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Original Article

Effect of honey and calcium dips on quality of fresh-cut nectarine (*Prunus persica* L. Batsch)

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ABSTRACT

The effects of calcium chloride ($CaCl_2$) and honey dips were investigated on the quality of fresh-cut nectarines. Nectarine fruit samples at the commercially ripe stage were wedged and then dipped in distilled water, 50% honey, 1% $CaCl_2$ or 1% $CaCl_2$ combined with 50% honey solutions, followed by storage at 4 ± 0.5 °C and 90 ± 2% relative humidity for 7 d. The following parameters were investigated during storage: firmness, total soluble solids (TSS), superficial color, color darkening score and index, total phenols content and the enzyme activities of peroxidase and polyphenol oxidase (PPO). $CaCl_2$ and $CaCl_2$ + honey solution dips improved the texture and maintained the TSS content. Honey and $CaCl_2$ + honey suppressed an increase in the color difference. Minor changes were found in color attributes (lightness (L^*), hue and chroma values), color darkening, total phenols content and PPO activity during storage. $CaCl_2$ + honey maintained the quality of the nectarines by delaying color change and firmness loss.

Introduction

The fresh-cut fruit market has been growing rapidly because consumers are interested in healthy and ready-to-eat fruit products (Olivas and Barbosa-Cánovas, 2005). Fresh-cut fruit is normally processed by trimming, peeling, washing and/or cutting which will physically alter its original state (Ergun and Ergun, 2010; Supapvanich and Boonyaritthongchai, 2016). The physical damage and wounding caused by processing increase ethylene production leading to changes in the texture, color and flavor during storage, so retention of fresh-cut produce quality is a big challenge (Lamikanra et al., 2000; Supapvanich and Tucker, 2013). Edible coatings can be used to preserve minimally processed fruits, as the coatings provide a partial barrier to moisture, oxygen and carbon dioxide, improve mechanical handling properties, can carry additives and avoid volatiles loss (Song et al., 2013; Supapvanich et al., 2016).

Honey is an ideal edible coating agent due to it being tasty and having antioxidant and gelling properties which could help to prevent enzymatic browning in fresh-cut fruit (Olivas and Barbosa-Cánovas, 2005). Ates et al. (2001) reported that a peptide from honey could inhibit polyphenol oxidase (PPO) extracted from mushroom. Recently, honey has been proved as an effective anti-browning agent by inhibiting browning activity in raisins (McLellan et al., 1995), fresh-cut apple (Oszmianskii and Lee, 1990; Jeon and Zhao, 2005), fresh-cut persimmon (Son et al., 2001; Ergun and Ergun, 2010) and fresh-cut mango fruit (Supapvanich and Boonyaritthongchai, 2016).

The application of calcium is also a potential approach to maintaining postharvest quality, especially texture, and to control certain physiological disorders of fresh commodities (Lester and Grusak, 1999). Manganaris et al. (2007) demonstrated that post-harvest application of calcium inhibited flesh softening and limited the intensity of chilling injury symptoms. It is recognized that calcium inhibits the increase of water-soluble pectin by creating calcium pectate and inhibiting the activity of pectin modifying enzymes, helping to retain fruit texture (Lara et al., 2004;

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Manganaris et al., 2007). Calcium also maintains the cell wall structure and functions by controlling osmotic tonicity and lipid membrane degradation (Lester, 1996). In addition, calcium treatment has been found to retard the senescence of fruits and vegetables by increasing the microviscosity of membranes (Poovaiah, 1986).

Nectarine (*Prunus persica* L. *Batsch*) is a high-functional fruit containing bioactive compounds and antioxidants (Legua et al., 2011). Loss of texture and color change are the main causes of loss of quality in fresh-cut nectarines. In this work, the effectiveness of honey and calcium in maintaining the texture and color quality of fresh-cut nectarine during storage was investigated.

Materials and methods

Plant materials and minimal processing

Samples of nectarines (*Prunus persica* L. *Batsch*) cv. 'Manyuan Hong' fruit were obtained from a local farm in Hefei City, Anhui province, China. The fruits were selected based on uniformity of size, blush and background color and the absence of physical damage and infections. The fruits were washed with tap water and then immersed in 50 μL/L sodium hypochlorite for 5 min. The fruits were cut in half with a sharp knife and each half was cut at the exposed end into three equal pieces. The endocarp tissue and calyx end of the fruit were removed. All experiments were repeated with four fruits.

Effects of honey dips on fresh-cut nectarine quality

Commercial locust honey from the Anhui Agricultural University Research Farm, China was diluted with distilled water to 10%, 20%, 30%, 40% or 50% (volume per volume, v/v). The fresh-cut fruits were dipped into one of the different concentrations of honey solution for 1 min and samples dipped in distilled water for 1 min were used as the control. The treated fruit was placed on a foam tray (15 cm × 21 cm × 2.5 cm) and wrapped with polyvinylchloride (PVC) cling film (11 μm thickness). The color darkening scores and overall acceptability scores were determined after storage at 4 ± 0.5 °C and 90 ± 2% relative humidity (RH) for 5 d. The best treatment in this study was selected for the next experiment.

Effects of $CaCl_2$ incorporated with honey dips on quality of fresh-cut nectarine

The fresh-cut fruit was dipped in 50% honey, 1% $CaCl_2$ or 1% $CaCl_2$ + 50% honey for 1 min; fruits were dipped in distilled water for 1 min for the control. Four pieces of the fresh-cut fruit from each treatment were placed on a foam tray (15 cm × 21 cm × 2.5 cm) and wrapped with PVC cling film as previously. The color darkening score was determined every 2 d during storage at 4 ± 0.5 °C and 90 ± 2% RH for 7 days.

Color darkening and overall acceptability score evaluations

The color darkening and overall acceptability scores were estimated using hedonic scoring evaluation. The appraisal was performed by 20 semi-trained panelist and 50 panelists for color darkening and overall acceptability evaluations, respectively. The color darkening score was evaluated as 0 (no change), 1 (slightly dark), 3 (moderately dark) and 5 (extremely dark). The overall acceptability score was evaluated using scores of 0 (unacceptable), 1 (slightly acceptable), 5 (moderately acceptable) and 9 (extremely acceptable).

Browning index

The browning index was determined using the method described by Supapvanich et al. (2011). Two grams of the nectarine flesh were homogenized with 100 mL of 65% (v/v) ethanol and then stirred at room temperature for 1 h. The extraction sample was filtered using Whatman No.1 filter paper. The absorbance at 420 nm (OD_{420}) was measured using a visible-ultraviolet spectrophotometer (UV-5100; Lengguang, Shanghai, China). The browning index was expressed as OD_{420} per 100 g fresh weight (OD_{420}/100 g FW).

Firmness measurement

The texture of the flesh was determined using a CT3 texture analyzer with a TA39 adapter (Brookfield; Middleboro, MA, USA). The probe was driven at a crosshead speed of 0.5 mm/s to a depth of 4 mm. TMiddleboro, MA he maximum force exerted during penetration was expressed in grams.

Total soluble solids content measurement

Juice was squeezed from the nectarine tissues and then measured at room temperature (RT; 20 ± 5 °C) using a hand refractometer (PAL-1; Atago; Tokyo, Japan). The TSS contents were expressed in °Brix.

Superficial color measurement

The flesh color was measured using a Hunter Lab MiniScan@XE Plus (Hunter Associates Laboratory Inc.; Reston, VA, USA). The superficial tristimulus color was presented as lightness (L* value), hue value, chroma value and color difference (ΔE^*) value. The ΔE^* value was calculated using Equation (1) which was slightly modified from Robertson (1990):

$$\Delta E^* = \left[\left(L_0^* - L_x^*\right)^2 + \left(hue_0 - hue_x^2\right) + (chroma_0 - chroma_x)^2\right]^{1/2} \quad (1)$$

Analysis of total phenols content and the activities of polyphenol oxidase and peroxidase

Three grams of the flesh were extracted by homogenizing with 25 mL of 4 °C cold, distilled water and then centrifuged at 10,000 × *g* for 20 min at 4 °C using a centrifuge (Allegra X-30R; Beckman Coulter; Brea, CA, USA). The supernatant was collected. Total phenols content was determined using the method described by Slinkard and Singleton (1977). Data were expressed in milligrams of gallic acid per 100 g fresh weight (mg GA/100 g FW).

Three grams of the flesh were homogenized with 10 mL of 0.1 M phosphate buffer (pH 6.0) using a homogenizer (ESB-500; Shanghai ELE Mechanical & Electrical Equipment Co., Ltd.; Shanghai, China). The extraction sample was centrifuged at 10,000 × g for 20 min at 4 °C using the centrifuge. The supernatant was collected. Polyphenol oxidase (PPO) activity was performed using the method of Galeazzi et al. (1981). One unit of PPO activity was defined as a change of 0.01 in absorbance per min.

Peroxidase (POD) activity was assayed by the method of Andrade Cuvi et al. (2011), where one unit of POD activity was defined as a change of 0.01 in absorbance per min. Both PPO and POD activities were presented as units per 100 g fresh weight (U/100 g FW).

Statistical analysis

A complete randomized design was used. Statistical analysis was carried out using analysis of variance and the means were compared using a *post hoc* least significant difference (LSD) test at a significance level of $p \leq 0.05$ with the SPSS software program (version 19.0; SPSS Inc.; Chicago, IL, USA).

Results and discussion

Effect of honey concentrations on color darkening and overall acceptability scores

Fig. 1 shows the color darkening and overall acceptability scores of nectarine wedges dipped in honey solution at various concentrations. The results showed that a honey solution higher than 30% concentration delayed color darkening, with the lowest color darkening score for the flesh dipped in 50% honey solution. The overall acceptability score of the flesh increased with increased honey concentration. The highest score for overall acceptability was for the flesh dipped in 50% honey solution. These results suggested that dipping in 50% honey solution could maintain the cut-surface color darkening and overall acceptability of fresh-cut nectarines during cold storage. Thus, the effect of $CaCl_2$ incorporated with 50% honey solution was selected to investigate the physicochemical quality of fresh-cut nectarines during cold storage.

Effect of honey and calcium dips on firmness and total soluble solids content

Fig. 2 shows the values for firmness and TSS content of fresh-cut nectarines during storage. The firmness of fresh-cut nectarines dipped in $CaCl_2$ and $CaCl_2$ + 50% honey solution significantly increased ($p = 0.038$) compared to those dipped in the 50% honey solution and the control (Fig. 2A). The TSS content of fresh-cut nectarines slightly decreased during storage, with the lowest TSS content in the flesh dipped in $CaCl_2$ + 50% honey solution (Fig. 2B). Dipping fresh-cut nectarines in 50% honey solution delayed the loss of TSS content during storage. Ergun and Ergun (2009) reported that pomegranate arils treated with 20% honey solution had significantly higher TSS than untreated arils. However, there was little effect of the honey solution dips on fresh-cut persimmon (Ergun and Ergun, 2010). The loss of firmness was a key factor limiting the quality of fresh-cut nectarines (Legua et al., 2011). In the current research, $CaCl_2$ and $CaCl_2$ + 50% honey solution effectively delayed the softening of fresh-cut nectarines during storage. Calcium can improve the texture of both intact and processed fruit and vegetables by creating an egg-box structure, maintaining osmotic tonicity, and retarding plasma membrane lipid degradation (Lester, 1996). However, $CaCl_2$ dips alone might give an undesirable taste to the fresh-cut fruits. Preliminary work in the current study showed that fresh-cut nectarines dipped in 50% honey solution had the highest overall acceptability score (Fig. 1). Ergun and Ergun (2010) reported that off-flavor and softening of fresh-cut persimmon fruits were suppressed by honey solutions dips as was also the case for pomegranate arils dipped in honey solution (Ergun and Ergun, 2009). Thus, it is suggested that $CaCl_2$ + 50% honey solution dip is an alternative to improve the texture and taste of fresh-cut nectarines during storage.

Effect of honey and calcium dips on superficial color attributes

The changes in the superficial color of the fresh-cut nectarines are shown in Fig. 3. The flesh brightness (L^* value) and hue value of all fresh-cut nectarine treatments were constant during storage (Fig. 3A and B). Dea et al. (2010) suggested that the L^* value is an effective indicator of color darkening in fresh-cut produce. The chroma value of the control slightly decreased during storage, whereas those of $CaCl_2$, 50% honey solution, and $CaCl_2$ + 50% honey solution dips remained constant during storage. The chroma value of fresh-cut nectarine dipped in 50% honey solution was higher than the other treatments, indicating that honey solution, $CaCl_2$ and $CaCl_2$ + 50% honey solution dips had an effect on the chroma values of fresh-cut nectarine. The color difference (ΔE^* value) indicated the difference of the sample color during storage compared with the reference color or the best color of the sample. In this research, the ΔE^* value of the control was higher than those of the other treatments throughout storage. Fresh-cut nectarines dipped in 50% honey solution had the lowest ΔE^* value. This suggested that 50% honey solution could maintain the color of fresh-cut nectarines compared to the other treatments.

Effect of honey and calcium dips on color darkening score and browning index

Fig. 4 shows the darkening score and browning of fresh-cut nectarine during storage. Darkening of the fruit cut-surface was apparent on day 3 of storage. However, after treatment for 1 d, the darkening score of fresh-cut nectarines was zero in all treatments. The browning index of all treatments was similar and close to zero. This suggested that cold storage at 4 °C and PVC film wrapping could delay the surface darkening of the fresh-cut nectarines. On

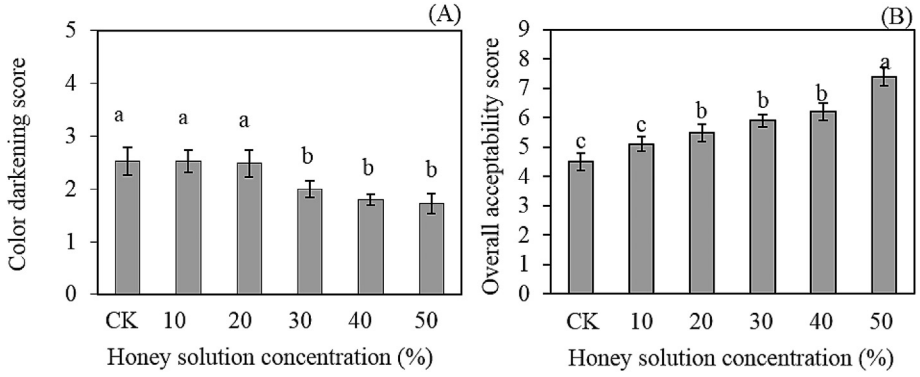

Fig. 1. Color darkening (A); overall acceptability scores (B); of fresh-cut nectarines dipped in honey solution at concentrations of 0% (CK), 10%, 20%, 30%, 40% and 50% and held at 4 ± 0.5 °C and 90 ± 2% relative humidity for 5 d. Vertical bars represent standard deviation of the means ($n = 4$). Significant differences ($p < 0.05$) between means are indicated by different lowercase letters.

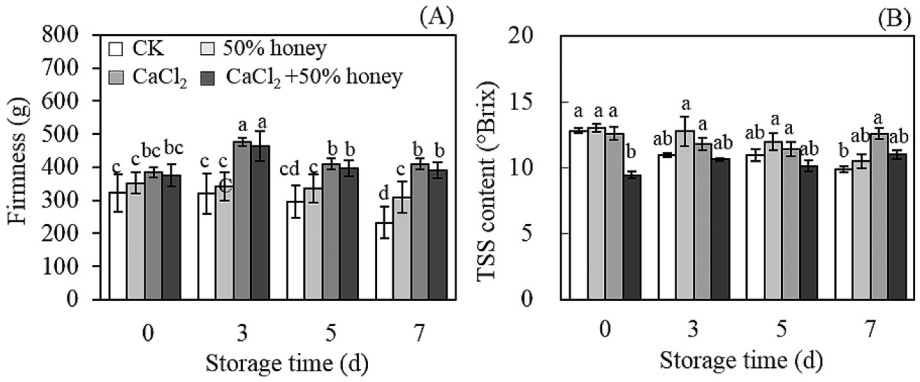

Fig. 2. Firmness (A); Total soluble solids (TSS) content (B); of fresh-cut nectarines dipped in 50% honey, $CaCl_2$ and $CaCl_2$ + 50% honey during storage at 4 ± 0.5 °C and 90 ± 2% relative humidity for 7 d. Vertical bars represent standard deviation of the means ($n = 4$). Significant differences ($p < 0.05$) between means are indicated by different lowercase letters.

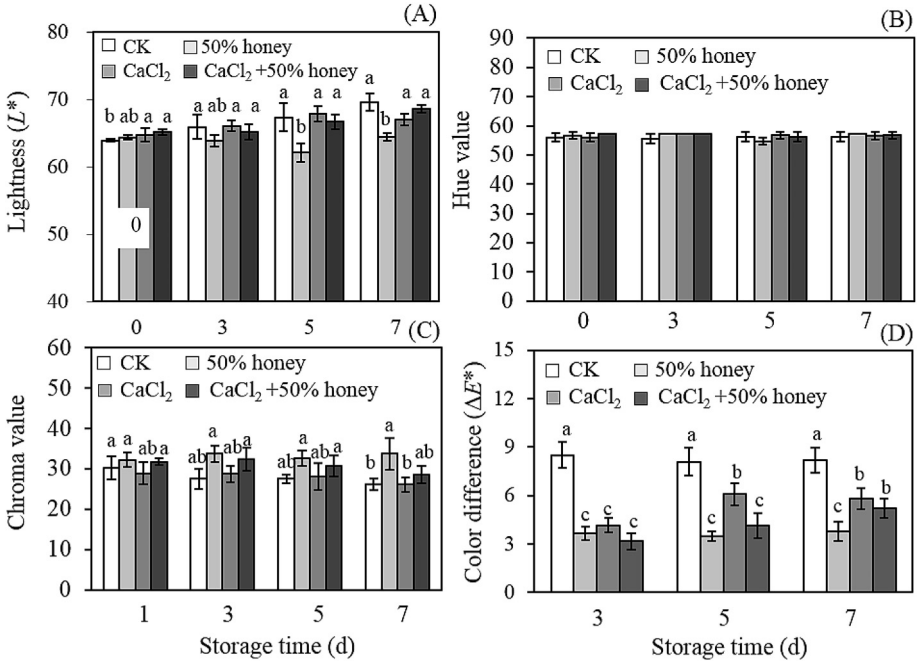

Fig. 3. L* value (A); hue value (B); chroma value (C); color difference (ΔE^*) (D) of fresh-cut nectarines dipped in 50% honey, $CaCl_2$ and $CaCl_2$ + 50% honey during storage at 4 ± 0.5 °C and 90 ± 2% relative humidity for 7 d. Vertical bars represent standard deviation of the means ($n = 4$). Significant differences ($p < 0.05$) between means are indicated by different lowercase letters.

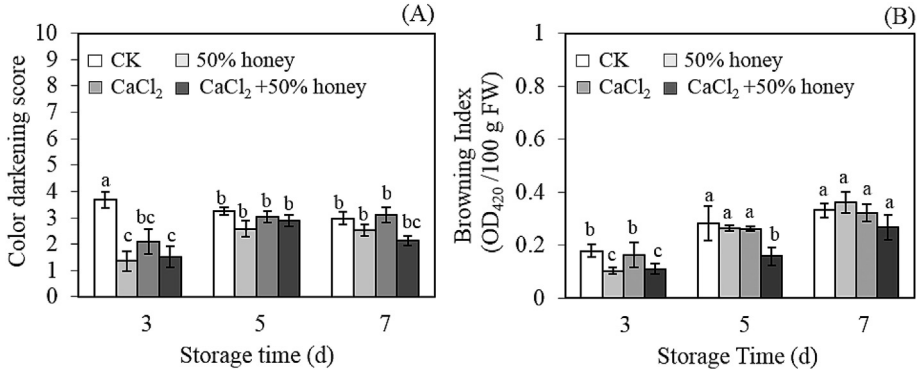

Fig. 4. Color darkening score (A); browning index (B); of fresh-cut nectarines dipped in 50% honey, $CaCl_2$ and $CaCl_2$ + 50% honey during storage at 4 ± 0.5 °C and 90 ± 2% relative humidity for 7 d. Vertical bars represent standard deviation of the means ($n = 4$). Significant differences ($p < 0.05$) between means are indicated by different lowercase letters (FW = fresh weight).

day 3, the color darkening score of the control sample was significantly higher than that of the other treatments whilst those of both the 50% honey and $CaCl_2$ + 50% honey dips were lower than that of the $CaCl_2$ treatment alone. On day 5 and day 7 of storage, the color darkening scores of all treatments were not significantly different. The browning index (OD_{420}) of fresh-cut nectarines was in the range 0.1–0.4 (Fig. 4B). On day 3 of storage, the browning index of both honey treatments was clearly lower than that of the $CaCl_2$ treatment and the control. $CaCl_2$ + 50% honey dip could delay the increase in the browning index of the fresh-cut nectarines in contrast to the other treatments. It was noted that the browning index of the fresh-cut nectarines was low in this cultivar. Thus, this could indicate that browning incidence might not be the main factor affecting the superficial color of fresh-cut nectarines cv. 'Manyuan Hong' as was found in the changes in the L^* value (Fig. 3A). The change in the browning index of fresh-cut nectarines was associated with the color darkening score. Hopfinger et al. (1984) reported that $CaCl_2$ could delay the darkening of apple flesh color by decreasing the enzymatic browning reaction; however, $CaCl_2$ dip alone was not sufficient to inhibit browning incidence. Moreover, the effect of honey dip on the browning inhibition of fresh-cut fruits was reported for 'Nam Dok Mai' mango cubes (Supapvanich and Boonyaritthongchai, 2016), persimmon cubes (Ergun and Ergun, 2010) and apple slices (Jeon and Zhao, 2005). Moreover, Sapers and Miller (1998) reported that the addition of $CaCl_2$ enhanced browning inhibitor performance in pear wedges. The browning inhibition property of honey might be related to its high antioxidant content (Ergun and Ergun, 2009). Thus, the use of $CaCl_2$ incorporated with honey was an effective alternative for maintaining the color of fresh-cut nectarines during storage.

Effect of honey and calcium dips on total phenols content, and polyphenol oxidase and peroxidase activities

The total phenols content, PPO, and POD activities of fresh-cut nectarines are shown in Fig. 5. The total phenols content and both browning enzymes activities started to change on day 3 because darkening and browning were not apparent on the fresh-cut fruit on day 1. No significant differences were found among the total phenols content for all treatments during storage (Fig. 5A). The PPO and POD activities of fresh-cut nectarine increased throughout storage (Fig. 5B and C). At day 7 of storage, the $CaCl_2$ dip alone stimulated PPO and POD activities compared to the other treatments. Dipping in 50% honey solution decreased the activities of PPO and POD compared to the control sample. Gacche et al. (2009) considered that honey is an inhibitor of PPO activity. Moreover, Jeon and Zhao (2005) suggested that honey had an inhibitory effect against superoxide anion radicals, which resulted in the inhibition of the enzymatic browning reaction. Induced POD activity by calcium treatment has been reported for pear fruit (Tian et al., 2006) and sweet potato (Kwak et al., 1996). However, in the current study, the change in POD was not related to the browning incidence of the nectarine wedges. POD is widely known as an antioxidant enzyme. Thus the use of calcium might enhance antioxidants in the fresh-cut fruit. Thus, the changes in total phenols, PPO, and POD activities might be not related to the browning incidence (Fig. 4) and total color changes (Fig. 3D) of fresh-cut nectarines during storage.

In conclusion, the loss of firmness was the main problem limiting the quality of fresh-cut nectarines. The use of $CaCl_2$ and $CaCl_2$ + 50% honey solution could improve the firmness of fresh-cut nectarines. The honey solution dip alone slightly prevented the softening of fresh-cut nectarines. Both the 50% honey solution and $CaCl_2$+50% honey solution dip maintained the color of fresh-cut nectarines over the storage period. Browning incidence was not

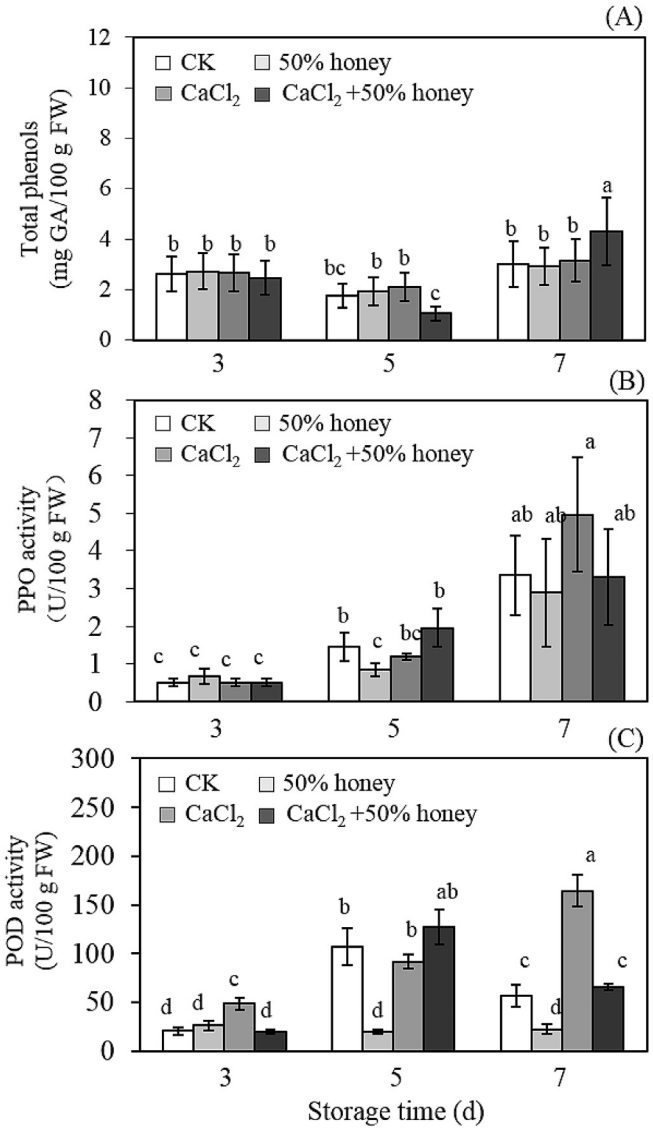

Fig. 5. Total phenols content (A); polyphenol oxidase (PPO) (B); peroxidase (POD) (C) activities of fresh-cut nectarines dipped in 50% honey, $CaCl_2$ and $CaCl_2$ + 50% honey during storage at 4 ± 0.5 °C and 90 ± 2% relative humidity for 7 d. Vertical bars represent standard deviation of the means (n = 4). Significant differences ($p < 0.05$) between means are indicated by different lowercase letters (FW = fresh weight).

the key factor limiting the quality of fresh-cut nectarines. The changes in the total phenols, PPO and POD activities seemed not to be related to browning incidence. Interestingly, the PPO and POD activities were inhibited by the 50% honey solution dip. It is suggested that the use of $CaCl_2$ + 50% honey dip is an alternative for improving the quality of fresh-cut nectarines during storage.

Conflict of interest statement

The authors declared that they have no conflicts of interest regarding this work.

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