Quality and biochemical changes of ‘Hindi-Besennara’ mangoes during shelf life as affected by chitosan, gallic acid and chitosan gallate

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Abstract Quality and biochemical changes of ‘Hindi-Besennara’ mangoes in response to chitosan, gallic acid (GA) and chitosan gallate (CG) postharvest dipping were studied during 2 weeks of storage at 20 ± 2 °C and 60–70% RH. Both GA and CG lowered decay and weight loss during storage. Chitosan and GA at high level and CG at both level maintained higher membrane stability index of peel than control. Fruits treated only CG and GA at high level and chitosan at both levels retained higher acidity and vitamin C but lower pH and total soluble solids (TSS) than control. All treatments resulted with fruits with higher flesh firmness and lower TSS/acid ratio than untreated fruits. GA at both rates gave lower total phenols after 1 week of storage than control. Both levels of GA and low level of chitosan resulted with fruits with higher antioxidant capacity (lower IC₅₀ values) after 1 week of storage than control. All treatments decreased α -amylase activity of fruit peel compared to control. CG and GA

at high level and chitosan at low level increased peroxidase activity compared to control. It was concluded that CG and GA dipping delayed ripening and maintained quality of ‘Hindi-Besennara’ mangoes during 2 weeks of shelf life.

Keywords Mango · Edible coatings · Chitosan · Gallic acid · Quality · Enzymes

Introduction

The postharvest losses of fresh horticultural commodities such as mangoes may be estimated as high as 50% due to several physiological and pathological disorders (Sivakumar et al. 2011; López-Mora et al. 2013). Mango is a climacteric fruit with high perishability nature due to rapid ripening, softening and microbial decay (Sivakumar et al. 2011). Disease susceptibility, sensitivity to chilling injuries (CI) (below 13 °C) and high perishability limit the storage, handling and transport potential of fruit (Sivakumar et al. 2011). On the other hand, modified atmosphere (MA) or controlled atmosphere (CA) application is not always compatible with this fruit due to high cost, CO₂ injuries and development of off-flavor by anaerobic respiration and ethanol production (Noomhorm and Tiasuwan 1995; Sivakumar et al. 2011). Chitosan, a bioactive natural edible coating, is attracting a worldwide interest in postharvest technology owing to its antioxidant and antimicrobial properties (Romanazzi et al. 2013; Al-Qurashi and Awad 2015). Postharvest dipping of ‘Tainong’ mangoes in 2% chitosan decreased respiration rate, and the loss of firmness, color change, acidity, ascorbic acid and fruit weight as well as inhibited diseases progress during storage at 15 °C (Zhu et al. 2008). Also dipping ‘Nam Dok Mai’ mangoes, previously inoculated with *C. gloeosporioides*, in chitosan

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(from 0.5 to 2.0%) delayed ripening and reduced respiration rate, ethylene production, and weight loss, ascorbic acid, and acidity and reduced diseases progression (Jitareerat et al. 2007). However, ‘Tommy Atkins’ mangoes dipped in 1% chitosan had no effects on fruit ripening, weight loss and black spot incidence, but inhibited the extension of this disease during storage at 12 and 25 °C (López-Mora et al. 2013). In addition to its function as a protective barrier, chitosan coating can work as carrier for bioactive antioxidants and antimicrobials compounds, such as GA (Yen et al. 2002; Chanwitheesuk et al. 2007; Sun et al. 2014). It was reported that the incorporation of GA into the chitosan matrix not only improved the elasticity and physical properties of chitosan coating (Alkan et al. 2011; Hager et al.

2012; Sun et al. 2014) but also increased the hydroxyl radical scavenging capacity of the produced coat (Pasanphan et al. 2010). Accordingly, it is hypothesized that the use of chitosan in conjunction with GA would be beneficial for fruit preservation. GA was selected in the present study owing to the fact that it is a natural water soluble antioxidant compound. Chitosan as the film forming agent, is soluble in aqueous acetic acid. Since GA ($pK_a = 4.5$) is more acidic than acetic acid ($pK_a = 4.76$), therefore it is anticipated that mixing aqueous solutions of both GA in water and chitosan in acetic acid would result in a homogeneous solution in which GA would replace acetic acid in the composite to produce chitosan–gallic acid formulation [referred to as chitosan gallate (CG)] as shown below.

To the best of our knowledge, there is no published information on the response of mangoes to postharvest GA and CG treatments. Therefore, this study aim to evaluate quality and biochemical changes of ‘Hindi-Besennara’ mangoes during 2 weeks of shelf life in response to chitosan, GA and CG postharvest dipping.

Materials and methods

Plant materials and experimental procedure

This experiment was performed on mature hard-green ‘Hindi-Besennara’ mangoes collected from a commercial orchard located in Jizan region (17.4751°N, 42.7076°E), Kingdom of Saudi Arabia. Fruit were packed in perforated cardboard (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 °C. Fruit of uniform size, weight (250–300 g/fruit) and appearance and also free from visual defects were selected for this experiment.

Preparation of chitosan gallate formulation (stock solution)

CG coating was prepared by mixing equal volumes of a clear solution of 1% (w/v) of GA with a clear solution of 2% (w/v) of chitosan (100,000–300,000 MW; Acros Organic, NJ, USA) and stirring for 1 h at room temperature. GA solution was dissolved in distilled water and chitosan solution was dissolved in 2% acetic acid (v/v). This composite of chitosan: gallic acid: acetic acid (2:1:1) considered as CG stock solution.

Fruit treatments

A completely randomized experimental design with three replicates (15 fruit of each) was established. Fruit of each treatment were soaked either into water (control), 1% acetic acid, 0.15 or 1% chitosan (dissolved in 1% acetic acid), 0.075 or 0.15% GA, and 25, 50 or 75 mL/L of CG stock solution for 5 min. A surfactant (Tween 20 at 0.5 mL/L) was added to all treatments. Following air drying of about 1 h, all treatments were weighted and stored at 20 ± 2 °C and 60–70% (RH) in perforated cardboard cartons for 2 weeks. Before applying the treatments, additional three samples (5 fruit of each) were randomly collected for initial quality and biochemical analyses as described below. After 1 and 2 weeks of shelf life, weight loss and decay incidence were recorded for each treatment as described below. Also, samples (5 fruit of each) from each replicate were randomly collected for

quality and biochemical analyses. Then, these fruit samples were peeled and the peel tissue was sliced and mixed. Random part of this peel was used for electrolyte leakage measurement and the remaining peel was kept at -80 °C for enzyme, total flavonoids, phenols and antioxidant activity analysis. Pulp firmness was measured in each sample directly following peeling then, the pulp tissue was sliced and mixed. Random portion of this pulp tissue was directly used for TSS, titratable acidity, pH, and vitamin C determinations.

Weight loss determination

The total fruit weight loss was calculated on initial weight basis and expressed in percentage.

Decay incidence

Decay incidence, due to skin browning, shriveling and diseases, was recorded and calculated on initial fruit number basis for each samples and expressed in percentage.

Firmness, TSS, acidity, pH and vitamin C of fruit pulp

Fruit pulp firmness 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 50 N (Mecmesin, Sterling, VA, 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, acidity, pH and vitamin C. TSS concentration was measured in fruit pulp juice with a digital refractometer (Pocket Refractometer PAL 3, ATAGO, Japan) and expressed in percentage. Titratable acidity was determined in distilled water diluted fruit juice (1:2) by titrating with 0.1 N 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 the oxidation of ascorbic acid with 2,6-dichlorophenol endophenol dye and the results expressed as g/kg on a fresh weight (FW) basis.

Leakage of ions from fruit peel

Leakage of ions from peel disks was measured according to Sairam et al. (1997) with some modifications and was expressed as membrane stability index percentage (MSI%) as described by Awad et al. (2017).

Table 1 Decay, weight loss and peel membrane stability index of 'Hindi-Besennara' mangoes during shelf life as affected by postharvest chitosan, gallic acid and chitosan gallate dipping

	Decay (%)	Weight loss (%)	Membrane stability (index)
Initial	0.0	0.00	19.0
Treatments (T)			
Control	20.5b	9.95ab	8.5de
Acetic acid 1%	24.3a	9.79abc	11.3cd
Chitosan (%)			
0.15	21.8ab	10.19a	7.2e
1	22.9ab	10.21a	18.6a
Gallic acid (%)			
0.075	12.7cd	8.82d	6.7e
0.15	13.2cd	8.69d	18.8a
Chitosan gallate (mL/L) ^a			
25	14.0cd	9.87abc	9.7de
50	15.1c	9.54bc	13.9bc
75	11.9d	9.42c	16.3ab
<i>F</i> test	***	***	***
LSD (0.05)	3.1	0.46	3.4
Shelf life period (SP) (weeks)			
1	11.1b	7.3b	12.1
2	23.6a	12.1a	12.6
<i>F</i> test	***	***	NS
T × SP			
<i>F</i> test	***	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

^a Chitosan gallate was prepared by mixing equal volumes of 1% (w/v) gallic acid with 2% (w/v) chitosan

Preparation of the methanol extract of fruit peel

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

Estimation of total phenols

Total phenols concentration was measured according to Hoff and Singleton (1977) as described by Awad et al. (2017).

Estimation of total flavonoids

Total flavonoids concentration was determined using a modified colorimetric method described previously by Zhishen et al. (1999) as described by Awad et al. (2017).

Evaluation of antioxidant activity by DPPH radical scavenging assay of fruit peel

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

Enzymes measurements of fruit peel

Crude extract

One gram of fruit peel (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 °C. The supernatant was designated as crude extract and stored at −20 °C for both α -amylase and peroxidase assay.

Table 2 Firmness, TSS, acidity, TSS/acid ratio, pH and vitamin C of ‘Hindi-Besennara’ mangoes during shelf life as affected by postharvest chitosan, gallic acid and chitosan gallate dipping

	Firmness (N)	TSS (%)	Acidity (%)	TSS/acid (ratio)	pH	Vitamin C (g/kg)
Initial	6.77	12.1	1.40	8.7	3.30	0.42
Treatments (T)						
Control	3.72e	17.3a	0.25d	69.5a	5.34a	0.32d
Acetic acid 1%	3.68e	12.9c	0.27d	51.1b	4.91cd	0.37bc
Chitosan (%)						
0.15	4.72ab	17.2a	0.46abc	50.1b	4.91cd	0.41ab
1	4.30cd	17.5a	0.43bc	53.1b	4.86cd	0.39abc
Gallic acid (%)						
0.075	4.31cd	16.0ab	0.40cd	46.0bc	4.78de	0.36cd
0.15	4.55bc	17.4a	0.59a	33.6c	4.60e	0.43a
Chitosan gallate (mL/L) ^a						
25	4.13d	16.8a	0.34cd	52.5b	5.21ab	0.39abc
50	4.89ab	16.9a	0.34cd	55.8b	5.12abc	0.40abc
75	4.96a	14.6bc	0.57ab	36.1c	5.07bc	0.39abc
<i>F</i> test	***	***	***	***	***	**
LSD (0.05)	0.38	1.78	0.15	13.0	0.25	0.048
Shelf life period (SP) (weeks)						
1	4.6a	15.5b	0.54a	34.5b	4.63b	0.39
2	4.1b	17.1a	0.28b	65.0a	5.33a	0.38
<i>F</i> test	***	***	***	***	***	NS
T × SP						
<i>F</i> test	NS	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

^a Chitosan gallate was prepared by mixing equal volumes of 1% (w/v) gallic acid with 2% (w/v) chitosan

α-Amylase assay

α-Amylase (EC 3.2.1.1) activity was assayed by determining the liberated reducing end products using maltose as a standard (Miller 1959) as described by Awad et al. (2017).

Peroxidase assay

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

Statistical analysis

The obtained data were statistically analyzed as a completely randomized design with three replicates by analysis of variance (ANOVA) using the statistical package software SAS (SAS Institute Inc., 2000, Cary, NC, USA). Comparisons between means were made by *F* test and the least significant differences (LSD) at $P \leq 5\%$.

Results

Decay increased during storage and was significantly lower with both GA and CG than other treatments (Table 1). The significant interaction effects between treatment and storage on decay revealed that there were no significant differences between the medium dose CG and lower of GA and control after 2 weeks of storage. Weight loss increased during storage from 11.1 to 23.6% and was lower at both doses of GA than all other treatments (Table 1). CG at the high dose showed lower weight loss than chitosan treatments and control. Membrane stability index of peel was higher at the high rate of both chitosan and GA, medium and high doses of CG and acetic acid than other treatments including control (Table 1). Membrane stability index of peel decreased during storage and showed lower values than initial (Table 1). Firmness was higher for all treatments than acetic acid and control. In this respect, the highest firmness was at the high and medium application doses of CG followed by the low dose of chitosan

Table 3 Total flavonoids and phenols concentration and antioxidant capacity of ‘Hindi-Besennara’ mangoes peel during shelf life as affected by postharvest chitosan, gallic acid and chitosan gallate dipping

	Flavonoids (g/kg)	Phenols (g/kg)	Antioxidant capacity (DPPH IC ₅₀ values)
Initial	1.15	19.5	10.0
Treatments (T)			
Control	1.72	21.3a	13.1b
Acetic acid 1%	1.34	21.5a	20.6a
Chitosan (%)			
0.15	1.83	20.2ab	6.3d
1	1.72	21.1a	17.0a
Gallic acid (%)			
0.075	1.73	17.7c	8.8cd
0.15	1.77	18.4bc	9.9bcd
Chitosan gallate (mL/L) ^a			
25	1.89	21.4a	13.3b
50	1.84	20.8ab	12.3bc
75	1.77	20.6ab	11.4bc
<i>F</i> test	NS	**	***
LSD (0.05)	–	2.40	3.67
Shelf life period (SP) (weeks)			
1	1.74	23.3a	21.4a
2	1.73	17.4b	3.7b
<i>F</i> test	NS	***	***
T × SP			
<i>F</i> test	NS	*	***

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

^a Chitosan gallate was prepared by mixing equal volumes of 1% (w/v) gallic acid with 2% (w/v) chitosan

(Table 2). Firmness decreased during storage from 4.6 to 4.1 N and showed lower values than initial. TSS concentration was lower at the high application dose of CG and acetic acid than control. TSS increased during storage from 15.5 to 17.1% and showed higher value than initial. Acidity was higher at the low dose of application of chitosan and high dose of both GA and CG than other treatments and control (Table 2). Acidity decreased during storage from 0.54 to 0.28% and showed much lower value than initial. TSS/acid ratio was lower for all treatments than control. This ratio increased during storage from 34.5 to 65 and showed higher value after storage than initial (Table 2). However, the pH value was higher for the control than all other treatments except for, the CG at both low and

medium rates (Table 2). The pH values increased during storage from 4.36 to 5.33 and showed higher level than initial. Vitamin C concentration was higher for all treatments than control except for, the low dose of GA. Vitamin C concentration was not significantly changed during storage and showed slightly lower values than initial (Table 2). The significant interaction effects between treatment and storage period on vitamin C concentration revealed that, after 1 week of storage, both acetic acid and chitosan at high dose showed similar values to control. While, after 2 weeks of storage, the low dose of both GA and CG gave similar values for control. Total flavonoids concentration was not affected either by the applied treatments or during storage life and showed higher values than initial (Table 3). Total phenols was lower at both doses of GA than control (Table 3). Total phenols decreased during storage from 23.3 to 17.4 g/kg and showed higher value after 1 week but lower after 2 weeks of storage than initial. The significant interaction effects between treatment and storage period on total phenols revealed that, after 2 weeks of storage, GA at high rate gave similar value for control and that was not significantly changed during storage (Table 4). The antioxidant capacity of fruit peel extract measured by the DPPH method (IC₅₀ values) ranged from 6.3 to 20.6 µg phenolics concentration among all treatments. It was lower (higher IC₅₀ values) for acetic acid and at the high rate of chitosan than all other treatments including control. While, it was higher (lower IC₅₀ values) at the low dose of both chitosan and GA than control. The antioxidant capacity increased (lower IC₅₀ value) during storage from 21.4 to 3.7 IC₅₀ and showed lower capacity after 1 week but higher after 2 weeks of storage than initial. The significant interaction effects between treatment and storage period on antioxidant capacity revealed that, after 1 week of storage, both rates of GA showed higher antioxidant capacity (lower IC₅₀ values) than control while, after 2 weeks, there were no significant differences among all treatments (Table 4). α -Amylase activity was lower at all treatments than control (Table 5). The low rate of GA showed higher α -amylase activity than other treatments except for, the low rate of chitosan and control. α -Amylase activity increased during shelf life from 0.52 to 0.78 U min g FW and showed higher values than initial. The significant interaction effects between treatment and storage period on α -amylase activity revealed that, after 1 and 2 weeks of shelf life, all the treatments decreased α -amylase activity compared to control (Table 6). In addition, after 1 week of shelf life, the low and medium rates of CG and acetic acid showed the lowest α -amylase activity compared with other treatments. While, after 2 weeks of shelf life, the high rate of GA and acetic acid gave the lowest α -amylase activity compared with other treatments. Peroxidase activity was higher at the low rate of both

chitosan and GA than other treatments including control (Table 5). Also, peroxidase activity was higher for acetic acid and the high dose of CG than control. Peroxidase activity increased from 1.11 to 1.73 U min⁻¹ g FW during storage and showed higher value than initial. The significant interaction effects between treatment and storage period on peroxidase activity revealed that, peroxidase activity was not significantly changed during storage at the high rate of chitosan treatment (Table 6).

Discussion

In the current experiment, both decay incidence and weight loss significantly increased during storage (Table 1). Mango fruit is a typical climacteric type of fruit with a relatively high rate of metabolic activity such as high ethylene production and respiration rate that accelerate the ripening processes following harvest. These processes are coincided with an increase in weight loss, rapid softening, peel browning, shriveling and decay that shorten fruit storability and storage. Weight loss occurs during storage is due to respiration process and loss of water through fruit peel. However, GA at both rates and the high rate of CG decreased weight loss compared to chitosan and control treatments (Table 1). In addition, the reduction in decay incidence by both CG and GA treatments might partly due to the primary antioxidant and antimicrobial properties of GA (Yen et al. 2002; Chanwitheesuk et al. 2007; Sun et al. 2014). It has been reported that gallic acid and gallotannins decline during mango fruit ripening or in association with

loss of astringency (Lakshminarayanan et al. 1970). Thus, the exogenous application of GA with or without chitosan might contribute to its endogenous level and enhance the defensive system of fruit. Also, the incorporation of GA into chitosan matrix might enhanced the effectiveness of chitosan in decreasing weight loss and decay via the improvement of the tensile strength of the coat and decreased the permeability of both water vapor and oxygen (Sun et al. 2014). The maintenance of higher membrane stability index by the medium and high rates of CG and the high rate of GA and chitosan compared to other treatments (Table 1) might be attributed to the antioxidant actions of these compounds (Pasanphan et al. 2010; Alkan et al. 2011; Hager et al. 2012; Sun et al. 2014). Our results are also partially in accordance with those of Jitareerat et al. (2007) and Zhu et al. (2008) on mangoes where edible coatings such as chitosan and gum Arabic serves as a semipermeable barrier against oxygen, carbon dioxide, and moisture, thus reducing respiration, water loss and oxidation reactions. In addition, CG, GA and chitosan treatments retained higher vitamin C and delayed fruit ripening as reflected by a higher firmness and a lower TSS/acid ratio than other treatments (Tables 3, 4). These results might be also attributed to the concept that the edible coatings are selective barriers to O₂ and CO₂ modifying internal atmospheres and decreased respiration rate and fruit ripening (Debeaufort et al. 1998; Jitareerat et al. 2007; Zhu et al. 2008; Velickova et al. 2013). Our results showed that chitosan and CG treatments had no significant effect on both total flavonoids and phenols concentration in the peel. Chitosan dipping treatment increased total phenols in

Table 4 The interaction effect between treatments and shelf life period on total phenols and antioxidant capacity of ‘Hindi-Besennara’ mangoes during shelf life as affected by postharvest chitosan, gallic acid and chitosan gallate dipping

Treatment	Shelf life period (weeks)			
	Total phenols (g/kg)		Antioxidant capacity (DPPH IC ₅₀ values)	
	1	2	1	2
Control	24.5abc	18.2efg	22.7b	3.5g
Acetic acid 1%	24.2abcd	18.8efg	35.8a	5.3fg
Chitosan (%)				
0.15	21.2cde	19.1efg	8.9ef	3.7g
1	25.0ab	17.3fgh	31.0a	2.9g
Gallic acid (%)				
0.075	21.0de	14.6h	13.8de	3.8fg
0.15	19.8ef	17.1fgh	15.2cd	4.7fg
Chitosan gallate (mL/L) ^a				
25	26.7a	16.1gh	23.8b	2.8g
50	24.3abcd	17.4fgh	21.7b	3.0g
75	23.3bcd	17.9efgh	19.5bc	3.4g

For each parameter, means within and between columns followed by the same letter are not significantly different at level $P \leq 0.05$

^a Chitosan gallate was prepared by mixing equal volumes of 1% (w/v) gallic acid with 2% (w/v) chitosan

Table 5 α -Amylase and peroxidase activities of ‘Hindi-Besennara’ mangoes peel during shelf life as affected by postharvest chitosan, gallic acid and chitosan gallate dipping

	α -Amylase (U min g FW)	Peroxidase (U min g FW)
Initial	0.43	0.83
Treatments (T)		
Control	0.78a	1.13de
Acetic acid 1%	0.58e	1.58b
Chitosan (%)		
0.15	0.69bc	2.03a
1	0.62d	1.19d
Gallic acid (%)		
0.075	0.71b	1.92a
0.15	0.62d	1.30cd
Chitosan gallate (mL/L) ^a		
25	0.59e	1.01e
50	0.62d	1.20d
75	0.68c	1.44bc
<i>F</i> test	***	***
LSD (0.05)	0.021	0.17
Shelf life period (SP) (weeks)		
1	0.52b	1.11b
2	0.78a	1.73a
<i>F</i> test	***	***
T $\times$ SP		
<i>F</i> test	***	***

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

^a Chitosan gallate was prepared by mixing equal volumes of 1% (w/v) gallic acid with 2% (w/v) chitosan

Table 6 The interaction effect between treatment and shelf life period on α -amylase and peroxidase activities of ‘Hindi-Besennara’ mangoes peel during shelf life as affected by postharvest chitosan, gallic acid and chitosan gallate dipping

Treatment	Shelf life period (weeks)			
	α -Amylase (U min g FW)		Peroxidase (U min g FW)	
	1	2	1	2
Control	0.66f	0.89a	0.81ij	1.46cde
Acetic acid 1%	0.46k	0.70e	1.32ef	1.84b
Chitosan (%)				
0.15	0.53i	0.85b	1.60bcd	2.46a
1	0.49j	0.75d	1.11fgh	1.28efg
Gallic acid (%)				
0.075	0.62g	0.80c	1.46cde	2.39a
0.15	0.52ij	0.71e	0.94hij	1.66bc
Chitosan gallate (mL/L) ^a				
25	0.42l	0.76d	0.74j	1.27efg
50	0.44kl	0.79c	1.00hi	1.40de
75	0.57h	0.80c	1.06gh	1.82b

For each parameter, means within and between columns followed by the same letter are not significantly different at level $P \leq 0.05$

^a Chitosan gallate was prepared by mixing equal volumes of 1% (w/v) gallic acid with 2% (w/v) chitosan

several other fruits during storage (Pichyangkura and Chadchawan 2015). However, it reduced total phenols in strawberries during storage (Kerch et al. 2011). While, we have no explanation for the observed negative effect of GA, especially after 1 week of shelf life, on total phenols concentration (Tables 5, 6). Total phenols decreased during storage and showed higher values after 1 week of storage than initial (Table 5). In another study, total phenols concentration of ‘Choke anan’ mangoes peel decreased during storage at 6 °C for 10 days but was not changed in fruit stored at 12 °C (Kondo et al. 2005). The decrease of phenols concentration in fruit peel during storage (Tables 5, 6) might be due to breakdown of cell structure because of the senescence phenomena during ripening and the action of polyphenol oxidase (Macheix et al. 1990). Our results showed that, after 2 weeks of storage, total antioxidant capacity of fruit peel measured by DPPH assay was not affected by treatments, in contrast to the first week, where both rates of GA retained higher antioxidant capacity (lower IC₅₀ values) than control (Table 6). The increase in the antioxidant capacity (lower IC₅₀ values) during storage confirm those of Kondo et al. (2005) where DPPH-radical scavenging activity (IC₅₀ values) of ‘Choke anan’ mangoes peel increased during 10 days storage at 6 and 12 °C. Fernando et al. (2014) reported that total antioxidant activities (mmol TE/100 g FW) measured by DPPH and FRAP of ‘Hom Thong’ and ‘Khai’ bananas flesh during ripening at 25 °C for 10 days increased with ripening but rapidly decreased with senescence. However, the decrease in total phenols concentration with the increase in antioxidant capacity during ripening (Tables 3, 4) might suggest qualitative changes in phenolic classes toward higher antioxidant potential. In the current study, α -amylase activity of fruit peel significantly increased during storage and decreased by the applied treatments compared to control, suggesting a role of this enzyme in fruit ripening (Table 5). In confirmation, the climateric raising in ‘Tommy Atkins’ mangoes associated with a remarkable increase in amylase activity, reducing and non-reducing sugars contents and decrease in the starch content of fruit pulp (Lima et al. 1999). Our results showed that peroxidase activity was higher at the low rate of both chitosan, the high rate of CG and GA than control. Peroxidase activity increased during storage and showed higher value than initial (Tables 5, 6). POD is considered as an important antioxidant and defense-related enzymes. It has been found that chitosan dipping increased antioxidant enzymes activities such as POD, catalase, 1,3-glucanase and chitinase in several other fruit such as grapes (Al-Qurashi and Awad 2015), pears (Meng et al. 2010), peaches (Ma et al. 2013), papayas (Ali et al. 2012) and navel oranges (Zeng et al. 2010). However, other studies found that chitosan dipping decreased both POD and polyphenol oxidase

activates in litchi fruit during storage (Dong et al. 2004; De Reuck et al. 2009). Fruit ripening and senescence is possibly an oxidative process in which the transition from mature stage into ripening/senescence stage is accompanied by a progressive shift toward an oxidative state (Goulao and Oliveira 2008; Zeng et al. 2010; Awad et al. 2011). Accordingly, excessive reactive oxygen species production could participate in the oxidation of lipids and proteins of cell membrane that are involved in mango ripening. Indeed a steady decrease in membrane stability index, as measured by the leakage of ions, was observed upon the progression of fruit ripening, indicates a gradual loss of membrane’s stability due to changes occurring in the biochemical and biophysical properties of cell membranes (Tables 1, 5, 6). In conclusion, postharvest CG and GA treatments decreased decay, delayed ripening and maintained better quality of ‘Hindi-Besennara’ mangoes during 2 weeks of shelf life than control.

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