PPO activity (Severini et al. 2003). In many horticultural crops, PPO activity is involved in tissue browning. Research showed that β -aminobutyric acid (BABA) treatment inhibited PPO activity, and thus promoted resistance against blue mold in apple fruit (Zhang et al. 2011). This indicates that the PPO activity is negatively related to the BI. Combined with the Figs. 6, 7 of Appendix data, this demonstrates that GABA inhibited the browning of fresh-cut potatoes by decreasing the PPO activity.

In the enzymatic defense system, POD plays a major role in scavenging ROS, which could eliminate the excess peroxide in cells, protect the membrane from destruction, and decrease the peroxidation of membrane lipids. The activities of POD in all treatments were increased trend after 2 days, but showed no significance difference ($p > 0.05$). The POD activities reached the minimum on Day 2, and the POD activity of the GABA-treated potatoes was 2.54 times that in the control potatoes. It may be the catalytic reaction of PPO, which generates and accumulates a certain amount of H_2O_2 , that provides sufficient substrate

for the POD catalytic reaction and accelerates browning to some extent.

Antioxidant enzymes

The activity of PAL dramatically increased in the control during the first day, whereas those in the GABA-treated potatoes slightly decreased (Fig. 4a). After Day 1, the activities of PAL slightly increased and the differences were not significant between samples. Overall, the PAL content in the GABA-treated samples was lower than that of the control. This result was consistent with those from earlier studies which showed that tissue wounding, the key factor in the synthesis of phenolic compounds, can induce the synthesis and activity of PAL (Saltveit 2000). Thus, GABA has less effect than control of tissue wounding on the PAL activities. Earlier studies have shown that the PAL activities in curing-treated potatoes were lower than that in the control, thus delaying enzymatic browning (Hou et al. 2014). Furthermore, the PAL activities were inhibited in treated potatoes stored in controlled atmospheres (Ma et al. 2010).

When the capacity for eliminating ROS is weakened, the accumulation of ROS damages the cell membrane and further reduces the quality of fresh-cut products (Duan et al. 2011). Plant tissues contain a variety of enzymes such as POD, SOD, and CAT to limit the ROS content. CAT removes H_2O_2 from plants, whereas SOD eliminates the ROS produced by metabolic processes and reduces the amount of active oxygen required for enzymatic browning. SOD activates O_2^- to H_2O_2 , whereas eliminating H_2O_2 is the responsibility of CAT (Blokina et al. 2003). With time, the CAT activity in potatoes increased and then decreased. However, the CAT activities in the GABA-treated and CA-treated samples were significantly higher than those in the control potatoes during storage ($p \leq 0.05$). As shown in Fig. 4c, the SOD activity in the GABA-treated and CA-treated potatoes steadily rose to a peak at 2 days but declined 2 day after of storage. The SOD activity in the GABA-treated potatoes were significantly higher than that in the control for up to 4 days ($p < 0.05$). On Day 2, the SOD activity of the GABA-treated potatoes was 1.62 times that in the control potatoes. GABA treatment activates CAT and SOD to scavenge excess ROS from tissues, thus protecting cell membranes from damage and inhibiting senescence and browning during storage. Similarly, apple polyphenol treatment enhanced the activities of the antioxidant enzymes (SOD and CAT) in litchi fruit, which might be beneficial for scavenging ROS (Zhang et al. 2015c). Thus, GABA can increase the activities of CAT and SOD and inhibit browning.

Fig. 5 Effect of GABA treatment on O_2^- production rate (a), content of H_2O_2 (b), and MDA (c) in fresh-cut potatoes during storage at 4 °C

ROS generation and MDA content

ROS, including superoxide radicals (O_2^-), hydrogen peroxide (H_2O_2), singlet oxygen (1O_2), and hydroxyl radicals ($OH^\cdot$), affect many cellular functions through the oxidation of proteins. A strong oxidative burst will cause cellular damage and death. Under normal and healthy conditions, the ROS molecules are scavenged by various antioxidative defense mechanisms.

The O_2^- production rate and the content of H_2O_2 and MDA in potatoes in response to GABA treatments are

shown in Fig. 5a–c. The O_2^- production rate in the GABA-treated and CA-treated samples were slightly decreased for 2 days. An increase in the O_2^- production rate in all the samples was observed after 2 days. Decreases in H_2O_2 content were observed before Day 5, with sharp decreases on Day 2 in all the samples. The H_2O_2 contents in the GABA-treated and CA-treated samples were significantly lower than those in the control potatoes during storage ($p \leq 0.05$). This corresponded with the earlier results, indicating that GABA treatment activated CAT, SOD, and POD to remove the excess ROS from tissues.

MDA is the product of membrane lipid peroxidation and it can directly reflect the extent of membrane lipid peroxidation induced by tissue wounding. The MDA content in all treatments were decreased trend during storage. The MDA content sharply decreased from 2 to 4 days of storage after GABA treatment. On Day 4, it reached the lowest value, at 60.2% of the control. It may be the enhancement of cell membrane permeability after segmentation, that accelerates tissue aging and quality deterioration.

The results showed that the O_2^- production rate and the contents of H_2O_2 in the GABA- and CA-treated samples were significantly lower than those in the control potatoes during the entire storage study ($p \leq 0.05$).

Conclusion

The results showed that GABA treatments with different concentrations and rinsing times could reduce the browning of fresh-cut potatoes, 20 g/L for 10 min being the most effective treatment. The BI decreased due to exogenous GABA treatment. GABA treatment decreased the activity of PPO, which led to the accumulation of quinones. A lower content of ROS was also observed in the fresh-cut potatoes, accompanied by an increase in the CAT and SOD activities. Therefore, GABA treatment could be considered an effective approach to retard the browning of fresh-cut potatoes. Future research on the effects of GABA treatments on the nutrient and sensory parameters of fresh-cut potatoes is necessary before they can be commercially applied.

Acknowledgements This research was supported by the project of the Science and Technology Innovation Action Plan of the Shanghai Science and Technology Commission (No. 18391901300) and the National Science and Technology Support Plan Project (No. 2015BAD16B02). This study was also supported by the project of the Food Science Discipline Construction of Shanghai University.

Appendix

See Figs. 6, 7.

Fig. 6 Color (a, b, and c) of fresh-cut potatoes treated with different concentrations of GABA, during storage, and appearance of fresh-cut potatoes (d) on Day 6

Fig. 7 Color (a, b, and c) of fresh-cut potatoes during storage, for different GABA soaking times in treatments, and appearance of fresh-cut potatoes (d) on Day 6

References

- Ali HM, El-Gizawy AM, El-Bassiouny RI, Saleh MA (2016) The role of various amino acids in enzymatic browning process in potato tubers, and identifying the browning products. *Food Chem* 192:879–885
- Blokhina O, Virolainen E, Fagerstedt KV (2003) Antioxidants, oxidative damage and oxygen deprivation stress: a review. *Ann Bot-London* 91:179–194
- Cantos E, Tudela JA, Gil MI, Espín JC (2002) Phenolic compounds and related enzymes are not rate-limiting in browning development of fresh-cut potatoes. *J Agr Food Chem* 50(10):3015–3023
- Cao JK, Jiang WB, Zhao YM (2013) Experiments guide of physiological and biochemical for postharvest fruits and vegetables, 1st edn. China Light Industry Press, Beijing
- Chen BN, Xing R, Wang F, Zheng AP (2015) Inhibitory effects of α - $\text{Na}_3\text{SiW}_{11}\text{CoO}_{40}$ on tyrosinase and its application in controlling browning of fresh-cut apples. *Food Chem* 188:177–183
- Chen C, Hu W, He Y, Jiang A, Zhang R (2016) Effect of citric acid combined with UV-C on the quality of fresh-cut apples. *Food Chem* 111:126–131
- Derossi A, Mastrandrea ML, Amodio ML, de Chiara MLV, Colehhi G (2016) Application of multivariate accelerated test for the shelf life estimation of fresh-cut lettuce. *J Food Eng* 169:122–130
- Duan X, You Y, Qu H, Li Y, Jiang Y (2007) Effect of nitric oxide on pericarp browning of harvested longan fruit in relation to phenolic metabolism. *Food Chem* 104:571–576
- Duan X, Liu T, Zhang D, Su X, Lin H, Jiang Y (2011) Effect of pure oxygen atmosphere on antioxidant enzyme and antioxidant activity of harvested litchi fruit during storage. *Food Res Int* 44:1905–1911
- Elstner EF, Heupel A (1976) Inhibition of nitrite formation from hydroxylammonium-chloride: a simple assay for superoxide dismutase. *Anal Biochem* 70:616–620
- Hou Z, Feng Y, Wei S, Wang Q (2014) Effects of curing treatment on the browning of fresh-cut potatoes. *Am J Potato Res* 91(6):655–662
- Ma Y, Wang Q, Hong G, 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 Tech* 45(7):1486–1494
- Manzocco L, Pieve SD, Maifreni M (2011) Impact of UV-C light on safety and quality of fresh-cut melon. *Innov Food Sci Emerg* 12(1):13–17
- Mishra BB, Gautam S, Sharma A (2013) Free phenolics and polyphenoloxidase (PPO): the factors affecting post-cut browning in eggplant (*Solanum melongena*). *Food Chem* 139:105–114
- Mody I, De Koninck Y, Otis T, Soltesz I (1994) Bridging the cleft at GABA synapses in the brain. *Trends Neurosci* 17(12):517–525
- Notice of the Ministry of Health of the People's Republic of China, 2009
- Prochazkova D, Sairam RK, Srivastava GC (2001) Oxidative stress and antioxidant activity as the basis of senescence in maize leaves. *Plant Sci* 161(4):765–771
- Queiroz C, da Silva AJR, Lopes MLM, Fialho E, Valente-Mesquita VL (2011) Polyphenol oxidase activity, phenolic acid composition and browning in cashew apple (*Anacardium occidentale*, L.) after processing. *Food Chem* 125(1):128–132
- Rechner AR, Pannala AS, Rice-Evans CA (2001) Caffeic acid derivatives in artichoke extract are metabolised to phenolic acids in vivo. *Free Radical Res* 35(2):195–202
- Saltveit ME (2000) Wound induced changes in phenolic metabolism and tissue browning are altered by heat shock. *Postharvest Biol Technol* 21(1):61–69
- Severini C, De Pilli T, Romaniello R, Derossi A (2003) Prevention of enzymatic browning in sliced potatoes by blanching in boiling saline solutions. *LWT-Food Sci Technol* 36(07):657–665
- Shang HT, Cao SF, Yang ZF, Cai YT, Zheng YH (2011) Effects of exogenous gamma-aminobutyric acid treatment on proline accumulation and chilling injury in peach fruit after long-term cold storage. *J Agr Food Chem* 59:1264–1268
- Soliva-Fortuny RC, Martin-Belloso O (2003) New advances in extending the shelf-life of fresh-cut fruits: a review. *Trends Food Sci Tech* 14:41–353
- Song HM, Xu XB, Wang H, Wang HZ, Tao YZ (2010) Exogenous gamma-aminobutyric acid alleviates oxidative damage caused by aluminium and proton stresses on barley seedlings. *J Sci Food Agr* 90:1410–1416
- Thybo AK, Christiansen J, Kaack K, Petersen MA (2006) Effect of cultivars, wound healing and storage on sensory quality and chemical components in pre-peeled potatoes. *LWT-Food Sci Technol* 39(2):166–176
- Toivonen PMA, Sweeney M (1998) Differences in chlorophyll loss at 13 & #xB0;C for two broccoli (*Brassica oleracea* L.) cultivars associated with antioxidant enzyme activities. *J Agr Food Chem* 46(1):20–24
- Wang Q, Cao Y, Zhou L, Jiang C, Feng Y, Wei S (2015) Effects of postharvest curing treatment on flesh color and phenolic metabolism in fresh-cut potato products. *Food Chem* 165:246–254
- Yoruk R, Marshall MR (2003) A survey on the potential mode of inhibition for oxalic acid on polyphenol oxidase. *J Food Sci* 68(8):2479–2485
- Yu C, Zeng L, Sheng K, Chen F, Zhou T, Zheng X, Yu T (2014) γ -Aminobutyric acid induces resistance against *Penicillium expansum* by priming of defence responses in pear fruit. *Food Chem* 159:29–37
- Zambrano-Zaragoza ML, Mercado-Silva E, Del Real A, Gutierrez-Cortez E, Cornejo-Villegas MA, Quintanar-Guerrero D (2014) The effect of nano-coatings with α -tocopherol and xanthan gum on shelf-life and browning index of fresh-cut fresh-cut “Red Delicious” apples. *Innov Food Sci Emerg* 22:188–196
- Zhang CF, Wang JM, Zhang JG, Hou CJ, Wang GL (2011) Effect of β -aminobutyric acid on control of postharvest blue mould of apple fruit and its possible mechanisms of action. *Postharvest Biol Technol* 61:145–151
- Zhang Q, Liu Y, He C, Zhu S (2015a) Postharvest exogenous application of abscisic acid reduces internal browning in pineapple. *J Agr Food Chem* 63(22):5313–5320
- Zhang ZK, Huber DJ, Qu HX, Yun Z, Wang H, Huang ZH, Huang H, Jiang YM (2015b) Enzymatic browning and antioxidant activities in harvested litchi fruit as influenced by apple polyphenols. *Food Chem* 171:191–199
- Zhang ZZ, Huber DJ, Qu H, Yun Z, Wang H, Huang Z (2015c) Enzymatic browning and antioxidant activities in harvested litchi fruit as influenced by apple polyphenols. *Food Chem* 171:191–199
- Zhu L, Zhou J, Zhu SH, Guo LH (2009) Inhibition of browning on the surface of peach slices by short-term exposure to nitric oxide and ascorbic acid. *Food Chem* 114:174–179