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Effects of chitosan–glucose complex coating on postharvest quality and shelf life of table grapes

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ABSTRACT

Surface coatings and films are prospective alternatives for extending the postharvest life of fresh fruits and vegetables. In this study, freshly harvested grapes were treated with chitosan, glucose, chitosan–glucose complex (CGC), or water (control) for up to 60 days at 0 °C in 95% relative humidity followed by 3 days in the air at 20 °C. The results showed that coated samples were effective in terms of senescence inhibition and postharvest diseases prevention. Chitosan–glucose complex showed better effects on delaying the declines of total soluble solids, ascorbic acid and titratable acidity, decreasing decay and weight loss, suppressing respiration rate, inducing POD and SOD activities, in comparison with pure chitosan or glucose. In addition, CGC coating treatment ensured better berry texture and higher sensory scores, compared with those treated with chitosan or glucose alone. The results indicated that CGC may be a promising strategy for improving the postharvest quality and extending the shelf life of table grapes.

1. Introduction

Chitosan a high molecular weight cationic polysaccharide, which is obtained by deacetylation of chitin that is extracted from the exoskeleton of crustaceans, fungi, and insects, has numerous applications in fields of agriculture and food because of its excellent film-forming ability, antimicrobial and antifungal activities, biocompatibility, biodegradability and non-toxicity for people (Muzzarelli et al., 2012). Chitosan is used as a coating material in various domains and particularly in fruit postharvest field (Olivas & Barbosa-Canovas, 2005). Previous studies indicated that chitosan had good potential to extend the postharvest storage time and control decay for Huanghua pears (Zhou et al., 2008), tomato fruit (Badawy & Rabea, 2009), strawberries (Ghaouth, Arul, Ponnamapalam, & Boulet, 1991) and table grapes (Meng, Li, Liu, & Tian, 2008).

In recent years, chitosan coating has been used as a matrix for entrapping chemical compounds or enzymes to be applied in the food field. The incorporation of minor constituents into the chitosan matrices can markedly improve antimicrobial activities and some physicochemical properties such as film-forming ability, biodegradability and water vapour barriers. However, chemical modifications can be limited for food applications because of the formation of potential detrimental products (Kanatt, Chander, & Sharma, 2008).

The Maillard reaction is a very complex reaction between an amino compound, often an amino acid, peptide, or protein, and a carbonyl compound, usually a reducing sugar, such as glucose, fructose, or lactose. It occurs spontaneously during food processing and storage. The Maillard reaction compounds contribute to the formation of specific flavor and improve some functional properties of foods (Chang, Chen, & Tan, 2011). Moreover, some Maillard reaction products have been found to exhibit strong antimicrobial and antioxidant activity (Rao, Chawla, Chander, & Sharma, 2011). Chitosan possessing an amino group makes it a candidate to take part in the Maillard reaction. Kanatt et al. (2008) found that chitosan–glucose complex (CGC), a modified form of chitosan, showed superior antioxidant activity as compared to chitosan/glucose alone. Their results also showed that CGC increased the shelf life of pork cocktail salami to 28 days. Similarly, Chang et al. (2011) reported that the incorporation of 1% chitosan with glucose effectively maintained pork qualities during refrigerated storage. In addition, the investigation of Jiang, Feng, and Li (2012) found that shiitake mushroom treated with chitosan–glucose complex (CGC) had significantly better storage quality than those of chitosan or glucose alone. However, there are only a few researches on the application of chitosan–glucose complex (CGC) to fruits and vegetables. The objectives of this work were to study the

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effects of chitosan–glucose complex on the postharvest quality of grapes.

2. Materials and methods

2.1. Materials

Muscat Hamburg, a kind of table grape, was hand-harvested at optimum maturity in an organic orchard located in Chadian, Tianjin, China. Harvested fruits were immediately transported to Laboratory of Physiology and Storage of Agricultural Products. And the clusters without diseases, bruises, or injuries were chosen for the study.

Chitosan (90% of deacetylated degree and the intrinsic viscosity of 14 centipoises) was provided by Zhejiang Jinke Bioengineering Co. Ltd., China. All other chemicals were of analytic grade and obtained from commercial sources.

2.2. Treatments

The preparation of chitosan–glucose solution was carried out according to the methods of Chang et al. (2011) with some modifications. Chitosan solution (1%, w/v) was prepared in deionized water containing 1% (v/v) acetic acid. Glucose solution (1%, w/v) was prepared by dissolving glucose in deionized water. For preparation of chitosan–glucose complex, 1.0% chitosan was dissolved in acetic acid in which 1.0% glucose was added. The pH value of solution was adjusted to 6.0 by adding 1 N NaOH. At last, chitosan–glucose complex (CGC) was prepared by autoclaving chitosan (1%) and glucose (1%) for 15 min. Fruits were randomly assigned to four groups, with 15 plastic boxes (≈5 kg each) per group. One was dipped in the deionized water as the controls. The second group was dipped in solution containing 1% chitosan. The third group was dipped in 1% glucose solution, and the last group was dipped in chitosan–glucose complex (CGC) solution. The dipping time of all samples was for 1 min. All clusters were suspended on shelves by fastening their stems, and dried under fans. After dried, all fruits were packed into the original boxes and sealed in PE films (0.03 mm thickness) to maintain the humidity. When finished, all boxes were stored at 0 °C for 60 d and then at 20 °C for 3 d.

2.3. Decay rates and weight loss

Decay rates (DR) and weight loss (WL) were calculated by using following formulas and recorded using a scale with an accuracy of 0.01 g (L12, Bingjing Haitai Electronic Apparatus Co., China).

$$\mathrm{DR}\% = \frac{\mathrm{DW}}{\mathrm{IW}} \times 100$$

$$\mathrm{WL}\% = \frac{\mathrm{IW} - \mathrm{FW}}{\mathrm{IW}} \times 100$$

with DW, weight of decay fruits; IW, initial fruit weight; and FW, final fruit weight after storage.

2.4. Respiration

Determination of respiratory intensity was by the static method. About 1 kg of fruits was sealed in a 2.5 L glass container with a small hole on the lid. Subsequently, adhesive tape covered the hole of lid and left the container at 0 °C and 95% RH for 4 h prior to measure the CO_2 production. A gas analyzer equipped with a thermal conductivity detector (CheckMate 9900, PBI Dansensor, Denmark) was used to measure the respiration rate of fruits. Each treatment was repeated three times and respiration rate of the fruits was expressed as mg kg^{-1} h^{-1} of CO_2 evolved.

2.5. Texture profile analysis (TPA) of the samples

To determine the TPA values of grapes, TA.XT Plus Texture Analyzer (Stable Microsystems Ltd., UK) was used with the following parameters: load cell = 40 kg, pre-tests peed = 5.0 mm/s, test-speed = 2.0 mm/s, post-test speed = 2.0 mm/s, compression degree = 25%, time = 5.0 s, and trigger force = 4.0 g. A standard compression platen (SMS P/75) was used for TPA. Four textural parameters (hardness, springiness, chewiness and cohesiveness) were obtained from the analyses of the typical TPA curves of texture character. 20 peeled berries from each sample were measured.

2.6. Determination of chemical quality attributes

Soluble solids content (SSC) was quantified by a hand-held sugar refract meter (PAL-1, ATAGO Co. Ltd., Japan). Titratable acidity (TA) was measured by titration with 0.05 mol/L NaOH to pH 8.2 and expressed as percentage of tartaric acid. The ascorbic acid (Vc) contents were determined by the Molybdenum blue method and expressed in milligrams of ascorbic acid per 100 g fruit weight (Li, 2000). Each measurement was performed in triplicate.

2.7. Peroxidase (POD) activities and superoxide dismutase (SOD) activities

Tissue (10 g) from triplicate samples was homogenized in 20 ml of ice-cold extraction buffers containing 0.5 g polyvinyl polypyrrolidone (PVPP) and then centrifuged at 15,000 × *g* for 30 min at 4 °C. The supernatant was used to determine enzyme activity.

Determination of POD was performed by the method of Wang, Tian, and Xu (2005) with slight modifications. 1.0 ml of enzyme was incubated in a mixture (2 ml) containing 100 mmol L^{-1} sodium phosphate (pH 6.4), 0.1% (v/v) guaiacol and 1 ml of 0.08% (v/v) H_2O_2. The increasing absorbance was recorded at 460 nm for 2 min. The specific activity was expressed as U mg^{-1} protein, where one unit was defined as increase ΔOD460 min^{-1} mg^{-1} protein.

SOD activities were performed by assaying its ability to inhibit the photochemical reduction of nitroblue tetrazolium (NBT) using the method of Meng et al. (2008). The specific activity was expressed as U mg^{-1} protein, and one SOD unit was defined as the amount of enzyme required to inhibit NBT reduction by 50%.

Protein content of samples was determined according to Bradford (1976), using bovine serum albumin (BSA) as the standard protein.

2.8. Sensory evaluation

Samples were evaluated by a six-member trained panel (three men and three women: aged between 20 and 50 years old). The evaluation was performed under controlled temperature and lighting conditions in individual booths. Each sample was presented in dishes coded with 3-digit random numbers to each panelist for evaluation. The panelists were subsequently asked to score each sample for visual appearance, color, flavor, taste and overall preference based on a nine-point scale [1: extremely poor, 3: poor, 5: acceptable (limit of marketability), 7: good, 9: excellent].

2.9. Statistical analyses

All data were analyzed by one-way analysis of variance (ANOVA). Mean separations were compared by the Duncan's multiple range tests (significance level 95%).

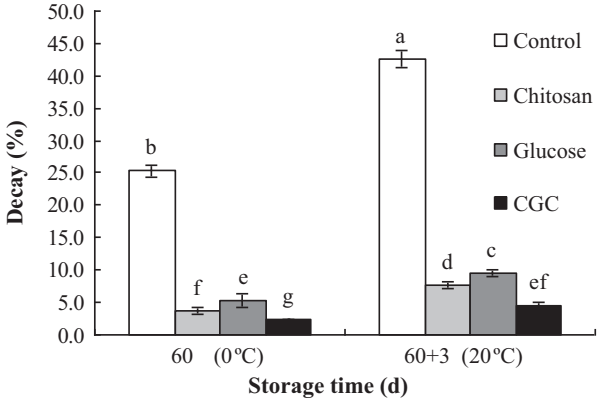

Fig. 1. Effects of control, chitosan, glucose, and chitosan–glucose complex on decay rates of table grapes during 60 days of storage at 0 °C and after 3 days of shelf life in air at 20 °C. Means in each bar with different lower case letters were significantly differences by Duncan's multiple range test ($P < 0.05$). Vertical bars represent standard error of the mean.

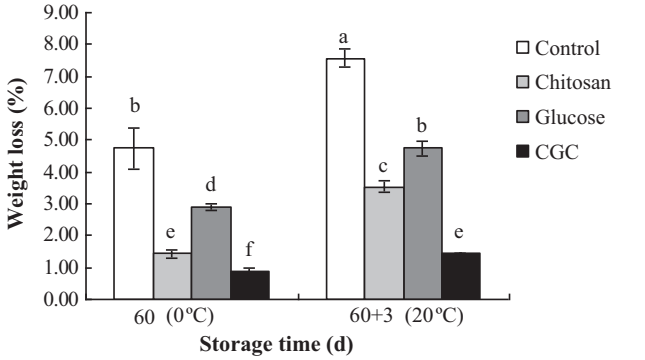

Fig. 2. Effects of control, chitosan, glucose, and chitosan–glucose complex on weight loss rates of table grapes during 60 days of storage at 0 °C and after 3 days of shelf life in air at 20 °C. Means in each bar with different lower case letters were significantly differences by Duncan's multiple range test ($P < 0.05$). Vertical bars represent standard error of the mean.

3. Results and discussion

3.1. Decay rate of fruits

During the storage period, the incidence of berry decay was gradually increased (Fig. 1). After 60 days storage at 0 °C, the decay rate of control (25.27%) was significantly higher than that of other samples (CGC, 2.29%; chitosan, 3.65%; glucose, 5.27%). At the 5 d shelf life, decay levels of all samples obviously increased. Berry decay in the control was 42.6%, whereas fruits treated with chitosan, glucose, or chitosan–glucose complex showed the values of 7.55%, 9.60% and 4.52%, respectively. Throughout the storage period, the decay rate of fruits coated with chitosan–glucose complex was the lowest.

In this experiment, we found that the coated samples markedly decreased decay rates, and chitosan–glucose complex showed the best effect on inhibiting the incidence of berry decay. Gray mold, which caused by *Botrytis cinerea* Pers., is a direct cause of postharvest decay for table grapes. In the previous researches, two mechanisms have been described about chitosan to control the growth of pathogens. One theory is that chitosan by interfering with the negatively charged residues of macromolecules exposed on the fungal cell surface lead to the loss of intracellular electrolytes and proteinaceous constituents (Meng et al., 2008; Xu, Zhao, Han, & Du, 2006). Another argument is that diffused hydrolysis products from chitosan may be to interact with the fungal DNA, thus affecting mRNA and protein synthesis (Zakrzewska, Boorsma, Brul, Hellingwerf, & Klis, 2005). Liu, Tian, Meng, and Xu (2007) found that chitosan could significantly inhibit spore germination and mycelial growth of *B. cinerea* by damaging the plasma membrane of the spore in vitro. In addition, chitosan preharvest spray and postharvest coating were reported to have a good control effect on decay of table grapes (Meng et al., 2008). In our study, the results supported the ideas that the chitosan coatings were effective to reduce decay of grapes. Also, the results in the experiment showed that chitosan–glucose complex coating had a better function to reduce the natural decay incidence of grape fruit, compared with chitosan or glucose alone. The mechanism of microorganism inhibition by chitosan–glucose complex is not fully understood, but it can be guessed that Maillard reaction products, from chitosan and glucose, enhanced the antimicrobial properties of chitosan. A soy protein–chitosan conjugate, produced by the Maillard reaction, has been reported to enhance antimicrobial activity (Usui et al., 2004). Similarly, Chung, Kuo, and Chen (2005) found that the chitosan–glucosamine derivatives, formed using the Maillard reaction, had relatively high antibacterial action as compared with pure chitosan. In addition, glucose coatings showed a good function to reduce decay of grapes. It can be guessed that glucose coatings could hinder or defer pathogen infections.

3.2. Weight loss

Weight loss in all samples showed an increasing pattern over storage (Fig. 2). After 60 days storage at 0 °C, weight loss of controls reached the amount of 4.74%, whereas chitosan, glucose and CGC reached values of 1.44%, 2.89% and 0.89%, respectively. And, when fruits were transferred to 20 °C in air for shelf life, all samples with higher weight loss rates were observed. Weight loss of controls reached the amount of 7.57% was 1.60-fold, 2.15-fold and 5.32-fold higher than these of glucose, chitosan or CGC.

Previous studies indicated that approximately 5% weight loss was the normal acceptable limit for table grapes (Deng, Wu, & Li, 2006). In this experiment, except controls, other samples showed low weight loss ($\leq$5%). Numerous researches demonstrated weight loss was associated with respiration processes and evaporation of water from the fruit (Amarante, Banks, & Ganesh, 2001). In our study, chitosan coating showed a low weight loss probably due to a protective barrier forming by chitosan on the surface of fresh fruit, which reduced water evaporation, inhibited gas exchange and decreased nutrient loss. Similar performances of deferring weight loss have been reported in chitosan-coated peach, mango, banana and longan (Jiang & Li, 2001; Kittur, Saroja, & Habibunnisa-Tharanathan, 2001; Li & Yu, 2001). After an additional 5 days in air at 20 °C, weight loss of the fruits significantly increased. The phenomenon may be caused by the increase of temperature following an increase of respiration rate of fruits. And the other reason was probably that water was absorbed by the chitosan on the fruit surface. The property of chitosan to absorb moisture at relative high temperature has been reported (Olivas & Barbosa-Canovas, 2005). In addition, our data also showed that CGC was the most effective in reducing weight loss. The detailed mechanism, which chitosan–glucose complex inhibits the increase of weight loss, is not clear. However, similar performances have been found at the previous study which Jiang et al. (2012) reported chitosan–glucose complex was more effective to inhibit weight loss in shiitake mushroom under cold storage, when compared with chitosan or glucose alone. Also, the results in this experiment showed that glucose coatings effectively reduced the weight loss of grapes over the storage period. That maybe because glucose coatings could form a physical barrier to moisture loss and therefore retarding dehydration and shriveling.

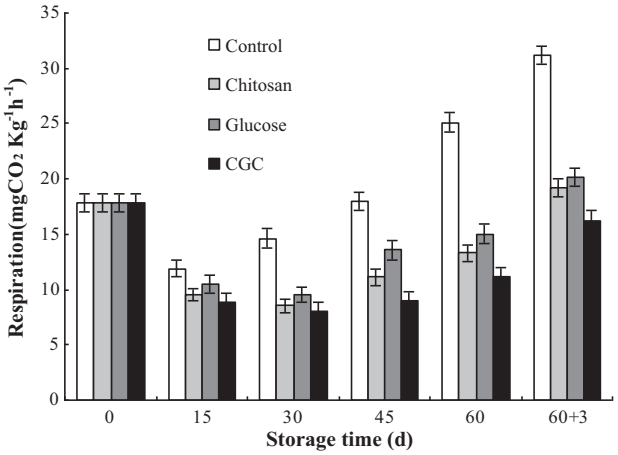

Fig. 3. Effects of control, chitosan, glucose, and chitosan–glucose complex on respiration rates of table grapes during 60 days of storage at 0 °C and after 3 days of shelf life in air at 20 °C. Each data point is the mean of three replicate samples. Vertical bars represent standard deviation of means.

3.3. Respiration

Respiration rates of all samples are shown in Fig. 3. Grapes, do not have a distinct after-ripening stage, is a non-climacteric fruit. During low temperature storage, the pattern of change in respiratory intensity was sharply decreased within early days, and then increased gradually during the remaining days. By day 60, the respirations of fruit reached 25.1 mg CO_2 kg^{-1} h^{-1} in controls, 15.0 mg CO_2 kg^{-1} h^{-1} in the glucose coating treatment, 13.3 mg CO_2 kg^{-1} h^{-1} in the chitosan coating treatment and 11.1 mg CO_2 kg^{-1} h^{-1} in the CGC treatment. The value of controls was almost two-fold higher than those of glucose or chitosan fruits. Significant differences were observed between controls and the coated grapes at the end of cold storage. In the following shelf life, respiration rates increased rapidly in all samples. In short, both the cold storage and shelf life, the respiration rate of controls was higher than that of coated samples, and the lowest respiration rate was found in fruits treated with chitosan–glucose complex.

The respiration rate is a good index to assess the quality of fruits during storage. It is known that grapes are still in the state of living body after harvest and necessary to maintain their respiration intensity at a suitable level. However, high respiratory intensity will lead to the nutrients consumption of fruit, thereby accelerating ripening and senescence process (Zhang, Li, Huan, Tao, & Wang, 2001). In our study, glucose coatings had a good effect on reducing the respiration rate of table grapes. This could be because glucose coatings modify the internal atmosphere of grapes by depletion of endogenous O_2 and a rise in CO_2. Previous studies indicated that the gas exchange between fruit and the atmosphere occurred mainly by open pores and permeation through fruit skin (Amarante et al., 2001). Our results indicated that chitosan effectively controlled respiratory intensity, which could be due to the partial or complete blockage of pores by chitosan coatings. Similar performances by the use of chitosan coatings have been reported for fruits including strawberry (Vargas, Albors, Chiralt, & Gonzalez-Martinez, 2006), sweet cherry (Alonso & Alique, 2004) and avocado (Maftoonazad & Ramaswamy, 2005). In addition, the effectiveness of CGC in restricting respiration may be largely due to efficient regulation of the gas exchange between grapes and the surrounding atmosphere during storage.

3.4. Texture profile analysis

TPA values of all berries decreased with increased storage time to varying degrees (Fig. 4). During the cold storage period, a significant decline of hardness was observed in control fruits compared to treatment samples (Fig. 4A). For 60d storage, springiness in the control fruits decreased by 47.68%, whereas grapes coated with glucose, chitosan, or CGC showed the values of 22.26%, 12.62% and 10.16%, respectively (Fig. 4B). Grapes exposed to long storage time

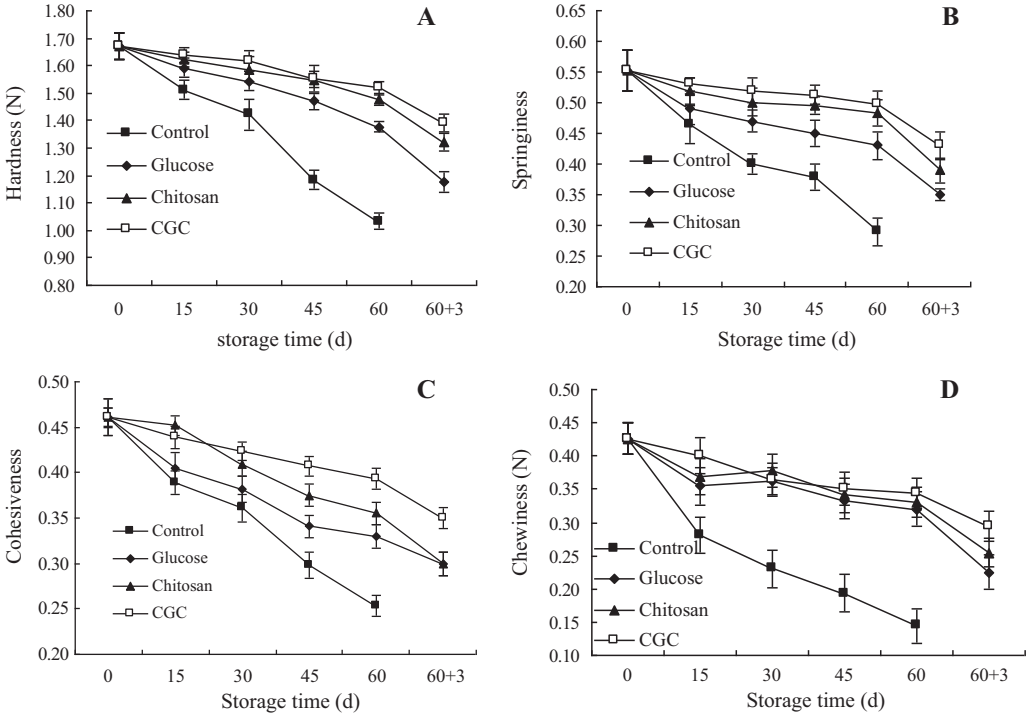

Fig. 4. Changes in the TPA results of hardness (A), springiness (B), cohesiveness (C), and chewiness (D) for grapes treated with different coatings during 60 days of storage at 0 °C and after 3 days of shelf life in air at 20 °C. Each point represents the mean value ± SE.

lost 14.67–44.95% of their original chewiness on day 60. The maximum retention in chewiness was obtained by CGC and chitosan coating, with 0.39 and 0.36 chewiness values, respectively, at the end of cold storage period (Fig. 4C). In addition, the cohesiveness in the control rapidly declined from an initial value of 0.43–0.14 on day 60. While the cohesiveness of coated samples had relatively slight declines from 0.43 to 0.32–0.34 at the end of cold storage (Fig. 4D). When transferred to 20 °C in air for shelf life, all TPA values of berries in CGC were higher than that in chitosan or glucose, in spite of texture parameters decreased in all treatments. In addition, fruits in control could not be carried out texture profile analysis because of severe decay.

Earlier researches indicated that textural changes of fruit flesh during storage attributed to degradation of primary cell wall and middle lamella structures (Huber, 1983; Yang et al., 2007). In addition, it has been reported that the softening of fruits was influenced by cell wall-degrading enzymes, such as polygalacturonas (PG), pectinesterase (PE) and cellulase (Cx). During storage, pectinases catalyze protopectin to water-soluble pectin. When pectin enters the cell sap under osmotic pressure, it forms a gel, causing fruit softening (Deng, Wu, & Li, 2005). In the study, the results indicated that CGC and chitosan coatings might be to delay berry softening by inhibiting the activities of cell wall-degrading enzymes. Previous studies have reported a similar performance of delaying softening by chitosan coating in Huanghua pears (Zhou et al., 2008) and by CGC coating in shiitake mushroom (Jiang et al., 2012). Hardness of fruits was related to loss of turgor pressure in the cells reduced by water loss (Lin, Xi, & Chen, 2003; Lohani, Trivedi, & Nath, 2004). According to the results (Fig. 4), we guessed that CGC and chitosan coatings may maintain hardness of grapes by reducing water loss. This result was consistent with the weight loss of grapes (Fig. 2).

3.5. Chemical quality attributes

The SSC, TA and ascorbic acid levels decreased in all samples after 60 days storage at 0 °C (Table 1). Although the SSC, TA and ascorbic acid contents of both coated and uncoated samples decreased after cold storage, the use of CGC coating and chitosan coating significantly reduced the loss of SSC, TA and ascorbic acid. In the following shelf life, TA, SSC and Vc levels declined continuously in all samples. Compared to coated fruits, a quicker decrease for SSC, TA and ascorbic acid occurred in controls. It's worth noting that CGC coating treatment showed the best effect on delaying the declines of soluble solids, ascorbic acid and titratable acidity both in cold storage and shelf time.

It is well known that SSC, ascorbic acid and TA are the most important quality parameters used to evaluate the storage effect of table grapes. Previous studies indicated that soluble solids and organic acids were consumed by respiration to support the normal activities of life during storage (Zhou et al., 2008). Ascorbic acid was one of the most important nutritional components in table grapes and also as an antioxidant to participate in the resistance of senescence (Zhou et al., 2008). In our study, we found that chitosan had a beneficial effect on SSC, ascorbic acid and TA. Similar performances were obtained in chitosan-treated guava fruit and chitosan-coated papaya fruit (Ali, Muhammad, Sijam, & Siddiqui, 2011; Hong, Xie, Zhang, Sun, & Gong, 2012). The results may be attributed to low respiration and the growth of spoilage organisms (Jiang & Li, 2001). Previous studies revealed that chitosan coating, by creating semi-permeable film on fruit surface, resulted in limiting fruit respiration metabolism and fungal growth, thereby delaying the declines of nutritional components such as soluble solids, ascorbic acid and titratable acidity (Hagenmaier, 2005). Fruits treated with CGC had the best effect on retarding consumption of important nutritional components. This may be due to the slow changes in respiration and metabolic activity. Jiang et al. (2012) reported that CGC coating was more effective in delaying changes of soluble solids, ascorbic acid and titratable acidity of shiitake mushroom during the storage period, as compared to chitosan or glucose alone.

3.6. POD and SOD activities chitosan or glucose

As shown in Fig. 5A, during cold storage, the pattern of changes in PODs increased first, and then decreased. POD activity in the control increased to a peak on the 15th day, and then dropped quickly for the following day. While fruits treated with chitosan, glucose or CGC attained the maximums by day 45, which higher than the peak of controls. When fruits were transferred to 20 °C in air for shelf life, POD activities in all samples decreased sharply.

The changes in SOD activity are shown in Fig. 5B. Under storage at 0 °C, SOD activity in all fruits increased rapidly and reached peaks on day 15, following to drop at the remainder of time. In the shelf life, SOD activities in chitosan–glucose complex or chitosan-treated fruits were higher than that in the control or glucose treatment, in spite of SOD activities decreased in all samples.

Senescence is considered to associated with reactive oxygen species (ROS), such as superoxide ($O_2^{\bullet -}$) and singlet oxygen. The defense system, which included antioxidant enzymes and antioxidants, play an important role in the oxyradical detoxification process (Han et al., 2006; Mittler, 2002). It is well known that POD and SOD are important oxyradical detoxification enzymes in plant tissue, thus these enzymes were assayed in our study. SOD can catalyze $O_2^{\bullet -}$ into H_2O_2, and then POD changes H_2O_2 into H_2O and O_2, whose do not harm to the tissue cells. The united action of antioxidant enzymes can scavenge excessive reactive oxygen species and protect the tissues from injury. Chitosan exhibits antioxidant properties due to its ability to form complexes with many of the transition metals, as well as some of those from groups 3–7 of the periodic table (Kosaraju, Weerakkody, & Augustin, 2010). Previous studies have already demonstrated that chitosan had a direct effect on induction of disease resistance by enhancing activities of POD and SOD in guava and papaya fruit (Ali et al., 2011;

Table 1
Changes of soluble solids content, titratable acidity and ascorbic acid in grapes.

Storage time	Treatments	SSC (%)	TA (% tartaric acid)	Vc (mg/100 g)
At harvest		17.33 ± 0.06a	0.53 ± 0.01a	5.12 ± 0.05a
After 60 days at 0 °C	Control	13.63 ± 0.21e	0.37 ± 0.01ef	2.99 ± 0.26f
	Chitosan	16.17 ± 0.29bc	0.47 ± 0.01c	4.42 ± 0.05c
	Glucose	15.60 ± 0.20c	0.44 ± 0.02d	4.25 ± 0.09c
	CGC	16.33 ± 0.35b	0.50 ± 0.01b	4.65 ± 0.08b
After shelf life at 20 °C	Control	12.20 ± 0.72f	0.31 ± 0.01 g	2.26 ± 0.13 g
	Chitosan	15.00 ± 0.26d	0.39 ± 0.02e	3.55 ± 0.08e
	Glucose	14.47 ± 0.15d	0.36 ± 0.01f	3.45 ± 0.12e
	CGC	15.77 ± 0.15bc	0.44 ± 0.01d	3.95 ± 0.09d

Values are expressed as either % ± SD or mg/100 g ± SD. Values within a column followed by the same lower case letters are not significantly different ($P > 0.05$).

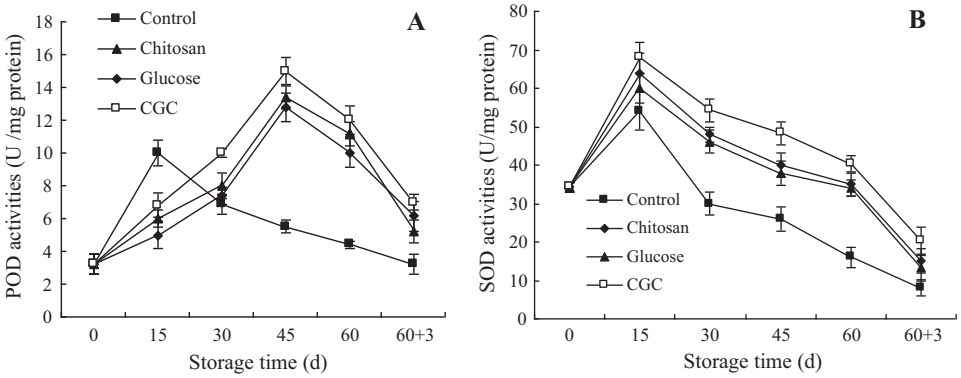

Fig. 5. Effects of control, chitosan, glucose, and chitosan–glucose complex on the activities of POD (A) and SOD (B) of table grapes during storage periods during 60 days of storage at 0 °C and after 3 days of shelf life in air at 20 °C. Each point represents the mean value ± SE.

Hong et al., 2012). In this present, we found that POD and SOD in chitosan coating fruits had consistently higher activities than those of controls or glucose. These facts together with the evidence in our work suggested that chitosan could induce activities of some antioxidant enzymes such as POD, SOD, thereby promoting tissue protection and delaying senescence. In addition, in the experiment, the chitosan–glucose complex coating treatment showed significantly higher POD and SOD activities as compared to chitosan/glucose alone. The reason was probably that CGC possessing superior hydrogen donating ability has the potential to react with the oxyradicals. Our results were in agreement with those of Kanatt et al. (2008), who found that chitosan–glucose complex had more superior antioxidant activity, as manifested by high DPPH and superoxide radical scavenging activities, when compared to chitosan and glucose alone.

3.7. Sensory evaluation

Changes in sensory attributes are presented in Table 2. Compared to scores at harvest, sharp or slight reductions in all analyzed

Table 2
Sensory attributes of grapes during 60 days at 0 °C and after 3 days of shelf life in air at 20 °C.

Storage time (d)	Control	Glucose	Chitosan	CGC
Flavor				
0	9.00	9.00	9.00	9.00
15	7.33bA	8.00abA	8.33abA	8.67aA
30	5.33bB	7.33aB	7.67aAB	8.33aAB
45	4.00bC	6.67aB	7.00aBC	7.67aAB
60	3.00dD	5.00cC	6.33bC	7.33aBC
60 + 3	1.00cE	4.67bC	5.00bD	6.33aC
Taste				
0	9.00	9.00	9.00	9.00
15	6.33bA	7.67aA	8.00aA	8.33aA
30	4.67bB	7.33aA	7.67aAB	8.00aAB
45	3.67bC	6.67aAB	7.00aABC	7.67aABC
60	2.67bD	6.00aBC	6.67aBC	7.00aBC
60 + 3	1.00cE	5.00bC	6.33aC	6.67aC
Visual appearance				
0	9.00	9.00	9.00	9.00
15	7.33aA	8.00aA	8.33aA	7.67aA
30	5.00bB	7.67aAB	8.00aA	7.33aA
45	4.33bB	7.00aABC	7.67aA	7.00aAB
60	3.33bC	6.33aBC	7.00aAB	6.67aAB
60 + 3	1.67bD	5.67aC	6.00aB	6.00aB
Color				
0	9.00	9.00	9.00	9.00
15	7.67aA	8.00aA	8.67aA	7.67aA
30	6.67aA	7.67aAB	8.00aAB	7.33aA
45	5.00bB	7.00aAB	7.33aBC	7.00aAB
60	3.67bC	6.67aBC	7.00aBC	6.67aAB
60 + 3	2.00bD	5.67aC	6.33aC	6.00aB
Overall preference				
0	9.00	9.00	9.00	9.00
15	6.67bA	8.00aA	8.67aA	8.33aA
30	5.33bB	7.67aA	8.00aAB	8.00aAB
45	4.67bB	7.00aAB	7.33aBC	7.67aABC
60	2.67bC	6.33aB	6.67aC	7.00aBC
60 + 3	1.33cD	5.00bC	6.33aC	6.67aC

Sensory evaluation was assessed on a nine-point scale 1–9. Means in same row with different lowercase letters are significantly different ($P < 0.05$). Means in same column with different capital letters are significantly different ($P < 0.05$).

attributes were observed on each sampling day (Table 2). Flavor significantly decreased after 15 days of storage in the control. Control fruits showed a flavor intensity of 4.00 at the 45th day of storage, which have reached the extent of being unacceptable for consumers. By day 60, the highest flavor score was found in chitosan–glucose complex treatment. Our data also showed that the CGC-coated samples had higher scores for taste parameters than chitosan/glucose alone during cold storage and shelf life, despite no significant difference was found among them. These results suggest that CGC was more effective in retarding sensory deterioration of grapes. In addition, the data showed that the CGC coating fruits had lower scores in visual appearance and color than the pure chitosan or glucose at the first 45 days. It might be due to the browning color of chitosan–glucose complex coating. The color of grapes in all samples gradually became browner with time. The browning of grapes was related to the action of polyphenol oxidase (PPO) and pathogen infections. Previous studies have demonstrated that CGC and chitosan coatings could effectively inhibit spoilage organisms and responsible for PPO-mediated oxidation of phenols to form melanin-like pigments, thus preventing the formation of a brown undesirable appearance and improving the visual appearance and color (Jiang et al., 2012; Liu et al., 2007). When asked to show about overall preference, except day 15, all panelists reported the fruit in CGC treatment was the most acceptability at each assessed points, followed by chitosan and glucose. All in all, chitosan–glucose complex could significantly maintain sensory attributes of Muscat Hamburg during long-term storage, as manifested by fruit visual appearance, color, flavor, taste and overall preference.

4. Conclusions

Compared to controls, the coated treatments significantly decreased decay, alleviated postharvest deterioration, reduced respiratory intensity and enhanced antioxidant enzymes activities. The results showed that the activities of POD and SOD in fruits treated with CGC coating were higher than those in other samples. Chitosan–glucose complex significantly alleviated the declines of total soluble solids, ascorbic acid and titratable acidity, when compared with other treatments. In addition, CGC also effectively maintained hardness, springiness, cohesiveness, and chewiness of fruits. Meanwhile CGC had a beneficial effect on sensory quality of grapes. These results indicated that chitosan–glucose complex was really a useful strategy for table grapes preservation.

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