Octanal incorporated in postharvest wax of Satsuma mandarin fruit as a botanical fungicide against *Penicillium digitatum*

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**Abstract**

The antifungal activity of octanal against *Penicillium digitatum*, the causal agent of citrus green mold, was assessed by *in vitro* and *in vivo* experiments. *In vitro* assays showed that the minimum inhibitory concentration and minimum fungicidal concentration (MFC) of octanal were 500 and 1000 μL/L, respectively. *In vivo* test results demonstrated that wax + octanal (WO; 2 x MFC) treatment but not WO (1 x MFC) treatment effectively inhibited the growth of *P. digitatum* after 6 d of storage at 25 ± 2 °C. The WO treatment remarkably increased the activities of antioxidant enzymes, such as catalase and superoxide dismutase, in Satsuma mandarin fruit. However, this treatment evidently decreased phenylalanine ammonia lyase activity and malondialdehyde content. The WO treatment also inhibited peroxidase activity and prevented hydrogen peroxide accumulation. Furthermore, the WO treatment did not impair the fruit quality parameters (vitamin C content, pH, coloration index, and total soluble solid content) of the tested fruit. This study provided theoretical data for the practical application of octanal to improve citrus fruit quality during postharvest storage.

**Keywords:** Citrus, Enzyme activity, Fruit quality, Octanal, *Penicillium digitatum*.

1. Introduction

Postharvest decay is one of the main problems that affect fruit and vegetable quality during storage (Liu, Sun, Wisniewski, Droby, & Liu, 2013; Pérez-Alfonso et al., 2012). Citrus fruit are susceptible to many postharvest fungal diseases, including green and blue molds caused by *Penicillium digitatum* and *Penicillium italicum*, respectively (Castillo et al., 2014; Droby et al., 2008). Although synthetic chemical fungicides can effectively control several diseases, the use of fungicides to control postharvest deterioration has been restricted because of their high and acute residual toxicity, long degradation period, environmental pollution, adverse effects on food, and possible side effects on human health (Askarne et al., 2013; Caccioni, Guizzardi, Biondi, Renda, & Ruberto, 1998; Droby et al., 2008; du Plooy, Regnier, & Combrinck, 2009; Tao, Jia, & Zhou, 2014a). Essential oils or their volatile compounds have also been incorporated in coatings to control postharvest diseases in mango, avocado, grape, pineapple, and citrus fruit (Avila-Sosa et al., 2012; Azaraksh, Osman, Ghazali, Tan, & Adzahanba, 2014; Bosque-Molina, Ronquillo-de Jesús, Bautista-Banos, Verde-Calvo, & Morales-López, 2010; Regnier, Combrinck, du Plooy, & Botha, 2010; Regnier, du Plooy, Combrinck, & Botha, 2008; Sellamuthu, Sivakumar, Soundy, & Korsten, 2013). Du Plooy et al. (2009) further observed that commercial coatings (Carnauba Tropical® supplied with *Lippia scaberrima* essential oils (2500 μL/L) can obtain 100% disease control (preventive treatment) against green mold of citrus fruit. Yahyazadeh, Zare, Omidbaigi, Faghih-Nasiri, and Abassi (2009) reported that thyme or clove oil (800 μL/L) applied on the outer surface of oranges in polyethylene films can effectively reduce green mold in vapor-phase experiments at 25 °C. Carnauba wax supplemented with *Cinnamomum zeylanicum* essential oil (0.5%, v/v) can also be used to control (90%) postharvest blue and green molds of citrus (*Kouassi*, Bajji, & Jiakli, 2012). Wax with thymol and carvacrol applied on lemons inoculated with *P. digitatum* reduces decay (expressed as a percentage of infected fruit surface), respiration rate, and ethylene production in a concentration-dependent manner (Castillo et al., 2014; Pérez-...
Alfonso et al., 2012). Our previous study also demonstrated that a wax + citral (40,000 µL/L) combination treatment significantly decreases the incidence rate of green mold after 6 d of storage at 25 ± 2 °C (Fan, Tao, Jia, & He, 2014).

Octanal, a naturally occurring aliphatic compound in citrus essential oils, reportedly exerts antifungal activity (Droby et al., 2008; Scora & Scora, 1998; Tao et al., 2014a). Droby et al. (2008) reported that 0.5 µL/plate octanal completely inhibits the spore germination and germb tube elongation of P. digitatum and P. italicum. We previously demonstrated that octanal also exhibits strong antifungal efficiency on the mycelial growth of P. italicum and P. digitatum, with minimum inhibitory concentration (MIC) and minimum fungicidal concentration (MFC) of 500 and 1000 µL/L, respectively (Tao, Jia, Zhou, & He, 2014b). However, limited information is available regarding the effects of wax coatings enriched with octanal on postharvest diseases and fruit quality of citrus.

The current study aimed to evaluate the ability of octanal to reduce green mold in Satsuma mandarin fruit in vivo. We also analyzed the effects of WO treatment on fruit quality parameters, such as pH, coloration index, total soluble solid (TSS) content, vitamin C (Vc) content, activities of antioxidant enzymes [catalase (CAT), superoxide dismutase (SOD), and peroxidase (POD)], activities of defense-related enzyme [phenylalanine ammonia lyase (PAL)], hydrogen peroxide (H₂O₂) content, and malondialdehyde (MDA) content.

Disease incidence(%) = (number of rotten fruit/total number of total fruit) × 100

2. Materials and methods

2.1. Fruit

The mature fruit of Satsuma mandarin (Citrus unshiu Marc. cv. Miyagawa Wase) were harvested on November 3, 2013 from a local orchard near Xiangtan University, Xiangtan, China. Defect-free fruits with uniform sizes were chosen for the experiments.

2.2. Pathogen

The fungal pathogen P. digitatum was isolated from infected citrus fruit and incubated on potato dextrose agar (PDA) for 7 d at 25 ± 2 °C. A spore suspension was then prepared. The suspension was adjusted to 1 × 10⁸ spore/L by using a hemocytometer with sterile distilled water.

2.3. Chemicals

Octanal (99%) was obtained from Sigma–Aldrich Corporation (St. Louis, MO, USA). Commercial wax coatings (SP-1) were provided by Bo Cheng Chemical Co., Ltd., Guangzhou, China.

2.4. In vitro experiments

The effect of octanal on the mycelial growth of P. digitatum was evaluated by using the poisoned food technique (Yahyazadeh, Omidbaigi, Zare, & Taheri, 2008). A 6 mm mycelial agar plug from a 7-day-old culture of P. digitatum was placed at the center of each PDA plate, and specific amounts of octanal were added to achieve the desired concentrations (0, 250, 500, 1000, 2000, 4000, and 8000 µL/L). Approximately 0.05% (v/v) Tween-80 was then added to the media. Petri dishes were sealed with parafilm and incubated for 5 d at 25 ± 2 °C. The diameter (in mm) of colony zone was measured with a caliper. All of the tests were performed in triplicate. The lowest concentration that completely inhibited the growth of the fungus after 48 h of incubation at 25 ± 2 °C was considered as the minimum inhibitory concentration (MIC). The minimum fungicidal concentration (MFC) was regarded as the lowest concentration that prevented pathogen growth after 96 h of incubation at 25 ± 2 °C on a fresh PDA plate, thereby indicating fungicidal activity >99.5% of the original inocula (Talibi et al., 2012).

2.5. In vivo assays

All of the fresh citrus fruit were surface-sterilized by immersing in 1% sodium hypochlorite solution (v/v) for 2 min; afterward, the fruits were washed with distilled water, wounded (depth of 1.5 mm and width of 2 mm) with a sterile needle, inoculated with 10 µL of a spore suspension of P. digitatum (10⁸ spores/L), and left to air-dried (Fan et al., 2014). After fungi were inoculated, the fruits were sprayed with wax amended with octanal at MFC or 2 × MFC. The inoculated fruit were kept in sealed incubators at 25 ± 2 °C to ensure high relative humidity (85% RH). The fruit with wax and pathogen inoculation was used as a control. Ten Satsuma mandarin fruit constituted a single replicate, and each treatment was performed in triplicate. The incidence rate of disease (measured by counting the number of green mold-inflicted lesions) was calculated as follows:

\[
\text{Disease incidence(%) = (number of rotten fruit/total number of total fruit)} × 100
\]

2.6. Fruit quality parameters

After storage at an interval of 2 d, pulp samples were collected from three fruit which were randomly chosen from each group. The pulp samples were homogenized in a grinder and centrifuged at 4000 g for 20 min, and the supernatant was used for further analysis. The Vc content was determined using 2, 6-dichlorophenolindol-henol titration method (Lemoine, Chaves, & Martinez, 2010). pH was determined using a Delta-320 pH-meter (Mettler-Toledo, OH, USA). TSS was analyzed by using an LB 32T hand-held refractometer (Mingrui Electron Science-Technology Co., Ltd., Guangzhou, China).

Fruit peel color was determined using a Minolta CR-330 chromameter (Minolta Co. Ltd., Osaka, Japan) on three locations around the equatorial plane of each fruit. The mean values for lightness (L), red-green (a), and yellow-blue (b) Hunter parameters were calculated for each fruit and expressed as a citrus color index [CCI = 1000a/(Lb)] (Fan et al., 2014). The fruit with wax but without inoculated pathogen was used as a control sample.

2.7. Determining CAT, SOD, and POD activities

The fruit pulp was homogenized in a grinder and used for further analysis. All of the experiments were conducted in triplicate for each treatment per sample. CAT, SOD, and POD activities were determined by photometric assay using a UV-2450 UV/Vis spectrophotometer [Shimadzu (China) Co., Ltd., Shanghai, China].

CAT activity was estimated using a previously described method (Lemoine et al., 2010). The reaction mixture contained 150 µL of phosphate buffer (200 mM, pH 7.8), 100 µL of distilled water, 30 µL...
of H$_2$O$_2$ (300 mM), and 20 μL of enzyme extract. H$_2$O$_2$ decommission was determined at 240 nm. SOD activity was measured according to the method proposed by Sellamuthu et al. (2013) and assayed by its ability to inhibit the photochemical reduction of nitrotetrazolium blue chloride (NBT) at 560 nm. The enzyme assay mixture contained sodium phosphate buffer (50 mM, pH 7.8), methionine (130 mM), NBT (3.75 μM), riboflavin (2 mM), EDTA (100 μM), and enzyme extract (50 μL). POD activity was assayed according to the method by Lemoine et al. (2010). Approximately 20 μL of enzyme extract in 300 μL of buffered substrate (50 mM sodium phosphate, pH 7.8, and 56 mM guaiacol) was incubated at 30 °C for 5 min. Afterward, 19 μL of H$_2$O$_2$ (38 mM) was added, and the increase in absorbance at 470 nm for 120 s was measured. The specific activities of the targeted enzymes were expressed in U/g FW.

2.8. Determining H$_2$O$_2$ content

H$_2$O$_2$ content was determined according to Vicente, Martínez, Chaves, and Civello (2006) with several modifications. In brief, frozen fruit tissue (15 g–20 g) was ground in liquid nitrogen, and 0.5 g of powder was extracted in 3 mL of ice-cold 5% (w/v) trichloroacetic acid. The crude extract was centrifuged at 10,000 g for 10 min. An aliquot of the supernatant (500 μL) was added to 500 μL of assay reagent (500 μM ferrous ammonium sulfate, 50 mM H$_2$SO$_4$, 200 μM xylene orange, and 200 mM sorbitol). After 45 min of incubation, peroxide-mediated oxidation of Fe$^{2+}$ to Fe$^{3+}$ was determined by measuring the absorbance of the ferric-xylene orange complex at 560 nm. Three extracts were prepared per treatment and storage-time analyzed, and the H$_2$O$_2$ content of each extract was determined in triplicate.

2.9. Determining PAL activity and MDA contents

PAL activity was assayed using the method described by Sellamuthu et al. (2013). The enzyme extract (100 μL) was incubated with 400 μL of borate buffer (50 mM, pH 8.8) containing 5 mM of L-phenylalanine for 30 min at 30 °C. After incubation, the reaction was terminated by adding 75 μL of 1 M HCl. The absorbance of the reaction mixture was determined at 290 nm. Enzyme activity was expressed in U/g FW.

MDA content was determined by MDA–thiobarbituric acid (TBA) assay (Meng, Zhang, & Adhikari, 2012). Fruit peels were homogenized in a grinder and centrifuged at 4000 g for 20 min. The reaction mixture contained 2000 μL of 0.6% TBA (w/v) and 200 μL of crude enzyme extract. The resulting mixture was incubated in boiling water for 30 min and rapidly cooled with cold water and then centrifuged for 10 min at 10,000 g. Absorbance was determined at 532 nm and 600 nm. MDA concentration was expressed in μM/g protein.

2.10. Statistical analysis

Each assay was performed in triplicate, and data were analyzed using ANOVA. Daily analysis results of the treatments were compared at P = 0.05 according to Duncan’s multiple range tests.

3. Results and discussion

3.1. In vitro experiments

Octanal elicited a satisfactory antifungal effect against P. digitatum (Fig. 1). Octanal inhibited the mycelial growth of P. digitatum in a dose-dependent manner (P < 0.05). High octanal concentration (≥1000 μL/L) completely inhibited the mycelial growth of P. digitatum, whereas low octanal concentration (<250 μL/L) showed only moderate antifungal activity against P. digitatum. About 50% inhibition of the mycelial growth of P. digitatum was induced by 250 μL/L of octanal. Moreover, 500 μL/L of octanal induced 100% inhibition of the mycelial growth of P. digitatum before 2 d of culture. Therefore, the MIC and MFC of octanal against P. digitatum were 500 and 1000 μL/L, respectively. This result confirmed those of previous reports describing the antifungal activity of octanal (Droby et al., 2008; Scora & Scora, 1998). The MIC and MFC values were equal to those revealed in our previous report (Tao et al., 2014b). By contrast, the MIC and MFC in this study are either lower than those of Eucalyptus globulus essential oil against P. digitatum (9 and 18 mg/mL, respectively) (Tyagi & Malik, 2011a) or lower than the corresponding MIC and MFC values of Mentha piperita essential oil against P. digitatum (2.25 and 4.5 mg/mL, respectively) (Tyagi & Malik, 2011b).

3.2. In vivo experiments

The ability of WO treatments to inhibit the disease development of citrus fruit inoculated with P. digitatum is presented in Table 1. After 3 d of incubation, the rot incidence rate in wax-treated fruit was 43%. By contrast, the fruit treated with WO (1 x MFC or 2 x MFC) was not infected. The rot incidence rates of green mold increased with prolonged time. After 5 d of storage, the green mold incidence rates in the WO (1 x MFC)-treated fruit and wax-treated fruit were both 100%, whereas in the WO (2 x MFC)-treated fruit was only 17%. After 6 d of storage, the incidence rate in the WO (2 x MFC)-treated fruit was 33%. This difference in antifungal efficiency between in vivo and in vitro

![Fig. 1. Effect of different octanal concentrations on the mycelial growth of P. digitatum incubated at 25 ± 2 °C for 5 d.](image-url)
conditions can be attributed to the high volatility of essential oils and volatile compounds. For example, Mexican lime essential oil and Eugenia caryophyllata crude extract at similar concentrations are more effective on postharvest pathogens in vitro bioassays than in in vivo applications (Bosquez-Molina et al., 2010; Sukorini, Sangchote, & Khewkhom, 2013). Kouassi et al. (2012) showed that a mixture of 0.5% C. zeylanicum essential oil and ethanol only exhibits partial pathogen inhibition under in vivo conditions but elicits complete pathogen inhibition under in vitro conditions even at 0.01% C. zeylanicum essential oil. The green mold incidence rate in the wax + citral (1 × MFC)-treated ‘Pon-kan’ fruit is equal to that in the wax-treated fruit after 6 d of storage; nevertheless, the incidence rate in the wax + citral (10 × MFC)-treated fruit is 50% (Fan et al., 2014). Another report described that the MIC values of mentha oil against Saccharomyces cerevisiae are similar in vitro and in vivo (real fruit juice) assessments, probably because of the lower pH (3.2) of fruit juices (Tyagi, Gottardi, Malik, & Guerzoni, 2013).

### 3.3. Effects of octanal on fruit quality

The effects of the WO treatment on fruit quality were further studied. The Vc content, which significantly contributes to the antioxidant activity and protects plant tissues against different biotic and abiotic stresses, was initially analyzed. Both treatments increased Vc content. The Vc content of the WO (2 × MFC)-treated fruit was comparable with that in the wax-treated fruit during the entire storage period (Table 2). Furthermore, no significant differences in pH, TSS content, and coloration index were found among all of the treatments (Table 2). Du Plooy et al. (2012) showed that a mixture of 0.5% C. zeylanicum essential oil and ethanol only exhibits partial pathogen inhibition under in vivo conditions but elicits complete pathogen inhibition under in vitro conditions even at 0.01% C. zeylanicum essential oil. The green mold incidence rate in the wax + citral (1 × MFC)-treated ‘Pon-kan’ fruit is equal to that in the wax-treated fruit after 6 d of storage; nevertheless, the incidence rate in the wax + citral (10 × MFC)-treated fruit is 50% (Fan et al., 2014). Another report described that the MIC values of mentha oil against Saccharomyces cerevisiae are similar in vitro and in vivo (real fruit juice) assessments, probably because of the lower pH (3.2) of fruit juices (Tyagi, Gottardi, Malik, & Guerzoni, 2013).

#### Table 2

<table>
<thead>
<tr>
<th>Physiological indicators</th>
<th>Treatment</th>
<th>Inoculation days (d)</th>
<th>0</th>
<th>2</th>
<th>4</th>
<th>6</th>
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<tbody>
<tr>
<td>Vc (mg/100 g)</td>
<td>Wax</td>
<td>4.64a</td>
<td>5.16a</td>
<td>5.55a</td>
<td>5.86a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WO (2 × MFC)</td>
<td>4.64a</td>
<td>5.37a</td>
<td>5.97a</td>
<td>5.32a</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>Wax</td>
<td>3.52a</td>
<td>4.19a</td>
<td>4.26a</td>
<td>4.26a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WO (2 × MFC)</td>
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<td>4.26a</td>
<td>4.26a</td>
<td>4.44a</td>
<td></td>
</tr>
<tr>
<td>TSS (%)</td>
<td>Wax</td>
<td>11.55a</td>
<td>12.9a</td>
<td>12.3a</td>
<td>12.2a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WO (2 × MFC)</td>
<td>11.55a</td>
<td>12.8a</td>
<td>12.7a</td>
<td>12.1a</td>
<td></td>
</tr>
<tr>
<td>Coloration index</td>
<td>Wax</td>
<td>7.29a</td>
<td>7.38a</td>
<td>7.41a</td>
<td>7.60a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WO (2 × MFC)</td>
<td>7.29a</td>
<td>7.46a</td>
<td>7.25a</td>
<td>7.85a</td>
<td></td>
</tr>
</tbody>
</table>

Data presented are the means of pooled data (n = 10). Rows with different letters in each physiological indicator at each time point between the two treatments indicate significant differences according to Duncan’s multiple range test at P = 0.05.

### 3.4. Activities of CAT, SOD, and POD

Fruit senescence positively correlates with antioxidant enzymes. Plants have evolved a well-integrated antioxidant system that includes enzymatic and nonenzymatic components to delay senescence caused by oxidative damage during fruit storage. CAT, SOD, and POD are the most important enzymes that can scavenge reactive oxygen species (Lemoine et al., 2010). The balance among the activities of SOD, POD, and CAT in cells is crucial to determine the steady-state level of reactive oxygen species, such as $O_2^-$ and $H_2O_2$. $O_2^-$ is efficiently converted to $H_2O_2$ by SOD, whereas $H_2O_2$ is predominantly broken down by POD and CAT (Jin, Wu, et al., 2012; Luo, Zhou, & Zeng, 2013; Shao, Wang, Xu, & Cheng, 2013). In the current study, the CAT activity significantly increased in the WO (2 × MFC)-treated fruit during the entire storage period but remained stable in the wax-treated fruit after 2 d of storage (Fig. 2a). The CAT activity in the WO (2 × MFC)-treated fruit was also significantly higher than that in the wax-treated fruit after 4 d of storage. Moreover, the SOD activity fluctuated during storage. The SOD activity in the WO (2 × MFC)-treated fruit decreased in the first 2 d (Fig. 2b), increased to 5.26 U/g FW at 4 d and corresponded to approximately 4.4 times of that in the wax-treated fruit (1.18 U/g FW), and decreased again thereafter (Fig. 2b). By contrast, the SOD activity in the wax-treated fruit continuously decreased. The POD activity in the wax-treated fruit increased before 4 d of storage and then declined after 6 d of storage (Fig. 2c). POD activity was clearly suppressed in the WO (2 × MFC)-treated fruit, and it remained stable throughout the entire storage time. These results indicated that WO treatment...
may inhibit the accumulation of reactive oxygen species during
the first 2 d, resulting in less oxidative stress and damage to
the citrus fruit. Furthermore, CAT and SOD activities can be induced
by WO treatment when the storage time was prolonged to 4 d. This
result is consistent with those in previous studies, in which
essential oils or volatile compounds can increase the activities of
antioxidant enzymes (Fan et al., 2014; Jin, Wang, et al., 2012; Jin,
Wu, et al., 2012; Sellamuthu et al., 2013; Shao et al., 2013; Xing
et al., 2011). In addition to the positive influence on scavenging
H2O2, cell wall cross-linking and repair of damaged tissues infec-
ted with pathogens are some of the functions of POD (Vicente
et al., 2006). Therefore, an increase in POD activity found in
the wax-treated Satsuma mandarin fruit could indicate the progress of
tissue damage during storage, and a decrease in POD activity in
the WO fruit could indicate that the treated fruits exhibited less
damage than the control sample.

3.5. H2O2 content

H2O2 content was determined to verify the changes in POD ac-
tivity. The H2O2 level exclusively increased in the wax-treated fruit
before 4 d of storage and then remained relatively stable thereafter
(Fig. 3). This increase was approximately 2.6-fold higher than the
H2O2 level at harvest. By contrast, WO treatment evidently inhibi-
ted H2O2; therefore, the H2O2 level did not change at harvest during
the entire storage period. This result is consistent with the POD
activity and suggested that POD did not contribute to the antioxi-
dant activity of WO-treated fruit.

3.6. PAL activity and MDA content

PAL is a key enzyme in phenylpropanoid metabolism and cata-
lyzes the formation of trans-cinnamic acid by L-deamination of
phenylalanine in various biotic and abiotic stresses (Lu et al., 2013).
PAL activity in the wax-treated fruit initially increased and then
sharply decreased (Fig. 4a). The highest level (240.0 U/g FW) of PAL
activity was remarkably decreased by WO treatment during the
first 2 d and then stabilized thereafter. This result suggested that the
synthesis of secondary metabolites was reduced, thereby delaying
maturity and mildewing, and maintaining citrus fruit quality (Fan
et al., 2014; Peng et al., 2014). However, Shao et al. (2013) found
that 0.9 g/L tea tree oil vapor can significantly reduce artificially
inoculated gray mold and soft rot in strawberries and the reduction
in fruit decay may be closely correlated with the induction of
disease resistance, as evidenced by high H2O2 level and activities of
SOD, PAL, POD, and 1,3-β-glucanase during the first period of
incubation. In avocado fruit, the activities of defense enzymes,
including chitinase, 1, 3-β-glucanase, PAL, and POD, are enhanced
by thyme oil (66.7 µL/L) treatment, and the level of total phenolics
in thyme oil-treated fruit is higher than that in untreated (control)
fruit (Sellamuthu et al., 2013). These differences may be attributed
to different fruit types, different chemical properties of essential
oils, or other unknown reasons.

MDA is a decomposition product of lipid hydroperoxides and
functions as an indicator of oxidative damage in cells and tissues
(Sui et al., 2012). As shown in Fig. 4b, the MDA contents of the
WO-treated and wax-treated fruit decreased during the storage
time. However, the MDA content in the WO (2 × MFC)-treated
fruit was significantly lower than that in the wax-treated fruit.
The MDA content in the WO (2 × MFC)-treated fruit was only
approximately 6.8%–21.4% of that in the wax-treated fruit. This
result indicated that fruit senescence was more effectively
delayed and quality maintenance was more effectively promoted
in WO (2 × MFC)-treated fruit than in wax-treated fruit. This
finding is consistent with previous results obtained on the ca-
pacity of essential oils or their volatile components to reduce
MDA content in sweet pepper and citrus fruit (Fan et al., 2014;
Xing et al., 2011).

4. Conclusions

Octanal exhibited antifungal activity against P. digitatum, with
MIC and MFC values of 500 and 1000 µL/L, respectively. WO
treatment decreased the incidence rate of postharvest rots in
Satsuma mandarin fruit and significantly decreased PAL activity
and MDA content compared with the control treatment. WO
 treatment only slightly affected VC content, pH, coloration index,
and TSS content of the fruit but significantly increased the activity
of antioxidant enzymes (CAT and SOD). WO treatment also inhibi-
ted POD activity and prevented H2O2 accumulation.

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Fig. 3. Changes in MDA content in wax-treated fruit (□) and WO (2 × MFC)-treated citrus fruit (□□) stored at 25 ± 2 °C for 6 d. Values represent the means of the replicates, and error bars represent the standard error of the means (n = 3). Values in columns with different letters are statistically different according to Duncan’s multiple range test at P = 0.05.

Fig. 4. Time course of changes in PAL activity and MDA content in the wax-treated fruit (□□) and WO (2 × MFC)-treated citrus fruit (□□□) stored at 25 ± 2 °C for 6 d. Values represent the means of replicates, and error bars represent the standard error of the means (n = 3). Values in columns with different letters are statistically different according to Duncan’s multiple range test at P = 0.05.
Acknowledgments

This work was supported by the National Natural Science Foundation of China (No. 31271964) and the Research Foundation of Education Bureau of Hunan Province (No. 12B126).

References


