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Influence of Polysaccharide-Based Edible Coatings on the Shelf Life and Nutritional Quality of Tomato Fruit

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ABSTRACT

The efficiency of polysaccharide-based edible coatings with regards to shelf life and nutritional quality of fresh tomato fruit has been evaluated. The tomatoes selected for the present study were treated with one of several coatings, carrageenan (0.5% and 0.3%), carrageenan + cinnamon oil (0.3% + 0.25%), carboxy methylcellulose (CMC) (1% and 0.5%), CMC + cinnamon oil (0.5% + 0.25%) for 2 min and stored at 25 ± 5°C and 60 ± 5% relative humidity. Physico-chemical and biochemical analyses revealed a significant decrease in the incidence of decay, weight loss, and delay in the change in colour, pH and titratable acidity of coated tomatoes relative to uncoated fruit. Coatings maintained the textural quality and antioxidant level of tomato fruit during the storage period. The shelf life of coated tomatoes could be extended by 12 days more than uncoated fruit. The results of this study show that edible coatings have the potential to control decaying incidence, extend the storage life and maintain valuable characteristics by delaying ripening and senescence processes in tomatoes.

Keywords: carrageenan, cinnamon oil, CMC, edible coating, fruit ripening

INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.) is one of the most important horticultural crops in the world having excellent nutritive values. However, being a climacteric fruit, it has a relatively short post harvest life and high perishability. Hence, its short ripening and senescence period encounters several problems in transportation and storage and makes their marketing a challenge. With that concern, there is a great need to develop viable post harvest technologies that can save the harvested tomato crop.

The main objective of post harvest research efforts is to retain the quality and safety of horticultural crops and reduce post harvest losses. Several successful techniques such as controlled atmosphere, modified atmosphere packaging, plastic film packaging, etc. have become standard practices to improve the quality and safety of fruits and vegetables. However, edible coatings have been in place to extend the marketing distances and are continuing to be under extensive research efforts for their potential capability to extend the shelf life and quality of fresh fruits and vegetables (Burtoom 2008; Lim *et al*. 2011). Edible coatings are considered to be a conventional practice, to enhance food appearance and conservation. During processing, handling and storage, they efficiently reduce fruit weight loss, extend storage life and retard the deterioration of fruits and vegetables by enhancing their quality. Moreover, they have natural biocide activity which can be improved by incorporation of antimicrobial compounds (Martinez-Romero *et al*. 2006).

The application of edible coatings has been significantly influenced by the development of polysaccharide-based edible coatings. Among those, several potential polysaccharide materials, carrageenan and carboxy methylcellulose (CMC) have been emphasized mainly in food application because of their ability to establish polymer interactions and form a continuous network responsible for the functional properties of films. Carrageenan and CMC are excellent barriers for oxygen, aroma and oil, and provide strength and structural integrity. Their tightly packed, ordered hydrogen bonded network structure and low solubility imparts oxygen barrier properties to the coating materials (Banker 1966).

Application of carrageenan-based coatings has been carried out on a variety of foods for a long time as a carrier of antimicrobials or antioxidants and for the reduction of moisture loss, oxidation or disintegration (Lacroix and Le Tien 2005). Additionally, edible coatings have the ability to carry functional ingredients such as antioxidants, antimicrobials, nutrients and flavors to further enhance food stability, quality, functionality and safety (Min and Krochta 2005; Lin and Zhao 2007). The addition of antimicrobial agents like essential oils in edible coatings can extend the post harvest shelf life of the fruit by releasing them slowly onto the surface of the product and maintaining their high concentration during the packaging process (Ouattara *et al*. 2000; Xing *et al*. 2011). Therefore, incorporation of essential oils in edible coatings could possibly be a means to control post harvest diseases and it can be employed as an additive in edible coating material which assists in protecting the fruit from the attack of microbial agents.

Taking these facts into consideration, the present study has been undertaken with the aim of determining the effect of composite edible coatings comprising carrageenan and CMC with the cinnamon oil incorporation to impart more nutritional quality and the shelf life of tomato fruit during its post harvest storage.

MATERIALS AND METHODS

Collection of sample

The tomato fruit of var. 'Desi' was harvested at their mature stage from the agricultural farm of Valasan village in Anand District of Gujarat state, India and they were transported immediately to the laboratory. These tomatoes were graded for maintaining unifor-

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mity in their size, maturity stage and for absence of any physical injury or disease.

Experimental design

The tomatoes selected for the present study were washed thoroughly with water and dipped in 2% sodium hypochlorite for 10 min to diminish the fungal infection and then air dried. After drying, the sanitized tomatoes were grouped into 7 sets with 15 fruits in each set and these were dipped completely into the coating solutions of following compositions, combinations and concentrations for 2 min at room temperature: (T1) carrageenan 0.5%, (T2) carrageenan 0.3%, (T3) carrageenan 0.3% + cinnamon oil 0.25%, (T4) CMC 1%, (T5) CMC 0.5%, (T6) CMC 0.5% + cinnamon oil 0.25% and (T7) control (treated with water).

After draining excess coating material, these coated fruits were dried at room temperature so as to allow the formation of a thin film on their surface. Both the coated and uncoated tomatoes were stored at room temperature (25 ± 5°C) for their experimental analysis. The fruit of coated as well as control have been evaluated for the following physico-chemical and biochemical parameters at the beginning of the experiment (i.e. 0 days) and after 7, 14, 21 and 30 days of their storage period. For control fruit the data were recorded only up to 21 days of storage period, as thereafter they began to decompose.

Fruit coating formulation

Two different polysaccharides based edible coatings, carrageenan and CMC, were used with the combination of cinnamon oil. CMC coating was prepared by solubilising 1 and 0.5 g of CMC powder in 100 ml of distilled water at 75°C under magnetic stirring for 15 min. Then 0.75% of glycerol was added as a plasticizer and the solution was stirred for 10 min under the same conditions (Maftoonazad *et al*. 2008). Carrageenan solution was prepared by dissolving 0.5 and 0.3 g carrageenan in 100 ml of distilled water. 0.75% glycerol was added. The solution was equilibrated at 70°C and stirred vigorously on a magnetic stirrer for 40 min, on a heating plate. The solution was cooled down to room temperature prior to pH adjustment (5.6), by using 2.6 M citric acid and mixed with Tween 80 (0.05%) to help as an emulsifier (Maftoonazad *et al*. 2008). Cinnamon oil (0.25%) was added to the CMC 0.5% and carrageenan 0.3% solution followed by stirring it using a magnetic stirrer for 30 min. The solution obtained was used for coating treatment after standing for 1 h and the residual bubbles were removed using a small spatula.

Weight loss percentage

The weight loss percentage (WLP) of tomato fruit was calculated by considering the difference between initial weight and final weight of presently tested tomato fruit divided by their initial weight.

Storage life

The shelf life of tomato fruit worked out under the current study was calculated by counting the days required for them to reach the last stage of ripening, when these are fir to the stored for marketing in the future.

pH, titrable acidity, total soluble solids and firmness of the sample

The pH of the tomato fruit samples was determined as per the method of AOAC (A.O.A.C. 1994), whereas the total soluble solids (TSS) content of the fruit was determined by using refractrometer (Atago Co., Tokyo, Japan). A homogenous sample was prepared by pounding tomato in a mortar and pestle with water to form a paste. Then, a few drops were taken from this homogenous sample and placed on the prism of refractrometer and direct reading was taken from the scale in the meter as described in AOAC. Titrable acidity (TA; expressed as citric acid %) was determined by titrating 1ml of freshly prepared tomato juice with 0.1 N sodium hydroxide, using phenolphthalein as an indicator (A.O.A.C. 1994). Firmness of the fruit was measured by a penetrometer.

Biochemical analysis

According to the methods of Thimmaiah (1999), reducing sugars and non-reducing sugars were estimated by using di-nitro-salicylic acid, while total sugars were estimated by using anthron method. Extractions and estimations of total chlorophylls, lycopene and total carotenoids were carried out by following the method of Wang *et al*. (2005). The quantitative analysis of ascorbic acid was carried out by using 2, 6-dinitrophenolyl hydrazine, as per the method of Roe (1964).

Statistical analyses

The experiment was conducted in a completely randomized design (CRD) with three replicates. All the performed analyses were carried out in triplicate and the standard deviation (SD) was calculated. Data analyses were performed by analysis of variance (ANOVA) using IRRISTAT statistical software (v. 3.1 IRRI, Manila, Philippines). Multiple comparisions among the treatments with significant differences tested with ANOVA were conducted by using least significant difference (LSD) at $P < 0.05$. Duncan's multiple range test (DMRT) was used to compare the mean values in different storage interval.

RESULTS AND DISCUSSION

Effect on physiological weight loss

The results of the currently analyzed tomato fruit indicate an increase in WLP of both coated and uncoated tomatoes with the advancement of their storage period (**Fig. 1A**). It was clearly observed on the 21st day of their storage, WLP was greater i.e. 23.44% in the uncoated fruit while the lowest, i.e. 9.89% of it occurred in the fruit coated with carrageenan 0.5%. The WLP of other treatments was also lower than that of the control set of fruits i.e. T2 (14.31%), T3 (10.60%), T4 (13.70%), T5 (13.06%) and T6 (10.40%). At the end of the storage, the lowest weight loss was observed in the T1 (5.38%) and T6 (10.40%) which is better

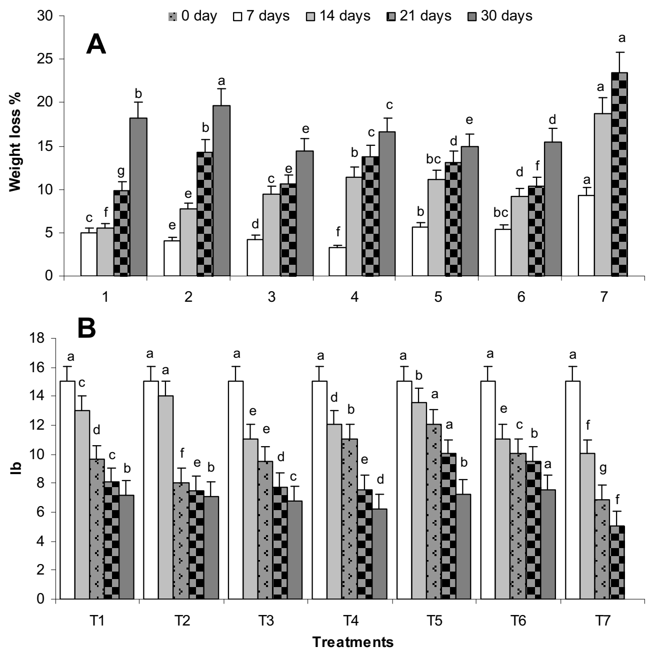

Fig. 1 Effect of edible coatings on (**A**) weight loss percentage and (**B**) firmness in tomatoes during storage at 25 ± 5°C. Vertical bars represent ± SE of means for three replicates. T1 = carrageenan 0.5%, T2 = carrageenan 0.3%, T3 = carrageenan 0.3% + cinnamon oil 0.25%, T4 = CMC 1%, T5 = CMC 0.5%, T6 = CMC 0.5% + cinnamon oil 0.25%, T7 = control (treated with water).

Table 1 Effect of different edible coating treatments and their concentrations on storage life of the tomato fruit stored at 25 ± 5°C.

Treatments	Storage life (days)
T1 (carrageenan 0.5%)	30^{a}
T2 (carrageenan 0.3%)	27^{d}
T3 (carrageenan 0.3% + CO 025%)	28^{c}
T4 (CMC 1%)	29^{b}
T5 (CMC 0.5%)	23^{f}
T6 (CMC 0.5% + CO 025%)	24^{e}
T7 (Control)	18^{g}
LSD 5%	0.2394

Means with the same letters within column are not significantly different at p<0.05 using LSD.
Each value is the mean for three replicates. The values represented (a-g) in the column indicate the
range from higher to lower rank.

than all other treatments and control set. This can be explained by the fact that by slowing down the respiration rate as well as transpiration, edible coatings helped in reducing the weight loss of the fruit. Lin and Zhao (2007) stated that edible coatings provide an effective barrier to oxygen, carbon dioxide and water vapour transmission thus helping to alleviate the problem of moisture loss. Baldwin *et al*. (1999) opined that the reduction in weight loss was probably due to the effects of edible coatings as a semi-permeable barrier against oxygen, carbon dioxide moisture and solute movement, thereby reducing respiration, water loss and oxidation reaction rates. Thus the results of the present study are in agreement with the findings of Davila-Avina *et al*. (2011) who reported higher weight loss in control tomato fruit (4.87%) than the fruit coated with edible coatings of carnauba and mineral oil (1.44 and 2.81%, respectively). The results of the present study are also in accordance with the findings of Ribeiro *et al*. (2007) who reported minimum weight loss with chitosan and carrageenan coatings than that of the control strawberry fruit.

Effect on shelf life

The shelf life of the tomatoes treated with carrageenan 0.5% was extended by 12 days and they remained fresher till the end of the storage period of 30 days; whereas the fruits in the of control set decayed after 18 days (**Table 1**). Other presently tested coating treatments also delayed the decay occurrence of fruit compared to control fruit. The obtained results indicate that the longest extension of shelf life (i.e. 30 days) was possible with the T1 treatment. Quezada-Gallo *et al*. (2003), who worked on the influence of starch and pectin-based coatings for the improvement of shelf life and aroma of Mexican guava, showed the same trends. Kittur *et al*. (2001) also reported that polysaccharide-based coating formulations slowed down metabolism to give prolonged storage life and they reported an extension in the shelf life of bananas by 21 days and of mangoes by 8 days relative to control fruits. Han *et al*. (2004) also reported that chitosan-based coatings extended the shelf-life of fresh strawberries and red raspberries by decreasing the incidence of decay. With respect to the beneficial effects of edible coatings, Baldwin (2001) opined that these coatings are a simple, environmentally friendly, and relatively inexpensive technology that can be used to extend the shelf life of tropical fruits and vegetables provided that there is good storage and temperature control.

The results of the present study suggest that the fruit treated with edible coatings like carrageenan and CMC have excellent ability to lengthen the shelf life of the tomatoes by reducing their decay incidence and retaining their nutritional quality.

Effect on firmness

Firmness of both the treated as well as untreated tomatoes were decreased with a prolongation of the storage period (**Fig. 1B**). On the 21st day of storage period, tomato fruits of control set clearly showed the minimum firmness (5.07 Lb), while the fruit coated with 0.5% CMC and carrageenan 0.5% with 0.25% cinnamon oil retained the maximum firmness i.e. 7.55 and 7.21 Lb, respectively than all other treatments. Fruits coated with other treatments were considerably softer, but edible coating still largely reduces firmness losses, compared to untreated fruits. The retention of firmness can be explained by the retarded degradation of insoluble protopectins to more soluble pectic acid and pectin. El Ghaouth *et al*. (1992) also found that fresh tomatoes coated with chitosan maintained more firmness than uncoated fruit after 28 days of storage at 20°C. Maftoonazad *et al*. (2005) also reported that avocados coated with methyl cellulose lost half of their firmness in 10 days compared to uncoated fruit which took only 5 days. An identical account was provided by Esteban *et al*. (2011) who reported that edible coatings significantly reduced the weight and firmness losses of tomatoes at both maturity stages. A similar effect was observed by Ribeiro *et al*. (2007) in strawberries coated with carrageenan and calcium chloride which showed a minimum loss of firmness.

Effect on pH, titrable acidity and total soluble solids

The results of the effect of edible coatings on pH, TA and TSS are presented in **Fig. 2**. The pH and TSS of both treated and untreated fruits increased while the TA of treated fruit decreased during the storage period. Since organic acids such as malic or citric acid are the primary substrates for respiration, a reduction in acidity and increase in pH are expected in highly respiring fruit (Yaman and

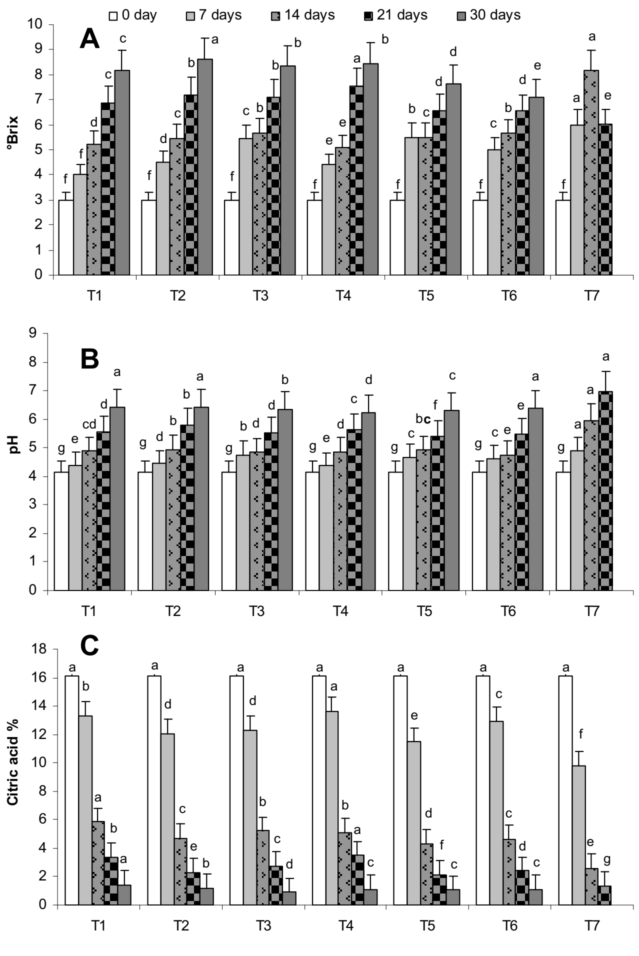

Fig. 2 Effect of edible coatings on content of (**A**) total soluble solids, (**B**) pH and (**C**) titrable acidity in tomatoes during storage at 25 ± 5°C. Vertical bars represent ± SE of means for three replicates. T1 = carrageenan 0.5%, T2 = carrageenan 0.3%, T3 = carrageenan 0.3% + cinnamon oil 0.25%, T4 = CMC 1%, T5 = CMC 0.5%, T6 = CMC 0.5% + cinnamon oil 0.25%, T7 = control (treated with water).

Bayoindirli 2002). Further, compared with treated fruit, the fruit of the control set had the highest pH (6.96) and lowest TA (1.36%), after 21 days of storage. All the treated fruits had lower pH and higher TA than the control set of fruits. After 21 days of storage, the treatments T1 (6.87%), T5 (6.57%) and T6 (6.55%) had a lower TSS value than other treatments, but in the fruits of the control set TSS peaked at 14 days of storage i.e. (8.17%) and then declined to (6.03%) after 21 days. After 30 days of storage, treatment T6 showed a lower value of TSS (7.10%) than all other treatments (**Fig. 2A**).

Coatings reduce respiratory and metabolic rates, and thereby delay the utilization of organic acids. Reduction in the rate of respiration through the chemical treatment, coating and controlling the atmosphere composition could be due to the delay in the use of organic acids in the enzymatic reactions of respiration (Bico *et al.* 2009). These results are also aligned with the results reported by Park *et al.* (1994) that TSS of the tomato fruit is significantly increased during storage period. The declining of TSS in the CMC treated tomato fruit was most likely the result of slowing down of respiratory and metabolic activity and delaying the ripening process. This finding is in agreement with that of Maftoonazad and Ramaswamy (2005) who reported that the low concentration of glycerol conjugated with high concentration of methyl cellulose strongly decreases the respiration rate of coated avocado as compared to control samples. Nisperos and Baldwin (1988) also opined that the reduction of the respiration rate in tomatoes is due to coating with edible films.

Effect on sugar content

Total sugars of the fruit are considered to be one of the basic criteria to evaluate fruit ripening. Reducing sugars such as glucose is the main substrate in the respiration process of producing the energy required in the metabolism of fruit. During the storage period, reducing sugars showed a general trend of an initial increase followed by a decreasing pattern (**Fig. 3**). During the 21 days of storage, treatments T1, T3 and T6 showed the lowest value of reducing sugar content i.e. 20.65, 21.54 and 21.58 mg/g, respectively (**Fig. 3A**), but in the control fruit, this value reached its peak i.e. 32.1 mg/g and then tumbled to 7.72 mg/g. After the 30 days of storage the least amount of reducing sugar was found in treatment T1 (21.08 mg/g), T3 (20.91 mg/g) and T4 (21.79 mg/g). During the 21 days of storage period, treatments T1 (11.56 mg/g) and T4 (10.84 mg/g) exhibited lower values of non-reducing sugars whereas in the control fruits, values peaked then decreased to 10.46 mg/g. After 21 days of storage the least value of total sugar content was obtained in treatment T1 (42.18 mg/g) and T4 (43.31 mg/g), among all the tested treatments.

Edible coatings affected the total sugar content of tomato fruit (**Fig. 3C**). Kittur *et al.* (2001) also found that the reducing sugar content of polysaccharide-based coated fruits was lower than the control, suggesting that the former synthesized reducing sugars at a slower rate than the control. Carrillo-Lopez *et al.* (2000) also reported that by increasing the concentration of carboxymethyle cellulose in edible emulsions caused a decrease in the rate of ethylene production and metabolic process of coated mangoes. It maintained lower total sugar contents in tomato fruit tested under the current study during the latter parts of the storage period than during the early days of storage. Ben-Yehoshua (1985) opined that coatings extend the shelf life of fruits and vegetables by decreasing O_2 and increasing CO_2 concentration which reduces the enzymatic activities responsible for quality deterioration. Therefore, the respiration rate of tomato fruit is reduced due to the lower level of O_2 and higher concentration of CO_2 influenced by coatings and the sugar utilized during the storage period is normally less.

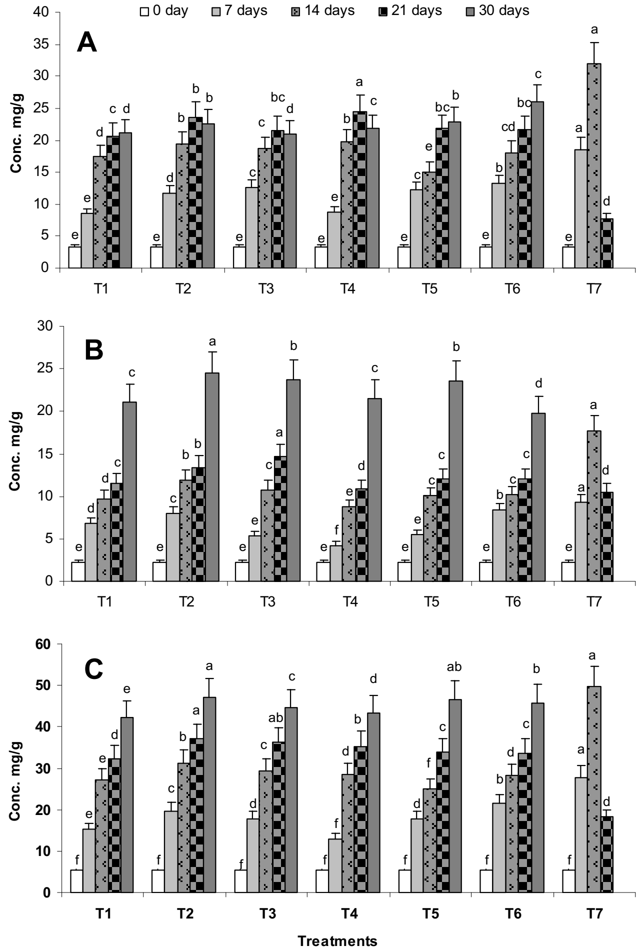

Fig. 3 Effect of edible coatings on content of (**A**) reducing sugars, (**B**) non-reducing sugars, and (**C**) total sugars in tomatoes during storage at 25 ± 5°C. Vertical bars represent ± SE of means for three replicates. T1 = carrageenan 0.5%, T2 = carrageenan 0.3%, T3 = carrageenan 0.3% + cinnamon oil 0.25%, T4 = CMC 1%, T5 = CMC 0.5%, T6 = CMC 0.5% + cinnamon oil 0.25%, T7 = control (treated with water).

Effect on pigments

During ripening, the color of the tomatoes basically changes from green to red due to the loss of chlorophyll and synthesis of carotenoids. In the present study, photosynthetic pigments were retained more in coated fruit than in control fruit (**Fig. 4A**). After 21 days of storage the amount of chlorophyll *a* and *b* were higher in the fruit treated with CMC 1% (3.80, 3.13 μg/g) and carrageenan 0.5% (3.60, 2.11 μg/g) than control fruit. At the end of the storage period of 21 days, chlorophyll pigments were not detected in the control fruit due to complete degradation, while in the treated fruit these pigments were still retained.

Likewise, less carotenoids and lycopene were found in the CMC- and carrageenan-coated tomato fruit than in control fruit (**Fig. 4B, 4C**). The higher level of these pigments indicates a higher rate of ripening in the fruit which could be observed more in the control fruit than in the treated fruit. During the 21 days of storage the lowest lycopene value was found in tomatoes treated with T1 (36.92 μg/g) and T4 (36.51 μg/g) and in the control fruits this value was highest i.e. 60.30 μg/g. CMC and carrageenan also efficiently slowed down the accumulation of lycopene in tomato fruit during storage. Carotene pigments were found to be highest in the control fruits on the 14th day of storage but declined as the storage period advanced. Plotto *et al.* (2007) investigated polysaccharide-based edible coatings, which efficiently helped to modify the internal atmosphere of banana and lichi, and strongly delayed color changes. Zapata *et al.* (2008) also noticed the delay of red color formation of coated tomatoes to be related to the modification of the

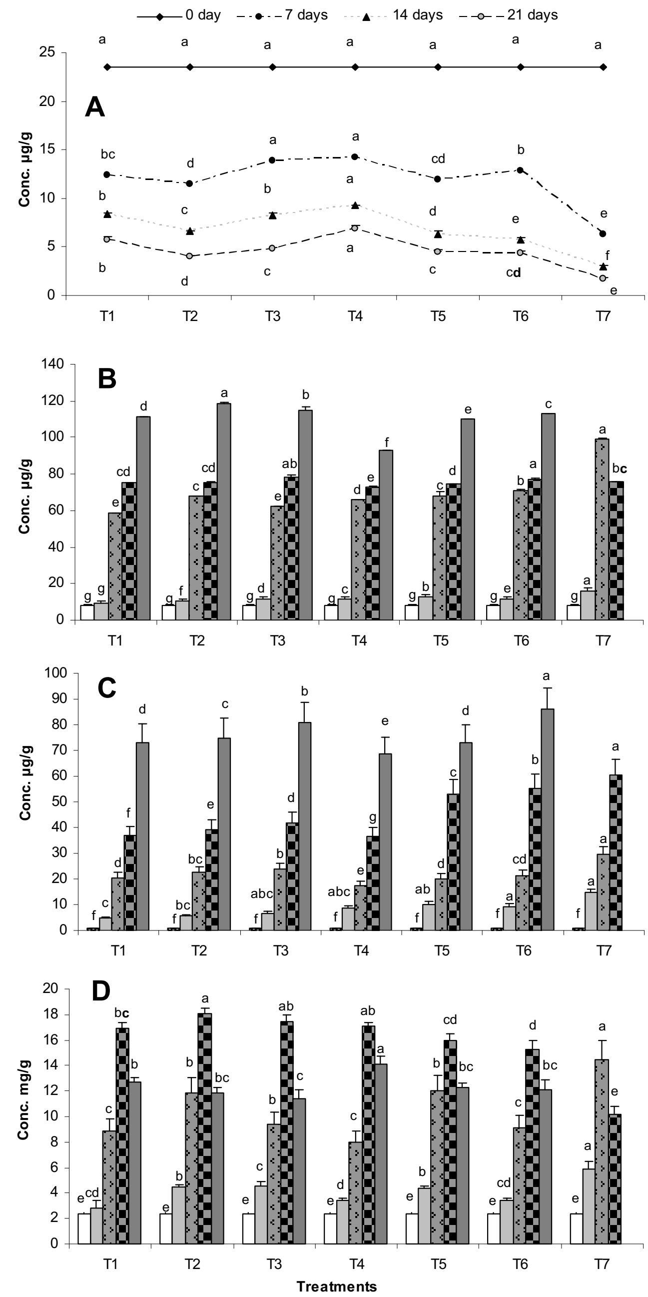

Fig. 4 Effect of edible coatings on (**A**) total chlorophylls, (**B**) carotenoids, (**C**) lycopene and (**D**) ascorbic acid in tomatoes during storage at 25 ± 5°C. Vertical bars represent ± SE of means for three replicates. T1 = carrageenan 0.5%, T2 = carrageenan 0.3%, T3 = carrageenan 0.3% + cinnamon oil 0.25%, T4 = CMC 1%, T5 = CMC 0.5%, T6 = CMC 0.5% + cinnamon oil 0.25%, T7 = control (treated with water).

internal atmosphere of the fruit, causing production of high CO_2 and low O_2, which affect the maturation process.

Effect on ascorbic acid

In the present study, the level of ascorbic acid gradually dropped due to degradation during the storage period (**Fig. 4D**). Fuke and Matsuoka (1983) found that the total ascorbic acid content decreased with fruit enlargement. Postharvest application of carrageenan and CMC and their combinations could help to maintain the level of ascorbic acid throughout the storage period. During the 21 days of storage the value of ascorbic acid was highest in fruits treated with carrageenan 0.3% (18.2 mg/g) among all treatments while in control fruits the content of ascorbic acid was 14.48 mg/g at 14 days and then declined to 10.15 mg/g after 21 days of storage. At the end of storage the highest retention of ascorbic acid i.e., 12.69 mg/g was detected in tomatoes treated with CMC + cinnamon oil. Jayaprakasha *et al.* (2007) noted that cinnamon is a good source of antioxidant and antimutagenic phenolics. The results of the present study are in accordance with the observations of Summu and Bayindirli (1994) that coating reduces fruit respiration and retains the ascorbic acid in fruit. Ayranci and Tunc (2003) also found that a methyl cellulose-based edible coating reduced the loss of vitamin C of both mushroom and cauliflower.

CONCLUSION

In the present study, the application of edible coatings like carrageenan and CMC combined with cinnamon oil on tomato fruit effectively extended the shelf life of tomato fruit by upholding and improving its nutritional quality. Carrageenan and CMC could postpone the ripening and senescence of fruit by lowering the pH and TSS, and also by enhancing the TA of the fruit. Likewise, polysaccharide-based edible coatings maintained the firmness of tomato fruit during the storage period. Carrageenan and CMC can decelerate the accumulation of reducing sugar and non-reducing sugar by preventing the degradation of starch and sucrose. A combination of cinnamon oil with the edible coatings tested helped to retain antioxidant compounds such as ascorbic acid during postharvest storage. The presently evaluated edible coatings potentially delay the degradation of chlorophyll pigments and synthesis of anthocyanins, lycopene and carotenes.

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