Effects of Relative Humidity, Coating Methods and Storage Periods on Some Qualitative Characteristics of Carrot During Cold Storage

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Abstract: This study was conducted on the effects of Relative Humidity (RH), Coating Methods (CM) and Storage Periods (SP) on Nantes carrot during cold storage at temperature of 0±0.5°C. Two RH (85% and 90%), four CM [Carboxy Methyl Cellulose + Cellophane Film (CMC + CF), Carboxy Methyl Cellulose (CMC), Cellophane Film (CF) and No-Coating (NC)] and nine SP (0, 30, 45, 60, 75, 90, 100, 110 and 120-days) were investigated for some qualitative characteristics including water content, total soluble solids (TSS), reducing sugars and firmness. Experiment was conducted in completely randomized design with three replications for each factor. Duncan's multiple range tests at 1% probability were performed to compare the means of different treatments. The statistical results of the study indicated that RH, CM and SP significantly (P = 0.01) affected all traits. Interactions of RH × SP, CM × SP for all traits and RH × CM for water content and TSS were also significant. However, interactions of RH × CM for reducing sugars and firmness and RH × CM × SP for all traits were not significant. The statistical results of the study also indicated that at 90% RH, carrots were firmer and had higher water content and reducing sugars than 85% RH. Moreover, CMC + CF for water content and reducing sugars, while CF for firmness were the best CM. In addition, water content, reducing sugars and firmness were decreased by increasing the SP, whereas TSS was increased by increasing SP.

Key words: Carrot, Cold storage, Relative humidity, Carboxy Methyl Cellulose, Storage period, Total soluble solids, Reducing sugars, Firmness

INTRODUCTION

Carrot (*Daucus carota* L.) belongs to the family Umbelliferae. The carrot is believed to have originated in Asia and now under cultivation in many countries. The carrot is an important vegetable because of its high yield per unit area throughout the world and its increasing importance as human food. It is orange-yellow in color, which adds attractiveness to foods on a plate and makes it rich in carotene, a precursor of vitamin A. it contains appreciable quantities of nutrients such as protein, carbohydrate, fiber, vitamin A, Potassium, Sodium, thiamine and riboflavin and is also high in sugar. Its use increases resistance against the blood and eye diseases. It is eaten raw as well as cooked in curries and is used for pickles and sweetmeats [1-3].

Methods that are being used to preserve whole fruits and vegetables during storage and marketing are generally based on refrigeration with or without control of composition of the atmosphere [4, 5]. However, temperature, atmosphere, relative humidity and sanitation must be regulated to maintain quality of fruits and vegetables [6-10]. The most prevalent method is rapid cooling at a low temperature with high relative humidity [11]. But, low temperature storage is not economically feasible in most developing countries [5, 12].

Fungicides control postharvest decay of whole fruits, but they leave residues that are potential risks to humans and the environment [12]. In addition, many consumers are suspicious of chemicals in their foods, especially in fruits and vegetables [7]. Sulfites were effective chemical preservative as they were both inhibitors of enzymatic

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browning and antimicrobial. But their use has been banned due to adverse reaction in consumers [7, 13]. Moreover, chemical preservatives affect the flavor of fruits and vegetables [14].

Plastic films are also effective in reducing desiccation (moisture loss), but are subject to microbial growth and disposal problems [9, 15]. Many years of research are needed to develop a material that would coat fruit so that an internal modified atmosphere would develop [16, 17]. Studies have shown that ripening can be retarded, color changes can be delayed, water loss and decay can be reduced and appearance can be improved by using a simple and environmentally friendly technology of edible coating [16-18]. The concept of edible films as protective films has been used since the 1800s [19]. The first edible coating used was a wax, in China [20]. Extensive research in this area has paved the way for different effective edible films and coatings.

The use of edible films and coatings is extended for a wide range of food products including fresh fruits and vegetables. The reasons for their use are: they extend product shelf life [16, 17], control oxidation and respiration reactions [21, 22], add to texture and sensory characteristics and are environmentally friendly [19]. Krochta [23] indicated that the present commercial edible coatings are solvent based (ethanol) and the food industry should replace these solvent-based coatings with water-based coatings to ensure worker and environmental safety.

Coatings are applied and formed directly on the surface of the food product, whereas films are structures, which are applied after being formed separately. Because they may be consumed, the material used for the preparation of edible films and coatings should be approved by Food and Drug Administration (FDA) and must conform to the regulations that apply to the food product concerned [19]. The purpose of edible films or coatings is to inhibit migration of moisture, oxygen, carbon dioxide, or any other solute materials, serve as a carrier for food additives like antioxidants or antimicrobials and reduce the decay without affecting quality of the food. Specific requirements for edible films and coatings are: 1. The coating should be water-resistant so as to remain intact and to cover all parts of a product adequately when applied; 2. It should not deplete oxygen or build up excessive carbon dioxide. A minimum of 1-3% oxygen is required around a commodity to avoid a shift from aerobic to anaerobic respiration; 3. It should reduce water vapor permeability; 4. It should improve appearance, maintain structural integrity, improve mechanical handling properties, carry active agents (antioxidants, etc.) and retain volatile flavor compounds [24].

Edible coatings are thin layers of edible material applied to the product surface in addition to or as a replacement for natural protective waxy coatings and provide a barrier to moisture, oxygen and solute movement for the food [5, 15, 19, 25-27]. An ideal coating is defined as one that can extend storage life of fresh fruit without causing anaerobiosis and reduces decay without affecting the quality of the fruit [28]. They are applied directly on the food surface by dipping, spraying or brushing to create a modified atmosphere [19, 27, 29]. Previously, edible coatings have been used to reduce water loss, but recent developments of formulated edible coatings with a wider range of permeability characteristics has extended the potential for fresh produce application [30]. Also, the effect of coatings on fruits and vegetables depends greatly on temperature, alkalinity, thickness and type of coating and the variety and condition of fruits [16, 17]. The functional characteristics required for the coating depend on the product matrix (low to high moisture content) and deterioration process to which the product is subject [19].

Edible coatings may be composed of polysaccharides, proteins, lipids or a blend of these compounds [16, 17, 19, 24, 31, 32]. Their presence and abundance determine the barrier properties of material with regard to water vapor, oxygen, carbon dioxide and lipid transfer in food systems [19]. However, none of the three constituents can provide the needed protection by themselves and so are usually used in a combination for best results [19, 21, 22].

Some of the polysaccharides that have been used in coating formulations are starch and pectin [18], cellulose [18, 32, 33], chitosan [9, 11, 12, 18, 34-37] and alginate [18, 33]. These films are excellent oxygen, aroma and oil barriers and provide strength and structural integrity; but are not effective moisture barriers due to their hydrophilic nature [23, 38]. The oxygen barrier properties are due to their tightly packed, ordered hydrogen bonded network structure and low solubility [39]. These coatings may retard ripening and increase shelf life of coated produce, without creating severe anaerobic conditions [24, 40].

In this study, the effect of Relative Humidity (RH), Coating Methods (CM) and Storage Periods (SP) on some qualitative characteristics including water content, total soluble solids (TSS), reducing sugars and firmness of Nantes carrot, during cold storage at temperature of $0 \pm 0.5°C$ is reported.

MATERIALS AND METHODS

Plant Materials: Carrots (*Daucus carota* L., cv. Nantes) were purchased from a local market in Karaj, Iran. They were visually inspected for freedom of defects and blemishes. Carrots were then washed with tap water and treated for the prevention of development of decay by dipping for 20 min at 20°C in 0.5 g L^{-1} aqueous solution of iprodione and then air dried for approximately 1 h.

CMC Application: Carrots were placed in 30-liter plastic boxes and soaked for 5 min at 20°C in 20 g L^{-1} aqueous solution of CMC. They were then removed from the plastic boxes and then air dried for approximately 1 h.

Water Content: The water content of carrots was determined using the Eq. (1):

$$\text{Water content (\%)} = 100 \times (M_1 - M_2)/M_1 \qquad (1)$$

Where:
M_1 = Mass of sample before drying, g
M_2 = Mass of sample after drying, g

Total Soluble Solids (TSS): The total soluble solids of carrots (TSS) were measured using an ATC-1E hand-held refractometer (ATAGO, Japan) at temperature of 20°C.

Reducing Sugars: The reducing sugars of carrots were determined using Fehling method. This method can be used as a basis for the analysis of reducing sugars. Fehling's solution contains Cu^{2+} ions that can be reduced by some sugars to Cu^+ ions. As the Fehling's solution is added the blue Cu^{2+} ions will be reduced to Cu^+ ions. These will precipitate out of solution as red Cu^+ ions. The resulting solution will be colorless. A titration can be carried out to determine an equivalent amount of the sugar to the Fehling's solution. The end point would be when the blue color has just disappeared. This reaction can be used for the quantitative analysis of reducing sugars [41].

Firmness: The firmness of carrots was analyzed using a Hounsfield texture analyzer (Hounsfield Corp., UK). The test used was a shear or cut test on the 50 g carrot pieces closely placed into a 6×6×6 cm test box with 8 chisel knife blades. The variations in carrots size and geometry were minimized by testing the pieces of same thickness from the carrots. The test mode used for the texture analysis was "Force in Compression". A 5000 N load cell, test speed of 100 mm min^{-1} and post-test speed 600 mm min^{-1} were used. The "Trigger Type" was set to "Button" and distance to be traveled was set to 68 mm. Based on the average firmness of carrots in 0-days (3200 N); the range of the cutting force was set to 2000-3400 N and the maximum cutting force measured during each test was considered as stiffness.

Statistical Analysis: The experiment had factorial structure with two RH (85% and 90%), four CM [Carboxy Methyl Cellulose + Cellophane Film (CMC + CF), Carboxy Methyl Cellulose (CMC), Cellophane Film (CF) and No-Coating (NC)] and nine SP (0, 30, 45, 60, 75, 90, 100, 110 and 120-days) at cold storage temperature 0±0.5°C. The experiment had a complete random design for each factor combination with 3 replications. The effects of the factors on each qualitative characteristic were determined by analysis of variance using SPSS 12.0 (Version, 2003). Also, Duncan's multiple range tests (DMRT) at 1% probability (P = 0.01) were performed to compare the means of different treatments.

RESULTS AND DISCUSSION

Effect on Water Content: RH, CM and SP significantly affected water content (Table 1). The highest water content of 83.40% was observed in 90% RH and the lowest (82.48%) in 85% RH (Table 2). Also, the highest water content of 85.78% was observed in the first CM (CMC + CF) and the lowest (80.09%) in the fourth CM (NC) and CM affected water content in the order of CMC + CF > CF > CMC > NC (Table 2). Moreover, the highest water content of 87.80% was observed in 0-days, while the lowest (80.58%) in 120-days SP, water content decreased with increasing SP (Table 2). Furthermore, among different interactions, RH × CM, RH × SP and CM × SP showed significant effect on water content, but RH × CM × SP had no significant effect on water content (Table 1). The study of RH and CM combinations on water content showed that in each RH water content had

Table 1: Analysis of variance for several carrot quality characteristics

Source of variation	Df	Mean square			
		Water content	TSS	Reducing sugars	Firmness
RH	1	45.79 **	3.604 **	4.004 **	111612 **
CM	3	317.7 **	25.08 **	11.07 **	1488204 **
SP	8	126.0 **	10.52 **	16.43 **	776110 **
RH × CM	3	1.773 **	0.325 **	0.070 ns	746.574 ns
RH × SP	8	0.796 **	0.115 **	0.143 **	2420.89 **
CM × SP	24	6.597 **	1.012 **	0.637 **	31525.1 **
RH ×CM × SP	24	0.077 ns	0.002 ns	0.003 ns	266.762 ns
Error	142	0.284	0.001	0.026	797.331
C.V. (%)	---	0.64	0.36	2.26	0.99

** = Significant at 0.01 probability level

ns = Non-significant

Table 2: Means comparison for different carrot quality characteristics for different studied treatments using DMRT at 1% probability

Treatment		Water content (%)	TSS (%)	Reducing sugars (%)	Firmness (N)
RH	85%	82.48 b	9.83 a	7.01 b	2825 b
	90%	83.40 a	9.58 b	7.28 a	2871 a
LSD$_{1\%}$	----	----	----	----	----
CM	CMC + CF	85.78 a	8.85 d	7.61 a	2830 b
	CMC	82.08 c	9.94 b	7.43 b	2807 c
	CF	83.82 b	9.55 c	6.91 c	3041 a
	NC	80.09 d	10.5 a	6.64 d	2645 d
LSD$_{1\%}$	0.268	0.016	0.081	14.19	
SP	0 - time	87.80 a	8.63 i	8.26 a	3200 a
	30 - days	84.88 b	9.03 h	8.05 b	3019 b
	45 - days	83.94 c	9.27 g	7.81 c	2940 c
	60 - days	82.82 d	9.48 f	7.50 d	2875 d
	75 - days	82.32 e	9.76 e	7.19 e	2804 e
	90 - days	81.83 f	9.93 d	6.81 f	2749 f
	100 - days	81.35 g	10.2 c	6.56 g	2713 g
	110 - days	80.97 gh	10.4 b	6.25 h	2681 h
	120 - days	80.58 h	10.6 a	5.89 i	2652 I
LSD$_{1\%}$		0.402	0.024	0.122	21.28

Means in the same column with different letters differ significantly at 0.01 probability level according to DMRT

Table 3: Means comparison for different carrot quality characteristics of Relative Humidity (RH) and Coating Method (CM) combinations using DMRT at 1% probability

RH × CM		Water content (%)	TSS (%)	Reducing sugars (%)	Firmness (N)
85%	CMC + CF	85.57 b	8.87 g	7.51 b	2880 d
	CMC	81.56 f	10.1 c	7.32 c	2784 f
	CF	83.33 d	9.71 e	6.75 e	3013 b
	NC	79.47 h	10.6 a	6.46 f	2625 h
90%	CMC + CF	85.98 a	8.83 h	7.71 a	2919 c
	CMC	82.60 e	9.74 d	7.55 b	2830 e
	CF	84.32 c	9.39 f	7.06 d	3069 a
	NC	80.72 g	10.3 b	6.81 e	2666 g
LSD$_{1\%}$		0.379	0.023	0.115	20.07

Means in the same column with different letters differ significantly at 0.01 probability level according to DMRT

Table 4: Means comparison for different carrot quality characteristics of Relative Humidity (RH) and Storage Period (SP) combinations using DMRT at 1% probability

RH × SP		Water content (%)	TSS (%)	Reducing sugars (%)	Firmness (N)
85%	0 - days	87.80 a	8.63 n	8.26 a	3200 a
	30 - days	84.44 c	9.09 l	7.99 bc	2991 c
	45 - days	83.51 d	9.36 j	7.72 d	2909 d
	60 - days	82.35 fgh	9.58 i	7.38 e	2840 e
	75 - days	81.79 hij	9.94 g	7.04 f	2777 f
	90 - days	81.25 jkl	10.1 f	6.63 gh	2725 gh
	100 - days	80.77 lm	10.4 d	6.35 i	2691 ij
	110 - days	80.40 mn	10.6 b	6.03 j	2660 jk
	120 - days	80.03 n	10.8 a	5.67 k	2634 k
90%	0 - days	87.80 a	8.63 n	8.26 a	3200 a
	30 - days	85.32 b	8.98 m	8.10 ab	3046 b
	45 - days	84.37 c	9.18 k	7.90 c	2971 c
	60 - days	83.29 de	9.37 j	7.62 d	2910 d
	75 - days	82.84 ef	9.58 i	7.34 e	2832 e
	90 - days	82.41 fg	9.77 h	6.98 f	2772 f
	100 - days	81.93 ghi	9.97 g	6.76 g	2734 g
	110 - days	81.53 ijk	10.3 e	6.46 hi	2701 hi
	120 - days	81.13 kl	10.4 c	6.11 j	2670 ij
LSD$_{1\%}$		0.568	0.034	0.172	30.10

Means in the same column with different letters differ significantly at 0.01 probability level according to DMRT

Table 5: Means comparison for different carrot quality characteristics of Coating Method (CM) and Storage Period (SP) combinations using DMRT at 1% probability

CM × SP		Water content (%)	TSS (%)	Reducing sugars (%)	Firmness (N)
CMC + CF	0 - days	87.80 a	8.63 z	8.26 a	3200 a
	30 - days	87.03 ab	8.72 y	8.14 ab	3052 de
	45 - days	86.53 bc	8.72 y	8.00 abc	2980 fg
	60 - days	85.83 cd	8.83 x	7.83 cde	2921 h
	75 - days	85.50 def	8.85 x	7.62 efg	2863 i
	90 - days	85.19 defg	8.90 w	7.43 ghi	2814 jk
	100 - days	84.90 efgh	8.97 v	7.27 hij	2782 kl
	110 - days	84.68 fgh	9.02 tu	7.08 jkl	2754 lm
	120 - days	84.49 ghi	9.05 t	6.86 lmn	2729 mn
CMC	0 - days	87.80 a	8.63 z	8.26 a	3200 a
	30 - days	84.12 hij	9.05 t	8.09 abc	3013 ef
	45 - days	82.99 klm	9.40 q	7.93 bcd	2923 h
	60 - days	81.78 op	9.62 o	7.71 def	2850 ij
	75 - days	81.25 pq	10.0 l	7.49 fgh	2768 lm
	90 - days	80.80 qr	10.2 i	7.18 ijk	2698 n
	100 - days	80.03 rs	10.5 g	6.98 klm	2648 o
	110 - days	79.99 rst	10.8 e	6.75 mno	2602 p
	120 - days	79.69 st	11.1 d	6.47 p	2561 p
CF	0 - days	87.80 a	8.63 z	8.26 a	3200 a
	30 - days	85.58 de	8.98 uv	8.02 abc	3147 b
	45 - days	84.60 gh	9.20 s	7.73 def	3111 bc
	60 - days	83.72 ijk	9.35 r	7.37 ghi	3081 cd
	75 - days	83.39 jkl	9.55 p	7.01 jklm	3022 ef
	90 - days	83.07 klm	9.75 n	6.50 op	2982 fg
	100 - days	82.50 mno	9.95 m	6.17 q	2960 gh
	110 - days	82.10 nop	10.2 j	5.76 r	2940 gh
	120 - days	81.64 pq	10.4 h	5.33 s	2922 h

Table 5: Continued

NC					
NC	0 - days	87.80 a	8.63 z	8.26 a	3200 a
	30 - days	82.78 lmn	9.37 qr	7.94 bcd	2862 i
	45 - days	81.63 pq	9.77 n	7.58 efg	2747 lm
	60 - days	79.94 rst	10.1 k	7.10 jkl	2647 o
	75 - days	79.14 t	10.6 f	6.64 nop	2564 p
	90 - days	78.27 u	10.8 e	6.11 q	2500 q
	100 - days	77.69 uv	11.2 c	5.79 r	2460 qr
	110 - days	77.09 vw	11.7 b	5.39 s	2426 rs
	120 - days	76.50 w	12.0 a	4.90 t	2397 s
$LSD_{1\%}$		0.803	0.048	0.243	42.56

Means in the same column with different letters differ significantly at 0.01 probability level according to DMRT

the highest value in the first CM (CMC + CF) and the lowest value in the fourth CM (NC). The maximum mean value for water content was observed in the first CM (CMC + CF) and 90% RH and minimum mean value for water content was observed in the fourth CM (NC) and 85% RH. Also, in each RH CM affected water content in the same order as mentioned before (Table 3). Mean comparison for RH × SP combinations on water content revealed that in each RH water content had the highest value in 0-days and lowest value in 120-days SP. The maximum mean value for water content was observed in 0-days of both RH and minimum mean value for water content was observed in 120-days SP and 85% RH. Moreover, water content in each RH was decreased with increasing SP (Table 4). The study of CM and SP combinations on water content showed that in each CM water content had the highest value in 0-days and the lowest value in 120-days SP. The maximum mean value for water content was observed in 0-days of each CM and minimum mean value for water content was observed in 120-days SP and the fourth CM (NC). Also, in each SP CM affected water content in the same order as mentioned before (Table 5). These results are in agreement with those of Mahmoud and Savello [31] and Avena-Bustillos *et al.* [26] who concluded that coatings and/or films significantly conserved water content. These results are also in line with the results reported by Smith and Stow [4], El Ghaouth *et al.* [28] and Baldwin *et al.* [7] that water content was significantly decreased with increasing SP.

Effect on Total Soluble Solids (TSS): The effect of RH, CM and SP on TSS was found significant (Table 1). The highest TSS of 9.83% was observed in 85% RH and the lowest (9.58%) in 90% RH (Table 2). Also, the highest TSS of 10.5% was observed in the fourth CM (NC) and lowest (8.85%) in the first CM (CMC + CF) and CM affected TSS in the order of NC > CMC > CF > CMC + CF (Table 2).

Moreover, the highest TSS of 10.6% was observed in 120-days SP and lowest (8.63%) in 0-days and TSS increased with increased SP (Table 2). Furthermore, among different interactions, RH × CM, RH × SP and CM × SP showed significant effect on TSS, however RH × CM × SP had no significant effect on TSS (Table 1). Mean comparison for RH × CM combinations on TSS revealed that in each RH TSS had the highest value in the fourth CM (NC) and the lowest value in the first CM (CMC + CF). The maximum mean value for TSS was observed in the fourth CM (NC) and 85% RH and minimum mean value for TSS was observed in the first CM (CMC + CF) and 90% RH. Also, in each RH CM affected TSS in the same order as mentioned before (Table 3). The study of RH and SP combinations on TSS showed that in each RH TSS had the highest value in 120-days SP and lowest value in 0-days. The maximum mean value for TSS was observed in 120-days SP and 85% RH and minimum mean value for TSS was observed in 0-days of both RH. Moreover, TSS in each RH increased with increased SP (Table 4). Mean comparison of CM × SP combinations on TSS revealed that in each CM TSS had the highest value in 120-days SP and lowest value in 0-days. The maximum mean value for TSS was observed in 120-days SP and the fourth CM (NC) and minimum mean value for TSS was observed in 0-days of each CM. Also, in each SP CM affected TSS in the same order as mentioned before (Table 5). These results are in agreement with those of Smith and Stow [4] who concluded that coatings and/or films significantly affected TSS. These results are also in line with the results reported by Park *et al.* [16, 17] and Hussain *et al.* [42] that TSS was significantly increased by increasing SP.

Effect on Reducing Sugars: The effect of RH, CM and SP on reducing sugars was also found significant (Table 1). The highest reducing sugars of 7.28% was observed in 90% RH and the lowest (7.01%) in 85% RH (Table 2).

Also, the highest reducing sugars of 7.61% was observed in the first CM (CMC + CF) and the lowest (6.64%) in the fourth CM (NC) and CM affected reducing sugars in the order of CMC + CF > CMC > CF > NC (Table 2). Moreover, the highest reducing sugars of 8.26% was observed in 0-days and the lowest (5.89%) in 120-days SP and reducing sugars was decreased with increasing SP (Table 2). Furthermore, among different interactions, RH × SP and CM × SP showed significant effect on reducing sugars, but RH × CM and RH × CM × SP had no significant effect on reducing sugars (Table 1). The study of RH and CM combinations on reducing sugars showed that in each RH reducing sugars had the highest value in the first CM (CMC + CF) and the lowest value in the fourth CM (NC). The maximum mean value for reducing sugars was observed in the first CM (CMC + CF) and 90% RH and minimum mean value for reducing sugars was observed in the fourth CM (NC) and 85% RH. Also, in each RH CM affected reducing sugars in the same order as mentioned before (Table 3). Mean comparison for RH × SP combinations on reducing sugars revealed that in each RH reducing sugars had the highest value in 0-days and the lowest value in 120-days SP. The maximum mean value for reducing sugars was observed in 0-days of both RH and minimum mean value for reducing sugars was observed in 120-days SP and 85% RH. Moreover, reducing sugars in each RH was decreased with increasing SP (Table 4). The study of CM and SP combinations on reducing sugars showed that in each CM reducing sugars had the highest value in 0-days and the lowest value in 120-days SP. The maximum mean value for reducing sugars was observed in 0-days of each CM and minimum mean value for reducing sugars was observed in 120-days SP and the fourth CM (NC). Also, in each SP CM affected reducing sugars in the same order as mentioned before (Table 5). These results are in agreement with those of Ahmad and Khan [6], El Ghaouth *et al.* [11] and Li and Yu [12] and McHugh and Senesi [27] who concluded that coatings and/or films significantly affected reducing sugars. These results are also in line with the results reported by Suojala [43] and Forney *et al.* [44] that reducing sugars significantly was decreased with increasing SP.

Effect on Firmness: RH, CM and SP significantly affected firmness (Table 1). The highest firmness of 2871 N was observed in 90% RH and the lowest (2825 N) in 85% RH (Table 2). Also, the highest firmness of 3041 N was observed in the third CM (CF) and the lowest (2645%) in the fourth CM (NC) and CM affected firmness in the order

of CF > CMC + CF > CMC > NC (Table 2). Moreover, the highest firmness of 3200 N was observed in 0-days and the lowest (2652 N) in 120-days SP and firmness was decreased with increasing SP (Table 2). Furthermore, among different interactions, RH × SP and CM × SP showed significant effect on firmness, but RH × CM and RH × CM × SP had no significant effect on firmness (Table 1). Mean comparison for RH × CM combinations on firmness revealed that in each RH firmness had the highest value in the third CM (CF) and the lowest value in the fourth CM (NC). The maximum mean value for firmness was observed in the third CM (CF) and 90% RH and the minimum mean value for firmness was observed in the fourth CM (NC) and 85% RH. Also, in each RH CM affected firmness in the same order as mentioned before (Table 3). The study of RH and SP combinations on firmness showed that in each RH firmness had the highest value in 0-days and the lowest value in 120-days SP. The maximum mean value for firmness was observed in 0-days of both RH and minimum mean value for firmness was observed in 120-days SP and 85% RH. Moreover, firmness in each RH was decreased with increasing SP (Table 4). Mean comparison of CM × SP combinations on firmness revealed that in each CM firmness had the highest value in 0-days and lowest value in 120-days SP. The maximum mean value for firmness was observed in 0-days of each CM and minimum mean value for firmness content was observed in 120-days SP and the fourth CM (NC). Also, in each SP CM affected firmness in the same order as mentioned before (Table 5). These results are in line with the results reported by Park *et al.* [16, 17] who concluded that RH had significant effects on firmness. These results are also in agreement with those of Lerdthanangkul and Krochta [15] who concluded that coatings and/or films significantly affected firmness. These results are also in line with the results reported by Mostofi and Toivonen [10] that firmness significantly decreased by increasing SP.

CONCLUSION

Relative Humidity (RH), Coating Methods (CM) and Storage Periods (SP) significantly affected water content, total soluble solids (TSS), reducing sugars and firmness of Nantes carrot during cold storage. Results of the study indicated that at 90% RH, carrots were firmer and had higher water content and reducing sugars than 85% RH. Moreover, Carboxy Methyl Cellulous + Cellophane Film (CMC + CF) for water content and reducing sugars and Cellophane Film (CF) for firmness were the best CM.

Also, water content, reducing sugars and firmness decreased by increasing the SP, whereas TSS increased by an increase in SP.

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