



Research article

Hot air treatment mitigates chilling injury in mango fruit by enhancing antioxidant system activity

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Abstract

Importance of the work: Mango fruit is sensitive to chilling injury when stored below 12°C. Heat treatment can delay or reduce this chilling injury.

Objectives: To investigate the effects of heated air treatment on chilling injury and the antioxidant system in mango stored at 4°C.

Materials & Methods: Mature fruits of the mango cultivar Nam Dok Mai were treated with heated air at 38°C for 3 d, while the control fruits were held at room temperature. After heated air treatment, all fruits were stored at 4°C. Control and stored fruits were assessed for chilling injury and antioxidant system activity in the peel.

Results: The mango fruits stored at 4°C had significant peel browning (chilling injury) that became more severe after transfer to room temperature. Fruits exposed to heated air treatment at 38°C (60% relative humidity, RH) for 3 d before storage at 4°C had delayed peel browning for up to 3.5 d during and after cold storage. Heat treatment increased total antioxidant activity capacity and catalase activity. The heated air treatment did not reduce ascorbate peroxidase, guaiacol peroxidase or superoxide dismutase activity levels in the mango peel, both during storage at 4°C and after transfer to room temperature (27–28°C, 75% RH).

Main finding: The heated air treatment increased chilling injury tolerance in mango and was associated with total antioxidant capacity and catalase activity, but not with the activity levels of ascorbate peroxidase, guaiacol peroxidase or superoxide dismutase.

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Introduction

Mango is one of the important economic tropical fruits of Thailand (Tjiptono et al., 1984). Mango fruit is highly sensitive to chilling injury when stored below 12°C with the most common symptom of such chilling injury being peel browning, with major differences in chilling injury among mango cultivars (Phakawatmongkol et al., 2004). For example, the Nam Dok Mai mango cultivar, which is one of the most popular among mangoes grown commercially in Thailand (Kusumo et al., 1984), when held at 4°C has more peel browning than the Choke Anan mango. Peel browning is especially manifest when mango fruits are transferred from low temperature conditions to room temperature (Chongchatuporn et al., 2013).

The production of reactive oxygen species (ROS) in plant tissues is induced by abiotic stresses, including exposure to low temperature, with the ROS reacting rapidly with a range of different molecules, resulting in cellular damage (Blokhina et al., 2003). ROS species include superoxide ($O_2^{\cdot-}$), hydrogen peroxide (H_2O_2), the hydroxyl radical ($OH^{\cdot}$) and singlet oxygen (1O_2) (Lee and Lee, 2000). One of the effects of ROS is peroxidation of membrane lipids (Shewfelt and Rosario, 2000). The destructive properties of superoxide and hydrogen peroxide are increased further when they interact in the presence of metal ions to form the highly reactive hydroxyl radical that can damage many biological molecules such as proteins, unsaturated fatty acids and DNA (Sharma et al., 2012). Plants have various mechanisms for defending against ROS, including the synthesis of some specific compounds (Blokhina et al., 2003) and various antioxidant enzymes, including catalase (CAT), superoxide dismutase (SOD), ascorbate peroxidase (APX), guaiacol peroxidase (GPX), and peroxidase (POD) (Apel and Hirt, 2004). Chilling injury is thought to induce an increase in ROS content during low temperature storage (Lee et al., 2020).

High temperature, including the use of heated air or hot water, has been shown to delay or reduce chilling injury in a number of different tropical and subtropical fruits (Lurie and Pedreschi, 2014). For example, heat treatment has alleviated chilling injury in avocado (Donadon et al., 2012), mango (Vega-Alvarez et al., 2020), banana (Promyou et al., 2008), loquat (Shao and Tu, 2012), papaya (Huajaikaew et al., 2005) and persimmon (Besada et al., 2008). This treatment has been reported to reduce phenylalanine ammonia lyase (PAL) and polyphenol oxidase (PPO) activity levels, as well as the total

phenolic content (Shao and Tu, 2012), to increase the activity levels of POD, CAT and SOD (Huajaikaew et al., 2005), and to decrease ROS production (Blokhina et al., 2003) in different fruit species. PODs can contribute to maintaining low levels of hydrogen peroxide (Wang et al., 2019) which is important as many POD reactions require hydrogen peroxide, which is converted to water, while the substrate is converted into a free radical. APX and GPX are important peroxidases in H_2O_2 detoxification, catalyzing the reduction of H_2O_2 to water by using the reducing power of ascorbate or guaiacol (Jebara et al., 2005; Van Doorn and Ketsa, 2014). CAT catalyzes the reaction of H_2O_2 conversion into H_2O and $1/2 O_2$ (Sofa et al., 2015), while SOD catalyzes the reaction of superoxide anion ($O_2^{\cdot-}$) conversion into hydrogen peroxide (H_2O_2), which is then transformed into H_2O and O_2 by CAT (Wang et al., 2018).

Another study (Ketsa et al., 2000) harvested fruits of the cultivar Nam Dok Mai were assessed for quality changes after being heat treated at 38°C for 3 d or by heating and then storing at 4°C for 3 wk, before being transferred to storage at 25°C, with the control fruits not being exposed to the heat treatment. After cold storage and ripening, the heat-treated fruits had a lower incidence of disease and developed less chilling injury than non-heated fruits. In addition, the non-heated fruits stored at 4°C developed off-flavors, whereas the heat-treated fruits did not. The heat treatment did not inhibit ripening but did ameliorate low-temperature injury (Ketsa et al., 2000).

The objectives of the current research were to investigate the effects of a heated-air pre-storage treatment on chilling injury induced by exposure to a temperature of 4°C in relation to changes in total antioxidant capacity (TAC) and the activity levels of CAT, SOD, APX and GPX in mango peel during and after storage at 4°C.

Materials and Methods

Hot air treatment

Mango (*Mangifera indica* L.) fruit samples of the cultivar Nam Dok Mai were harvested at maturity from a commercial orchard in Thailand. After washing with water, 20 fruits per box were randomly placed in individual paper boxes (three replicates for each of the two post-storage assessments) and held in a heated-air chamber for 3 d at 38°C (68–72% RH) for the heated-air treatment (HT). Control fruits (similarly 20 fruit in each individual paper box replicated three times

for each of the two post-storage assessments) were held at room temperature (27–28°C, 75% RH) for 3 d. After being exposed to HT or the room temperature conditions for 3 d, all fruit were stored at 4°C and 85% RH. Five fruits per replicate from the non-heated and heated treatments stored at 4°C were randomly selected every 5 d (four times) and determined for chilling injury and TAC, CAT, SOD, APX and GPX activity levels in the peel immediately after removal from cold storage. A further five fruits per replicate from each treatment were transferred to room temperature (27–28°C, 67–69% RH) every 5 d (four times) and similarly assessed 3 d after transfer from the cold storage to room temperature (27–28°C, 67–69% RH). There were three replications per treatment and each replication consisted of the whole peel from the five randomly sampled fruits per replication. The peels within a replication were pooled, frozen in liquid nitrogen and stored at -80°C for later analysis. The peel material was thoroughly homogenized and a 5 g sample was taken from each replicate for individual analyses.

Chilling injury and storage life

Mango fruits were randomly sampled (15 fruits from 3 replicates) for determination of chilling injury, using a scale of 1–5, similar to that used by Chongchatuporn et al. (2013). The degree of browning was visually assessed using the following scale: 0 = no browning; 1 = up to 10% of the peel or pulp was brown; 2 = 11–25% of the peel or pulp was brown; 3 = 26–40% of the peel or pulp was brown; 4 = 40–55% of the peel or pulp was brown; and 5 = >55% of the peel or pulp was brown. The chilling injury (CI) index was calculated using equation 1:

$$\text{CI index} = \frac{\sum (\text{Injury classification level} \times \text{Number of fruit at that level})}{\text{Total number of fruit in the treatment}} \quad (1)$$

Peel browning was determined externally, while browning of the pulp was examined after cutting the pulp longitudinally close to the endocarp, with the browning determined using a scale similar to that used for peel browning. The length of storage life was defined as the time until the peel or pulp had turned brown at level 3 = 26–40%.

Chongchatuporn (2014) reported quality parameters consisting of a^* , b^* , L^* , firmness, TSS, TA and TSS:TA. Therefore, for the current study, it was decided to not include data on these quality parameters in the HT experiment.

Total antioxidant capacity

The total antioxidant capacity (TAC) was determined in a 0.5 g sample of frozen peel tissue. The sample was homogenized in 10 mL of cold 0.1 M phosphate buffer (pH 7.0) with 2% (w/v) polyvinylpyrrolidone. The homogenate was filtered through four layers of Miracloth™ and then centrifuged at 9,170×g for 30 min at 4°C. The TAC activity was assayed using the ferric reducing ability of plasma (FRAP) assay, following the method of Benzie and Strain (1996). The assay mixture consisted of 2.4 mL reagent (300 mM acetate buffer consisting of: 2, 4, 6 -tripyridyl-s-triazine; and pure iron (II) chloride hexahydrate in a 10:1:1 ratio) and 0.2 mL of tissue extract. The color intensity after incubation for 5 min was measured as absorbance at 593 nm.

Catalase and superoxide dismutase activity levels

CAT and SOD were determined in 0.5 g samples of frozen peel tissue. Each sample was homogenized in 10 mL 0.1 M phosphate buffer (pH 7.0). Then, the homogenate was filtered through four layers of Miracloth™ and centrifuged at 17,000×g for 20 min at 4°C. The supernatant was used as a crude extract and the CAT activity was assayed using a modification of the method of Aebi et al. (1983). The activity was determined by monitoring the decomposition of H_2O_2 at 420 nm. The reaction mixture contained 50 mM phosphate buffer (pH 7.0), 30 mM H_2O_2 and enzyme extract. The SOD activity was assayed using the method of Ukeda et al. (1997). The reaction mixture contained 50 mM phosphate buffer (pH 8.0), 3 mM xanthine, 3 mM ethylenediaminetetraacetic acid, 0.75 mM (2,3-bis(2-methoxy-4-nitro-5-sulphophenyl)-2H-tetrazolium-5- carboxanilide (XTT) and 0.14 units of xanthine oxidase. The activity was determined by monitoring the reduction rate of XTT at 470 nm. The protein content was determined using the Bradford method, with bovine serum albumin as a standard (Bradford, 1976).

Guaiacol peroxidase and ascorbate peroxidase activity levels

Extractions were carried out as for CAT and SOD above. The GPX activity was assayed using a modification of the method of Wang et al. (2005). The reaction mixture contained 0.1 M phosphate buffer (pH 7.0), 24 mM H_2O_2 , 8 mM guaiacol and enzyme extract. The activity was determined by measuring absorbance at 470 nm due to the production of cinnamic acid, where one unit of activity was defined as a 0.001/min

increase in absorbance at 470 nm. The APX activity was assayed using a modification of the method of Ali et al. (2005). The reaction mixture contained 0.5 mM ascorbic acid in 0.1 M phosphate buffer (pH 7.0), 100 μ L of crude extract and a final concentration of 0.1 mM H_2O_2 . The activity was determined by monitoring ascorbate oxidation at 290 nm.

Statistical analysis

Each sample comprised three replicates and had five fruits per replicate as outlined above. Data for the peel browning, CAT, SOD, APX and GPX activity levels were compared based on the least significant difference (LSD) method using the SPSS Statistics version 23.0 software (IBM Corp.; New York, NY, USA). Significance was tested at $p < 0.05$.

Results

Chilling injury index and storage life

The browning values of mango fruits, without and with HT, were expressed using the CI index for peel browning during and after storage. Fruits without HT showed peel browning on day 5 that rapidly increased throughout the period of storage at 4°C. HT delayed peel browning by about 5 d, with the level of browning on day 10 being similar to that on day 5 for the untreated control (Fig. 1A); however, there was no significant effect of heat treatment from day 15 onwards. No pulp browning was observed during cold storage (data not shown). Storage life (defined as the time until the CI index in peel was at level 3) for the heated mango fruits stored at 4°C was 13.5 d, while non-heated mango fruits had a storage life of only 10 d (Fig. 1A).

Upon transfer to room temperature for 3 d, peel browning of the control fruits increased more rapidly compared to the fruits held continuously in 4°C storage (compare Fig. 1A with Fig. 1B). HT delayed and significantly reduced peel browning until day 10; however, there were no significant differences between the control and the HT fruits after day 15 (Fig. 1B). The fruit pulp samples showed a small increase in browning over the 20 d assessment period. However, the pulp of the cold-stored (4°C) fruits was white whereas, in contrast, the pulp in the fruits that had ripened without cold storage had a normal yellow color (data not shown).

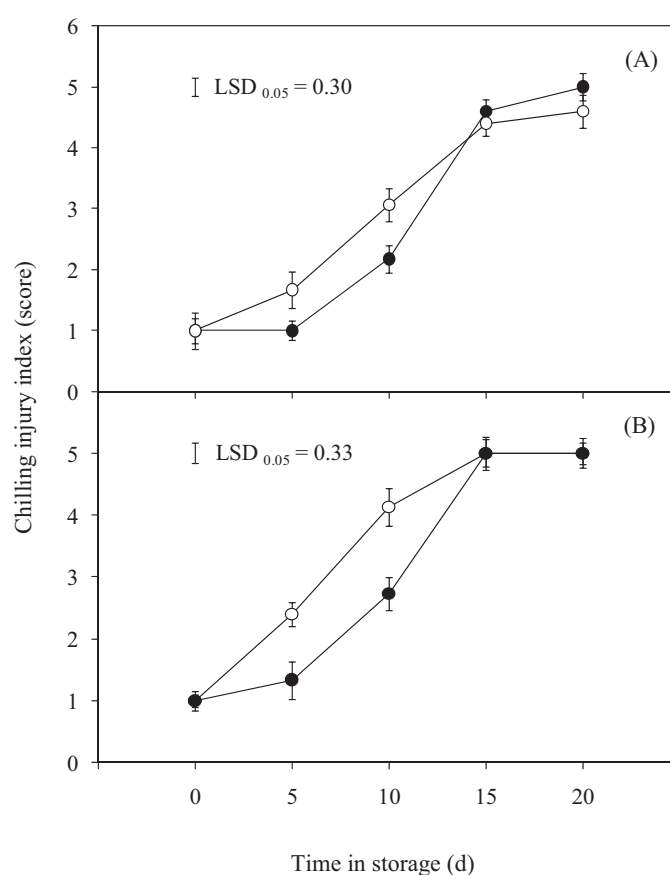


Fig. 1 Chilling injury (CI) index in peels of fruits of mango (cultivar Nam Dok Mai) without (○) and with (●) a 3 d heat treatment after a subsequent 5 d period of storage at 4°C (A) or following a subsequent 3 d placement at room temperature (B), where measurements were taken at 5 d intervals that began immediately after 5 d of cold storage or after 3 d of placement at room temperature, data are mean $\pm$ SD values of three replicates (total 15 fruit) and statistical significance of differences between means was estimated based on least significant differences (LSD)

Total antioxidant capacity

The TAC values (measured using FRAP assay) of the heat-treated peel steadily increased from day 5 until day 20 and were significantly higher than those of the control peel that remained almost constant throughout the storage period at 4°C (Fig. 2A). The TAC values of the heat-treated peel for the fruits transferred from 4°C to room temperature for 3 d were significantly higher than those of the control peel until day 10, after which there were no significant differences between the control and heat-treated samples (Fig. 2B).

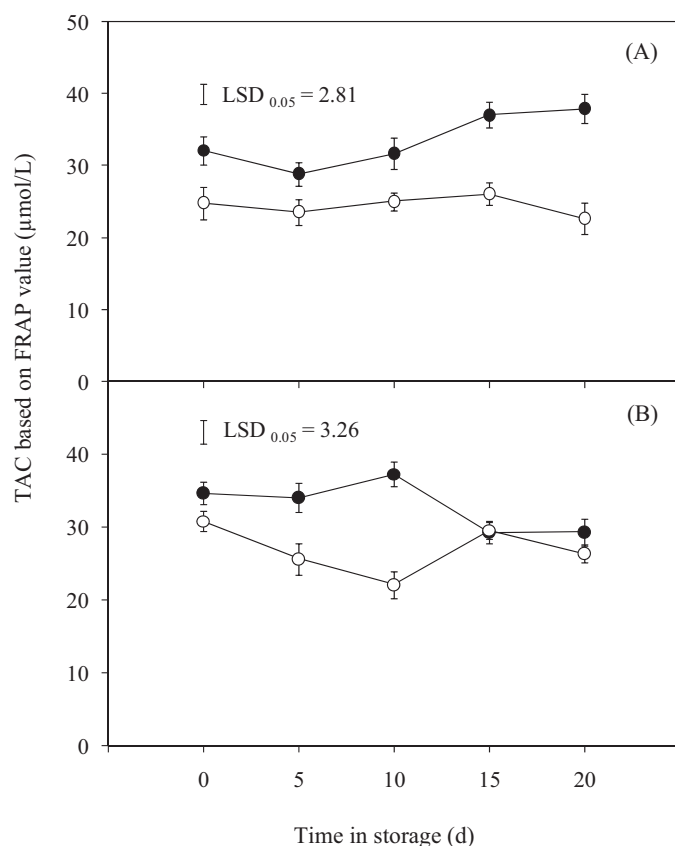


Fig. 2 Total antioxidant capacity (TAC) in peels of fruits of mango (cultivar Nam Dok Mai) without (○) and with (●) a 3 d heat treatment after a subsequent 5 d period of storage at 4°C (A) or following a subsequent 3 d placement at room temperature (B), where FRAP = ferric reducing ability of plasma, measurements were taken at 5 d intervals that began immediately after 5 d of cold storage or after 3 d of placement at room temperature, data are mean ± SD values of three replicates (total 15 fruit) and statistical significance of differences between means was estimated based on least significant differences (LSD)

Catalase activity

At the initial time of assessment (day 0), the CAT activity in the control peel was significantly higher than that of the heat-treated peel. CAT activity levels in the control peel then increased to a maximum on day 5 and progressively declined thereafter. In contrast, CAT activity levels in the heat-treated peel steadily increased from day 0 to day 20 and were significantly higher than the control peel between days 10 and 20 (Fig. 3A). The overall patterns of changes in CAT activity were generally similar for both the control and heat-treated peels transferred from 4°C to room temperature. The CAT activity in the heat-treated peel was significantly higher than that in the control peel from day 0 to 10 (Fig. 3B).

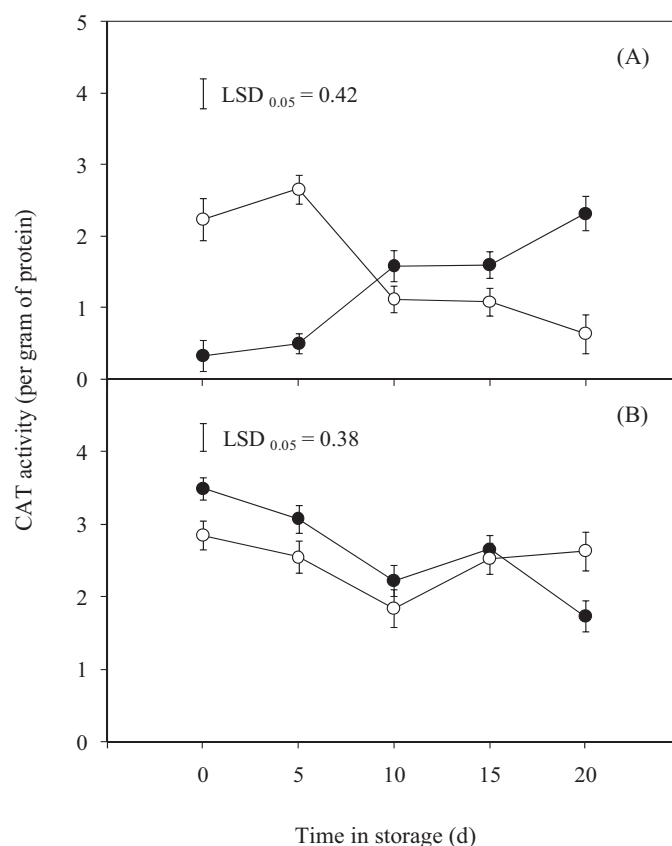


Fig. 3 Catalase (CAT) activity in peels of fruits of mango (cultivar Nam Dok Mai) without (○) and with (●) a 3 d heat treatment after a subsequent 5 d period of storage at 4°C (A) or following a subsequent 3 d placement at room temperature (B), where measurements were taken at 5 d intervals that began immediately after 5 d of cold storage or after 3 d of placement at room temperature, data are mean ± SD values of three replicates (total 15 fruit) and statistical significance of differences between means was estimated based on least significant differences (LSD)

Superoxide dismutase activity

The SOD activity within the control peel decreased slightly during storage at 4°C, whereas the SOD activity in the heat-treated peel slightly increased from day 5 to day 15; furthermore, the rates were significantly higher than those in the control peel between days 10 and 20 (Fig. 4A). For the fruits transferred from 4°C to room temperature, the SOD activity in the control peel was initially high and decreased rapidly from day 0 until day 20, while the SOD activity levels in the heat-treated peel remained constant and were significantly lower than the control on days 0, 5 and 10 (Fig. 4B).

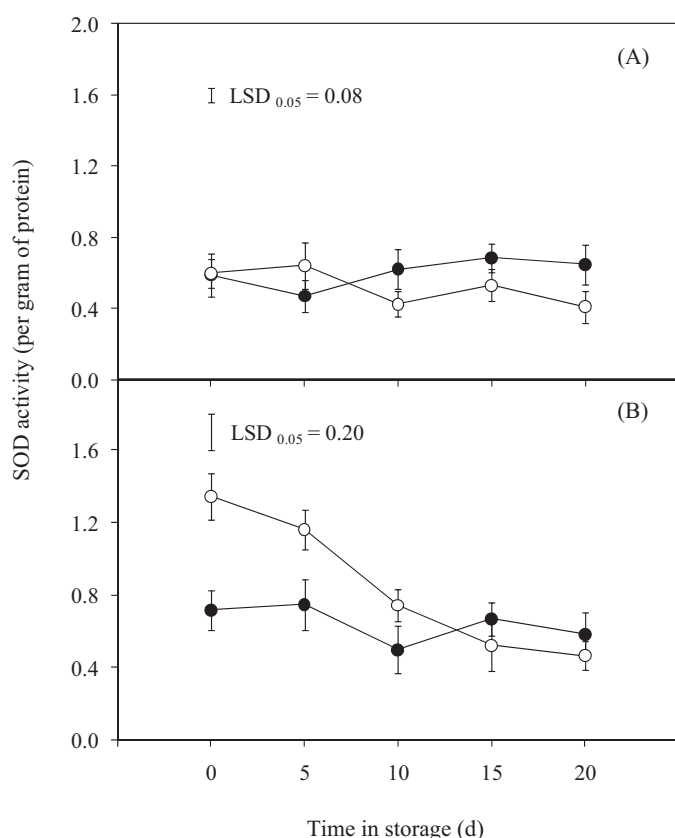


Fig. 4 Superoxide dismutase (SOD) activity levels in peels of fruits of mango (cultivar Nam Dok Mai) without (o) and with (●) a 3 d heat treatment after a subsequent 5 d period of storage at 4°C (A) or following a subsequent 3 d placement at room temperature (B), where measurements were taken at 5 d intervals that began immediately after 5 d of cold storage or after 3 d of placement at room temperature, data are mean $\pm$ SD values of three replicates (total 15 fruit) and statistical significance of differences between means was estimated based on least significant differences (LSD)

Ascorbate peroxidase activity

The APX activity in the control peel reached a maximum on day 10 and declined thereafter during storage at 4°C. In contrast, the APX activity in the heat-treated peel progressively declined throughout the assessment period and was lower than that of the control peel on days 10, 15, and 20 (Fig. 5A). For the fruits transferred from 4°C to room temperature, the APX activity levels in the control and heat-treated peels remained almost constant; however, the APX activity in the heat-treated peel was slightly lower than that in the control peel throughout (Fig. 5B).

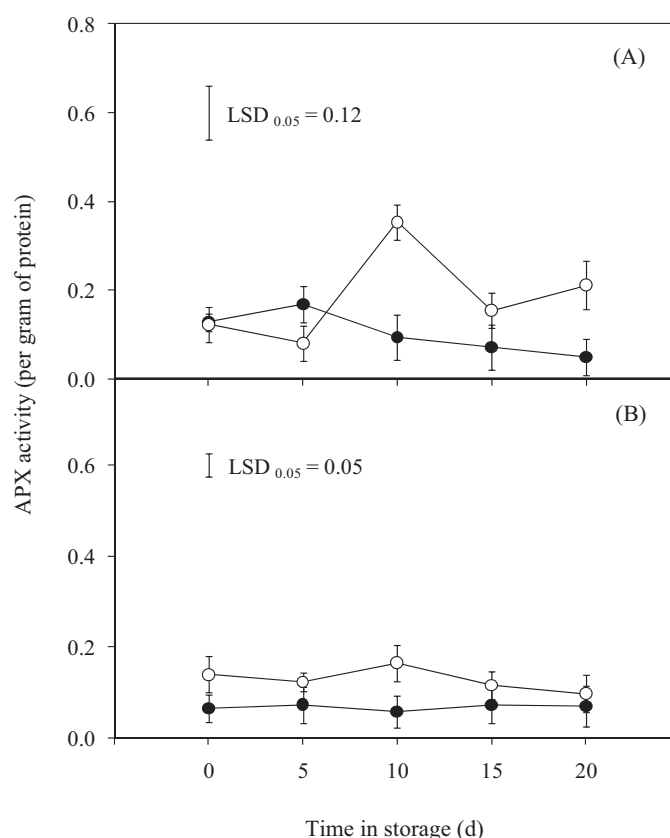


Fig. 5 Ascorbate peroxidase (APX) activity in peels of fruits of mango (cultivar Nam Dok Mai) without (o) and with (●) a 3 d heat treatment after a subsequent 5 d period of storage at 4°C (A) or following a subsequent 3 d placement at room temperature (B), where measurements were taken at 5 d intervals that began immediately after 5 d of cold storage or after 3 d of placement at room temperature, data are mean $\pm$ SD values of three replicates (total 15 fruit) and statistical significance of differences between means was estimated based on least significant differences (LSD)

Guaiacol peroxidase activity

The GPX activity in the control peel increased steadily over the 20 d of storage, while the GPX activity in the heat-treated peel steadily decreased throughout (Fig. 6A). For the fruits transferred from 4°C to room temperature, the GPX activity levels in the control peel steadily increased to a maximum on day 10 and decreased thereafter, while the GPX activity levels in the heat-treated peel remained unchanged (Fig. 6B).

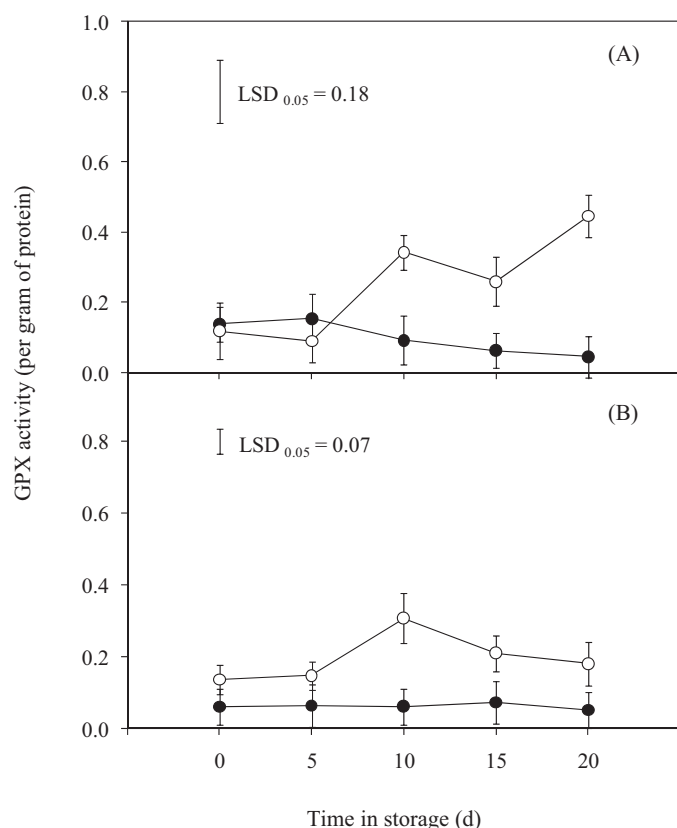


Fig. 6 Guaiacol peroxidase (GPX) activity in peels of fruits of mango (cultivar Nam Dok Mai) without (○) and with (●) a 3 d heat treatment after a subsequent 5 d period of storage at 4°C (A) or following a subsequent 3 d placement at room temperature (B), where measurements were taken at 5 d intervals that began immediately after 5 d of cold storage or after 3 d of placement at room temperature, data are mean $\pm$ SD values of three replicates (total 15 fruit) and statistical significance of differences between means was estimated based on least significant differences (LSD)

Discussion

The cultivar Nam Dok Mai mango fruits stored at 4°C showed peel browning within 5 d. Such symptoms are typical of CI in mango fruit during low temperature storage (Chongchatuporn et al., 2013). Peel browning has been reported to be enhanced when the mango fruits were removed from low temperature storage and then placed at room temperature (Mohammed and Brecht, 2000). Browning that is induced by CI is commonly found in many other tropical fruit species, including avocado (Donadon et al., 2012), banana (Promyou et al., 2008) and pineapple (Luengwilai et al., 2016). Browning in fruit and vegetable tissues is thought to be associated with the enzymatic oxidation of phenolics into quinones, which then

polymerize into brown-colored products, with PPO and POD are the main enzymes responsible for browning (Moon et al., 2020) and the presence of PPO, POD and phenolics in the peel and pulp of mango fruits has been reported (Trejo-Márquez et al., 2010; Lin et al., 2011). The presence of PPO would enhance POD-mediated browning reactions (Richard-Forget and Gauillard, 1997). PODs have been reported to be involved in tissue browning in many plants, including litchi (Mishar et al., 2012), loquat (Shao and Tu, 2012) and pineapple (Weerahewa and Adikaram, 2005). In the current study, the browning of the mango peel was found to be more severe than that of the pulp. Phenolic compounds are the main substrates for the browning reactions catalyzed by PPO and POD, with the total phenolic content in the peel of mango being reported to be much higher than that in the pulp (Trejo-Márquez et al., 2010), similar to that occurring in banana fruit (Passo Tsamo et al., 2015). This was likely the reason why the browning that was associated with CI was greater in the mango peel than in the pulp.

In the current study, HT delayed and inhibited CI-induced peel browning of the mango fruits during and after cold storage. HT has been reported to inhibit tissue browning in mango (Ketsa et al., 2000; Vega-Alvarez et al., 2020; Javed et al., 2022), banana (Promyou et al., 2008), persimmon (Khademi et al., 2013) and loquat (Shao and Tu, 2012). HT has been reported to significantly increase the storage life of mango fruit by approximately 5 d (Ketsa et al., 2000; Javed et al., 2022). Furthermore, HT has been shown to reduce PAL or PPO activity, or both, as well as tissue browning in mango (Mukhtar et al., 2020), apple (Shrestha et al., 2020), banana (Promyou et al., 2008), loquat (Shao and Tu, 2012) and persimmon (Khademi et al., 2013). However, in the current study neither PAL nor PPO activity was investigated in the peel of the mango fruits after HT. Therefore, it cannot be ruled out that HT reduced peel browning of the mango fruits of the cultivar Nam Dok Mai that was induced by CI via an effect of the modified atmosphere packaging on PAL and PPO activity (Chidtragool and Ketsa, 2013) nor by the HT affecting the PPO activity directly (Mukhtar et al., 2020). The impacts of these and other related enzymes could be the focus of future studies.

HT has been shown to inhibit the cold-induced browning of a number of different fruit species by enhancing their antioxidant systems (Huajaikaew et al., 2005; Khademi et al., 2013; Shadmani et al. 2015). In the current study, the HT treatment increased the levels of TAC, CAT and SOD activity in the mango peel both during and after the cold storage period. Specifically, the TAC values of the heat-treated peel

were significantly higher than those of the control peel for the first 10 d of cold storage in the fruits that had been ripened at room temperature and this enhancement occurred in parallel with the reduction in CI of the mango fruits for a similar 10 d period. Therefore, the impact of HT may not persist beyond 10 d of storage. TAC can be measured using a range of methods, including oxygen radical absorption capacity, hydroxyl radical antioxidant capacity, the total peroxyl radical trapping antioxidant parameter, total oxyradical scavenging capacity, cupric reducing antioxidant power, FRAP, 2,2'-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid) and [2,2-di(4-tert-octylphenyl)-1-picrylhydrazyl] (Munteanu and Apetrei, 2021). In the current study, TAC was measured only by using the FRAP assay, whereas other methods might have better reflected the impact of HT on the increased TAC values. CAT catalyzes the reaction of H_2O_2 conversion into H_2O and $1/2 \text{ O}_2$ (Sofa et al., 2015), while SOD catalyzes the reaction of the conversion of the superoxide anion (O_2^-) into hydrogen peroxide (H_2O_2), which is then transformed into H_2O and O_2 by CAT (Wang et al., 2018). Junmatong et al. (2015) reported that methyl jasmonate treatment reduced CI in mango fruits by decreasing the free radical content and increasing the antioxidant capacity. Therefore, based on the results from the current study, ROS may have been involved in the CI development in the mango fruits.

One of the causes of CI is stress at the cellular level (Einset et al., 2007), including an increase in the ROS contents during low temperature storage (Lee et al., 2020). The generation of free radicals and the content of malondialdehyde, a product of lipid peroxidation, were reported to be significantly increased in mango fruit stored at low temperature (Junmatong et al., 2015; Shivashankar et al., 2022). As indicated, low temperature induced the production of ROS (Shewfelt and Del Rosario, 2000; Lee et al., 2020) and ROS can damage plasma and organelle membranes via degradation of proteins, lipids and nucleic acids in plant cells, especially through promoting cell membrane lipid peroxidation (Blokina et al., 2003; Sharma et al., 2012). HT has been reported to increase the levels of TAC, CAT and SOD activity and to decrease tissue browning in several other fruits, including loquat (Shao and Tu, 2012), peach (Huan et al., 2017) and persimmon (Khademi et al., 2013). In addition, HT has been reported to reduce H_2O_2 formation in peach (Wang et al., 2014), and loquat (Shao and Tu, 2012). In the current study, it was assumed that an increase in ROS and free radicals in the mango fruits during and after low temperature storage was prevented by HT-induced increases in the activity levels of the TAC, CAT and, to a lesser

extent, SOD. Enhanced antioxidant systems in plant tissues would enable them to improve their CI tolerance (Blokina et al., 2003). Therefore, in general, the current results indicated that the HT-induced CI tolerance of the mango fruits was associated with the activation of antioxidants and defense systems via an increase in the activity levels of TAC, CAT and SOD, as supported by the research of Uarrotta et al. (2016).

Under environmental stress conditions, plants utilize APX and GPX activity levels to defend against ROS (Das and Roychoudhury, 2014) as APX and GPX are able to scavenge H_2O_2 (Jebara et al., 2005; Van Doorn and Ketsa, 2014). In contrast to CAT, APX requires an ascorbate and glutathione (GSH) regeneration system—the ascorbate-glutathione cycle. The first reaction in this cycle, catalyzed by APX, is $\text{H}_2\text{O}_2 + \text{ascorbate} \rightarrow \text{H}_2\text{O} + \text{monodehydroascorbate}$. As with APX, GPX also detoxifies H_2O_2 to H_2O ; however, it uses GSH directly as a reducing agent (Sofa et al., 2015). HT has been reported to increase the APX and GPX activity levels in persimmon (Khademi et al., 2013). In contrast, in the current study HT led to a decrease in the activity levels of both APX and GPX in the mango peel samples both during and after cold storage. Chilling tolerance of heated mango fruits may be due partly to the regulation of antioxidant metabolism to alleviate ROS damage (Pan et al., 2019). These responses indicate that both APX and GPX were not likely to be involved in the mechanisms that counteracted ROS and free radicals to alleviate CI in the HT-treated mangoes.

Conclusion

The exposure of mango fruits to heat treatment prior to low temperature storage reduced and delayed peel browning both during low temperature storage and after being transferred to room temperature. There was a strong relationship between the reduction of CI by HT and an increase in the activity levels of TAC, CAT and, to a lesser extent, SOD in the mango peel. No relationship was found between the reduction of peel browning by HT and the measured activity levels of APX and GPX. The results were in accordance with the proposition that antioxidative enzymes may be involved in the reduction of chilling injury in mango fruit.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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