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Postharvest oxalic acid dipping affects ripening, quality and antioxidant system of 'Hindi-Besennara' mangoes during ripening

Mohamed A. Awad[1,2]* and Adel D. Al-Qurashi[1]

[1]Department of Arid land Agriculture, Faculty of Meteorology, Environment and Arid land Agriculture, King Abdulaziz University, P. O. Box. 80208, Jeddah, **Saudi Arabia**
[2]Pomology Department, Faculty of Agriculture, Mansoura University, El-Mansoura, **Egypt.**

***Correspondence:** mawad@mans.edu.eg **Received 18-02-2020, Revised: 05-05-2020, Accepted: 06-05-2020 e-Published: 10-05-2020**

Effects of oxalic acid (OA) (10 and 20 mM) dipping on quality and antioxidant system of 'Hindi-Besennara' mangoes were studied during ripening for 8 days at 20± 2°C and 60–70% RH. Weight loss increased during ripening to 12.2% and was lower in OA treated fruit than control. Unmarketable fruit percentage (UFP) reached 6.7% in the control with no UFP in OA treated fruit after 5 days while, after 8 days, it was lower in treated fruit 19.1 and 13.3% at 10 and 20 mM OA, respectively than control (35.6%). OA treated fruit retained higher green color (a* values), firmness, titratable acidity (TA) and membrane stability index (MSI) but lower total soluble solids (TSS) and TSS/TA ratio during ripening especially after 3 and 5 days. Total phenol and flavonoid contents of fruit peel and pulp showed higher values during ripening than initial, fluctuated during ripening, and were higher in OA treated fruit especially at 20 mM than control. Vitamin C content was higher in OA treated fruit especially at 20 mM than control after 3 and 5 days. Radical scavenging capacity (RSC) of fruit pulp decreased (higher DPPH IC_{50} values) during ripening compared to initial and was higher in OA treated fruit than control after 8 days. While, RSC in peel was not changed during ripening and was higher in OA treated fruit than control. In both peel and pulp, polyphenoloxidase (PPO) activity gradually increased during ripening and was lower in OA treated fruit than control. While, peroxidase (POD) activity gradually increased during ripening and was higher in OA treated fruit than control. Polygalacturonase (PG), xylanase and α-amylase activities, in both peel and pulp, showed higher levels than initial, fluctuated during ripening and were lower in OA treated fruit than control. In conclusion, postharvest dipping in 20 mM OA retard ripening, retained and improved quality of 'Hindi-Besennara' mangoes during ripening via inhibiting hydrolytic enzymes and enhancing fruit antioxidant system.

Keywords: Mango, Shelf life, Ripening, Quality, Antioxidant, Enzymes

INTRODUCTION

Mango (*Mangifera indica* L.) is a popular tropical and subtropical fruit with high worldwide marketing value due to its favorable flavor, nutrition and health value (Sivakumar et al. 2011). It is a climacteric fruit that can be harvested at the mature hard-green stage and resume normal ripening processes during storage and SL (Mitra and Baldwin, 1997; Sivakumar et al. 2011). The high perishability of mangoes following harvest is due to rapid ripening processes, decay and/or physiological disorders, resulting in great economic losses (Yashoda et al. 2006; Tian et al. 2010; Zhang et al. 2013). The susceptibility of mangoes

to chilling injuries (CI) that develop at lower storage temperature limit fruit storability, transporting and marketing (Zheng et al. 2007a; Sivakumar et al. 2011). Synthetic fungicides and growth regulators application, especially at a pre or postharvest phases, is rather prohibited because of possible negative impacts on both human health and environment. The approach of inducing resistant to pathogens in fruit following harvest by physical, biological, and chemical elicitors is a promising alternative to reduce postharvest losses and regulate ripening (Terry and Joyce, 2004; Zhang et al. 2013; Awad et al. 2017; Al-Qurashi and Awad, 2018). Oxalic acid (OA) is a naturally occurring carboxylic acid having different roles in living organisms and has been used as a food preservative and anti-browning for fresh fruit and vegetables (Libert and Franceschi, 1987; Yoruk et al. 2002; Zheng and Tian, 2006). There are some published work on the effects of OA treatment at 5 to 10 mM to reduce decay and maintain quality of mango fruit at ambient conditions or to reduce CI at cold storage. However, all of these research work were performed on only 'Zill' mango cultivar (Zheng et al. 2005; Ding et al. 2007; Zheng et al., 2007a, b; Li et al. 2015). In the Kingdom of Saudi Arabia (KSA), a considerable postharvest loss occur in 'Hindi-Besennara' mangoes, one of the most commercially growing cultivar, due to inappropriate postharvest handling especially with high climatic temperature and humidity which favor rapid softening, browning and pathogens attack (Awad et al. 2017; Al-Qurashi and Awad, 2018). Therefore, this study aim to evaluate the response of 'Hindi-Besennara' mangoes to postharvest dipping in OA at 10 and 20 mM as an attempt to regulate postharvest ripening, retain and improve quality at ambient conditions. The effects of OA treatment on membrane stability, hydrolytic and oxidative enzymes activities and antioxidant system of both peel and pulp in relation to fruit quality during ripening were evaluated.

MATERIALS AND METHODS

Plant materials and experimental procedure

In 2019 growing season, uniform samples of 'Hindi-Besennara' mangoes were harvested at mature hard-green stage from a commercial orchard in Jizan region (17.4751° N, 42.7076° E), KSA. Fruit were packed in perforated cardbox (12 fruit of each box, about 3.0-3.5 kg) and transported to the postharvest laboratory at King Abdulaziz University in Jeddah within about 8 h at 15 ^{o}C. Fruit of uniform size, weight (200-250 g/fruit) and appearance and free of visual defects were selected for this experiment.

Fruit treatments

A completely randomized experimental design with three replicates (30 fruit of each) for each treatment was arranged. Fruit of each treatment/replicate were drenched into either water (control), oxalic acid solution (10 or 20 mM) for 10 min. The wetting agent Tween 20 at 1ml/l was added to all treatments solutions. After air draying of about 1 h, all treatments/replicates were weighted and stored at 20±2 ^{o}C and 60–70% (RH) in perforated cardboard cartons for 8 days. A separate three replicates (5 fruits of each) for each treatment were stored at the same conditions and periodically weighed (at 0, 3, 5 and 8 days) for loss in weight calculation and expressed in percentage. At the beginning of storage (0 days), another three samples (5 fruit of each) were randomly collected for initial quality and biochemical measurements as detailed below. After 3, 5 and 8 days during ripening, random samples (5 fruit) per replicate were taken for quality and biochemical measurements as indicated below. Following peel color and pulp firmness measurements, samples of both pulp and peel were taken, sliced and stored at –80 ^{o}C for enzyme, total phenol, total flavonoid and antioxidant capacity determinations. Additional portion of fruit pulp were directly used for TA, pH, TSS and vitamin C measurements.

Unmarketable fruit percentage (UFP)

Fruit that showed browning and shriveling of about 10% of its total surface area (visually estimated) or fungal infection symptoms was considered unmarketable and was calculated on initial fruit number basis for each samples and expressed in percentage.

Peel color measurement

Peel color was measured independently in 5 randomly selected fruit per replicate by a Minolta Chroma Meter CR-410 (Minolta Camera Co. Ltd., Osaka, Japan). The values of L*, a* and b* were measured in the middle of each of the five fruit/replicate. Chroma = $(a^{*2}+b^{*2})^{½}$ which represented the hypotenuse of a right triangle with values ranging from 0 = least intense to 60 = most intense. The chroma values indicate the saturation of the color.

Firmness, TSS, TA, pH and vitamin C measurements in fruit pulp

Pulp firmness of fruit was measured independently in 5 fruit (two opposite measurements in the middle of each fruit) per replicate by a digital basic force gauge, model BFG 50N (Mecmesin, Sterling, Virginia, USA) supplemented with a probe of 11 mm diameter and the results were expressed as Newton. A homogeneous sample was prepared from these 5 fruit per replicate for measuring TSS content, TA, pH and vitamin C concentration. TSS content was measured in fruit pulp juice with a digital refractometer (Pocket Refractometer PAL 3, ATAGO, Japan) and expressed in percentage. TA was determined in distilled water diluted fruit juice (1: 2) by titrating with 0.1N sodium hydroxide up to pH 8.2, using automatic titrator (HI 902, HANNA Instrument, USA) and the results expressed as a percentage of citric acid. Fruit juice pH was measured by a pH meter (WTW 82382, Weilheim, Germany). Vitamin C was measured by titrating juice sample with freshly prepared dye solution of 2,6-dichlorophenol-indophenol until pink color and the results expressed as g Kg^{-1} on a fresh weight (FW) basis (Ranganna, 2000).

Leakage of ions from peel

Leakage of ions was measured in peel disks according to Awad et al. (2017) and was expressed as membrane stability index percentage (MSI %).

Preparation of methanol extract of peel and pulp

Two grams of fruit peel and pulp (randomly collected from 5 fruit/replicate) were extracted by shaking at 150 rpm for 12 h with 20 ml methanol (80%) and filtered with Whatman No. 1 paper. The filtrate designated as methanol extract that was used for total phenols, total flavonoids and antioxidant activity estimations.

Estimation of total phenol and flavonoid contents

Total phenol content was measured according to Hoff and Singleton (1977) as detailed in Awad et al. (2017). Total flavonoid content was determined according to Zhishen et al. (1999) as detailed in Awad et al. (2017).

Evaluation of DPPH radical scavenging assay of peel and pulp

Free radical scavenging activity of methanol extract of peel and pulp was determined using the 1,1-diphenyl-2-picrylhydrazyl (DPPH) method (Ao et al. 2008) as described in in Awad et al. (2017).

Enzymes measurements of peel and pulp

Crude extract

One gram of fruit peel and pulp (randomly collected from 5 fruit/replicate) was homogenized with 20 mM Tris–HCl buffer, pH 7.2 using homogenizer. The homogenate was centrifuged at 10,000 rpm for 10 min at 4 ºC. The supernatant was designed as crude extract and stored at -20 ºC for peroxidase, polyphenoloxidase, polygalacturonase, xylanase and *α*-amylase assay.

Polyphenoloxidase assay

Polyphenoloxidase (EC 1.14.18.1) (PPO) activity was assayed with catechol as a substrate according to the spectrophotometric procedure of Jiang et al. (2002) as detailed in Awad et al. (2017).

Peroxidase assay

Peroxidase (EC 1.11.1.7) activity (POD) was assayed according to Miranda et al. (1995) as detailed in Awad et al. (2017).

Polygalacturonase, α-amylase and xylanase assays

Polygalacturonase (EC 3.2.1.15) (PG), *α*-amylase (EC 3.2.1.1) and xylanase (EC 3.2.1.8) activities were assayed by determining the liberated reducing end products using galacturonic acid, maltose and xylose, respectively as standards (Miller 1959) as detailed in Awad et al. (2017).

Statistical analysis

The data were statistically analyzed as a completely randomized design with three replicates by analysis of variance (two ways ANOVA) using the statistical package software SAS (SAS Institute Inc., 2000, Cary, NC., USA). Comparisons between means were made by the Duncan's multiple range test at $P \leq 5\%$.

RESULTS

In case of significant interactions between treatments and ripening period, we passed over the main effects and focused instead on the interactions and vice versa. Weight loss percentage gradually increased during ripening reaching 12.2% after 8 days and was significantly lower in OA treated fruit than control (Table 1).

Table 1. Fruit weight loss, firmness, total soluble solids (TSS) and pH of 'Hindi-Besennara' mangoes during ripening period (RP) as affected by postharvest oxalic acid (OA) dipping.

	Weight loss	**Firmness**	**TSS**	**pH**
	(%)	(N)	(%)	
Initial	*0.0*	*7.80*	*3.4*	*2.44*
Treatments (T)				
Control	9.6a	2.50b	17.7a	5.6
OA (mM)				
10	8.6b	2.91a	16.0b	5.8
20	8.8b	3.14a	16.3b	5.8
F-test	***	***	**	*NS*
RP (d)				
3	5.9c	4.07a	15.1c	5.3b
5	8.9b	2.44b	16.7b	5.6b
8	12.2a	2.04c	18.3a	6.3a
F-test	***	***	***	***
T x SL				
F-test	*NS*	*NS*	*NS*	*NS*

Means within each column followed by the same letter are not significantly different at level $P \leq 0.05$. (**) and (***), significant at $P \leq 0.01$ and 0.001, respectively; (NS), not significant.

Table 2. The interaction effect between treatments and ripening period on unmarketable fruit percentage (UFP), peel membrane stability index (MSI), pulp titratable acidity (TA), total soluble solids (TSS)/TA (ratio) of 'Hindi-Besennara' mangoes as affected by postharvest oxalic acid (OA) dipping.

	UFP	**MSI**	**TA**	**TSS/TA**
	(%)	(index)	(%)	(Ratio)
Initial	*0.0*	*46.6*	*3.14*	*1.1*
After 3 days				
Treatments				
Control	0.0e	19.3c	1.06b	15.7e
OA (mM)				
10	0.0e	32.1a	1.35a	10.5e
20	0.0e	27.1b	1.28a	11.3e
After 5 days				
Control	6.7d	7.0f	0.32d	55.3b
OA (mM)				
10	0.0e	11.4de	0.76c	21.1d
20	0.0e	13.6d	0.77c	21.9d
After 8 days				
Control	35.6a	7.8ef	0.30d	63.0a
OA (mM)				
10	19.1b	8.1ef	0.40d	46.0c
20	13.3c	10.0ef	0.34d	53.0b

Means within each column followed by the same letter are not significantly different at level $P \leq 0.05$.

Table 3. The interaction effect between treatments and ripening period on Minolta color values L*, a*, b* and chroma of 'Hindi-Besennara' mangoes as affected by postharvest oxalic acid (OA) dipping.

	L*	a*	b*	Chroma
Initial	*50.6*	*-15.3*	*27.1*	*31.2*
After 3 days				
Treatments				
Control	50.0ab	-12.0cd	23.1e	26.1d
OA				
10	50.1ab	-13.0d	25.3cd	28.0c
20	51.1ab	-12.7cd	24.4de	27.5cd
After 5 days				
Control	50.7ab	-10.3b	26.7c	28.6c
OA (mM)				
10	49.5b	-12.2cd	26.5c	29.2bc
20	50.1ab	-11.6c	25.0cd	27.6cd
After 8 days				
Control	53.0a	-7.0a	31.1a	31.9a
OA				
10	49.8b	-9.7b	28.9b	30.5ab
20	48.7b	-10.5b	28.4b	30.3ab

Means within each column followed by the same letter are not significantly different at level $P \leq 0.05$.

Firmness gradually decreased during ripening and was higher in OA treated fruit than control. TSS increased during ripening and was significantly lower in OA treated fruit than control. The pH values increased during ripening but were not significantly affected by the applied treatments (Table 1). After 5 days, UFP reached 6.7% in the control, while OA treated fruit exhibited no browning, shriveling or fungal infection symptoms (Table 2). After 8 days, UFP was significantly lower in OA treated fruit, especially at 20 mM that showed the lowest value (13.3%), than other treatments including control (35.6%). MSI of fruit peel decreased during ripening and was higher after 3 and 5 days in OA treated fruit than control. However, after 8 days, there were no significant differences among treatments in MSI. TA content decreased during ripening and was significantly higher in all treatments after 3 and 5 days than control. However, after 8 days, there were no significant differences among treatments in TA content. TSS/TA ratio increased during ripening and was lower in OA treated fruit, especially at 10 mM, after 5 and 8 days than control (Table 2). The L* values slightly changed during ripening but were lower in OA treated fruit than control after 8 days. The values of a* increased during ripening and were lower in OA treated fruit than control after 5 and 8 days. The values of b* slightly changed during ripening and were lower in OA treated fruit than control after 8 days. The chroma values slightly changed during ripening and were higher in 10 mM OA than control after 3 days (Table 3). Total phenol content of fruit peel showed higher values during ripening than initial and was higher in 20 mM OA than control after 3 days. After both 5 and 8 days, OA treated fruit at both rates exhibited higher total phenol concentration than control (Table 4). Vitamin C content showed lower values during ripening than initial and was significantly higher in OA treated fruit than control after 3 days. After 5 days, 20 mM OA treated fruit exhibited higher vitamin C than control. While, there were no significant differences in vitamin C content among treatments after 8 days. RSC of fruit pulp decreased (higher DPPH IC_{50} values) during ripening compared to initial and was significantly higher (lower DPPH IC_{50} values) in OA treated fruit than control after 8 days (Table 4). Total phenol content of fruit pulp showed higher values than initial, fluctuated during ripening, and was significantly higher in OA treated fruit especially at 20 mM than other treatments (Table 5). Total flavonoid content of both fruit peel and pulp showed higher values than initial, fluctuated during ripening, and were higher in OA treated fruit than other control. RSC (DPPH IC_{50} values) of fruit peel showed no significant changes during ripening and was significantly higher (lower DPPH IC_{50} values) in OA treated fruit than control (Table 5). PPO

activity of fruit peel gradually increased during ripening and was lower in OA treated fruit than other control (Table 6). POD activity of fruit peel gradually increased during ripening and was higher in OA treated fruit than control. PG activity of peel showed higher level than initial, fluctuated during ripening and was significantly lower in OA treated fruit than control. α-amylase activity of fruit peel showed higher level than initial, fluctuated during ripening and was significantly lower in OA treated fruit than control. Xylanase activity of fruit peel slightly changed during ripening and was significantly lower in 20 mM OA treated fruit than control (Table 6). PPO activity of fruit pulp increased during ripening and was lower in OA treated fruit than control (Table 6).

Table 4. The interaction effect between treatments and ripening period on peel total phenol (TPC) and pulp vitamin C concentrations (g Kg^{-1} FW), and pulp radical scavenging capacity (RSC) (DPPH IC_{50} values) of 'Hindi-Besennara' mangoes as affected by postharvest oxalic acid (OA) dipping.

	TPC (peel)	Vitamin C (pulp)	RSC (pulp)
Initial	*2.47*	*0.61*	*3.3*
After 3 days			
Treatments			
Control	2.74e	0.54b	4.3c
OA			
10	3.01cde	0.56a	4.5c
20	3.20bcd	0.57a	5.2ab
After 5 days			
Control	3.38bc	0.38d	5.3ab
OA (mM)			
10	4.37a	0.36e	5.6a
20	4.45a	0.43c	5.1ab
After 8 days			
Control	2.84de	0.34f	5.0b
OA			
10	3.39bc	0.34f	4.5c
20	3.57b	0.33f	4.5c

Means within each column followed by the same letter are not significantly different at level $P \leq 0.05$.

Table 5. Pulp total phenol (TPC), peel and pulp total flavonoid concentrations (TFC) (g Kg^{-1} FW), and peel radical scavenging capacity (RSC) (DPPH IC_{50} values) of 'Hindi-Besennara' mangoes during ripening period (RP) as affected by postharvest oxalic acid (OA) dipping.

	TPC (pulp)	TFC (peel)	TFC (pulp)	RSC (peel)
Initial	*0.78*	*0.40*	*0.22*	*7.6*
Treatments (T)				
Control	1.21c	0.66b	0.43c	9.5a
OA (mM)				
10	1.41b	0.83a	0.54b	8.0b
20	1.58a	0.88a	0.61a	8.3b
F-test	***	***	***	***
RP (d)				
3	1.18c	0.66c	0.36c	8.3
5	1.69a	0.93a	0.68a	9.0
8	1.32b	0.78b	0.54b	8.5
F-test	***	***	***	*NS*
T x SL				
F-test	*NS*	*NS*	*NS*	*NS*

Means within each column followed by the same letter are not significantly different at level $P \leq 0.05$. (***), significant at $P \leq 0.001$; (NS), not significant.

Table 6. Antioxidant and hydrolytic enzymes activity (U min g FW) in peel and pulp of 'Hindi-Besennara' mangoes during ripening period (RP) as affected by postharvest oxalic acid (OA) dipping.

	PPO	POD	PG	α-amylase	Xylanase
Peel					
Initial	*33.3*	*1.17*	*0.57*	*0.39*	*0.60*
Treatments (T)					
Control	59.2a	2.03b	0.93a	0.50a	0.75a
OA (mM)					
10	51.5b	2.51a	0.83b	0.45b	0.73a
20	48.6b	2.61a	0.83b	0.43b	0.63b
F-test	***	***	***	***	***
RP (d)					
3	43.6c	1.88c	0.85b	0.41b	0.69
5	52.7b	2.40b	1.06a	0.56a	0.69
8	63.1a	2.86a	0.68c	0.40b	0.74
F-test	***	***	***	***	*NS*
T x SL					
F-test	*NS*	*NS*	*NS*	*NS*	*NS*
Pulp					
Initial	*40.7*	*0.97*	*0.49*	*0.28*	*0.55*
Treatments (T)					
Control	69.1a	1.91b	0.87a	0.37a	0.69a
OA (mM)					
10	60.2b	2.29a	0.78b	0.32b	0.65b
20	57.2b	2.26a	0.73b	0.30b	0.61c
F-test	***	***	***	***	***
RP (d)					
3	53.9b	1.58c	0.85b	0.32b	0.60c
5	64.4a	2.15b	0.94a	0.40a	0.66b
8	68.2a	2.72a	0.58c	0.28c	0.70a
F-test	***	***	***	***	***
T x SL					
F-test	*NS*	*NS*	*NS*	*NS*	*NS*

PPO, POD and PG refereeing to polyphenoloxidase, peroxidase and polygalacturornase, respectively. Means within each column followed by the same letter are not significantly different at level $P \leq 0.05$. (***), significant at $P \leq 0.001$; (NS), not significant.

POD activity of fruit pulp gradually increased during ripening and was higher in OA treated fruit than control. PG activity of fruit pulp showed higher level than initial, fluctuated during ripening and was significantly lower in OA treated fruit than control. α-amylase activity of fruit pulp showed higher level than initial, fluctuated during ripening and was significantly lower in OA treated fruit than control. Xylanase activity of fruit pulp gradually increased during ripening and was significantly lower in OA treated fruit, especially at 20 mM, than control (Table 6).

DISCUSSION

As a typical climacteric fruit, mango express high metabolic activities leading to rapid softening with increase in TSS and a decrease in TA during ripening at ambient conditions (Mitra and Baldwin, 1997; Yashoda et al. 2006; Sivakumar et al. 2011). Thus, searching for natural elicitors such as OA to regulate fruit ripening and reduce postharvest losses are critically required. Weight loss is an important quality factor that affect fruit integrity and freshness. In the current experiment, 'Hindi-Besennara' mangoes exhibited a continuous

weight loss increase during ripening. However, OA treated fruit showed lower weight loss than control during ripening, with no significant difference between 10 and 20 mM (Table 1). The loss in fruit weight is mainly attributed to transpiration and respiration processes during ripening at ambient conditions (Narayana et al., 1996; Razzaq et al. 2015). OA reduced weight loss during ripening possibly via slowing down metabolic activities of fruit including respiration and ethylene production as found in 'Zill' mangoes treated with 5 mM OA (Zheng et al. 2007b) and 'Samar Bahisht Chaunsa' mangoes treated with 8 mM OA (Razzaq et al. 2015). In confirmation, it was reported that OA treatment inhibited ACC synthase activity, a key enzyme in ethylene biosynthesis, in jujube fruit (Wang et al. 2009). As overall, OA treatment retarded ripening of 'Hindi-Besennara' mangoes during ripening for 8 days, as reflected by higher peel green color (lower a* values), firmness, TA, and MSI, and lower TSS content and TSS/TA ratio than control (Tables 1, 2 and 3). Similarly, on other mango cultivars, OA delayed ripening of 'Zill' mangoes during ripening at 25 °C (Zheng et al. 2007b) and 'Samar Bahisht Chaunsa' during either cold storage or ambient conditions (Razzaq et al. 2015). Such results might be due to the general preservative effects of OA as a ripening and senescence inhibitor possibly via reducing respiration rate, ethylene production and oxidation processes as previously reported (Zheng et al. 2007a, b; Wang et al. 2009; Razzaq et al. 2015). OA treated fruit retained higher pulp firmness and peel MSI (Tables 1 and 2). These results might be ascribed to the inhibition of hydrolytic enzymes activities PG, α-amylase and xylanase as well as the activation of the antioxidant enzyme POD in both fruit peel and pulp (Table 6). OA treatment significantly reduced unmarketable fruit percentage after 8 days compared to control (Table 2) confirming those of Zheng et al. (2007a, b) on 'Zill' mangoes. These results possibly due to that OA enhanced the activity of defensive enzymes such as POD in both peel and pulp (Table 6) as well as β-1,3-glucanase and phenylalanine ammonia-lyase (PAL) as reported in pears (Tian et al. 2006) or catalase, superoxide dismutase and POD in mangoes (Razzaq et al. 2015). Mangoes are rich in antioxidant compounds including phenolics, carotenoids and vitamins (Sivakumar et al. 2011; Razzaq et al. 2015; Al-Qurashi and Awad, 2018). In the current study, total phenol and flavonoid contents of fruit peel and pulp showed higher values than initial, fluctuated during ripening, and were higher in OA treated fruit especially at 20 mM than control (Tables 4 and 5). Vitamin C content showed lower values during ripening than initial and was higher in 20 mM OA than control after 5 days (Table 4). The mechanism by which OA increased/retained antioxidant compounds is not completely clear, although OA has been considered as a natural antioxidant as suppressed lipid peroxidation in vitro in a concentration-dependent manner and reduced the ascorbic acid oxidation (Kayashima and Katayama, 2002). The increase in PAL activity as a key enzyme in the phenylpropanoid biosynthetic pathway by OA application might explain the higher accumulation of total phenol and flavonoid in OA treated fruit compared to control as reported in pears (Tian et al. 2006). However, the increase in total phenol and flavonoid contents with the decrease in RSC during ripening (Tables 4 and 5) suggest qualitative changes in antioxidant compounds toward lower antioxidant potential. In another study, total phenol content of 'Choke anan' mangoes peel decreased during storage at 6 °C for 10 days but was not changed in fruit stored at 12 °C while, DPPH-radical scavenging activity increased at both storage temperatures (Kondo et al. 2005). In banana fruit, no significant correlation between total phenol content and antioxidant activity assayed either by FRAP (Fernando et al. 2014) or by DPPH assay (Youryon and Supapvanich, 2017) was detected during ripening. The contribution of other antioxidant compounds such as carotenoids, vitamins and minerals should also be considered as might work synergistically with phenolic compounds and vitamin C (Dani et al. 2012). Accordingly, parallel several methods for measuring antioxidant should be applied to explore the principles of antioxidant/oxidation activity of a certain horticultural commodity.

CONCLUSION

In overall, it is concluded that postharvest dipping in 20 mM OA retarded ripening, retained and improved quality of 'Hindi-Besennara' mangoes during ripening via inhibiting hydrolytic enzymes and enhancing fruit antioxidant system. In addition, this treatment significantly decreased decayed and unmarketable fruit percentage during 8 days of ripening.

CONFLICT OF INTEREST

The authors declared that present study was performed in absence of any conflict of interest.

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AUTHOR CONTRIBUTIONS

All authors contributed equally to this manuscript.

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