Future Foods 5 (2022) 100116

Contents lists available at ScienceDirect

Future Foods

journal homepage: www.elsevier.com/locate/fufo

Effect of α-dl tocopherol acetate (antioxidant) enriched edible coating on the physicochemical, functional properties and shelf life of minimally processed carrots (*Daucus carota* subsp. *sativus*)

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ARTICLE INFO

Keywords:
Antioxidant
Edible coating
Minimally processed carrots
Physicochemical properties
Functional properties
Shelf life extension

ABSTRACT

The present study was carried out to investigate the effect of varying sodium alginate-based edible coating (1, 2, and 3 %, w/v) supplemented with α- tocopherol acetate (antioxidant) at different concentrations (0.5 and 1 % w/v) on minimally processed carrot slices during 15 d storage at 10 °C and 65 % relative humidity. Seven different formulations (T_1- T_7) comprising different alginate and antioxidant combination were tested for selecting the best formulation maintaining the physicochemical attributes, antioxidant potential, carotenoid content, and overall acceptability (microbial counts) of carrot slices. Treatment T_4 (2% sodium alginate + 1% α-tocopherol acetate) served as the best formulation in maintaining the quality, acceptability, nutritive value of minimally processed carrots. The T_4 treated carrot samples showed minimum variation in weight loss, TSS, pH, whiteness index, reducing sugar, ascorbic acid content, TPC, antioxidant activity, total carotenoids, total aerobic bacterial count and yeast and mold counts, respectively in comparison to other treatments during storage. The statistical analysis also confirmed the significant ($p<0.05$) variation in physicochemical properties, antioxidant potential, carotenoid content and microbial count in control samples than edible coating formulations during storage.

1. Introduction

Carrot (*Daucus carrota* subsp.*sativus*) is a root vegetable, usually orange in color, though purple-black, red, white and yellow cultivars exist. It is a domesticated form of wild carrot *D. carrota*, native to Europe and southwestern Asia. It is one of the most popular consumed vegetables and is in demand throughout the year. Its roots contain high quantities of α- and β-carotene and are a good source of vitamin K, vitamin B6, phenolic compounds (Alasalvar et al. 2001). Consumption of carrots helps in lowering cholesterol, risk of heart attacks, anticancer effects, reduces signs of premature aging. It is also enriched in phenols like chlorogenic, hydroxyl cinnamic acids (caffeic acid, coumaric acid, ferulic acid), and anthocyanins (da Silva Dias, 2014). In todays' era, minimally processed produce, for example, fresh cuts fruits and vegetables are in more demand than whole produce due to an increase in health consciousness and purchasing power of the consumers (Condurso et al. 2020). But the maintenance of the quality of fresh produce is still a major challenge for the food industry. To maintain and preserve its fresh quality for a longer duration there is a need to develop preservation technologies such as edible coating, refrigeration and plastic packaging with an idea to effectively enhance the shelf life and preserve the nutritional and physicochemical attributes of fresh-cut produce (Cha and Chinnan 2004; Vu et al. 2011). Certain processing measures, such as removing the skin from the surface or altering the size of fruits and vegetables lead to nutrients loss, accelerated enzymatic reactions, rapid microbial growth, color change, texture change and weight losses, resulting in quality deterioration of the product. Preservation strategies based on low-temperature storage, controlled and modified atmosphere packaging and edible coatings have been previously used to extend the shelf life of fresh produce (Parreidt et al. 2018). Edible coatings based on alginate, chitosan, and other biopolymers have advantages, as they act as moisture and gas barriers to control the microbial growth, preserve the color, texture and also enhanced the shelf life of the product (Nísperos-Carriedo et al. 1992; Petriccione et al. 2015). Alginate based edible coatings possess good film-forming properties and minimizes weight loss, maintain firmness and extend the shelf life of fruits and vegetables (Amanatidou et al. 2000; Senturk Parreidt et al. 2018; Sarker and Grift, 2021). Alginate and gellan based coating acts as a texture enhancer and maintains the initial firmness of fruits during refrigerated storage (Rojas-Grauet al., 2007a, 2007b and Tapia et al. 2008). The problems associated with the minimally processed carrots include

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https://doi.org/10.1016/j.fufo.2022.100116
Received 6 March 2021; Received in revised form 8 January 2022; Accepted 17 January 2022

the formation of whitish coloration, dried appearance on the surface of peeled carrots and quality deterioration, carotene loss and development of bitter flavor (Avena-Bustillos et al. 1994). The addition of active ingredients such as antioxidants to these films and coatings enhance their functional properties and make them potentially applicable in food preservation (Sánchez-Gonzálezet al. 2011). The addition of ingredients like candelilla wax emulsion in CMC (carboxy-methyl cellulose) coated minimally processed carrots improved water vapour resistance and decreased the activity of polyphenol oxidase. The treatment did not alter the total phenolic content, and texture of the minimally processed carrots (Kowalczyk et al. 2020). It has been proven fact that functional ingredients like antioxidants, antimicrobials, nutraceuticals and probiotics enhance the quality, stability and safety of the fruits and vegetables (Galus et al. 2020; Maringgal et al. 2020). Xanthan gum edible film added with α-tocopherol increased the content of Vitamin E and calcium in the baby carrots and sensory properties and level of β-carotene (Tahir et al. 2019). Fat-soluble natural antioxidant (dl-α-tocopherol acetate) has been used to prevent the loss of β- carotene, enhance the antioxidant properties and improve the functional quality of sliced produce and thus extending its shelf life (Tahir et al. 2019).

Several reports are available on the development of antioxidant enriched edible coating for prolonged shelf life of cut fruits and vegetables ((Nísperos-Carriedo, et al, 1992; Mastromatteo et al, 2011; Sánchez-González et al, 2011; Lago-Vanzela et al, 2014; Ullah et al, 2017; Tahir et al. 2019; Kowalczyk et al, 2020). In view of the growing importance of utilization of cut fresh fruits in our day-to-day foods, the objective of the present research was to evaluate the effect of antioxidant-enriched edible coating on the shelf life and nutritional quality retention of minimally processed carrots. The developed technology can be scale up and efficiently utilized in shelf life extension of other minimally processed fruits and vegetables at commercial level.

2. Materials and methods

2.1. Materials

Fresh carrots (*D. carota* subsp. *sativus*) used for this study were purchased from Agricultural Market Sundarpur, Varanasi, India. Different chemicals and analytical reagents such as sodium alginate (Molecular weight: 216.12, 99.9 % Pure), dl-α-tocopherol acetate (Molecular weight: 472.74), calcium chloride and glycerol were purchased from Himedia, Mumbai, India. LDPE (low-density polyethylene) (Thickness: 150 gauge with dimension 18 × 30 cm) pouches used for the packaging of the control and treated sliced carrots were supplied by IIP (Indian Institute of Packaging, New Delhi).

2.2. Minimally processed carrots

The carrots were procured from the local market and carried to the laboratory for analysis. The sorted carrots were first washed with tap water followed by peeling and slicing giving each slice of 2-3 mm thickness having an average diameter of about 3 cm using a sharp stainless steel vegetable cutter (Philips HR7627/00, Philips India Limited, Kolkata, West Bengal, India). Further, the sliced carrots were treated with 50 ppm sodium hypochlorite solution for 20 minutes for surface disinfection. The sliced carrots were distributed into two groups i.e. control (without coating material) and with edible coating.

2.3. Preparation of coating solution

Seven different edible coating treatments were developed by dissolving sodium alginate (SA) solution with varying amounts of dl-α-tocopherol acetate as an antioxidant. For the edible coating, sodium alginate (SA) (1%, 2 %, 3 % w/v) powder was dissolved in distilled water in a stainless steel vessel and stirringgently with a glass rod under controlled heating condition using water bath at 70°C for 10 min, until the powder was dissolved as previously reported (Rojas-Grau et al. 2007a, 2007b). After cooling, glycerol (20 % of sodium alginate solids) was added as a plasticizer (Valero et al. 2013). Then,-dl α-tocopherol acetate was added at two different concentrations (0.5 and 1%, w/v) as an antioxidant. Calcium chloride was added at the rate of 2 % w/v in the coating solution to provide firmness. The final coating solution was ready with seven different combinations which are; T_1 (uncoated sample or control), T_2 (1% SA + 0.5 % Antioxidant), T_3 (1% SA + 1% Antioxidant), T_4 (2% SA + 0.5% Antioxidant), T_5 (2% SA+ 1% Antioxidant), T_6 (3% SA + 0.5% Antioxidant), T_7 (3% SA + 1% Antioxidant).After preparing the coating solution, the sliced carrots were dipped in the different coating solutions for 5 min and then the coated sliced carrots were air-dried for 20 min on a flat surface followed by packaging of 120 g of carrots in LDPE pouches having 150 gauge thickness with dimension 18 × 30 cm. Similarly, the control samples were dipped in distilled water for the same period as coating treatment and air-dried followed by packaging. Both the coated and uncoated (control) samples were stored at 10±2°C and 65 % Relative Humidity (% RH) for 15 d.

2.4. Physicochemical, antioxidants, carotenoids, firmness and microbial analysis of sliced carrots

The physicochemical attributes, antioxidants and carotenoid content of all the samples were measured on regular time intervals i.e., 0, 5, 10 and 15 d, respectively. Similarly, microbial analysis was done on 0, 7 and 15d, respectively.

2.4.1. Physicochemical analysis

2.4.1.1. Weight loss. All the packages of control and coated sliced carrots were weighed initially before packaging and kept at 10°C. The carrot samples were weighed at every 5 d intervals for up to 15 d. Weight loss percentage was calculated as sample weight before packing minus sample weight after storage temperature at 10°C and multiplied with 100 to get the percentage loss value. Measurements were carried up by taking 10.0 g carrot samples from each treatment for 15 d at every 5 d interval.

% Moisture loss= (initial weight – final weight/initial weight) × 100

2.4.1.2. Total soluble solids (TSS), pH, reducing sugar, total sugar and Ascorbic acid estimation. For determination of Physiochemical properties, 0.5 g sample was homogenized in 50 mL distilled water, filtered and then used for analytical study. The TSS content of the samples (1.0 mL extracted sample) was determined using the refractometer (Digital Abbe refractometers CAR-02, Contech Instruments Ltd. India) as per the method of AOAC (1994). Similarly, 10 mL of carrot juice was used for pH measurement using a calibrated glass electrode pH meter (Orion 2 Star, Thermo Scientific, USA). The reducing sugar was determined by DNS method (Miller, 1959) by using 10.0 mL of homogenised carrot juice. The total sugar was determined the Lane-Eynon method by using 10.0 mL of homogenised carrot juice and expressed as % (AOAC, 1970). 5.0 g of extracted juice samples were used for ascorbic acid estimation by DCPIP method (AOAC, 1994).

2.4.1.3. Color measurement. For determination of whiteness index, L^* a^* and b^* values were determined by colorimeter (Jenway colorimetrer 6051, Cole-Parmer India Pvt. Ltd., Mumbai, India), where L^* indicates lightness (0 to 100) with 0 being black and 100 being white. The coordinate a^* is for red (+) and green (-), and b^* is for yellow (+) and blue (-) (Lago-Vanzela et al. 2014). From the obtained L, a, b values, the whiteness index can be calculated. Whiteness index is in the range of 0 to 100, which is expressed as (Bolin and Huxsoll, 1991): $WI= 100-[(100-L)^2 + a^2 + b^2]^{0.5}$

The numerical scale of WI is from 0 to 100, where higher WI values represent more severe white surface coloration.

2.4.2. Antioxidant analysis

2.4.2.1. DPPH radical scavenging method. One mL of extracted juice of carrots was taken and diluted 10 times with distilled water. Determination of the antioxidant activity of the sample was done by DPPH inhibition method (Nagatsu et al. 2000). The 2, 2-diphenyl-1-picrylhydrazyl radical (DPPH) assay was carried out using a spectrophotometer (Shimadzu UV Spectrophotometer UV-1800, Cole-Parmer India).

2.4.2.2. TEAC assay. The procedure described by Ferruzzi et al. 1998 was used for the extraction of antioxidants. The antioxidant activities of the extracts were determined by applying the ABTS radical cation decolorization assay (Heinonen, 1990). All determinations were carried out in triplicate and the results were expressed in equivalents of μmol Trolox Equivalent/100 g (μmol TE/100 g).

2.4.2.3. Total phenolic content. The total phenolic content (TPC) was determined by the Folin-Ciocalteau method (Kaur and Kapoor, 2002; Singleton and Rossi, 1965). For TPC, 2 g samples were homogenized in 15 mL of 80 % v/v aqueous ethanol at room temperature and centrifuged in cold condition at 10,000 rpm for 15 minutes at 4°C and the supernatant was extracted. The residue obtained was re-extracted twice and the supernatant was poured into Petri dishes and evaporate to dryness at room temperature. The residue was dissolved in 5 mL of distilled water. 100 μL of this extract was diluted to 3 mL of water and 0.02 mL of Folin-Ciocalteau reagent was added. After 3 minutes, 2 mL of 20% sodium carbonate was added and contents were mixed thoroughly and blue color was developed. The absorbance was measured at 725 nm in UV-Spectrophotometer (UH 4150, Hitachi High Technology, India) using gallic acid as a standard. The results were expressed as mg gallic acid/ 100 g fresh material.

2.4.3. Carotenoid content and provitamin A activity

The estimation of β-carotene, α-carotene and total carotenoids was done by HPLC analysis following previous protocol (Ferruzzi et al. 1998). The carotenoids were separated on a Zorbax ODS column (5 μm, 250 × 4.6 mm i.d.) (Agilent Technologies, Santa Clara, CA, USA) proceeded by a Zorbax ODS column (5 μm, 12.5 × 4.6 mm i.d.) at ambient temperature by using the method described by Heinonen 1990. The HPLC was equipped with a Waters 510 pump (Millipore Co., Milford, MA, USA) and a Waters 486 UV-VIS detector (Millipore Co.) at 450 nm. The isocratic mobile phase of acetonitrile, dichloromethane, methanol, 70:20:10 v/v/v was used at a flow rate of 1 mL/min. The sample size was 20 μL. The carotenoids were identified by comparing retention times with those of sample standards. Provitamin A activity was calculated as retinol activity equivalents (RAE) using 6 μg per RAE for all-trans β-carotene and 12 μg per RAE for all-trans α-carotene [retinol activity equivalent (μg 100 g−1)=(μg β-karoten/12) + (μg α-karoten/24)].

2.4.4. Firmness

For the analysis of the firmness of the carrot samples, samples were cut into 2 × 2 square cm slices. The firmness of each sliced sample was determined with a Texture Analyzer (TA-XT, Stable Micro Systems, UK) by measuring the force required for a 1 mm probe to puncture and penetrate 5 mm into the slice. The firmness measurement (puncture) was carried out using a cylindrical stainless steel probe of 1mm in diameter. The speed of the probe was set to 1 $mm^{*}s^{-1}$. Puncture tests were carried out on rectangular samples (20 × 20 mm) taken from the two opposite equatorial sides of the same fruit as per the previous protocol (Manolopoulou *et al.*, 2010). The firmness was determined under ambient conditions (25±0.2°C, 85 % RH) and was expressed in unit N.

2.4.5. Microbiological quality

2.4.5.1. Preparation of samples for microbial analysis. The sample preparation was done by taking 100 mg of carrot slices from all the treatments aseptically. The carrot slices were then macerated and ground in the grinder (Bajaj GX1, India) for juice extraction. 1 mL of extracted juice from each treatment was then diluted in 10 mL of normal saline. Further, serial dilution was done and seven dilutions ranging from 10^{-1} to 10^{-7} were prepared.

2.4.5.2. Media preparation and microbial count. Total plate count was used for the determination of the total bacterial count of carrot samples. PDA (Potato Dextrose Agar) was used to determine yeast and mold count. The prepared media was sterilized in an autoclave at 121°C at 15 psi for 20 min. Inoculation of the sample was done aseptically in the laminar airflow (Labtech LCB 1201V, Daihan Pvt. Lmt, India) chamber by adding 100 μL of serially diluted carrot extract samples of each treatment in Petri plates containing nutrient agar and PDA. Duplicate samples were taken for each dilution, a control of nutrient agar media was also kept without inoculation. The inoculated Petri-dishes were incubated in a BOD incubator (BOD incubator IK-120, IKON instruments, New Delhi, India) for 72 h at 25±0.2 °C. The colony count was performed after 72 h of incubation using a colony counter. The colony counts are expressed as CFU/g (A colony-forming unit (CFU) is a unit used in microbiology to estimate the number of *viable* bacteria cells in a sample). Samples were analyzed on day 0, 7, 14 and 21 and microbial count was expressed as log CFU/g.

2.5. Statistical analysis

All the experiments were performed in triplicate. The data of the analyses were pooled and averaged and the mean and standard deviation were calculated using MS-Excel software. Experiments were laid out in a Completely Randomized Design with three replications. Data on weight loss, color, pH, TSS, reducing sugar, whiteness index, antioxidant activity, total phenolic content and microbiological counts were subjected to an analysis of variance (one-way ANOVA). Differences at $p < 0.05$ were considered significant.

3. Result and discussion

3.1. Physiochemical evaluation

The data presented in Table 1, indicates that weight loss increased during storage, reaching values of 11.45 ± 0.20 % in the control sample after 15 d. The weight loss is related to an increase in water loss due to increased transpiration and respiration rate (Díaz-Mula et al. 2012). However, the interaction between the different concentrations of alginate and α-tocopherol acetate treatment on minimally sliced carrots stored at 10°C significantly ($p<0.05$) affected the variation in weight loss. It is probably related to the barrier to water vapor of the coatings (Olivas and Barbosa-Cánovas, 2008). Among coated samples, the minimum weight loss of 2.89±0.07 % was observed in T_4 after 15 d of storage (Table 1). TSS of fruits and vegetable increases due to the conversion of starch to sugar as ripening takes place. The TSS content after harvesting in control samples was 8.2 ± 0 %, increased to 12.99 ± 0.17 % after 15 d of storage. The TSS content in T_1, T_2, T_3, T_4, T_5, T_6 and T_7 samples were found to be 12.99±0.17, 11.46 ± 0.06, 11.78 ± 0.08, 10.26 ± 0.03, 10.31 ± 0.08, 10.85 ± 0.03 and 10.85 ± 0.05 %, respectively after 15 d of storage (Table 1). Treatment T4 (2% SA + 0.5% Antioxidant) showed the least increase in TSS (10.26±0.03 %) during storage. The reduction in TSS content of the coated fruits can be attributed to the slowing down of respiration and metabolic activity and thus retarding the ripening process (Rao et al., 2011). There was a significant increase ($p<0.05$) in the pH of the control samples and carrots coated with different alginate concentrations (Table 1). The treatment T_3 and T_4 showed minimum pH change during storage after harvesting in comparison to control and other coated samples.The organic acid content decreases with maturation due to the increased respiration due to its conversion into sugars

Table 1
Effect of edible coating on the physicochemical properties of sliced carrot during storage (10±0.2°C).

Physicochemical Properties	d	T1	T2	T3	T4	T5	T6	T7
% Weight loss	0	0.1±0.1 ^{ax}	0.1±0.2 ^{ax}	0.2±0.1 ^{ax}	0.2±0.2 ^{ax}	0.1±0.2 ^{ax}	0.1±0.03 ^{ax}	0.2±0 ^{ax}
	5	1.01±0.03^{by}	0.5±0.03 ^{ax}	0.51±0.03^{bx}	0.25±0.02^{bx}	0.26±0.01^{dz}	0.33±0.03^{by}	0.32±0.02^{by}
	10	3.77±0.12^{cz}	2.12±0.02 ^{by}	2.18±0.04^{cy}	1.66±0.11^{dz}	1.24±0.07^{bz}	1.65±0.04^{cz}	1.56±0.01^{cw}
	15	7.88±0.14^{cz}	5.8±0.06^{cz}	5.29±0.02 ^{dx}	2.89±0.07^{az}	3.55±0.06^{cx}	4±0.01^{dw}	3.21±0.1^{dz}
TSS	0	8.2±0 ^{ax}	8.2±0 ^{ax}	8.2±0 ^{ax}	8.2±0 ^{ax}	8.2±0 ^{ax}	8.2±0 ^{ax}	8.2±0 ^{ax}
	5	9.93±0.05 ^{ax}	9.31±0.12 ^{ax}	9.22±0.18^{bx}	8.8±0.1 ^{ay}	9.01±0.04^{bx}	9.08±0.04 ^{ax}	9.08±0.13 ^{ax}
	10	11.3±0.29 ^{ax}	10.39±0.08 ^{by}	10.52±0.1^{cz}	9.63±0.1^{bx}	9.42±0.09 ^{ay}	9.94±0.05 ^{ax}	9.94±0.05 ^{ax}
	15	12.99±0.17 ^{ax}	11.46±0.06^{cz}	11.78±0.08 ^{dx}	10.26±0.03 ^{dx}	10.31±0.03^{az}	10.85±0.03 ^{ax}	10.85±0.05 ^{ax}
pH	0	6.52±0 ^{ax}	6.52±0 ^{ax}	6.52±0 ^{ax}	6.52±0 ^{ax}	6.52±0 ^{ax}	6.52±0 ^{ax}	6.52±0 ^{ax}
	5	6.87±0.02 ^{ay}	6.77±0.01^{bx}	6.77±0.02 ^{cy}	6.63±0.01^{bw}	6.65±0.02^{az}	6.69±0.01^{az}	6.71±0.01 ^{ay}
	10	7.14±0.005^{az}	6.95±0.03 ^{cx}	6.94±0.03 ^{by}	6.75±0.02 ^{cx}	6.76±0.02 ^{cy}	6.82±0.02 ^{aw}	6.81±0.02^{az}
	15	7.34±0.02^{cw}	7.15±0.02 ^{dx}	7.12±0.005^{az}	6.85±0.01 ^{dx}	6.88±0.01^{bz}	6.97±0.02^{bw}	6.93±0.01 ^{ax}
Whiteness Index	0	36±0 ^{ax}	36±0 ^{ax}	36±0 ^{ax}	36±0 ^{ax}	36±0 ^{ax}	36±0 ^{ax}	36±0 ^{ax}
	5	38.2±0.09^{az}	34.9±0.06 ^{ax}	34.7±0.06 ^{ax}	34.2±0.04 ^{cy}	33.5±0.1^{az}	35.8±0.06^{bx}	35.3±0.1 ^{aw}
	10	42.5±0.05 ^{ay}	37.8±0.07^{bx}	37.1±0.07^{bw}	35.7±0.05^{bw}	34.5±0.03 ^{ay}	36.7±0.13 ^{ay}	36.1±0.1^{bw}
	15	45.6±0.06^{cw}	38.7±0.07 ^{cx}	38.2±0.04^{cw}	36.2±0.02^{dw}	36.9±0.03 ^{ay}	37.8±0.04^{az}	37.3±0.03^{dz}
Reducing sugar (%)	0	4.02±0 ^{ax}	4.02±0 ^{ax}	4.02±0 ^{ax}	4.02±0 ^{ax}	4.02±0 ^{ax}	4.02±0 ^{ax}	4.02±0 ^{ax}
	5	5.3±0.1^{by}	5.19±0.05 ^{by}	5.12±0.07^{by}	4.79±0.07 ^{by}	4.64±0.05^{cz}	5.05±0.03 ^{by}	4.98±0.03 ^{by}
	10	6.48±0.07^{dw}	6.34±0.08^{cw}	6.29±0.06^{cw}	5.78±0.05^{az}	5.96±0.07^{bx}	6.19±0.08^{cw}	6.08±0.1^{cz}
	15	7.84±0.06^{cz}	7.54±0.02^{dw}	7.47±±0.07^{dz}	6.77±0.04 ^{cy}	6.62±0.25 ^{cy}	7.24±0.005 ^{aw}	7.12±0.1^{dz}
Total Sugar (%)	0	6.85±0.05 ^{ax}	6.85±0.01 ^{ax}	6.85±0.005 ^{ax}	6.85±0.05^{bz}	6.85±0.005 ^{aw}	6.85±0.01^{bx}	6.85±0.01 ^{ax}
	5	8.19±0.02^{bw}	7.12±0.04 ^{by}	7.39±0.00 ^{ay}	7.19±0.002^{dz}	7.34±0.005^{dw}	7.58±0.02^{cz}	7.67±0.8 ^{ax}
	10	9.34±0.01^{cw}	8.34±0.005 ^{cx}	8.56±0.05^{az}	8.01±0.01^{bx}	8.45±0.8^{dw}	8.62±0.05 ^{ax}	8.7±0.5 ^{ax}
	15	12.12±1.0^{dz}	10.78±0.8^{az}	10.85±0.05^{bw}	9.45±0.35^{dz}	9.88±0.5 ^{ax}	10.11±0.7 ^{ax}	10.25±0.6 ^{ax}
Ascorbic acid (mg/100 g carrot)	0	5.70±0.03 ^{ax}	5.70±0.03 ^{ax}	5.70±0.03 ^{ax}	5.70±0.03 ^{ax}	5.70±0.03 ^{ax}	5.70±0.03 ^{ax}	5.70±0.03 ^{ax}
	5	4.70±0.05 ^{ax}	5.10±0.07 ^{ax}	5.39±0.07 ^{ax}	5.50±0.05 ^{ax}	5.30±0.03 ^{ax}	5.38±0.03 ^{ax}	5.42±0.1 ^{ax}
	10	3.78±0.08 ^{ax}	4.56±0.06 ^{ax}	4.96±0.07 ^{ax}	5.20±0.05 ^{ax}	4.79±0.08 ^{ax}	4.88±0.1 ^{ax}	4.98±0.07 ^{ax}
	15	2.50±0.02 ^{ax}	4.2±0.07 ^{ax}	4.34±0.04 ^{ax}	4.98±0.25 ^{ax}	4.10±0.005 ^{ax}	4.19±0.1 ^{ax}	4.20±0.06 ^{ax}

First superscript letter (a-d) shows the significant difference ($p<0.05$) among a particular row, second superscript letter (w-z) shows the significant difference ($p<0.05$) among a particular column for a specific attribute.

(Chitarra and Chitarra, 2005). Maftoonazad et al. (2008) also reported a rapid pH increase in control samples in comparison to peaches coated with SA and methylcellulose. The reducing sugar content significantly ($p<0.05$) was affected by different concentrations of edible coating at 10°C storage. The initial reducing sugar content of 4.02±0 % increased in all seven treatments during storage. However, the minimum increase in reducing sugar was found to be 6.62 ± 0.25 % in the treatment T_4 and the maximum increase was observed in the treatment T_1 i.e 7.54 ±0.02 % closes to control samples (Table 1). The reducing sugar content increased during storage due to the enhanced conversion of starch to sugar. A similar trend in increment in total sugar content was observed in the current investigation. This is in conformity with previous findings of Ullah et al. (2017) in bell pepper fruit during 24 d of storage. The initial ascorbic acid content of 5.70±0.03 (mg/100g) decreased to 2.50±0.02 (mg/100g) during 15 d storage at 10°C in control samples (Table 1). However, maximum ascorbic acid retention was observed in T_4 and T_7 samples. Ascorbic acid retention is maximum in T_4 and T_7 samples due to the high antioxidant level (1 % dl-α-tocopherol acetate) in the edible coating matrix.

The whiteness index (WI) indicates the development of white surface discoloration. It was observed that minimally processed carrots hadsignificantly lower WI scores than controls (Table 1). The WI of the control sample increased from 36.00 ± 0 to 45.60 ± 0.06 during storage. However, in treated samples, the WI increased slowly and minimum variation was observed in T_4 samples. This may be due to the synergistic effect of alginate and tocopherol in retarding the white discoloration by limiting the surface moisture loss (Cisneros-Zevallos et al. 1997). The coating retarded surface dehydration, which is the main cause of white blush formation (Emmambux et al., 2003). Mei et al. 2002 also showed similar results in xanthan gum-coated baby carrots.

3.2. Antioxidant potential

Orange-colored carrots are a good source of β-carotene content as compared to other varieties of carrots. The initial DPPH inhibition activity of 20.14 ± 0 % changed to 13.70 ± 0.08 % in control (T_1) during storage. The DPPH inhibition activity of 27.50 ± 1.7 % in carrot was previously reported (Chatatikun and Chiabchalard, 2013). The antioxidant activity of coated sample showed a significant ($p<0.05$) increase till the fifth day of storage followed by reduced DPPH inhibition activity (Table 2). T_2, T_4 and T_6 samples containing 1% α-tocopherol acetate, showed maximum retention in antioxidant capacity in comparison to treatments containing 0.5 % α-tocopherol acetate. This suggests that higher antioxidant containing edible coated samples showed better antioxidant potential which is similar to previous findings (Díaz-Mula et al. 2012). The initial TEAC value of 47.50 ± 0.35 µmol TE/100 g in control samples decreased to 12.98 ± 0.30 µmol TE/100 g during storage. The maximum TEAC activity of 30.67 ± 0.35 and 28.98 ± 0.005 µmol TE/100 g was found in T_4 and T_3, respectively under the similar condition which was higher than other treated samples. The uncoated (control) and coated sliced carrots showed a significant ($p<0.05$) difference in TPC content during storage at 10°C. After 15 d of storage, control samples showed a decrease in TPC content ranging from 46.75 ± 0 to 4.70 ± 0.17 mg/ 100 g of gallic acid equivalent (gaE) as compared to treated samples. Among different treatments, T4 and T2 showed maximum TPC of 18.25 ± 0.10 and 11.75 ± 0.08, respectively. This may be attributed to the fact that the antioxidant-enriched edible coating produced abiotic stress on tissue plants, modifying their metabolism and affecting the production of secondary metabolites such as phenolic. Robles-Sánchez et al. (2013) reported decreased TPC during 12 d storage in alginate-coated fresh-cut Kent mangoes. The initial provitamin A activity of 620.00 ± 0.05 µg RAE/100g in carrot slices reduced to 498.00 ± 0.05, 450.00 ± 0.05 and 435.00 ± 0.05 µg RAE/100g in T_4, T_2 and T_6, respectively. The minimum decrease in provitamin A activity in T_4 may be attributed to the shielding effect imparted by 1 % antioxidant. The T_4 stored samples can contribute 80-85 % of provitamin A requirement in adults, as the RDA value of vitamin A as Retinol in adults (Normal Indian Men and Women) is 600 µg per day (FSSAI, 2020). Recommended Dietary Allowances (RDA) are the levels of intake of the essential nutrients that are judged to be adequate or sufficient to meet

Table 2
Effect of edible coating on the antioxidant and total phenolic content (TPC) of sliced carrots during storage (10±0.2°C).

Antioxidant properties	d	T1	T2	T3	T4	T5	T6	T7
% DPPH inhibition	0	20.14±0 ^{ax}	20.14±0 ^{ax}	20.14±0 ^{ax}	20.14±0 ^{ax}	20.14±0 ^{ax}	20.14±0 ^{ax}	20.14±0 ^{ax}
	5	23.62±0.07 ^{by}	26.02±0.07 ^{ay}	24.56±0.03^{by}	26.6±0.1^{bx}	25.02±0.04^{by}	26.8±0.05^{cx}	19.5±0.05^{by}
	10	21.02±0.08 ^{by}	22.3±0.03 ^{by}	23.2±0.05^{cy}	22.8±0.06 ^{ax}	22.7±0.06^{cx}	23.9±0.02 ^{ax}	16.4±0.05^{cx}
	15	18.3±0.06 ^{cx}	19.3±0.05^{bz}	17.8±0.04^{ax}	19.9±0.04 ^{ax}	17.4±0.13^{dx}	20.5±0.04^{az}	13.7±0.08^{cx}
TPC (%)	0	46.75±0 ^{ax}	46.75±0 ^{ax}	46.75±0 ^{ax}	46.75±0 ^{ax}	46.75±0 ^{ax}	46.75±0 ^{ax}	46.75±0 ^{ax}
	5	31.25±0.6^{bz}	22±0.02 ^{by}	25.25±0.27^{bx}	36.5±0.02^{bz}	22.75±0.13^{cx}	21.5±0.16^{bx}	21±0.08^{dw}
	10	23.75±0.35^{cz}	21.75±0.84^{cy}	24.5±0.21^{bz}	31±0.28^{bx}	16.75±0.16^{aw}	19.25±0.05 ^{ax}	20.5±0.10^{cx}
	15	9±0.19 ^{ay}	11.75±0.08^{dz}	7.75±0.07^{cx}	18.25±0.10^{cz}	6.75±0.05^{cw}	9.5±0.12^{dw}	4.7±0.17^{cyx}
Provitamin A activity (µg RAE/100g)	0	620±0.05 ^{ax}	620±0.05 ^{ax}	620±0.05 ^{ax}	620±0.05 ^{ax}	620±0.05 ^{ax}	620±0.05^{ax}	620±0.05 ^{ax}
	5	510±0.5^{bx}	570±0.01^{by}	590±0.05^{bx}	600±0.01^{bx}	565±0.25^{dx}	567±0.05 ^{ax}	570±0.01^{aw}
	10	400±0.05 ^{cy}	500±0.05^{cx}	550±0.0^{dx}	588±0.05^{cw}	510±0.15^{aw}	520±0.5^{dx}	534±0.001^{bx}
	15	280±0.01 ^{cy}	450±0.05^{cx}	398±0.01 ^{ax}	498±0.05^{aw}	400±0.15^{aw}	435±0.05^{aw}	402±0.05^{cz}
Antioxidant activity (µmol TE/100 g FW)	0	47.5±0.35 ^{ax}	47.5±0.35 ^{cy}	47.5±0.35^{cx}	47.5±0.35 ^{ax}	47.5±0.35 ^{ax}	47.5±0.35 ^{ax}	47.5±0.35^{bw}
	5	32.64±0.05^{dy}	37.4±0.30^{dz}	38.2±0.1^{by}	40.56±0.1^{dw}	38.9±0.4^{cx}	37.9±0.0 ^{ax}	36.78±0.09 ^{ax}
	10	20.98±0.05^{dy}	30.65±0.5^{dx}	31.98±0.5^{cx}	34.76±0.5^{dx}	32.67±0.8 ^{ax}	31.5±0.005^{dw}	30.87±0.08^{az}
	15	12.98±0.3 ^{cx}	20.56±0.5 ^{ax}	23.89±0.05^{dz}	30.67±0.35^{cz}	28.9±0.005^{dw}	23.89±0.1 ^{ax}	22.68±0.01^{ay}

First superscript letter (a-d) shows the significant difference ($p<0.05$) among a particular row, second superscript letter (w-z) shows the significant difference ($p<0.05$) among a particular column for a specific attribute

Table 3
Effect of edible coatings on the carotenoid content of sliced carrots during storage (10±0.2 °C)

Carotenoids	d	T1	T2	T3	T4	T5	T6	T7
β-carotene (mg/100 g)	0	6.25±0 ^{ax}	6.25±0 ^{ax}	6.25±0 ^{ax}	6.25±0 ^{ax}	6.25±0 ^{ax}	6.25±0 ^{ax}	6.25±0 ^{ax}
	5	23.62±0.07^{az}	26.02±0.07^{ax}	24.56±0.03^{by}	26.6±0.1^{cw}	25.02±0.04 ^{ax}	26.8±0.05 ^{ay}	19.5±0.05^{az}
	10	21.02±0.08^{dy}	22.3±0.03^{bz}	23.2±0.05^{cz}	22.8±0.06^{cw}	22.7±0.06 ^{ax}	23.9±0.02 ^{cx}	16.4±0.05^{cz}
	15	2.95±0.06 ^{cx}	4.88±0.05^{dz}	5.2±0.04^{dw}	5.9±0.04 ^{ax}	5.4±0.13^{dz}	5.3±0.04 ^{by}	5.28±0.08 ^{aw}
α-carotene (mg/100 g)	0	2.75±0 ^{ax}	2.75±0 ^{ax}	2.75±0 ^{ax}	2.75±0 ^{ax}	2.75±0 ^{ax}	2.75±0 ^{ax}	2.75±0 ^{ax}
	5	2.10±0.4^{az}	2.45±0.5 ^{ay}	2.55±0001^{dw}	2.65±0.02 ^{ax}	22.75±0.13 ^{ax}	21.5±0.16^{ax}	21±0.08 ^{ax}
	10	1.25±0.3 ^{cx}	2.30±0.005^{dz}	2.30±0.5 ^{cx}	2.50±0.03 ^{ax}	16.75±0.16 ^{ax}	19.25±0.05^{dz}	20.5±0.10^{by}
	15	0.75±0.001^{dw}	1.95±0.01^{dw}	2.05±0.07^{cz}	2.25±0.00^{dz}	6.75±0.05^{cz}	9.5±0.12 ^{ay}	4.7±0.17^{cw}
Total carotenoids (mg/100 g)	0	9.45±0.4 ^{ax}	9.45±0.4 ^{ax}	9.45±0.4 ^{ax}	9.45±0.4 ^{ax}	9.45±0.01 ^{ax}	9.45±0.4^{cx}	9.45±0.4^{az}
	5	7.78±0.001 ^{aw}	8.05±0.05^{bx}	8.15±0.1^{cz}	8.45±0.01 ^{ax}	8.31±0.3^{by}	8.21±0.4^{dx}	8.00±0.3^{ay}
	10	5.98±0.002 ^{by}	6.45±0.01 ^{ax}	6.65±0.45^{dx}	6.98±0.001^{az}	6.76±0.2^{cz}	6.56±0.05^{cw}	6.35±0.5^{cx}
	15	3.95±0.005^{dz}	5.00±0.001 ^{ax}	5.25±0.23 ^{ax}	5.65±0.005^{by}	5.35±0.001^{az}	5.15±0.002^{dz}	5.00±0.001^{dz}
Firmness (N)	0	180±0.005^{cx}	180±0.005 ^{ax}	180±0.005 ^{ax}	180±0.005 ^{ax}	180±0.005 ^{ax}	180±0.005 ^{ax}	180±0.005 ^{ax}
	5	150±0.05 ^{cx}	160±2 ^{ax}	160±0.08^{ay}	165±0.01^{by}	165±0.001^{bz}	160±0.01^{by}	162±0.02^{bx}
	10	120±0.05 ^{ax}	130±0.05^{cw}	135±0.005^{cz}	145±1^{aw}	140±0.005dz	135±0.01^{cx}	132±0.005 ^{ax}
	15	90±0.00^{aw}	112±0.005^{dz}	118±0.005^{dz}	128±0.005^{dz}	120±0.05^{ay}	115±0.8^{cw}	115±1^{cw}

First superscript letter (a-d) shows the significant difference ($p<0.05$) among a particular row, second superscript letter (w-z) shows the significant difference ($p<0.05$) among a particular column for a specific attribute.

the nutrient requirement of nearly all (97 to 98 %) healthy individuals in a particular life stage and gender group.

3.3. Carotenoid contents and texture

The initial α-carotene, β-carotene and total carotenoid (TC) of 2.75 ± 0, 6.25±0 and 9.45±0.4 mg/100 g in control samples (T_1) after harvest reduced to 0.75±0.00, 2.95±0.06 and 3.95±0.005 mg/100g, respectively during the storage period of 15 d at 10°C (Table 3). The α-carotene, β-carotene and TC in antioxidant-rich samples (T_4 and T_6) showed minimum reduction during storage (Table 3). This may be due to stabilizing effect of tocopherol-rich edible coatings which scavenge the reactive oxygen species (ROS) produced due to metabolic and enzyme activities of carrot during storage. The edible-coated sliced carrot samples showed better textural attributes during storage. The initial firmness of 180.00 ± 0.005 N in freshly harvested samples changed to 90.00 ±0.00 N, 128.00 ±0.005 N and 120.00 ±0.05 N in T_1, T_4 and T_5 samples, respectively during 15 d of storage (Table 3). The better firmness in T_4 and T_5 was due to increased alginate concentration which posed better barrier properties in regulating moisture loss and transpiration rate. At the end of 15 d of cold storage, T_4 samples retained nearly 71.0 % firmness in comparison to 50 % firmness in control samples. Firmness retention of 55 % in edible coated plums was reported after 35 d of cold storage (Kumar et al. 2017).

3.4. Shelf life study

3.4.1. Microbiological quality

The initial bacterial cell load of 4.48 ± 0 log CFU/g in the control samples was enhanced to 6.40 ± 0.2 log CFU/g after 15 d (Table 4). On contrary, the TBC (total bacterial count) increase was minimum in coated samples. After 15 d of storage, a minimum increase in TBC was observed in T_3 and T_4 (Table 4). Similarly, T_1 and T_2 containing low SA and AO concentrations showed higher TBC under similar conditions. The TYMC (total yeast and mold count) in the control samples increased from 5.47 ± 0 log CFU/g to 7.60 ± 0.30 log CFU/g during storage.T_4 and T_3 showed the least TYMC i.e. 6.38 ± 0.01 and 6.50 ± 0.10 log CFU/g. The T_4 sample showed a 24.11 and 16.7 % increase in TBC and TYMC in comparison to 42.85 % and 38.93 % enhancement in control samples during cold storage. Literature suggested that edible coatings with antimicrobial compounds enhances the shelf life and stability of kiwi fruit and tomatoes (Zapata et al. 2008; Mastromatteo et al. 2011)

3.5. Statistical analysis

Statistical analysis was conducted to evaluate the synergistic effect of different parameters on the coating type, from a descriptive point of view. Statistical analysis of physico-chemical parameters on treated and untreated (control) carrot samples during storage showed positive correlations between TSS and pH. However, reducing sugar, ascorbic acid

Table 4
Effect of edible coatings on the microbiological properties of sliced carrots during storage (10±0.2 °C).

Microbiological Properties	d	T1	T2	T3	T4	T5	T6	T7
Total aerobic bacteria counts (log CFU/g)	0	4.48±0 ^{ax}	4.48±0^{ax}	4.48±0 ^{ax}	4.48±0 ^{ax}	4.48±0 ^{ax}	4.48±0 ^{ax}	4.48±0 ^{ax}
	7	5.1±0.2 ^{ax}	5.02±0.1 ^{by}	4.92±0.2 ^{by}	4.71±0.3^{bx}	4.67±0.02 ^{dx}	4.89±0.3 ^{ax}	4.8±0.01 ^{dx}
	15	6.4±0.2 ^{ay}	5.93±0.2^{bz}	5.84±0.01 ^{cx}	5.56±0.01 ^{ay}	5.60±0.04 ^{dx}	5.78±0.2 ^{by}	5.71±0.1 ^{ax}
Total yeast and mold counts (log CFU/g)	0	5.47±0 ^{ax}	5.47±0 ^{ax}	5.47±0 ^{ax}	5.47±0 ^{ax}	5.47±0 ^{ax}	5.47±0 ^{ax}	5.47±0 ^{ax}
	7	6.4±0.02 ^{cx}	6.26±0.3 ^{by}	6.01±0.23^{az}	5.82±0.04 ^{cy}	5.74±0.4 ^{by}	5.93±0.2^{cx}	5.89±0.04^{bx}
	15	7.6±0.3 ^{ax}	7.03±0.12 ^{cx}	6.9±0.02^{cz}	6.38±0.01^{cz}	6.5±0.1^{dz}	6.7±0.05^{cz}	6.61±0.01^{bz}

First superscript letter (a-d) shows the significant difference ($p<0.05$) among a particular row, second superscript letter (w-z) shows the significant difference ($p<0.05$) among a particular column for a specific attribute.

and weight loss showed a negative impact. Significant ($p<0.05$) variation in antioxidant activity, TPC, carotenoid and provitamin A activity was observed in T_1 in comparison to treated vegetable slices during storage. TC and carotene showed similar variation in treated samples compared to control. TBC and TYMC showed slight variation in T_3 and T_4 compared to control and other treated samples during storage.

4. Conclusion

Alginate-based coating supplemented with α- tocopherol acetate (antioxidant) is an effective preservative tool to enhance the shelf life of minimally sliced carrots manifested by reduced weight loss, whitening index changes and microbial count, as well as a positive effect in maintaining the higher concentration of TPC, reducing sugar, TSS and antioxidant activity. The present study deduced that out of six formulations, treatment T4 (containing 2% alginate and 1% dl-α-tocopherol acetate) served as the best formulation in maintaining the quality, acceptability, nutritive value and thus exhibiting a huge potential in extending the shelf life of fresh-cut carrots during cold storage.

Author contribution

DK performed the experimental trials and manuscript writing. SR carried out statistical analysis. ADT, SKS and AA performed manuscript writing and editing.

Conflict of Interest

There is no conflict of interest between the authors and all the authors mutually agree to submit the manuscript in the Journal.

Acknowledgments

Authors are thankful to the School of Biochemical Engineering, Indian Institute of Technology (IIT BHU), Varanasi for providing the necessary facilities to carry out physicochemical analysis of samples and other statistical analysis. The authors are grateful to Institute of Eminence (IOE) Devlopment Scheme 4058, Banaras Hindu University for financial assistance.

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