Journal of Food Science and Technology (Iran)

Homepage:www.fsct.modares.ir

Scientific Research

Reducing the effects of oxidative stress in sweet pepper fruit during storage by using an edible coating of gum Arabic

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ABSTRACT

This work's main objective was to investigate the gum Arabic effect on reducing oxidative stress in bell peppers during ripening. Gum Arabic in 6, 9, 12, and 15% aqueous solutions was applied as an edible coating before storage on mature bell peppers stored at 8°C and 90-95% relative humidity for 28 days. The fruits that were coated with 12% gum Arabic had the lowest rate of decay, weight loss, total carotenoid content, and peroxidation of membrane lipids, as well as the highest total antioxidant capacity, total phenol, ascorbic acid, and antioxidant enzyme activity (superoxide dismutase, peroxidase, and catalase) during storage compared to the control without coating and the fruit treated with 6 and 9% gum. Still, there was no statistically significant difference with the fruit treated with 15% gum Arabic except for the total carotenoid content. The amount of peroxidation of membrane lipids showed positive and high correlation coefficients with decay (0.93**) and physiological weight loss (0.89**), but with antioxidant capacity (-0.93**), ascorbic acid (-0.94**), total phenol (-0.92**), activity of SOD (-0.96**), CAT (-0.87**) and POD (-0.86**) correlation. It was negative and high. The results showed that the use of 12% gum Arabic as an edible coating can delay oxidative stress and decay and maintain the antioxidant properties of the fruit for up to 28 days during storage at 8 degrees Celsius.

ARTICLE INFO

Article History:

Received: 2023/8/31
Accepted: 2023/10/19

Keywords:

Antioxidant capacity,
Antioxidant enzymes,
Ascorbic acid,
Total phenol.

DOI :10.22034/FSCT.20.145.122

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[DOI: 10.22034/FSCT.20.145.122]

1- Introduction

Bell pepper (*Capsicum annuum* L.) is one of the most widely consumed vegetables from the Solanaceae family, known for its high nutritional value due to significant amounts of ascorbic acid and vitamins A, E, and B complex [Ullah et al., 2017]. However, bell peppers have a short shelf life and are susceptible to issues like wilting, shriveling, fungal diseases, and decay, which negatively impact consumer acceptance after harvest [Ullah et al., 2017; Sharma et al., 2018]. While storing peppers at low temperatures (7-10 degrees Celsius) is a common practice to maintain their quality and prolong shelf life, this technique alone is not entirely effective and may risk frost damage [Ullah et al., 2017; Xing et al., 2011].

There have been numerous reports on the detrimental effects of excessive production of reactive oxygen species (ROS) on harvested horticultural products. This imbalance in ROS metabolism leads to irreparable damage to cell membranes and organelles, reducing the shelf life of fresh fruits and vegetables. Similar findings have been observed in oranges [Khorram et al., 2017; Haider et al., 2020], pomelos [Nie et al., 2020], strawberries [Tahir et al., 2018], apricots [Ali et al., 2020], tomatoes [Ali et al., 2010], and lettuce [Li et al., 2020]. Harvested fruits and vegetables possess a functional ROS scavenging system, including enzymes such as superoxide dismutase (SOD), catalase (CAT), peroxidase (POD), ascorbate peroxidase (APX), glutathione reductase (GR), and non-oxidative antioxidants like ascorbic acid, phenols, flavonoids, and carotenoids [Nie et al., 2020; Gill and Tuteja, 2010]. The efficiency of this ROS removal system in plant cells plays a vital role in combating oxidative stress and increasing the shelf life of harvested produce. Consequently, activating the antioxidant defense system can be a promising strategy to enhance fruit resistance and extend shelf life [Huang et al., 2021].

The use of semi-permeable coatings has been shown to improve the shelf life of fruits and vegetables [Andriani and Handayani, 2023]. Edible coatings help maintain the quality of these perishable items by reducing oxygen absorption, moisture loss, and slowing down respiration [Xing et al., 2011; Adiletta et al., 2021]. For instance, chitosan, a natural biopolymer, finds wide applications in fruits and vegetables due to its ability to form edible films, biochemical properties, antimicrobial activity, and induction of defense responses in plant tissues [Adiletta et al., 2021; Kumar et al., 2021]. Chitosan coatings have been reported to reduce weight loss, respiration rate, color loss, fungal infection, and increase antioxidant activity in bell peppers [Xing et al., 2011; Kumar et al., 2021]. Researchers have also found that edible coatings based on polysaccharides like chitosan and tracaganth gum can enhance the antioxidant system and extend the post-harvest life of products [Adiletta et al., 2021; Li et al., 2021].

Meanwhile, gum arabic, which is a combination of polysaccharides, arabinogalactan oligosaccharides and glycoproteins [Verbeken, et al., 2003], is a natural polysaccharide obtained from the acacia tree. It is widely used in food, textile and Pharmacy is used [Ullah, et al., 2017]. In one study, gum arabic coating was found to reduce the tissue damage and decay of green pepper [Ochoa-Reyes et al., 2013], while another study showed that gum arabic in combination with silver nanoparticles, inhibited microbial growth and increased the shelf life of green pepper [Hedayati , S. and Niakousari, M., 2015]. Based on these reports, it appears that the post-harvest use of edible coatings such as gum arabic is beneficial in maintaining fruit quality in cold storage. However, the specific impact of this edible coating on the activity and antioxidant properties of greenhouse bell pepper has not been investigated yet. Therefore, the main aim of our study was to examine the effects of gum arabic edible coating on the oxidative aging of bell peppers during storage and after harvest. Changes in lipid peroxidation, some antioxidant enzymes and non-enzymatic antioxidant metabolites were analyzed. In addition, the physiological weight loss and the rate of decay of fruits covered with different concentrations of gum arabic were evaluated.

2- Materials and methods

2-1- Experimental materials:

This research was conducted in the laboratory and cold room of the Department of Horticultural Science, Agricultural Sciences and Natural Resources University of Khuzestan, during the spring of 1402. Sweet pepper fruits were obtained from a commercial greenhouse in Shushtar city (32°11′39″N 48°14′37″E). The fruits were manually harvested between 7 and 9 in the morning, without any signs of physical damage, disease, or pests. They were immediately transported to the laboratory in polystyrene boxes. Prior to treatment, the fruits were cooled, washed twice with distilled water for cleaning, and dried at room temperature to determine their moisture content.

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2-2-Preparation of gum arabic solutions and treatment

gum arabic powder (CAS: 9000-01-5 Sigma-Aldrich Chemical Co. USA) was dissolved in sterile distilled water (100 ml) at concentrations of 6, 9, 12, and 15% by weight and heated at 40 °C for 60 minutes. After cooling to 20°C, glycerol was added as a softener to enhance the strength and flexibility of the coating solutions at a rate of 1%. The pH of the solutions was adjusted to 5.6 using sodium hydroxide. Prior to treatment, the pepper fruits were washed with sodium hypochlorite (0.05%) for 3 minutes and air-dried at ambient temperature (25 ± 3 °C). Forty fruits were immersed in each concentration of gum arabic coating solution (6, 9, 12, and 15%) for 2-3 minutes, ensuring that the coating solution covered the entire surface. The control group consisted of fruits immersed in sterile distilled water. After air-drying, all coated and control groups were placed in plastic boxes (overall dimensions: 48 cm × 32 cm × 25 cm) and stored at a temperature of 8 ± 1 °C and a relative humidity of 90 to 95% in cold storage (Ullah, et al., 2017). Data were recorded before treatment (day zero) and at 7-day intervals for 28 days.

2-3- The evaluated indicators and traits

2-3-1- Percentage of fruit weight loss

Pepper fruits were first weighed immediately after treatment and before storage in cold storage. Then, they were weighed again at intervals of 7 days using a digital scale with an accuracy of 0.01 grams. The percentage of physiological of fruit weight loss was calculated as a percentage of the initial weight, using the following formula [Ullah et al., 2017]:

Physiological weight loss (%) = [(initial weight - secondary weight)/ initial weight]×100

2-3-2- Percentage of decay

The percentage of decay of covered and uncovered fruits was calculated as the number of rotten fruits divided by the initial number of all fruits, multiplied by 100 [Ali et al., 2020].

2-3-3- Total carotenoid measurement

Total carotenoid content was determined according to the method described by Burgos et al. (2009). Two grams of treated and untreated fruit tissue were homogenized with acetone. The extraction was repeated until the remaining samples became colorless. Petroleum ether was added to the extracts, and then they were washed with water to remove the residual acetone. Butylated hydroxytoluene was added to the extract to prevent the degradation of carotenoids. Saponification was done with methanolic potassium hydroxide (10%) with a volume equal to the extract in the dark at room temperature. The absorbance values of the samples were measured at a wavelength of 450 nm, and the total carotenoid content was calculated using the extinction coefficient of the mixture of carotenoids (2500) [Burgos et al., 2009].

2-3-4- Measurement of total phenol content

The concentration of total phenolic content was analyzed using the Folin-Ciocaltiu colorimetric method. The amount of total phenol and standard phenol was expressed from the absorbance of the sample at 750 nm in terms of milligrams of gallic acid per 100 grams of fresh tissue [Ali et al., 2013].

2-3-5- Ascorbic acid (vitamin C) assay

Vitamin C in fruit samples was measured using the method of Klein and Perry (1982) with minor modifications. Five grams of pepper samples were extracted with 50 ml of metaphosphoric acid (1% w/v). Then, the resulting extract was centrifuged by a refrigerated centrifuge at 5000 g for 5 minutes. After that, 1 ml of supernetant mixed with 9 milliliters of dichlorophenol indophenol (DCIPP) solution (0.05 mmol), and immediately the absorption of the samples was read using a spectrophotometer at a wavelength of 515 nm. L-ascorbic acid was used to prepare the standard. Vitamin C content will be calculated in terms of milligrams per 100 grams of fresh weight [Klein and Perry, 1982].

2-3-6- Determining the antioxidant capacity

The antioxidant capacity of fruits was determined by inhibiting soluble free radicals 2,2-diphenyl-1-picrylhydrazyl (DPPH). Fifty microliters of methanol extract of fruit flesh was reacted with 3 ml of 0.1 mM DPPH solution and kept for 30 minutes at 25°C in the dark. The absorbance change of the samples was measured at 517 nm against blank methanol without DPPH. The results were expressed as a percentage of reduction according to the absorbance value of the DPPH reference solution [Ali et al., 2020].

2-3-7- Measuring the activity of antioxidant enzymes: superoxide dismutase (SOD), peroxidase (POD), and catalase (CAT)

To measure the activity of antioxidant enzymes, namely superoxide dismutase (SOD), peroxidase (POD), and catalase (CAT), fruit flesh samples weighing 2 grams were extracted using a 10 ml sodium phosphate buffer solution (25 mM pH 7.8,

[DOI: 10.22034/FSCT.20.145.122]

containing 0.8 g/L PVPP and 1 mM EDTA) [Xing et al., 2011].

For SOD activity determination, 0.1 ml of the enzyme extract was mixed with 2.9 ml of sodium phosphate buffer (50 mM, pH 7.8, containing 13 mM methionine, 75 µM nitroblue tetrazolium, 2 µM riboflavin, 10 µM EDTA). The resulting mixture was exposed to a light intensity of 60 lmol/m2/s1 for 10 minutes, after which its absorbance was measured at a wavelength of 560 nm. Finally, SOD activity was reported as U/g FW [Xing et al., 2011].

To determine CAT activity, 0.5 ml of the enzyme extract was mixed with 0.5 ml of 50 mM sodium phosphate buffer (pH 7.0) and 0.5 ml of 40 µM hydrogen peroxide. The amount of CAT activity was reported as U/g FW [Xing et al., 2011].

To determine POD activity, 0.5 ml of the enzyme extract was mixed with 2 ml of 100 mM sodium phosphate buffer (pH 6.4) containing 8 mM guaiacol. The mixture was then incubated at 30 °C for 5 minutes. After adding 1 ml of 24 mM hydrogen peroxide, the increase in absorbance at a wavelength of 460 nm was measured at 30-second intervals for two minutes. The amount of POD activity was reported as U/g FW [Xing et al., 2011].

2-3-8- Malondialdehyde (MDA) content

The amount of lipids peroxidation of membrane was determined by measuring the quantity of malondialdehyde (MDA) produced [Xing et al., 2011]. Four grams of fleshy tissue samples from pepper fruits were extracted using 20 ml of 10% trichloroacetic acid. One milliliter of the extract was then mixed with 3 milliliters of 0.5% thiobarbituric acid. Finally, the absorbance of the samples at 532 and 600 nm was measured and the difference was calculated. The amount of malondialdehyde was determined using the extinction coefficient of 155 mM^{-1} cm^{-1} and reported as micromolar per gram of fresh weight.

2-4- Statistical analysis

The experiment was conducted using a completely randomized design with three replications. The experimental data were analyzed using SAS V: 9.1 software (SAS Institute Inc., Cary, NC). Mean comparisons were performed using the LSD test with a significance level of 5% error probability.

3- Results and Discussion

The results of the variance analysis of the data from this research indicate that the interaction effects of gum arabic and storage time were significant for all studied traits ($p \leq 0.01$).

3-1- Percentage of fruit weight loss:

During storage, the weight loss of capsicum fruits was significantly lower in fruits coated with gum arabic compared to the uncoated group. Figure 1 displays the results, showing that fruits treated with concentrations of 12% and 15% gum arabic had the lowest weight loss during storage. There was no statistically significant difference observed between these two concentrations, but there was a significant difference with the treatments of 9% and 6% gum arabic, as well as the control treatment. The control treatment experienced a weight loss of 18.92% by the end of storage, which was almost double that of the 15% and 12% gum arabic coating treatments, which had weight losses of 10.52% and 9.93%, respectively. Weight loss plays a crucial role in determining the post-harvest shelf life of fruit during storage [Adetunji et al., 2019]. The percentage of weight loss increased across all treatments during the storage period, which could be attributed to water loss caused by active metabolic processes such as transpiration and respiration in the fruit [Hajivand-Ghasemabadi et al., 2022]. However, fruits coated with gum arabic retained more weight during the storage period compared to uncoated fruit. The lower weight loss in gum arabic coated fruits could be due to the blockage of stomata and guard cells, ultimately slowing down active metabolic processes and respiration. It can also be attributed to the semi-permeable effect of coatings during moisture loss, respiration, and solute movement across the membrane [Ullah et al., 2017]. These findings are consistent with the reports of other researchers regarding green pepper [Ullah et al., 2017; Hedayati, S., and Niakousari, M., 2015], tomato [Ali et al., 2010], and ponkan (a type of citrus) [Huang et al., 2021].

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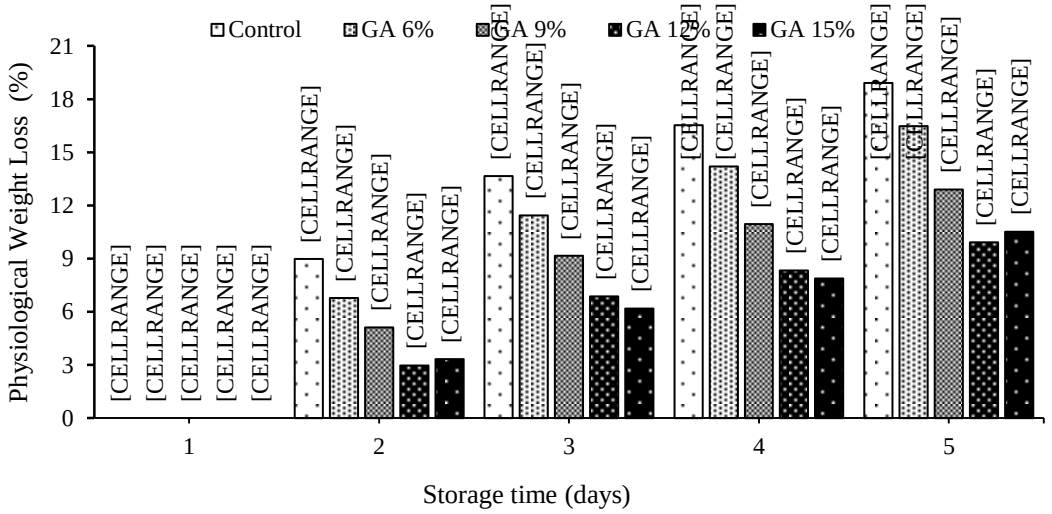

Figure 1- Effect of gum arabic coating on the weight loss of pepper fruit during cold storage at 8 ± 1°C for 28 days. Different letters indicate significant differences between the applied treatments ($p<0.05$).

3-2- Percentage of decay

The use of gum arabic coating significantly prevented rotting of stored bell peppers (Figure 2). The results demonstrate that at the end of the storage period, the gum arabic coating group had 12% (with 25.00% rotten fruits) fewer rotten and unusable fruits compared to the group without coating (with 58.83% rotten fruits) and other treatments. There was no statistically significant difference observed between the groups treated with 12% gum arabic and the group treated with 15% coating (Figure 2). Polysaccharide-based coatings have been reported to possess antimicrobial properties. The application of such coatings enhances defense against pathogenic organisms and suppresses diseases [Yao et al., 2013; Yao et al., 2015]. The formation of a coating-based layer on the product prevents disease-related organisms from multiplying, resulting in significantly reduced decay of the coated products [Ali et al., 2020]. The findings of this research align with the results reported by Olah et al. (2017), who observed a reduction in decay in green pepper fruit coated with gum arabic. The effect of other edible coatings in reducing decay in peppers [Adetunji et al., 2019] and tomatoes [Ali et al., 2020] has also been previously reported, further supporting the results of this research.

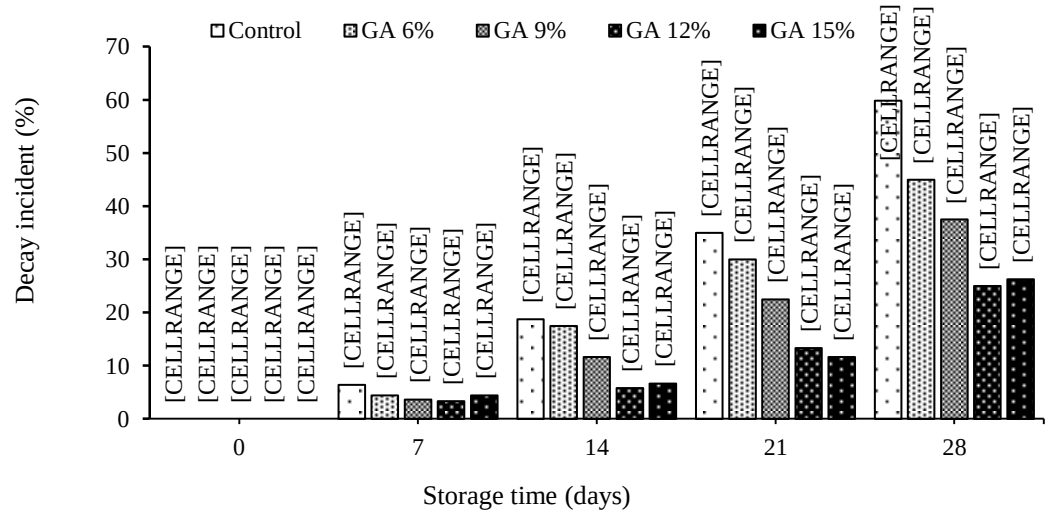

Figure 2- Effect of gum arabic coating on the decay incident of pepper fruit during cold storage at 8 ± 1°C for 28 days. Different letters indicate significant differences between the applied treatments ($p<0.05$).

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3-3- Total carotenoids

The total carotenoid content increased over time in all treatments (Figure 3). The highest increase in carotenoids was observed in the control treatment. In fruits coated with 12% gum arabic, the increase on the 7th day did not show a significant difference compared to the start of the experiment (Figure 3). By the end of the 28-day storage period, the total carotenoid content in fruits treated with a 12% concentration of gum arabic had increased by 140.69% compared to the beginning of the experiment, while in the untreated treatment, the increase was 216.85%.

The increase in carotenoids in the untreated control group and the fruits treated with a low concentration of gum arabic may be attributed to the faster ripening of the fruit compared to fruits treated with higher concentrations of gum arabic. The production of carotenoid content is directly related to fruit ripening (Ullah et al., 2017). It has also been reported that pigment formation depends on the temperature range and respiration rate during storage (Javanmardi and Kubota, 2006). In a recent study on tomatoes using gum arabic as an edible coating, minor color changes were observed in fruits coated with high concentrations of gum arabic even after 20 days of storage, indicating that at higher concentrations, the ripening and aging process of fruits is slowed down (Ali et al., 2013). The results of the present research align with the findings reported regarding the effect of gum arabic on tomato fruit pigments (Ali et al., 2013). Additionally, Olah et al. (2017) reported that green pepper fruits coated with 12% gum arabic better retained their color during storage, which is consistent with present research in terms of color retention.

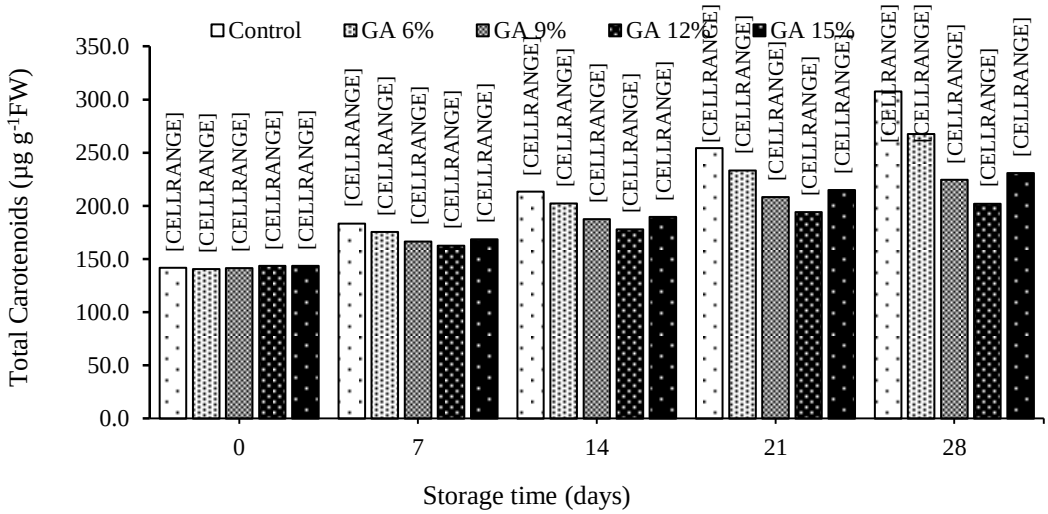

Figure 3- Effect of gum arabic coating on the total carotenoids of pepper fruit during cold storage at 8 ± 1°C for 28 days. Different letters indicate significant differences between the applied treatments ($p<0.05$).

3-4- Total phenol content

As shown in Figure 4, the total phenol content increased in all treatments during the first week, although the increase was not statistically significant. It then exhibited a significant decrease until the end of storage (Figure 4). The reduction in phenolic compounds at the end of storage was approximately 43% in the untreated treatment, while it was about 24% in the fruits coated with 12% and 15% gum arabic. Fruits coated with Arabic gum demonstrated a lower decrease in the amount of total phenol during storage.

It has been reported that phenolic compounds increase during the ripening stages in peppers (Kumar et al., 2010), which likely explains the initial increase in phenol content observed in all treatments at the beginning of storage. The decrease in phenolic compounds during storage can be attributed to the degradation of these compounds due to respiration, as well as the aging and decomposition of cell structures (Ali et al., 2013). The greater presence of phenolic compounds in gum arabic coatings may be associated with continuous biosynthesis (Nourozi and Sayyari, 2020; Ali et al., 2019a) and oxidation reduction, as

[DOI: 10.22034/FSCT.20.145.122]

phenols are susceptible to oxidative reduction during storage (Ali et al., 2019b). In other words, gum arabic coatings at concentrations of 12% and 15% have been effective in reducing oxidative stress and enhancing the preservation of phenolic compounds. The results of this study align with previous findings by other researchers regarding the effects of appropriate concentrations of gum arabic in preserving phenolic compounds in tomatoes (Ali et al., 2010, 2013).

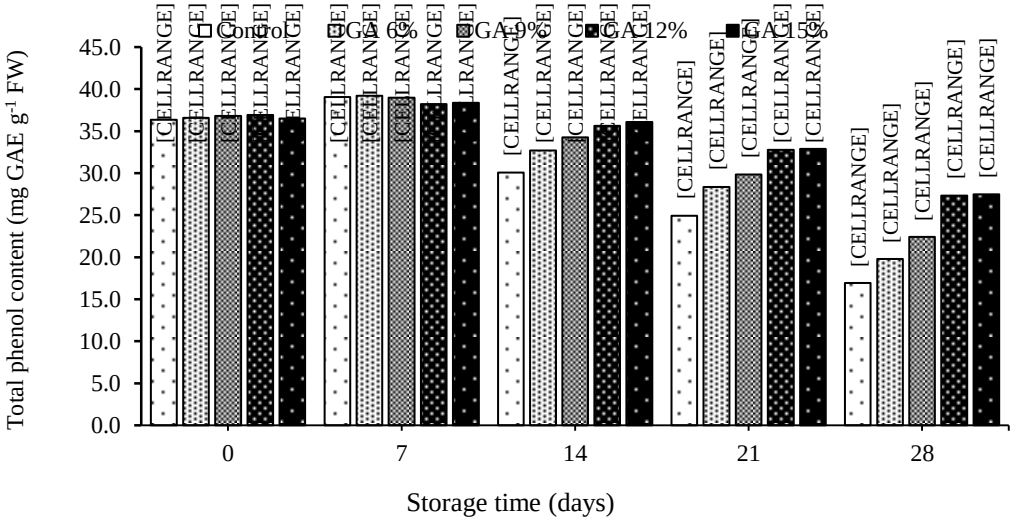

Figure 4- Effect of gum arabic coating on the total phenol content of pepper fruit during cold storage at 8 ± 1°C for 28 days. Different letters indicate significant differences between the applied treatments ($p<0.05$).

3-5- Ascorbic acid (vitamin C)

The results indicated that ascorbic acid levels decreased with longer storage periods, starting from day 7, in all treatments. However, this reduction was slower in fruits coated with gum arabic. Furthermore, increasing the concentration of gum coating slowed down this process even more. At the end of the storage period, the fruits treated with a 12% concentration of gum arabic exhibited the lowest reduction in ascorbic acid, with a recorded amount of 82.53 mg 100 g^{-1}FW (a reduction of 29%). The treatment with 15% gum arabic recorded 81.79 mg 100 g^{-1}FW (a reduction of 29%). These reductions were not significantly different. In contrast, the control treatment recorded a reduction of approximately 72%, with 32.66 mg 100 g^{-1}FW. Overall, fruits coated with gum arabic exhibited a smaller decrease in ascorbic acid content, and the 12% or 15% gum arabic treatments maintained the highest levels of ascorbic acid in the fruits. Ascorbic acid (vitamin C) acts as a potent water-soluble antioxidant, playing a role in preventing or reducing damage caused by reactive oxygen species (ROS) in fruits. Fruits naturally contain ascorbic acid, which is lost during ripening [Khaliq et al., 2016]. The reduction in ascorbic acid can be attributed to increased respiration and the oxidation of acids into sugars [Ullah et al., 2017]. Ascorbic acid is the primary compound responsible for detoxifying ROS, as it scavenges hydroxyl and superoxide radicals and reduces hydrogen peroxide to water through the reaction of ascorbate peroxidase [Blokhina et al., 2003]. The gum arabic coating may reduce acid oxidation by limiting oxygen exchange and slowing respiration, ultimately leading to better preservation of ascorbic acid in fruits during storage. The high levels of ascorbic acid in treated fruits can be attributed to the strengthening of the defense system and the maintenance of fruit quality without deterioration under stressful conditions [Khaliq et al., 2016]. Our results are consistent with the findings of Hedayati and Niakousari [Hedayati, S. and Niakousari, M., 2015] and Ullah et al. [2017], who reported a significant decrease in ascorbic acid content in green peppers due to the use of gum arabic coating.

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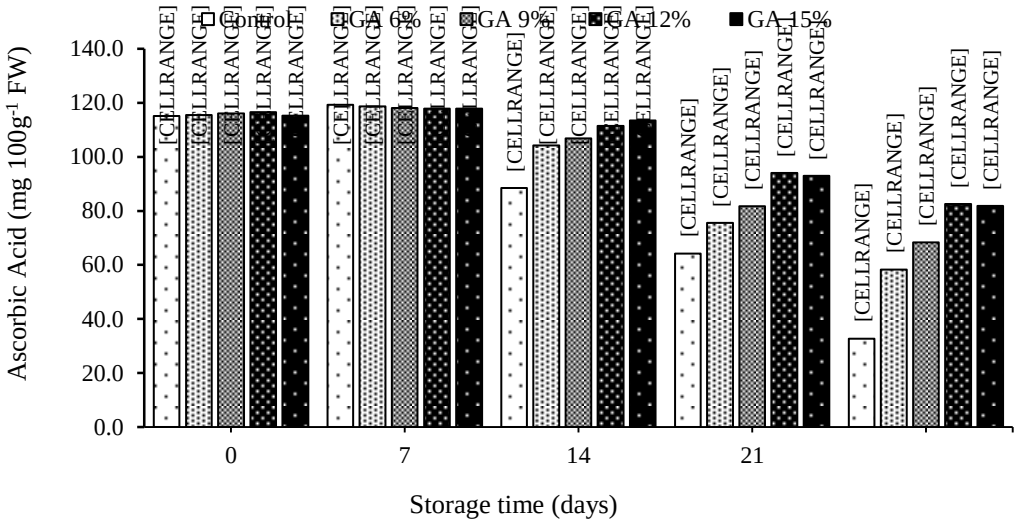

Figure 5- Effect of gum arabic coating on the Ascorbic acid of pepper fruit during cold storage at 8 ± 1°C for 28 days. Different letters indicate significant differences between the applied treatments ($p<0.05$).

3-6- Antioxidant capacity

The DPPH inhibitory activity decreased significantly from the seventh day of storage in all treatments and reached its lowest level at the end of storage (Figure 6). However, the decrease in antioxidant capacity was less pronounced in pepper fruits coated with gum arabic compared to the control. At the end of the storage period, the antioxidant capacity of pepper fruits coated with 12% gum arabic was 2.18 times higher than the control (Figure 6). Various non-enzymatic compounds, such as ascorbic acid and phenolic compounds, contribute to the overall antioxidant activity [Ullah et al., 2017]. Studies have reported an improvement in antioxidant capacity through the use of gum arabic coating in green peppers [Ullah et al., 2017] and tomatoes [Ali et al., 2010, 2013], which is consistent with our research results.

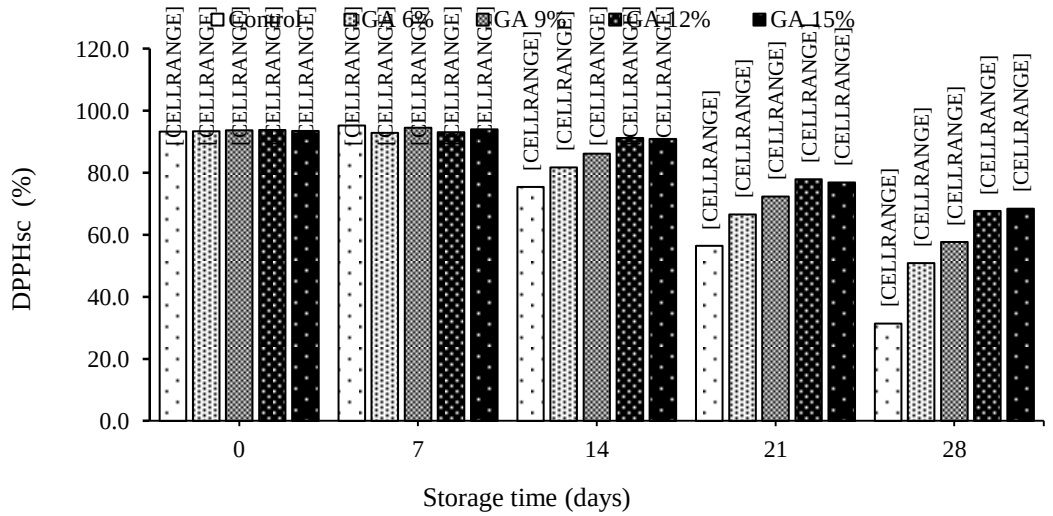

Figure 6- Effect of gum arabic coating on the antioxidant capacity of pepper fruit during cold storage at 8 ± 1°C for 28 days. Different letters indicate significant differences between the applied treatments ($p<0.05$).

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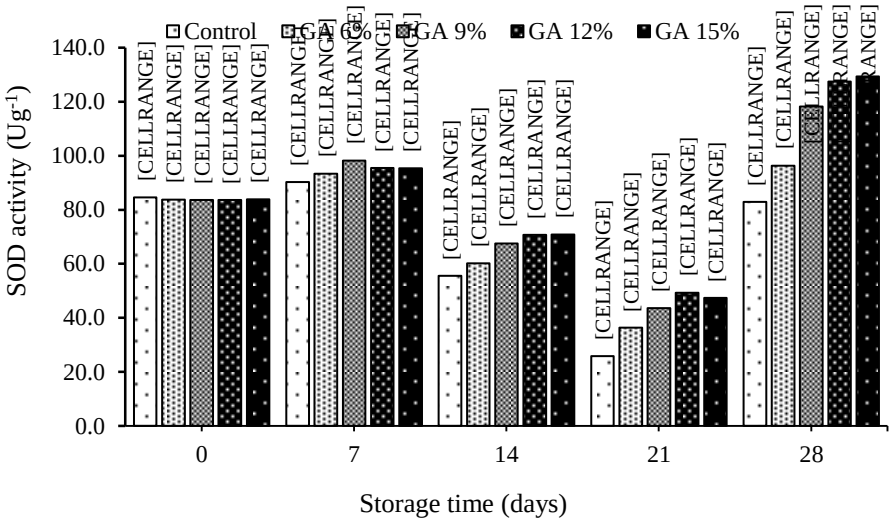
3-7- Activity of antioxidant enzymes SOD, POD, and CAT

As shown in Figure 7a, SOD activity gradually increased during the first 7 days, then decreased on days 14 and 21 of storage, and significantly increased again at the end of the storage period (day 28). The fruits coated with gum arabic exhibited higher SOD activity compared to the uncoated control fruits at all stages, with this difference increasing with both the coating concentration and the duration of storage. Notably, the peppers coated with 12% and 15% gum arabic showed the highest SOD activity during storage (Figure 7a).

POD activity gradually decreased in all treatments during storage until day 21, after which it increased until day 28 (Figure 7b). Peppers coated with gum arabic had significantly higher POD activity compared to the control throughout storage. Furthermore, the activity of POD increased with increasing gum arabic coating concentration. The treatment with 12% gum arabic exhibited the highest level of POD activity during storage, which was not significantly different from the treatment with 15% gum arabic.

CAT activities continuously decreased in all treatments during storage. The peppers coated with gum arabic showed higher CAT activities compared to the control throughout storage. Specifically, the treatment with 12% gum arabic exhibited the highest CAT activity, which was not significantly different from the treatment with 15% gum arabic (Figure 7c).

Aging is associated with the defense system, including antioxidant enzymes like POD, CAT, and SOD, as well as antioxidants [Xu et al., 2009; Xing et al., 2011]. The increased activity of antioxidant enzymes, including SOD, CAT, and POD, in peppers may be induced by gum arabic coating (Figure 3). Effective elimination of ROS requires the action of multiple antioxidant enzymes that work in conjunction with non-enzymatic antioxidants. POD, CAT, and SOD are crucial enzymes involved in the detoxification of oxyradicals in plant tissues [Xu et al., 2009]. In response to stress, plants typically increase the activity of these enzymes, and a decrease in enzyme potential may be associated with a decrease in the capacity to prevent damage [Xing et al., 2011]. Our results demonstrate that the higher activities of antioxidant enzymes, including SOD, CAT, and POD, in peppers contribute to better fruit preservation. In summary, gum arabic coating can reduce oxidative stress in bell peppers during storage by increasing the activity of antioxidant-related enzymes, indicating that gum arabic is an optimal polysaccharide-based coating for maintaining the quality of bell peppers. These findings align with the research conducted by Xing et al. (2011), who observed increased activity of antioxidant enzymes, reduced lipid peroxidation, and improved shelf life of bell pepper fruits through the use of chitosan edible coating.



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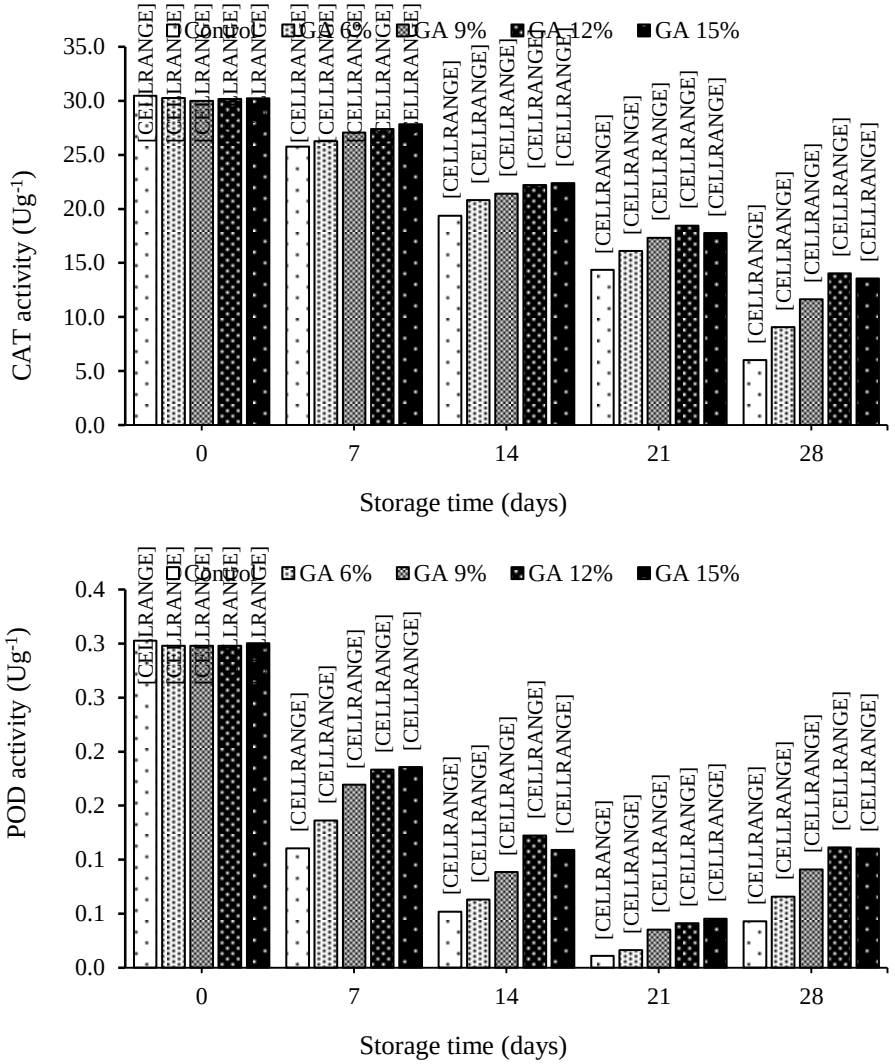

Figure 7- Effect of gum arabic coating on the antioxidant enzymes activity of pepper fruit during cold storage at 8 ± 1°C for 28 days. Different letters indicate significant differences between the applied treatments ($p<0.05$). Different letters indicate significant differences between the applied treatments ($p<0.05$).

3-8- Malondialdehyde (MDA) content

The content of MDA in sweet pepper fruit of the control treatment and those coated with gum arabic increased during the storage period (Figure 8). However, the fruits coated with gum arabic had lower MDA levels, and significant differences ($p<0.05$) were observed between the 12% and 15% gum arabic coating treatments and the control treatment regarding MDA accumulation. At the end of storage, the fruit coated with 12% gum arabic recorded the lowest MDA content (0.47 $\mu Mg^{-1}FW$), followed by the 15% gum arabic coating (0.48 $\mu Mg^{-1}FW$), with a statistical difference. The control fruit had the highest MDA content (0.9 $\mu Mg^{-1}FW$), indicating that gum coating treatments can prevent oxidative damage caused by lipid peroxidation and membrane damage in pepper fruit. MDA is a stress marker and the end product of membrane lipid peroxidation, and its accumulation is used as an important indicator to evaluate the level of oxidative damage in plant tissue membranes [12]. MDA is a good indicator of membrane structural integrity and is used to reflect oxidative deterioration during stress [31]. It has been reported that the storage conditions, ripening, and aging of the product can all play a role in inducing oxidative stress in fruit [34]. Excessive production of reactive oxygen species (ROS) during stress is one of the main causes of membrane damage, as ROS are highly reactive substances that induce lipid peroxidation. Ultimately, lipid peroxidation

[DOI: 10.22034/FSCT.20.145.122]

negatively affects membrane structure and function 32]. To combat oxidative stress and eliminate ROS, plants have developed two antioxidant defense mechanisms: enzymatic and non-enzymatic. When this defense system cannot eliminate the excessive production of ROS, oxidative damage occurs [31]. Gum arabic coatings have been reported to effectively preserve antioxidant and total phenolic content in tomato fruit [19] and papaya [35]. In another study, gum arabic treatment reduced the production of superoxide and hydrogen peroxide while increasing the antioxidant capacity of mango fruit [31]. The significant delay in MDA accumulation observed in this study due to gum arabic coating is consistent with the results reported for poncan fruit (a type of citrus) [12] and mango [31].

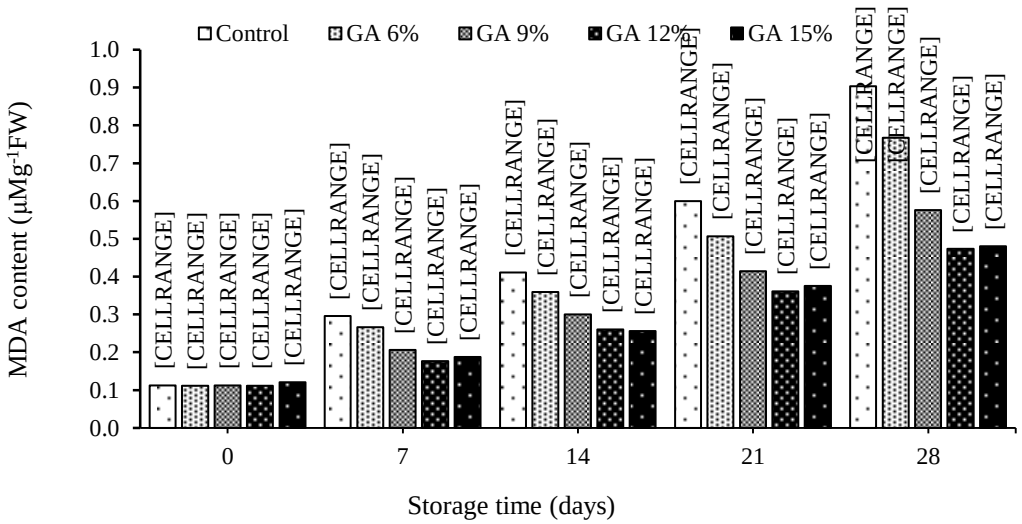

Figure 8- Effect of gum arabic coating on the lipid peroxidation of pepper fruit during cold storage at 8 ± 1°C for 28 days. Different letters indicate significant differences between the applied treatments ($p<0.05$).

Correlation Coefficient

Correlation analysis (Table 1) shows a positive and significant Pearson correlation between decay rate and weight loss, as well as MDA content. On the other hand, there was a negative and significant correlation between the decay rate and MDA content with total phenol, ascorbic acid, total carotenoids, total antioxidant capacity (DPPHsc%), and the activity of antioxidant enzymes (SOD, CAT, and POD). The occurrence of decay showed a positive and significant correlation with weight loss and peroxidation of membrane lipids (MDA content), but it exhibited a significant negative correlation with antioxidant capacity, antioxidant compounds, and antioxidant enzyme activity. Our correlation analysis showed that the reduction of oxidative stress damage and decay in treated fruits could be related to the reduction of changes in physicochemical properties, and gum arabic coating played a key role in minimizing the percentage of decay and better maintaining the measured biochemical properties. Similarly, the improvement of the fruit antioxidant system and the reduction of oxidative stress and rotting have been reported in Ponkan [12].

[DOI: 10.22034/FSCT.20.145.122]

Table1- Pearson correlation matrix for lipid peroxidation (MDA) and physiochemical properties (weight loss, total phenol, ascorbic acid, total Carotenoid content and DPPH sc (%), decay incidence, and antioxidant enzymes activity (CAT, POD, and SOD) in Sweet pepper fruit treated with gum arabic coating after 28 d of storage period at 8 ± 1°C.

Traits	MDA	Physiological Weight Loss	Total Phenol	Ascorbic Acid	DPPHsc	Total Carotenoid	SOD	CAT	POD
Physiological Weight Loss	0.89**								
Total Phenol	-0.92**	-0.81**							
Ascorbic Acid	-0.94**	-0.86**	0.88**						
DPPHsc	-0.93**	-0.84**	0.81**	0.96**					
Total Carotenoid	0.93**	0.90**	-0.84**	-0.88**	-0.89**				
SOD	-0.76**	-0.72**	0.73**	0.70**	0.79**	-0.59**			
CAT	-0.87**	-0.85**	0.83**	0.86**	0.80**	0.85**	0.78**		
POD	-0.86**	-0.84**	0.85**	0.87**	0.79**	0.73**	0.86**	0.89**	
Decay incident	0.93**	0.86**	-0.92**	-0.92**	-0.86**	-0.89**	-0.86**	-0.89**	-0.86**

** indicate significantly of correlation at the 1 %.

[DOI: 10.22034/FSCT.20.145.122]

4- Conclusion summary, post-harvest decay and the reduction in

In fresh bell pepper fruit quality were closely related to oxidative stress and antioxidant capacity. Our work demonstrates the positive effect of gum arabic coating in reducing oxidative stress, thereby reducing post-harvest decay and maintaining the nutritional quality of harvested bell pepper fruit during cold storage. Specifically, pre-storage treatment with a 12% gum arabic coating delayed MDA accumulation and induced an antioxidant defense system, as indicated by higher amounts of non-enzymatic antioxidants such as ascorbic acid, total phenols, phenol and higher activities of reactive oxygen species scavenging enzymes such as SOD, CAT and POD are shown. These results indicate that a 12% gum arabic coating effectively delays post-harvest loss (rotting and weight loss) because it increases the antioxidant capacity, reduces oxidative damage, and inhibits membrane lipid peroxidation, thereby preserving the bell pepper fruit. Overall, this study suggests that the post-harvest and pre-storage application of gum arabic-coated pepper fruits can be used as a prospective preservative to reduce post-harvest decay and maintain nutritional quality during storage at 8°C for 28 days.

5- Acknowledgement

Hereby, the authors of the article express their gratitude to the Agricultural Sciences and Natural Resources University of Khuzestan for providing financial and executive support for this research project (number 275/411/2)..

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[DOI: 10.22034/FSCT.20.145.122]

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سایت مجله: www.fsct.modares.ac.ir

مقاله علمی_پژوهشی

کاهش اثرات تنش اکسیداتیو در پس از برداشت میوه فلفل دلمه با استفاده از پوشش خوراکی صمغ عربی

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اطلاعات مقاله

تاریخ های مقاله :

تاریخ دریافت: ۱۴۰۲/۶/۹

تاریخ پذیرش: ۱۴۰۲/۷/۲۷

کلمات کلیدی:

اسید آسکوربیک،

آنزیم‌های آنتی‌اکسیدانی،

ظرفیت آنتی‌اکسیدانی،

فنل کل.

DOI: 10.22034/FSCT.20.145. 122

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چکیده

هدف اصلی این کار بررسی تأثیر صمغ عربی بر کاهش تنش اکسیداتیو در فلفل دلمه‌ای در طی انبامانی بود. صمغ عربی در محلول‌های آبی ۶، ۹، ۱۲ و ۱۵ درصد به‌عنوان یک پوشش خوراکی قبل از انبارداری روی فلفل‌های دلمه بالغ که در دمای ۸ درجه سانتیگراد و رطوبت نسبی ۹۰ تا ۹۵ درصد به مدت ۲۸ روز نگهداری شدند، اعمال شد. میوه‌های که با ۱۲ درصد صمغ عربی پوشانده شده بود، کمترین میزان پوسیدگی، کاهش وزن، محتوای کاروتنوئید کل و پراکسیداسیون لیپیدهای غشا و همچنین بیشترین ظرفیت آنتی‌اکسیدانی کل، فنل کل، اسیدآسکوربیک و فعالیت آنزیم‌های آنتی‌اکسیدانی (پوپراکسید دیسموتاز، پراکسیداز و کاتالار) را در طول نگهداری در مقایسه با شاهد بدون پوشش و میوه تیمار شده با ۶ و ۹ درصد صمغ داشت اما با میوه‌های تیمار شده با ۱۵٪ صمغ عربی به جز در محتوای کاروتنوئید کل تفاوت آماری معنی‌داری نداشت. میزان پراکسیداسیون لیپیدهای غشا ضرایب همبستگی مثبت و بالایی با پوسیدگی (**۰/۹۳) و کاهش وزن فیزیولوژیکی (**۰/۸۹) نشان داد اما با ظرفیت آنتی‌اکسیدانی (**-۰/۹۳)، اسید آسکوربیک (**-۰/۹۴)، فنل کل (**-۰/۹۲)، فعالیت آنزیم‌های SOD (**-۰/۹۶)، CAT (**-۰/۸۷) و POD (**-۰/۸۶) همبستگی منفی و بالایی داشت. نتایج نشان داد که استفاده از ۱۲ درصد صمغ عربی به‌عنوان پوشش خوراکی، می‌تواند تنش اکسیداتیو و پوسیدگی را به تأخیر انداخته و خصوصیات آنتی‌اکسیدانی میوه را تا ۲۸ روز در طول نگهداری در دمای ۸ درجه سلسیوس به‌صورت قابل قبولی حفظ کند.

[DOI: 10.22034/FSCT.20.145.122]