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THE QUALITY OF SLICED CARROTS AFFECTED BY MODIFIED POLYETHYLENE FOIL AND STORAGE TEMPERATURES

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The aim of this study was to examine the influence of different additive contents for oxygen absorption (5, 10 and 15%) in low-density polyethylene (PELD) plastic foils and storage temperatures (4 and 28 °C) on the quality and shelf-life of sliced carrots during storage. Quality and storage-life of packaged carrots slices were determined by observing changes of mass, total carotenoide pigments, microbial counts (mesophilic aerobic bacteria, enterobacteria, sulphite-reducing clostridia, yeast and moulds), sensory quality and texture by the use of penetrometer.

The PELD foils modified with 10 and 15% of oxygen absorber (O_2, CO_2 and N_2 permeability at 4 °C of around 700 ml $m^{-2}d^{-1}atm^{-1}$) were the most suitable for the storage and prevention of deterioration of minimally processed carrots. Findings indicated that in these foils the best quality and shelf-life of carrot were maintained by 6 days of storage at 4 °C, without significant changes in parameters studied.

The absorber for oxygen added to the foil had no influence on the permeability to CO_2, O_2 and N_2. The permeability of foils, which were used for carrot packaging increased by the increase of storage temperature to 28 °C and decreased by decreasing the temperature to 4 °C, and was not significantly affected by the additive content either. In the same time the diffusion constants of unused and used PELD foils for carrot packaging at 4 °C and 28 °C changed according to the change of film permeability during storage at those temperatures.

Keywords: PELD modified with oxygen absorber**,** permeability, sliced carrot, carotenoids, microbes, sensory

Recent years have seen a rapid expansion in small-batch packaging and sale of minimally ("light") processed vegetables, aimed at individual consumers (home consumption, restaurants, tourist camps), that can be used for salads or main courses.They are washed, peeled, sliced or shredded and, wrapped raw vegetables are stored below 10 °C and sold within 8 to 10 days (NGUYEN-THE & PRIUNER, 1989). The disadvantage of the pre-cut product is that its storage life may be greatly reduced as compared to the intact vegetable. Tissue disruption caused by cutting results in elevated respiration and transpiration, which leads to rapid deterioration and subsequently loss of quality (ROLLE & CHISM, 1987; WATADA et al., 1990). In addition, cutting increases the area of injured tissue available for microbial degradation (BREIDT & FLEMING, 1997). Some problems related to cell disruption are leakage of nutrients, enzymatic reactions, mould growth, lactic acid fermentation, loss of texture, development of off-flavors and off-odors and appearance defects (CARLIN et al., 1990). Minimally processed carrot may become slimy, lose firmness and produce off-odors (MCLACHLAN & STARK, 1985; CARLIN et al., 1989; POSPIŠIL et al., 1989).

The most common methods used to improve the storage stability of minimally processed vegetable are low temperature, chemical treatments, modification of pH, modified or controlled atmospheres, active packaging or combination of two or more of these (BRACKETT, 1987; HUXSOLL & BOLIN, 1989; KING & BOLIN, 1989; KADER et al., 1989; LABUZA & BREENE, 1989; BOLIN & HUXSOLL, 1991; IZUMA et al., 1996; VERMEIREN et al., 1999; DEVLIEGHERE et al., 2000). KADER (1986) critically reviewed the responses of fresh fruits and vegetables to modified atmosphere packaging, summarizing the implications, status and future of this technology.

No systematic study has been conducted to establish which commercially available plastic films would be most suitable for modified atmosphere packaging of a particular produce (EXAMA et al., 1993). It is well known that different polymer structures have very different properties, giving to the polyethylene family the opportunity to cover a wide range of applications. The reaction of oxidation in a polyethylene film can be slowed or inhibited by compounds that interrupt the chain reaction at some points.

Our work was undertaken to examine the effect of different additive contents (oxygen scavenger) in the low density polyethylene foil (PELD) on the quality and shelf-life of sliced carrot during storage at 4 and 28 °C. Changes in mass, total carotenoids, microbial count, sensory quality and texture in carrot slices were determined. The gas permeability and diffusivity coefficients of foils before and after being used for carrot packaging and storage at two temperatures, were measured.

1. Materials and methods

Carrots of the Nantes cultivar (Napoli variety) were grown on a local farm in the summer of 1998. Before the beginning of the experiments the carrots were held at 4 °C for two days. After washing and hand-peeling the carrots were cut into 5–7 mm thick slices (using a home food processor) and packed in polyethylene pouches (22×17 cm) made from modified polyethylene foils. Antioxidant was added to the plastic to inhibit its degradation during processing and subsequent usage. Although the exact chemical formula is not provided, the applied antioxidant belongs to the group of organic compounds, possesing double bounds, which act as oxygen scavengers. The antioxidant used is, according to the producer, on the EU list of additives which may be used in the manufacture of plastic materials and articles. (COUNCIL DIRECTIVE, 1990). Polyethylene foils had different additive contents: 5%, 10% and 15%, with an active component of 0.2%; 0.4% and 0.6%, respectively. As a control, a polyethylene foil containing no additive (0%) was used (Table 1).

Each polyethylene pouch contained 300 g of sliced carrots, stored at 4 and 28 °C and were removed periodically for chemical and sensory analysis (after 3, 6, 9 and 14 days at 4 °C and after 2, 5 and 9 days at 28 °C). The samples were evaluated in duplicate.

Chemical composition of sliced carrots was determined by official methods. Dry matter content was determined by drying at 105 °C to the constant mass (A.O.A.C, 1990). Total carotenoid pigments were determined in carrots by petrolether extract, according to the procedure for the vitamin A analysis in food products (VUILLEUMIER et al., 1967).

The sensory evaluation was carried out by 8 panelists, scoring on a rating scale from 1 to 5 (1 is very poor, 2 to 3 is fair and 5 is excellent). The scoring system included assessment of browning (color), odor (aroma), taste and texture. Fresh carrots, from the batch used for processing were used as the control (5 scores). To determine the shelf-life of sliced carrots, the sensory evaluation for single and total sensory attributes were used (in the first case the score of 3 or below and in the second case the score of 15 or below were taken to indicate the end of shelf-life). Besides, the texture of sliced carrots was determined by using a penetrometer (EFFEGI, Italy) with 8 mm radius cylinder.

Microbiological analyses were done after cutting carrots into slices and storing them for 14 days at 4 °C and for 9 days at 28 °C in modified polyethylene foils. Analysis included the determination of total number of mesophilic aerobic bacteria, enterobacteria, sulfite-reducing clostridia, yeast and moulds (ANON, 1980) and *Listeria* sp. (ISO 11290-1, 1996). Duplicate and control samples were prepared for each sample.

Table 1

Polyethylene foils used for packaging

Polymer	Thickness (μm)	Active component (%)
Polyethylene without additive	36	0
Polyethylene with 5% additive	42	0.2
Polyethylene with 10% additive	44	0.4
Polyethylene with 15% additive	44	0.6

Permeability to CO_2, O_2 and N_2 of modified polyethylene foils was measured using a manometric method on a permeability testing appliance, Type GDP-E (Burger Feinmechanik GmBH) (BECKER, 1982). Monofilm material was analysed using method A, which provides for the determination of permeability and diffusion constants of the gas in the film.

Gas permeability calculations for the samples (monofilms) analysed using method A were determined from the equation (1)

$$q = k_1 \frac{V}{T \times (29 \times N - t_L)} \tag{1}$$

where:
k_1: calibration constant (9.89×10^8)
q: gas permeability ($cm^3\ m^{-2}\ d^{-1}\ atm^{-1}$)
V: measurement volume (ml)
N: slope of the measurement curve (s)
T: temperature (K)

Diffusion constant was calculated according to the following equation (2)

$$D = \frac{l^2}{6 \times t_L} \tag{2}$$

where:
D: diffusion constant ($cm^2\ s^{-1}$)
l: polymer thickness (cm)
t_L: time –lag value

Determinations were made before and after usage of modified polyethylene foils for carrot packaging, at selected temperatures.

Variance analysis was used to determine the influence of various additive contents in the polyethylene foils, on the changes of analysed parameters in carrot during storage (DAVIES, 1961).

2. Results

The permeability of modified polyethylene (PE) foils for O_2, N_2 and CO_2, before and after usage for carrot packaging at 4 °C and 28 °C is represented in Fig. 1. The investigated samples of unused foils (A) show almost identical values for O_2 and CO_2 permeabilities at both tempratures, which is in particular expressed at 4 °C. Slightly higher values were observed in the case of nitrogen permeability for PE foils containing 5% and 10% of additive, as well as without the additive (0%). The foils permeability for all three gases increased by increasing the temperature to 28 °C.

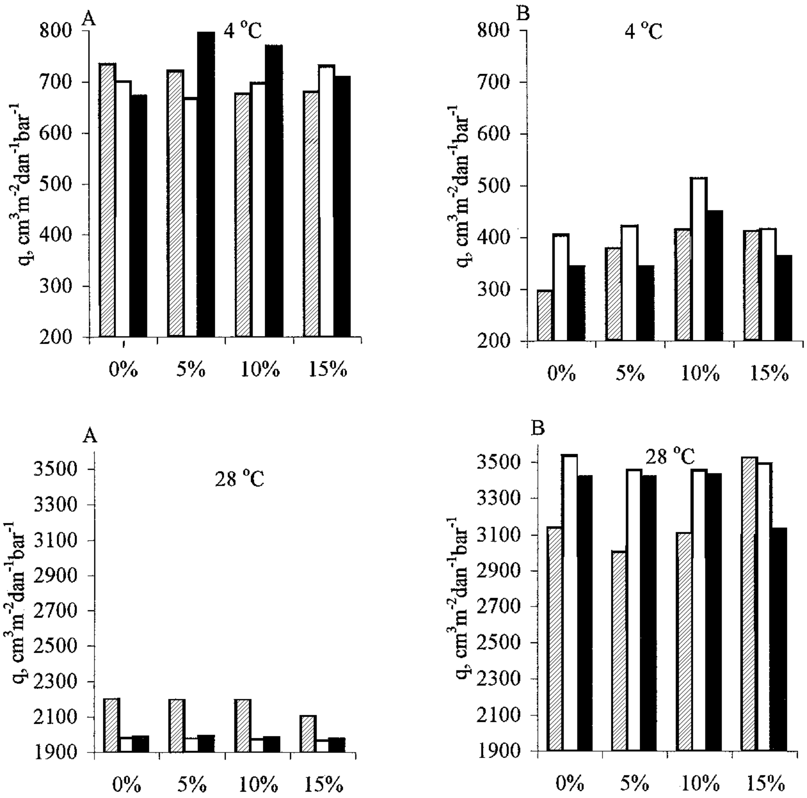

Fig. 1. Permeability values of gases in modified polyethylene foils at 4 and 28 °C, before (A) and after (B) usage for sliced carrot packaging. ▨: N_2; □: O_2; ■: CO_2

It is interesting to note that the permeability of the foils is not affected by the additive content. Such behavior may be attributed to antioxidant presence and an organic compound possessing reactive double bound for oxygen molecular bonding.

The modified PE foils after usage for carrot packaging (B) show decreasing permeability for O_2, N_2 and CO_2 at 4 °C and at 28 °C. This phenomenon is probably due to rising the small polymer crystals and less pronounced diffusion and solubility of gases. The increase of foil permeability at 28 °C is a consequence of foil swelling in the contact with metabolic products of the minimally processed carrots.

The polymer permeability to the gases depends on their diffusion and solubility constants as well. Diffusion coeffiecient presents the measure of polymer capability to differentiate the molecules of different dimensions and shapes (HOEKSTRA et al., 1996).

Diffusion coefficient values for gases in modified PELD foils are presented in Fig. 2. It was interesting that the diffusion constants remained unchanged regardless of the type of gas or percentage of the additive added at 4 °C and 28 °C (Fig. 2A). Because of the more intensive polymer segment movement at higher temperatures, the foils capability in differentiation of the molecules to different dimensions and shapes declined, which results in losing diffusion selectivity. It was probably the reason that the diffusion constants of unused foils at 28 °C were only somewhat higher than those at 4 °C. After the foils were in contact with sliced carrot, their diffusion constants changed in the same direction as their permeability values to the gases at 4 °C and 28 °C (Fig. 2B).

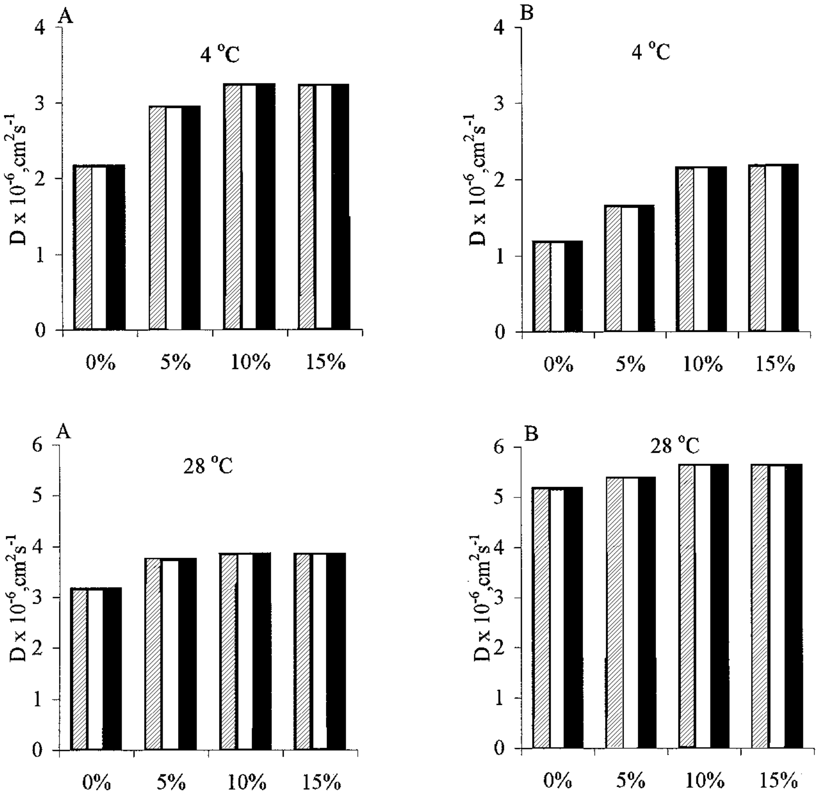

Fig. 2. Diffusion coefficient values for gases in modified polyethylene foils at 4 and 28 °C, before (A) and after (B) usage for sliced carrot packaging. ▨: N_2; □: O_2; ■: CO_2

The results linked to the changes in carrot mass show (Table 2) that storage caused mass losses in all packaged samples are more noticeable at 28 than at 4 °C. In the foil containing additive the mass showed little more losses compared to the foil without additive (0%). Our results showed that the highest losses in the mass content occurred after 6-day storage of samples, at both temperatures (0.57–0.63% at 4 °C and 3.93–4.23% at 28 °C).

The results of determining carotenoid pigments in sliced carrot indicate that storage caused their decomposition in all samples at both temperatures, but significantly more in the PE foil without additive (0%) and at 28 °C (Fig. 3). Namely, at 4 °C the additive for oxygen absorption in 5, 10 and 15% concentrations had a dominant effect on the stability of carotenoid pigments in carrot, whereas at 28 °C the increased temperature had a much greater influence. The foil with 10 and 15% of additives gave higher level of total carotenoid contents at 4 °C than the foil with 5% of additive.

Carotenoid pigments exhibited the highest losses after 6 days of storage (just like mass), when about 20% of the pigment was decomposed in the foils without additive stored at 4 °C, and in the foils with additive only about 5%. In samples stored at 28 °C, more than 50% of pigment was decomposed after 6 days as a consequence of high temperature influence, and greater foil permeability for oxygen at higher temperatures.

Aerobic microbial populations on fresh sliced carrots ranged from 10^4 to 10^7 CFU g^{-1} on 0 day (Table 3 and Fig. 4). Microbiological analyses of the sliced carrots revealed that after 14 days of storage at 4 °C and after 9 days of storage at 28 °C, all samples exhibited a slight decrease in the count of mesophilic aerobic bacteria and enterobacteria, and an increase in the number of yeasts (Table 3 and Fig. 4).

Table 2

Mass loss of sliced carrots in modified polyethylene foils, during storage at 4° and 28 °C

Measurements	Storage temp. (°C)	Storage time (days)	Additive (%) 0	5	10	15
Mass loss,%	4	3	0.53	0.27	0.37	0.37
		6	0.57	0.63	0.63	0.63
		9	0.73	0.83	0.97	0.97
		14	0.96	1.13	1.06	1.06
	28	3	0.73	0.97	0.83	0.61
		6	3.93	4.23	4.13	4.10
		9	4.01	4.20	4.12	4.07

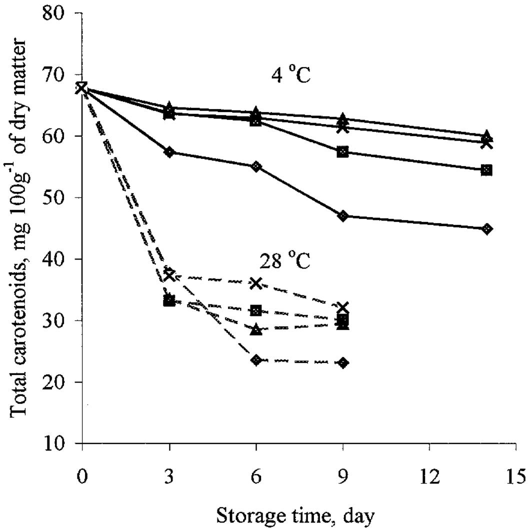

Fig. 3. Changes in total carotenoid pigments of sliced carrot packaged in modified polyethylene foils, during storage at 4 and 28 °C. ◆ = 0%; ■ = 5%; ▲ = 10%; ✕ = 15%

However, the decrease in the total count of mesophilic aerobic bacteria and enterobacteria was more pronounced in the samples stored at 28 °C than in those stored at 4 °C (Fig. 4). The similar trend was observed by MUNSCH and co-workers (1982) working on the effect of various treatments on the microflora of commercially washed carrot stored at 5, 22 and 37 °C. They found that microflora was the most abundant at 5 and 22 °C and significantly lower at 37 °C in all schemes.

Overall growth of mesophilic aerobic bacteria and enterobacteria on sliced carrots, during storage at 4 and 28 °C, were significantly influenced by the additive contents in the PE foils. The lowest number of the total aerobic bacteria was detected in the PE foil with 15% of additive at both temperatures (10^3–10^5 CFU g^{-1}). Storage life of most prepared vegetables is known to be terminated when microbial growth reaches 10^7–10^8 CFU g^{-1} (O'BEIRNE, 1989).

In the samples before storage, only the presence of yeasts (10^4 CFU g^{-1}) but not moulds was detected. During storage the yeast population increased to 10^5 CFU g^{-1} in all samples at both temperatures.Yeasts grow well at neutrality and under alkaline conditions but they do not compete well with bacteria at these pH values (BRACKETT, 1987). The level of additive in the PE foil did not significantly affect the population of moulds and yeasts.

Table 3

Growth of microorganisms in sliced carrot in modified polyethylene foils during storage at 4 and 28 °C[a]

Microorganisms ($\log_{10}$ CFU g^{-1})[b]	Storage temp. (°C)	Storage time (days)	Additive (%) 0	5	10	15
Mesophilic aerobic	4	0	7.60	7.60	7.60	7.60
		14	7.30	7.00	6.84	4.85
bacteria	28	0	7.60	7.60	7.60	7.60
		9	6.85	6.48	6.00	5.00
Enterobacteriaceae	4	0	6.00	6.00	6.00	6.00
		14	4.70	5.00	4.90	4.00
	28	0	6.00	6.00	6.00	6.00
		9	5.00	4.00	3.85	3.30
Yeasts and	4	0	4.00	4.00	4.00	4.00
		14	5.00	5.30	5.30	5.30
moulds	28	0	4.00	4.00	4.00	4.00
		9	5.00	4.00	5.00	5.00

[a] Evolution of sulfite-reducing clostridia or *Listeria* sp. were not detected
[b] CFU means colony forming unit

There was no increase in sulfite-reducing clostridia or *Listeria* sp. in the fresh sample or in samples stored at 4 °C and 28 °C.

In Fig. 5 the scores for sensory quality evaluation of sliced carrots are presented. It is evident that the appearance of sliced carrots is degraded during storage in all foils and depends primarily on the temperature, followed by the time of storage and additive content in the foil.

According to the total score for sensory quality of carrots, the samples in foils with and without additive were of satisfactory sensory quality after 6–9 days of storage at 4 °C (total score for the assessed properties was greater than 15, which is limit value of acceptability). During this storage time the highest scores for the color and aroma attributes of carrot were given in the modified foils containing 10 and 15% of additives (total score for the assessed properties was greater than 3). Samples stored in the foil without additive (0%) received lowest colour and aroma scores. On the other hand, at 28 °C the sensory quality of carrot samples became unsatisfactory as early as 3–4 days into the storage period.

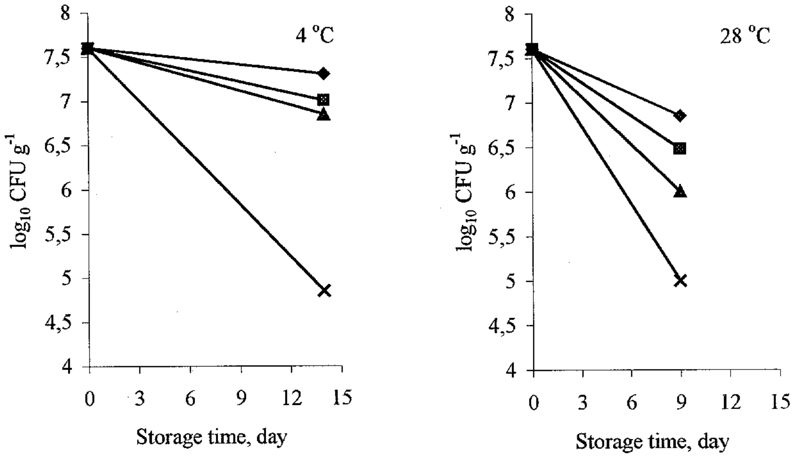

Fig. 4. Changes in number of total aerobic bacteria (CFU) of sliced carrot packaged in modified polyethylene foils, during storage at 4 and 28 °C. ◆ = 0%; ■ = 5%; ▲ = 10%; ✕ = 15%

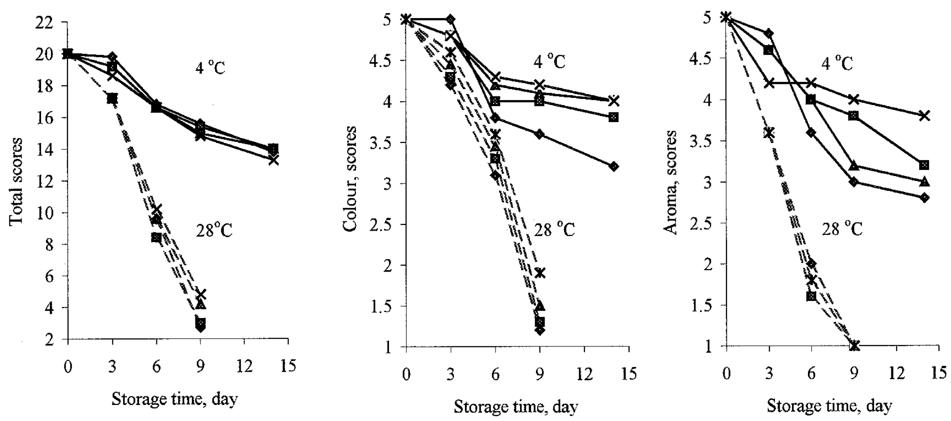

Fig. 5. Changes in total sensory scores and scores for colour and aroma of sliced carrot packaged in modified polyethylene foils, during storage at 4 and 28 °C. ◆ = 0%; ■ = 5%; ▲ = 10%; ✕ = 15%

The scores for colour were supported by the results of determinations of carotenoid pigment contents (Fig. 3). In addition, better colour quality correlated with lower total aerobic bacteria counts in sliced carrots (Fig. 4). Browning of injured vegetables is due to a large extent to oxidized phenols acting as an infection barrier (SKOVGAARD, 1984) and changes in tissue appearance caused by pectinolytic breakdown can be an indicator of microbial growth (WALL & ELLIOT, 1986).

The values for carrot texture measured instrumentally (Fig. 6) were very high in all samples stored for 6–9 days at 4 °C and very low in all samples stored at 28 °C. At 4 °C the significant differences were found in the texture between the foils with and without additive.

In order to examine the influence of various additive contents in the modified PELD foils and storage time at 4 °C and 28 °C on the changes of physico-chemical, microbiological and sensory variables in sliced (F) carrots, analysis of variance was done (Table 4). It was found that the Fisher quotient values for % of additive and storage days as sources of variation, were higher than the limit values ($F_{crit.}$) at P=0.05. It means that added absorber for oxygen to the foils and storage time had statisticaly significant influence on most investigated carrot parameters. The differences between additive fractions in the foils were examined by Duncan's test.

Table 4

Variance analysis of chemical variables in sliced carrots during storage in modified foils at 4 °C

Chemical variables	Source of variation	SS	df	MS	F	$F_{crit.}$
Mass loss	% additive	0.039	3	0.013	4.33	3.49
	Storage days	2.880	4	0.720	240	3.26
	Error	0.036	12	0.003		
	Total	2.955	19			
Carotenoids	% additive	268.1	3	89.64	10.11	3.49
	Storage days	418.72	4	104.68	11.81	3.26
	Error	106.27	12	8.86		
	Total	793.90	19			
Sensory evaluation	% additive	0.770	3	0.257	4.35	3.49
	Storage days	110.38	4	27.595	467.71	3.26
	Error	0.708	12	0.059		
	Total	11.858	19			

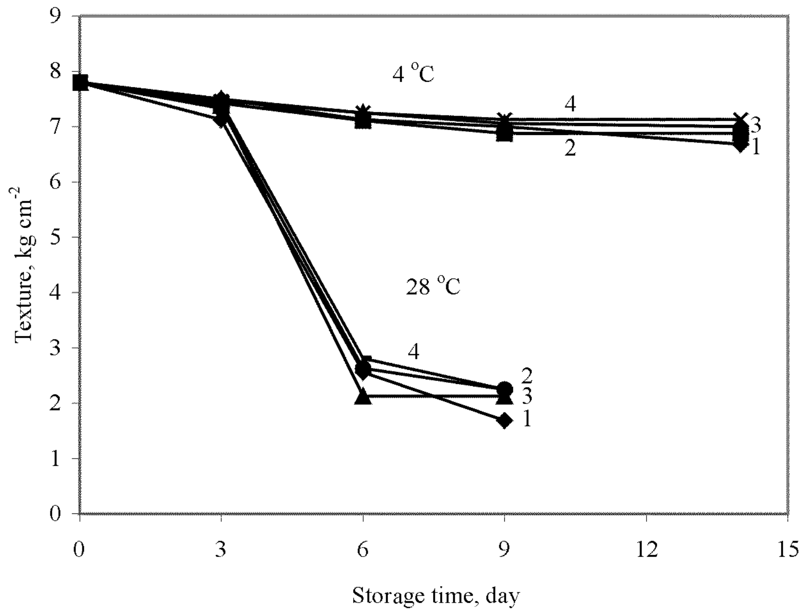

Fig. 6. Changes in texture of sliced carrot packaged in modified polyethylene foils, during storage at 4 and 28 °C. ◆ = 0%; ■ = 5%; ▲ = 10%; ✕= 15%

3. Conclusions

Based on the obtained results it may be concluded that the additives have no impact on the permeability of polyethylene foils to O_2, CO_2 or N_2. The permeability is significantly decreased in all foils (with or without additive) by storage at 4 °C for 14 days, and increased by storage at 28 °C for 9 days. The similar changes showed the values for the diffusion constants.

The addition of oxygen absorber to the foil and the creation of modified atmosphere in the packages, significantly reduced the mass loss, carotenoid pigments decomposition, microbial growth and changes in sensory properties of sliced carrots (particularly colour), probably by limiting plant and microbial enzyme activity. The best effects on the carrot quality was observed for the foil with 10 and 15% of additive at 4 °C. These conditions may prolong the shelf-life and appearance quality of sliced carrots by 6 days, with no significant changes in the assessed properties as compared with the original material.

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