Agriculture and Natural Resources 52 (2018) 543–549

Contents lists available at ScienceDirect

Agriculture and Natural Resources

journal homepage: http://www.journals.elsevier.com/agriculture-and-natural-resources/

Original Article

Combined effects of food additives and heat treatment on fruit rot disease and quality of harvested dragon fruit

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ARTICLE INFO

Article history:
Received 21 March 2018
Accepted 10 September 2018
Available online 24 November 2018

Keywords:
Dragon fruit
Food additives
Fruit rot disease
Hot water treatment
Potassium sorbate
Sodium carbonate

ABSTRACT

The effects of food additives (sodium carbonate, SC and potassium sorbate, PS) at 0%, 1%, 2%, 3% and 4% weight per volume on fungal spore germination of dragon fruit rot diseases, *Colletotrichum gloeosporioides*, *C. capsici* and *Fusarium* sp. were investigated on media. PS at all concentrations showed complete inhibition of spore germination in the three fungi. SC 2% inhibited the germination of *C. gloeosporioides* by 100% while SC 3% completely inhibited the germination of *C. capsici* and *Fusarium* sp. PS solution was selected to study its combined effects with hot water treatment on fruit rot disease and quality of dragon fruit artificially inoculated with *C. gloeosporioides*. The fruit samples were treated in a heated (55 °C) solution of 1% PS for 5 min and then cooled in tap water at 10 °C (PS-55 °C + cold H_2O). Non-treated fruit and fruit treated with the fungicide carbendazim were used as controls. All samples were assessed after being kept at 13 °C for 15 d. The treatment of PS-55 °C + cold H_2O reduced the severity of diseases and helped to delay chlorophyll degradation in the dragon fruit bracts, had little impact on the respiration rate, delayed ethylene production and maintained the total ascorbic acid content. However, PS-55 °C + cold H_2O treatment, while having little initial effect, did reduce fruit firmness after 15 d of storage. The PS-55 °C + cold H_2O treatment did not affect weight loss or the total soluble solids concentration. These findings showed that the PS-55 °C + cold H_2O treatment could act as a safe alternative method for suppressing fruit rot disease while maintaining the quality of dragon fruit during cold storage.

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Introduction

Dragon fruit (*Hylocereus* spp.) is gaining popularity in tropical and sub-tropical regions of the world, due to its rich nutrient and high antioxidant content (Rebecca et al., 2010; Choo and Yong, 2011). However, the fruit has a short shelf life because of its short storage time mainly due to diseases, especially fruit rot disease which in dragon fruit has been reported to be associated with many fungi, such as *Dothiorella dominicana*, *C. gloeosporioides*, *C. capsici* and *Bipolaris cactivora* (Athipunyakom et al., 2009; Masyahit et al., 2009). Currently, synthetic fungicides such as benomyl, carbendazim, propineb and difenoconazole (Ali et al., 2013) are commonly used for control. However, application over a prolonged time can cause fungal mutations and the build-up of resistance to specific fungicides (Deising et al., 2008). Residues of fungicides on fresh fruit are also potentially harmful to the environment and to human health (Aktar et al., 2009). Therefore, new and safer methods are needed to explore options for the control of fungal diseases and to reduce the use of synthetic fungicides. Hot water treatment (HWT) has been widely investigated as an effective method for the control of postharvest decay of fruit (Lurie, 1998). Several studies have shown that HWT has been successfully used to control postharvest diseases in many fruits such as pears, lemon, papaya, peach, nectarine, plum and mango (Nafussi et al., 2001; Zhang et al., 2008; Karabulut et al., 2010; Le et al., 2010; Li et al., 2013). With dragon fruit, HWT has been used for controlling postharvest diseases and for maintaining the quality of the fruit. For example, HWT at 53 °C

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https://doi.org/10.1016/j.anres.2018.11.019
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for 1 min reduced the incidence of fruit rot disease in dragon fruit by more than 40% (Sornvilai et al., 2012) and Wasantha et al. (2011) found that a HW dip at 50 °C for 5 min could retard fruit rot diseases of dragon fruit by 49%. However, a single treatment with HW alone was less effective than a chemical treatment (Prakash and Pandey, 2000; Wasker, 2005). For this reason, it would be worthwhile to find other treatments that are able to enhance the efficiency of hot water treatment to control postharvest diseases and to maintain the quality of dragon fruit.

Food additives or generally recognized as safe (GRAS) compounds are allowed to be used for the control of postharvest diseases of fruits and vegetables (Palou et al., 2002). Several such additives have been successfully applied for the control of postharvest diseases, including ammonium carbonate, ammonium bicarbonate, sodium bicarbonate, sodium benzoate, potassium sorbate and sodium carbonate (Smilanick et al., 2008; Karaca et al., 2014; Youssef et al., 2014; Montesinos-Herrero et al., 2016). D'Aquino et al. (2013) reported that potassium sorbate (PS) at 2 g/L reduced the incidence of *Penicillium digitatum*, the causal agent of green mold in citrus fruit, and a concentration of 12.5 g/L or 15.0 g/L reduced the incidence and severity of sour rot in lemon fruits by 76.0% and 78.0%, respectively (Abd-El-Kareem and Saied, 2015). Palou et al. (2002) found that 3% sodium carbonate (SC) reduced green and blue molds of clementine mandarins and similar results have been found for other citrus fruit (Youssef et al., 2014). In addition, a combination of food additives with hot water is recognized as enhancing the efficacy of the additives in controlling fruit decay. For example, Palou et al. (2002) found that heated 3% SC solution at 50 °C totally controlled green and blue molds better than when either an SC solution or HWT alone was used. Similarly, Fadda et al. (2015) indicated that 1% PS significantly reduced blue mold of apple, especially when applied at 53 °C.

The objectives of the present study were to investigate the antifungal properties of food additives in an *in vitro* test and to evaluate the application of food additives combined with HWT on controlling fruit rot disease and maintaining postharvest quality of dragon fruit.

Materials and methods

Fungus isolation and culture preparation

Fruit rot fungi were isolated from naturally infected dragon fruit and cultured on potato dextrose agar (PDA) at 27 °C for 2 wk. A pure culture of each fungal colony was collected and the genus identified based on morphological characteristics (Dugan, 2006). Three fungi (*Colletotrichum gloeosporioides*, *C. capsici* and *Fusarium* sp.) were used as the main pathogens of rot diseases in dragon fruit. Pure cultures from PDA media of each fungus were then transferred to new media for 10 d and the conidia harvested from the media to prepare the spore suspensions that were used in the *in vitro* tests. Fungal spores were obtained by flooding the surface of the culture with sterile distilled water containing 0.05% (volume per volume, v/v) Tween-20. The suspension was filtered through four layers of sterile cheesecloth and adjusted to a concentration of 5×10^4 spores/mL for spore germination testing and 1×10^6 spores/mL for inoculation of dragon fruit using a hemocytometer.

Fruit material

Dragon fruit samples with white flesh at 75–80% maturity were harvested from commercial orchards located in Pathum Thani province, Thailand. The fruits were selected for uniformity of size and shape and were free from defects. Each fruit was surface-disinfested with a solution of 200 parts per million sodium hypochlorite for 3 min and air-dried before treatment.

Methods

Effect of food additives on spore germination of fruit rot pathogens

The effect of food additives (SC and PS) on spore germination of fruit rot pathogens (*C. gloeosporioides*, *C. capsici* and *Fusarium* sp.) was tested using a potato dextrose agar (PDA) plate method as follows. SC and PS concentrations at 0 (control), 1%, 2%, 3% and 4% were mixed with molten PDA to give a volume of 20 mL per Petri dish (diameter 8 mm). After the PDA had solidified, each spore suspension of pathogens (5×10^4 spores/mL) was spread on the surface of the PDA. The medium was then incubated at room temperature for 72 h and the numbers of fungal colonies were counted. The results were calculated as the percentage of inhibition of spore germination compared with the control. Each treatment used three replicates and each replication comprised five Petri dishes.

Effect of heated food additives on the control of fruit rot diseases on individual fruit

C. gloeosporioides was used to inoculate the dragon fruits in this experiment as it was found to be the predominant pathogen. Individual fruit were wounded (2 mm deep × 2 mm wide) with the tip of a sterile needle. Each wound was inoculated with 50 μL of a spore suspension of *C. gloeosporioides* (1×10^6 spores/mL) and then the fruits were covered with a plastic bag and incubated at 25 °C for 12 h. The inoculated fruits were randomly divided into three groups. The first group was dipped in a solution of 500 ppm carbendazim; the second group was dipped in a heated solution of 1% potassium sorbate at 55 °C for 5 min, after which the fruit were immediately cooled in tap water (10 °C) for 10 min; and the third group of untreated fruit served as a control. All fruit samples were dried at 25 °C after treatment, and then packed in a carton. All treatments were kept at 13 °C under humidified conditions (85–90% relative humidity for 15 d. Sampling was carried out at 0 d, 3 d, 6 d, 9 d and 15 d to evaluate disease severity, quality parameters (weight loss, firmness, total soluble solids, color of the peel and the bracts), total chlorophyll in the bracts, total ascorbic acid in the pulp, ethylene production and the respiration rate. Each treatment contained four replicates and each replication comprised five fruits.

Evaluation of disease severity

Disease severity was assessed as the extent of the total decayed area on each fruit surface, using a 5-point scale, where 0 = no disease symptoms, 1 = 0.1–5% of disease spots, 2 = 5.1–10% of disease spots, 3 = 10.1–15% of disease spots, 4 = 15.1–20% of disease spots on the affected fruit surface.

Determination of fruit quality

The weight of fruit in grams was measured using an electronic scale and the results calculated as the percentage weight loss.

Flesh firmness was measured using a texture analyzer (Model; TA-XT2, Stable Micro-system; Godalming, UK), with a 5 mm diam. cylinder. The measurement was taken in the equatorial zone and the probe penetrated to a depth of 5 mm at a rate of 10 mm/min. The average value of firmness of each fruit was calculated from these values and expressed in newtons.

The total soluble solids (TSS) content of fruit juice was determined using a digital hand-held refractometer (0–52 °Brix; PAL-1; Atago Co Ltd; Tokyo, Japan) and results reported as °Brix at 25 °C.

The color of both the fruit peel and the bracts was measured using a colorimeter (CR 300; Minolta; Tokyo, Japan). The

measurements were expressed as a*, b* and L* values and hue angle. Three readings were taken three times on each fruit. The total difference results were calculated and reported as E values.

Determination of total chlorophyll content

The total chlorophyll content was analyzed according to the method of Moran (1982). The bracts of dragon fruit (0.5 g) were extracted in 5 mL of *N*,*N*-dimethylformamide and kept overnight at 4 °C in the dark, followed by filtering through Whatman No. 2 paper. The filtered solution was measured using a spectrophotometer (UV-1800; Shimadzu; Kyoto, Japan) at 663 nm and 645 nm.

Determination of total ascorbic acid content

Determination of total ascorbic acid was conducted according to Roe et al. (1948). A 5 g sample of tissue from the pulp was homogenized in 20 mL of aqueous solution of 1% metaphosphoric acid (weight per volume, w/v). The homogenate was centrifuged at 12,000×*g* for 30 min at 4 °C. The total ascorbic acid was measured by mixing 0.5 mL of the supernatant with 0.2 mL of 0.02% 2,6-dichlorophenol-indophenol sodium salt in distilled water and then incubating at room temperature for 1 h. A 0.5 mL aliquot of 2% thiourea in 5% meta-phosphoric acid and 0.25 mL of 2% 2,4-dinitrophenylhydrazine in 9 N sulfuric acid were then added. The mixture was kept in a water bath 60 °C for 3 h, followed by an ice bath for 30 min. The reaction in the mixture was stopped by adding 1.25 mL of 90% sulfuric acid and holding the solution at room temperature for 30 min before reading absorbance at 540 nm using the spectrophotometer. The ascorbic acid content was calculated using a standard curve generated using commercial L-(+)-ascorbic acid and then expressed as milligrams per 100 g fresh weight (FW).

Determination of ethylene production and respiration rate

Ethylene production from dragon fruit was measured using gas chromatography with a flame ionization detector (FID) equipped with an 80/100 mesh Porapack-Q column with nitrogen as a carrier gas (GC B14; Shimadzu: Kyoto, Japan). Fruit samples were kept in a 1.8 L sealed plastic container, and then incubated at 13 °C for 1 h. A 1 mL gas sample was withdrawn from the head space and used for ethylene determination. Respiration rates were also determined using gas chromatography with an 80/100 mesh Porapack-Q column and a thermal conductivity detector (GC A8; Shimadzu; Kyoto, Japan).

Statistical analysis

The results were analyzed using analysis of variance with the general linear models procedure of SAS (SAS Institute; Cary, NC, USA) for a completely randomized design. The data were presented as mean ± SE of the means.

Results

Effects of food additives on spore germination of rot pathogens of dragon fruit

The effects were investigated of SC and PS on fungal spore germination of dragon fruit rot diseases caused by *C. gloeosporioides*, *C. capsici* and *Fusarium* sp. The results showed that PS concentrations at 1%, 2%, 3% and 4% completely inhibited spore germination of the three fungi (Table 1). In comparison, SC 2% could inhibit the germination of *C. gloeosporioides* by 100% and SC 3% could inhibit the germination of *C. capsici* and *Fusarium* sp. by 100% (Table 1). Therefore, among the food additives tested, PS was the most effective in inhibiting the germination of the fungal spores.

Table 1
Effects of sodium carbonate (SC) and potassium sorbate (PS) on the inhibition of spore germination of *C. gloeosporioides*, *C. capsici* and *Fusarium* sp. on potato dextrose agar medium after incubating at room temperature for 72 h.

Food additive	Inhibition of spore germination (%)		
	C. gloeosporioides	C. capsici	Fusarium sp.
Control	0.00^{d}	0.00^{d}	0.00^{d}
1% SC	60.96^{b}	23.74^{c}	21.93^{c}
2% SC	100.00^{a}	33.53^{b}	27.02^{b}
3% SC	100.00^{a}	100.00^{a}	100.00^{a}
4% SC	100.00^{a}	100.00^{a}	100.00^{a}
1% PS	100.00^{a}	100.00^{a}	100.00^{a}
2% PS	100.00^{a}	100.00^{a}	100.00^{a}
3% PS	100.00^{a}	100.00^{a}	100.00^{a}
4% PS	100.00^{a}	100.00^{a}	100.00^{a}

^{a,b,c,d} mean values (± SE) followed by a different lowercase superscript letter within a column are significantly ($p < 0.05$) different according to Duncan's multiple range test.

Effects of PS solution combined with HWT on rot diseases of dragon fruit

None of the treated dragon fruit had any fruit rot symptoms during storage at 13 °C for the first 9 d. At day 15, fruit treated with PS-55 °C + cold H_2O had the lowest disease severity with a score of 2, which was significantly lower than either the control or the fungicide treatment which had similar disease severity (2.33 score; Fig. 1).

Effects of potassium sorbate solution combined with hot water treatment on the quality of dragon fruit

Color changes in the peel

The peel color of dragon fruit was evaluated and reported as a* (green-red) and ΔE (color difference) values. The a* values of all treated fruits increased during storage, indicating that the peel of

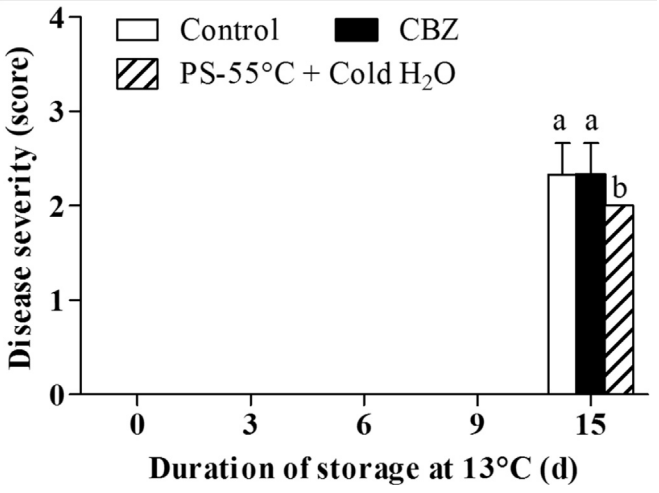

Fig. 1. Disease severity of fruit rot disease in dragon fruit when treated with 500 parts per million carbendazim (CBZ) or a heated solution of 1% potassium sorbate at 55 °C for 5 min and then cooled down in tap water (PS-55 °C + cold H_2O), and the untreated control fruit during storage at 13 °C for 15 d, where vertical bars represent ± SE for triplicate samples and different lowercase letters above bars indicate significant ($p < 0.05$) differences using Duncan's multiple range test.

those fruit became progressively darker red during the storage period. However, fruit treated with PS-55 °C + cold H_2O did not show any significant difference in a* value when compared with the control fruits at any assessment time (Fig. 2A). Similarly, with the ΔE values of the peel, the fruit treated with PS-55 °C + cold H_2O were not significantly different from those in the control fruit (Fig. 2B). Therefore, these results indicated that the PS-55 °C + cold H_2O treatment did not have any effect on the color change of the dragon fruit peel during the 15 d of storage.

Color changes and total chlorophyll contents in bracts

The ΔE value of the bracts in all treatments increased progressively during extended storage and corresponded to a decrease in the total chlorophyll concentration. The ΔE value for the dragon fruit bracts was significantly lowest in PS-55 °C + cold H_2O treated fruit after 9 d of storage (Fig. 3A). The total chlorophyll concentration in the bracts of fruit declined during storage in all treatments. However, the total chlorophyll concentration in the bracts in fruit treated with PS-55 °C + cold H_2O remained higher than that in the control or CBZ treated fruit throughout the storage period (Fig. 3B). Thus, the treatment with PS-55 °C + cold H_2O could maintain the green color and total chlorophyll concentration of the bracts of dragon fruit at higher values compared to the other treatments.

Total ascorbic acid concentration

The total ascorbic acid concentration in all treatments tended to decrease during storage. The total ascorbic acid concentration in fruit treated with PS-55 °C + cold H_2O remained highest, especially at 15 d (0.54 mg/100 g FW), followed by the CBZ treatment (0.43 mg/100 g FW) and the control (0.38 mg/100 g FW; Fig. 4A).

Fruit firmness

Fruit firmness declined steadily during 15 d of storage. During the first 6 d of storage, fruit treated with PS-55 °C + cold H_2O had the highest firmness but differences among treatments were small. At the end of the storage period, fruit from this treatment were softer than those in the other treatments (Fig. 4B).

Effects of potassium sorbate solution combined with hot water treatment on respiration rate and ethylene production

The respiration rate of all treatments declined rapidly until day 6 of storage, briefly increased on day 9 and then declined to very low values on day 15. There were no significant differences between the control and the PS-55 °C + cold H_2O-treated fruit throughout the storage period (Fig. 5A).

Ethylene production in all treatments tended to progressively increase during storage (Fig. 5B). It was significantly lower in the PS-55 °C + cold H_2O treated fruit at days 6 and 9 of storage (Fig. 5B).

Discussion

Alternative treatments to control fruit rot diseases of dragon fruit have been studied for many years. However, the current study was the first to investigate a combination of PS with hot water as a control option. In the *in vitro* study, different food additives at different concentrations were screened for their ability to inhibit the germination of dragon fruit rot pathogens (*C. gloeosporioides*, *C. capsici* and *Fusarium* sp.) which had been isolated and identified from the fruit used in this study. Among them, *C. gloeosporioides* was found to be the major pathogen involved with fruit rot disease. It was shown that PS at a concentration of 1–4% and SC at a concentration of 2–4% showed complete inhibition of spore germination of all three fungal pathogens. It has been reported previously that the effects of PS and SC on the inhibition of pathogen growth is probably due to a reduction of fungal cell turgor pressure which resulted in collapse and shrinkage of hyphae and spores, and consequently, an inability of the fungus to sporulate (Fallik et al., 1997). Fadda et al. (2015) reported that 2000 mg/L PS had fungistatic activity against *Penicillium expansum* and reduced blue mold on apple. Similarly, Palou et al. (2002) found that 3% SC had fungistatic activity and reduced the activities of both *P. digitatum* and *P. italicum*, the causal agents of green and blue mold on mandarins. However, the current study found that 2% SC inhibited the spore germination of *C. gloeosporioides* by 100% while 3% SC inhibited the spore germination of *C. capsici* and *Fusarium* sp. completely. In addition, several previous reports have indicated that pH plays an important role in the antifungal activity of food additive solutions (D'Aquino et al., 2013; Youssef et al., 2014; Montesinos-Herrero et al., 2016).

However, some literature has reported that the effectiveness of food additives can be improved when combined with hot water treatment. Smilanick et al. (2008) found that 0.5% potassium sorbate was more effective against *P. digitatum* when it was heated to 50 °C for 30 s. Similarly, PS completely inhibited spore germination of *Fusarium* sp., *Lasiodiplodia theobromae* and *Colletotrichum musae* when it was combined with heat treatment at 45 °C for 5 min (Jitareerat and Uthairatakij, 2010). However, the efficacy of the inhibition of spore germination from a hot water treatment was dependent on temperature and time. High temperature has been shown to improve the mode of action of food additives by increasing the permeability of the membrane and facilitating the

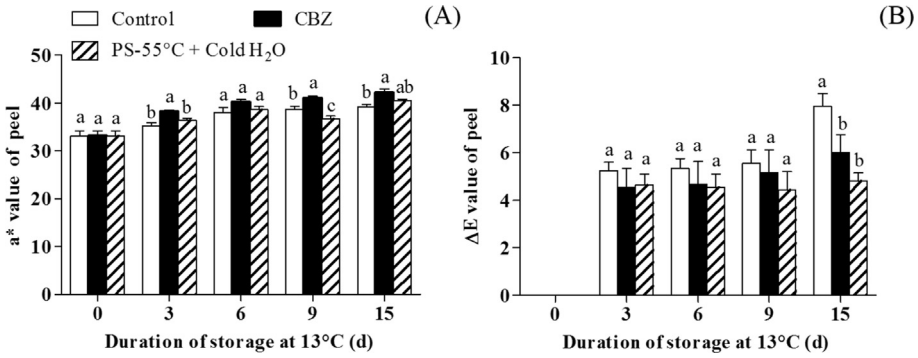

Fig. 2. a* value (A) and ΔE value (B) of the peel of dragon fruit when treated with 500 parts per million carbendazim (CBZ), a heated solution of 1% potassium sorbate at 55 °C for 5 min and then cooled down in tap water (PS-55 °C + cold H_2O), and an untreated control during storage at 13 °C for 15 d, where vertical bars represent ± SE for triplicate samples and different lowercase letters above bars indicate significant ($p < 0.05$) differences using Duncan's multiple range test.

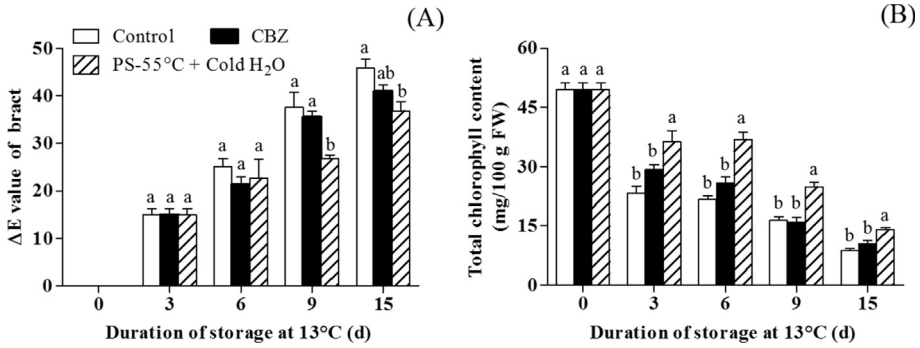

Fig. 3. Total color difference (ΔE) value (A) and total chlorophyll concentration on a fresh weight (FW) basis (B) in the bracts of dragon fruit when treated with either 500 parts per million carbendazim (CBZ) or a heated solution of 1% potassium sorbate at 55 °C for 5 min and then cooled down in tap water (PS-55 °C + cold H_2O), or in an untreated control during storage at 13 °C for 15 days, where vertical bars represent ± SE for triplicate samples and different lowercase letters above bars indicate significant ($p < 0.05$) differences using Duncan's multiple range test.

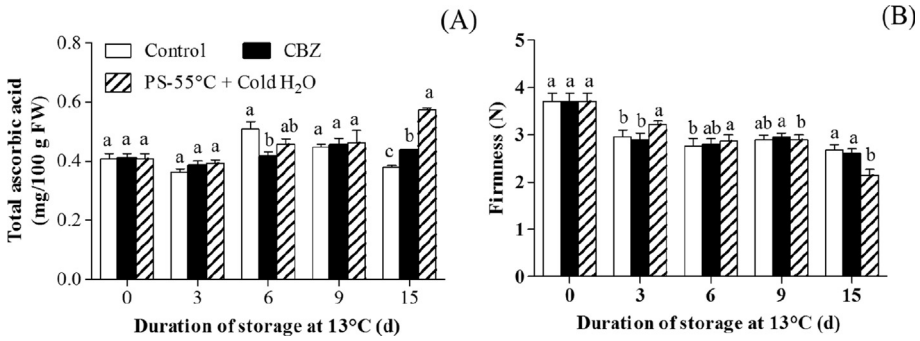

Fig. 4. Total ascorbic acid concentration on a fresh weight (FW) basis (A) and firmness (B) of the pulp of dragon fruit when treated with either 500 parts per million carbendazim (CBZ) or a heated solution of 1% potassium sorbate at 55 °C for 5 min and then cooled down in tap water (PS-55 °C + cold H_2O) or as an untreated control during storage at 13 °C for 15 d, where vertical bars represent ± SE for triplicate samples and different lowercase letters above bars indicate significant ($p < 0.05$) differences using Duncan's multiple range test.

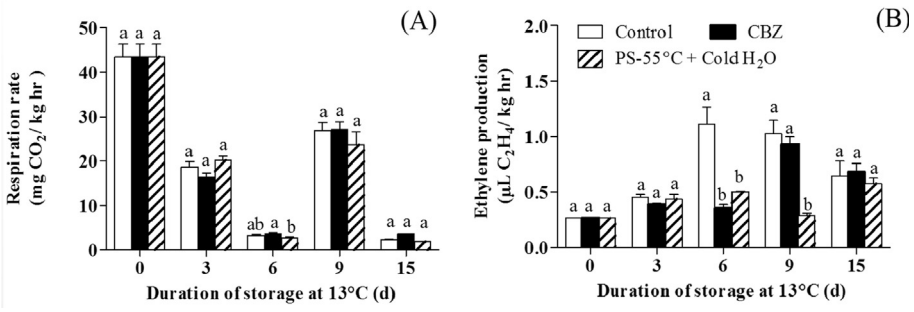

Fig. 5. Respiration rate (A) and ethylene production rate (B) of dragon fruit when treated with either 500 ppm carbendazim (CBZ), or a heated solution of 1% potassium sorbate at 55 °C for 5 min and then cooled down in tap water (PS-55 °C + cold H_2O) or as an untreated control during storage at 13 °C for 15 d, where vertical bars represent ± SE for triplicate samples and different lowercase letters above bars indicate significant ($p < 0.05$) differences using Duncan's multiple range test.

entrance of food additives (Montesinos-Herrero et al., 2016). The results from the *in vitro* study reported here demonstrated that the application of 1% PS solution was the best treatment for inhibiting the germination of three fungal pathogens. Moreover, the preliminary test showed that HWT at 55 °C for 5 min was very effective in reducing the fruit rot disease without negatively affecting fruit appearance. Therefore, the application of 1% PS solution combined with HWT at 55 °C for 5 min followed by cooling in tap water at 10 °C (PS-55 °C + cold H_2O) was selected for the *in vivo* test where disease severity was reduced by the treatment when compared with carbendazim and untreated fruit. The suppressed disease development by the heated 1% PS solution might have been related to direct effects on fungal growth and to indirect effects that induced plant defense mechanisms. Direct effects of HWT were reported by Liu et al. (2012) who found that heat treatments inhibited spore germination and germ tube elongation of *Monilinia fructicola*. The mode of action of the heat treatment may be related to a triggering of the accumulation of reactive oxygen species, a collapse of mitochondrial membrane potential and a decrease in intracellular adenosine triphosphate in *M. fructicola*. In addition, the application of PS has been reported to have direct effects on the inhibition of growth of several fungi including *P. digitatum*, *Geotrichum citri-aurantii*, *M. fructicola* and *P. expansum* (Smilanick et al., 2008; Karaca et al., 2014; Fadda et al., 2015). Indirect effects may have been due to the induction of defense mechanisms in the fruit (Schirra et al., 2000). HWT could induce such mechanisms possibly

through two major groups of proteins: heat shock proteins and pathogenesis-related (PR) proteins (Pavoncello et al., 2001). Pavoncello et al. (2001) found that HWT at 60 °C for 20 s was effective in inducing heat shock protein 70 and PR proteins, including chitinase and β-1,3-glucanase enzymes. Inkha and Boonyakiat (2010) also reported that HWT at 55 °C for 3 min increased the activity of chitinase, β-1,3-glucanase and peroxidase against *P. digitatum* in tangerine fruit. Moreover, the synergistic effects of hot water and PS solution have been reported to reduce postharvest disease in apple, citrus and lemon fruit (Smilanick et al., 2008; D'Aquino et al., 2013; Abd-El-Kareem et al., 2015; Fadda et al., 2015).

In addition to the impacts on fungal pathogens, treatment with PS-55 °C + cold H_2O significantly affected fruit quality, as indicated by the color of the peel and the bracts and by the total chlorophyll contents in bracts. This color is one of the main physical quality parameters that affects consumer acceptability. Normally, the peel of dragon fruit becomes dark red and the green color of the bracts turns to yellow with an increase in the storage period. However, fruit treated with PS-55 °C + cold H_2O maintained a better color of the peel and of the bracts than the other treatments. The maintenance of color in the bracts of dragon fruit during storage was correlated with the total chlorophyll concentration. HWT could delay chlorophyll degradation by inhibiting the activity of those enzymes involved in chlorophyll degradation. Kaewsuksaeng et al. (2015) reported that HWT at 50 °C for 5 min efficiently delayed the decrease in the total chlorophyll content in lime fruit, and the result correlated with low activities of chlorophyll degrading enzymes, including chlorophyllase, Chl-degrading peroxidase, pheophytinase and Mg-dechelatase. However, fruit firmness in the PS-55 °C + cold H_2O treated fruit was softer than that in the control fruit. This response was similar to that reported by Prusky et al. (1999), who found that HWT accelerated softening in mango fruit. Nonetheless, the PS-55 °C + cold H_2O treatment did not affect weight loss or the TSS concentration in the fruit (data not shown). The application of heat treatments has been shown to alter various biochemical and physiological processes and to disrupt fruit senescence. For example, the current results showed that although respiration was unchanged, ethylene production of dragon fruit was reduced after the treatments. In contrast, Hong et al. (2007) found that HWT reduced the respiration rate in Satsuma mandarin during storage at 5 °C. However, heat treatment was reported to reduce ethylene production in broccoli by suppressing 1-aminocyclopropane-1-carboxylic acid, 1-aminocyclopropane-1-carboxylic synthase (ACS) activity, and the accumulation of ACS transcripts (BO-ACS1) (Suzuki et al., 2005). Additionally, previous studies have shown that HWT affects the concentrations of nutrients and antioxidants in fruits (Ummarat et al., 2011; Shadmani et al., 2015). The current results demonstrated that the PS-55 °C + cold H_2O treatment could maintain the total ascorbic acid content in dragon fruit pulp.

In conclusion, the data presented here showed that PS and SC significantly inhibited spore germination of *C. gloeosporioides*, *C. capsici* and *Fusarium* sp., which are causal agents of fruit rot disease in dragon fruit. Fruit treated with the PS solution combined with hot water at 55 °C for 5 min followed by cooling in H_2O could reduce the severity of fruit rot disease and maintain the quality of dragon fruit during storage. This combined application could provide a promising, innovative and alternative approach to controlling fruit rot disease while maintaining the quality of dragon fruit.

Conflict of interest

The authors declare that there are no conflicts of interest.

Acknowledgements

This research was supported by the National Research Council of Thailand in 2015–2016.

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