Influence of Packaging Material and Storage Conditions on the Quality Attributes of Pressure-Assisted Thermally Processed Carrots

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Abstract

The influences of barrier properties of packaging materials and storage conditions on selected quality attributes of carrot samples processed by pressure-assisted thermal processing (PATP) were investigated. Baby carrots were packaged in three different pouches made of multilayer films (Nylon/EVOH/EVA, Nylon/EVA and MetPET/PE) and processed at 600 MPa and 110 °C for 10 minutes. Processed pouches were stored at 25 and 37 °C and withdrawn over 12 weeks of storage on a periodical basis and analyzed for color, β-carotene, and total mesophilic aerobic count. Oxygen transmission rates (OTR), water vapor transmission rates (WVTR), melting point and enthalpy of fusion of the packages were also evaluated. Scanning electron microscope images were utilized to document the impact of processing on the packages. Results showed that the chosen processing parameters resulted in shelf stability of processed carrots during 12 weeks storage at 25 and 37 °C. Packaging type, storage temperature and time significantly influenced ($p < 0.05$) product color and β-carotene content. Nylon/EVOH/EVA laminate pouch best preserved color and β-carotene. PATP increased OTR of the MetPET/PE, which might have caused considerable change in color and β-carotene content of carrot samples after 12 weeks storage. After 12 weeks of storage at 37 °C, Nylon/EVOH/EVA, Nylon/EVA and MetPET/PE lost 36, 100 and 100 % of β-carotene content, respectively. The red color of carrot samples was reduced by 20, 87 and 72 % for Nylon/EVOH/EVA, Nylon/EVA and MetPET/PE, respectively. Thermal analyses indicated a structural change in the packaging polymers following PATP treatment. In summary, our study demonstrated the importance of utilizing high barrier packaging material for preserving quality attributes of PATP-treated carrots.

Keywords: Barrier properties; packaging materials; pressure-assisted thermal processing; high pressure processing; baby carrots; storage

Introduction

Consumer interest in health and wellness has prompted the food industry to develop minimal processing technological solutions for preserving low-acid shelf stable foods (Galotto et al 2008). Pressure-assisted thermal processing (PATP) is one alternative sterilization technique, in which elevated pressures (500-700 MPa) and temperatures (90-120 °C) are used for a short time to sterilize low-acid foods (Balasubramaniam, Farkas and Turek, 2008). In February 2009, FDA issued a no objection letter to an industry petition for sterilization of a low-acid food product processed by PATP. This opened up opportunity for processing a variety of heat sensitive value added products such as soups, coffee, tea, meat entrees, egg products and mashed potatoes. Currently, there is no commercial food product produced with this treatment. Limited studies evaluated the impact of combined pressure heat treatment on food packaging materials (Galotto et al 2009; Canner et al 2000; Schauwecker et al 2002). Only a very limited number of studies have investigated whether or not barrier properties of the PATP-treated packages changed during extended storage periods. It is also important to understand the influence of barrier properties of the packaging, which underwent PATP treatment, on product quality during extended storage. The overall objective of this research was to investigate the influence of packaging material and storage conditions on quality attributes of PATP-treated carrots. Specific objectives include (a) documenting the combined pressure-heat effect on barrier and thermal properties and physical structure of selected packaging materials (b) evaluating the effect of different storage temperatures and storage times on selected quality attributes of PATP-treated carrots packaged in pouches with different barrier properties.

Materials and Methods

Baby carrots (*Daucus carota* L.) were sourced from a local grocery store in Columbus, Ohio. Samples were stored at refrigerated temperatures for up to three days before processing to minimize the extent of variation in raw product quality. Experimental design of the research can be seen in Figure 1. Samples were cleaned and undesired parts were removed. The packaging films were used to fabricate pouches of 15.2 x 20.3 mm dimension. The compositions of the films were (1) Nylon/EVOH (Ethylene-vinyl alcohol) / EVA (Ethylene-vinyl acetate) (2) Nylon/EVA (3) MetPET/PE (Metalized polyethylene terephthalate / Polyethylene). Water vapor transmission rates of the untreated pouches were reasonably similar. On the other hand, untreated Nylon/EVOH/EVA and MetPET/PE pouches had very low oxygen transmission rates, while the Nylon/EVA had a substantially higher oxygen transmission rate (Table 1). The pouches were then filled with 200 g baby carrots (approximately 16 baby carrots) suspended in 1 % NaCl solution (2 g NaCl / 200 ml distilled water) and heat sealed using a vacuum packaging machine (Ultravac, UV 250, Koch Supplies Inc., MO, USA). The ratio of carrots to NaCl solution was 1:1. The covering solution helped to minimize solid loss from the carrots (verified by preliminary experiments).Vacuum packaged pouches were preheated to an initial sample temperature of 86 ± 2 °C in a water kettle (maintained at 90 °C) for 15 min prior to pressure application. Sample initial temperature was estimated from the knowledge of heat of compression of the test sample and desired process pressure and temperature (Nguyen et al 2010). A thermocouple (Omega Engineering, CT, USA) inserted into the geometric center of the baby carrots was used to monitor sample temperature during preheating and processing. Preheated samples were then loaded into a temperature equilibrated carrier basket (102 mm dia x 559 mm height) and subjected to combined pressure-heat treatment at 600 MPa and 110 °C for

10 minutes using a pilot scale high pressure food processor (Iso-Lab FPG11500 Standsted Fluid Power Ltd, Essex, UK). Propylene glycol (Brenntag Mid-South, Inc., St. Louis, MO) was used as the pressure transmitting fluid. During the PATP treatment, sample temperature was monitored at different geometric locations (top, center and bottom) of the carrier basket by using T-type thermocouple (Omega engineering, CT, USA) secured through the pouch using C-5.2 stuffing box (Ecklund-Harrison Technologies, FL, USA) mechanism. After processing, samples were suspended in an ice-water bath to cool the product to room temperature. This helped to reduce any further thermal degradation in the product. Pouches containing untreated raw carrots were used as controls. The processed samples were immediately stored in the dark at two different temperatures (24 ± 1 °C and 37 ± 1 °C), withdrawn over 12 weeks of storage on a periodical basis and analyzed for color, β-carotene, and total mesophilic aerobic count. Oxygen transmission rates (OTR), water vapor transmission rates (WVTR), melting point and enthalpy of fusion of the packages were also evaluated. Scanning electron microscope images were utilized to document the impact of processing on the packages. Statistical analysis of data was performed using Minitab Statistical software version 16 (Minitab, Inc., State College, PA). Data was analyzed using General Linear Model (GLM) except the melting point and heat of fusion of the packages for which, one-way ANOVA with Tukey`s test at 95 % confidence interval was used. Significance for all statistical analysis was defined as $p<0.05$.

Results

Figure 2 shows a typical temperature-pressure history for PATP-application. Results showed that the chosen processing conditions reduced the total microflora to below detection limits (10 CFU per g of the product) and provided shelf-stability during 12 weeks storage at 25 and 37 °C. Packaging type, storage temperature and time significantly influenced ($p < 0.05$) the color and β-carotene content of carrots. Among the packages tested, Nylon/EVOH/EVA pouch helped to retain color (Figure 3 and 4) and β-carotene content of PATP carrots the most during 12 weeks at either 25 or 37 °C storage. Preheating and combined pressure-heat treatment minimally impacted the water vapor transmission rate (WVTR) of tested pouches ($p > 0.05$) except for MetPET/PE pouch in which a significant increase due to preheating was observed in WVTR ($p<0.05$) . Other pouches, Nylon/EVOH/EVA and Nylon/EVA were not affected considerably in terms of WVTR. Additionally, PATP treatment and following storage of 4 weeks at either 25 or 37 °C did not cause further significant increase in WVTR for any of the pouches tested. Processing (preheating and PATP) and storage increased OTR of MetPET/PE packaging drastically ($p < 0.05$). The change in OTR was more pronounced for those PATP-treated films stored at 37 °C. This led to adverse changes in color and β-carotene content of carrot samples stored in this type of pouch. Nylon/EVOH/EVA had minimal impact followed by intermediate barrier film Nylon/EVA. Since β-carotene is the major source of red color in carrot samples, similar trends were observed between the loss of β-carotene content in carrot samples and decrease in "*a*" values of carrot samples. After 12 weeks of storage at 37 °C, Nylon/EVOH/EVA, Nylon/EVA and MetPET/PE packages lost 36, 100 and 100 % of β-carotene content, respectively. The red color of carrot samples was reduced by 20, 87 and 72 % for Nylon/EVOH/EVA, Nylon/EVA and MetPET/PE, respectively. Thermal analyses indicated a structural change in the packaging polymers following PATP treatment (Table 2). The changes in the structures of the pouches were further analyzed by using scanning electron microscopy (Figure 5). No significant difference on the surface of Nylon/EVOH/EVA pouch was observed between untreated and PATP-treated pouch. On the other hand, PATP treatment created bubble look like structures in the Nylon/EVA pouch. SEM pictures of MetPET/PE pouch revealed that PATP treatment severely damaged the surface of the film.

Conclusions

Combined pressure-heat treatment (600 MPa, 110 °C for 10 minutes) caused β-carotene degradation and change in color of carrot samples. Packaging material barrier properties (particularly oxygen transmission rate) and storage temperature and time also affected the color change and β-carotene content ($p < 0.05$). Nylon/EVOH/EVA laminate pouch survived the processing and storage conditions the best and preserved the color and β-carotene content after PATP treatment and following storage. MetPET/PE pouch was damaged by the processing and its OTR increased drastically. Nylon/EVA pouch which was the lowest barrier pouch tested, also could not preserve the color and β-carotene content of carrots. Process conditions chosen resulted in shelf-stability of the processed carrot samples in any types of the pouches tested during the storage. The study demonstrated that the barrier properties of the packaging materials has significant role in preserving quality attributes of PATP processed carrot samples and high barrier pouches are required to preserve the quality attributes of PATP-treated products during extended storage.

References

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Tables:

Table 1. Barrier properties of the selected packaging materials (control samples)

Composition	**Thickness (Mils)**	**OTR ($cc/m^2/24$ hrs)**	**WVTR ($grams/m^2/24$ hrs)**
Nylon/EVOH/EVA	3.0	0.911 ± 0.098	4.511 ± 1.882
Nylon/EVA	3.0	47.791 ± 5.343	4.998 ± 0.681
MetPET/PE	2.6	1.329 ± 0.044	3.501 ± 0.012

Table 2. Thermal analysis results for control and packaging films subjected to various combined pressure heat treatment (HPP: 600 MPa and 25 °C for 10 min., PATP: 600 MPa and 110 °C for 10 minutes). T_m : Melting Temperature ; ΔH : Heat of Fusion.

Film Structure	**Conditions**						
		T_m (°C)	**ΔH (J/g)**	**Tm (°C)**	**ΔH (J/g)**	**Tm (°C)**	**ΔH (J/g)**
		EVA		**EVOH**		**NYLON**	
NYLON/EVOH/EVA	Control	104.7 ±0.3	34.5 ±13.4	170.1 ±0.3	9.2 ±0.8	218.3 ± 0.4	10.2 ±1.7
NYLON/EVOH/EVA	HPP	104.2 ±0.02	20.6 ±1.9	169.8 ±0.02	7.98 ±0.5	218.0 ±0.01	11.7 ±0.07
NYLON/EVOH/EVA	PATP	104.3 ±0.3	20.9 ±1.0	165.7 ±2.9	7.1 ±0.8	216.3 ±2.1	9.1 ± 4.3
		EVA				**NYLON**	
Nylon/EVA	Control	104.8 ±0.2	41.8 ±10.4	-	-	218.9 ±0.1	10.3 ±1.0
Nylon/EVA	HPP	104.8 ±0.3	38.96 ±1.6	-	-	218.8 ±0.3	10.0 ±0.6
Nylon/EVA	PATP	105.0 ±0.1	29.0 ±0.5	-	-	217.6 ±0.7	9.4 ± 0.5
		PE		**PET**			
MetPET/PE	Control	112.5 ±0.1	72.0 ±6.0	253.6 ±0.3	9.8 ±0.5	-	-
MetPET/PE	HPP	112.1 ±0.2	72.3 ±0.8	253.6 ±0.1	10.0 ±0.5	-	-
MetPET/PE	PATP	112.6 ±0.1	45.5 ±1.0	253.9 ±0.5	9.9 ±1.1	-	-

Figures:

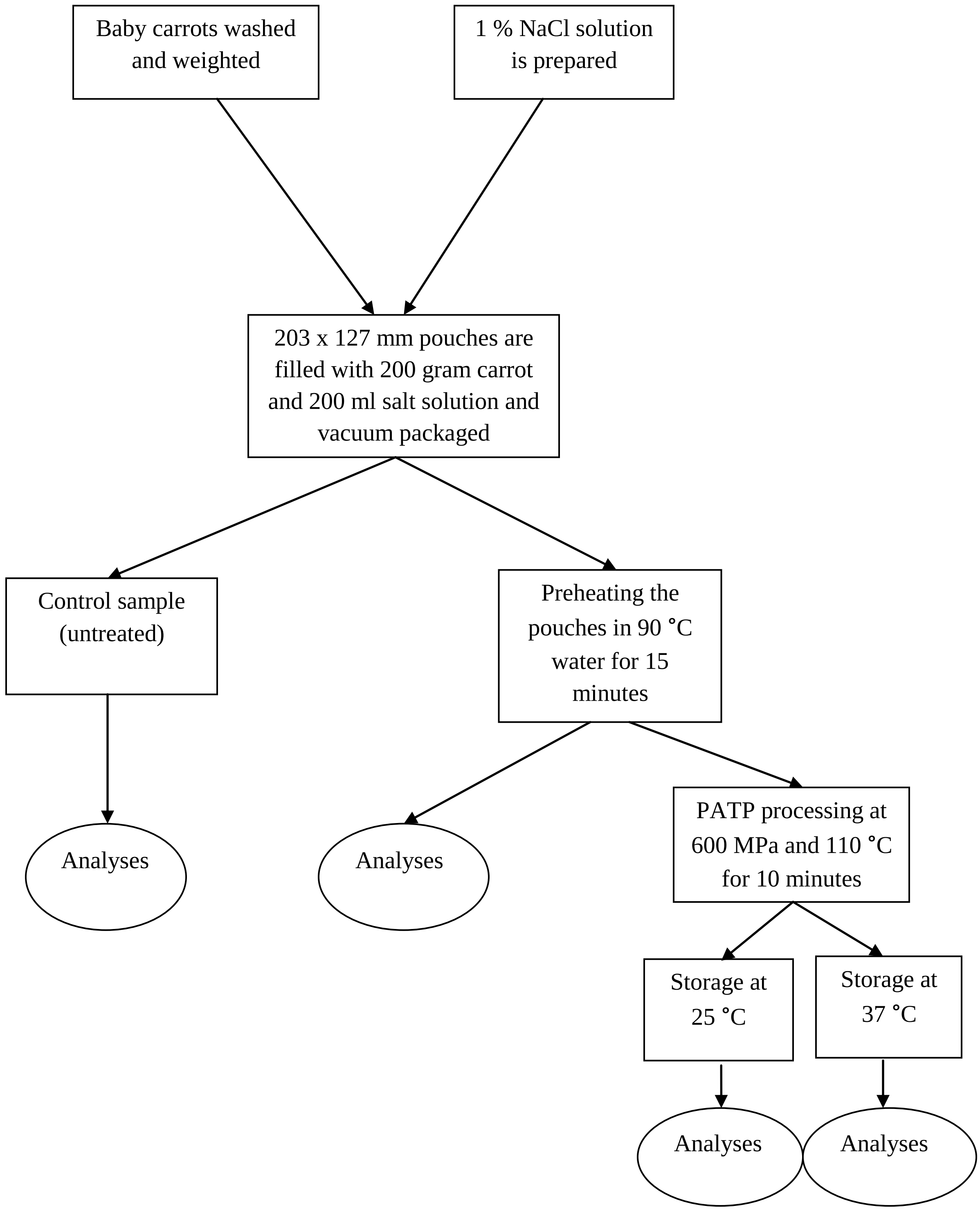

Figure 1. Process flow diagram for pressure-assisted thermal processing of carrots

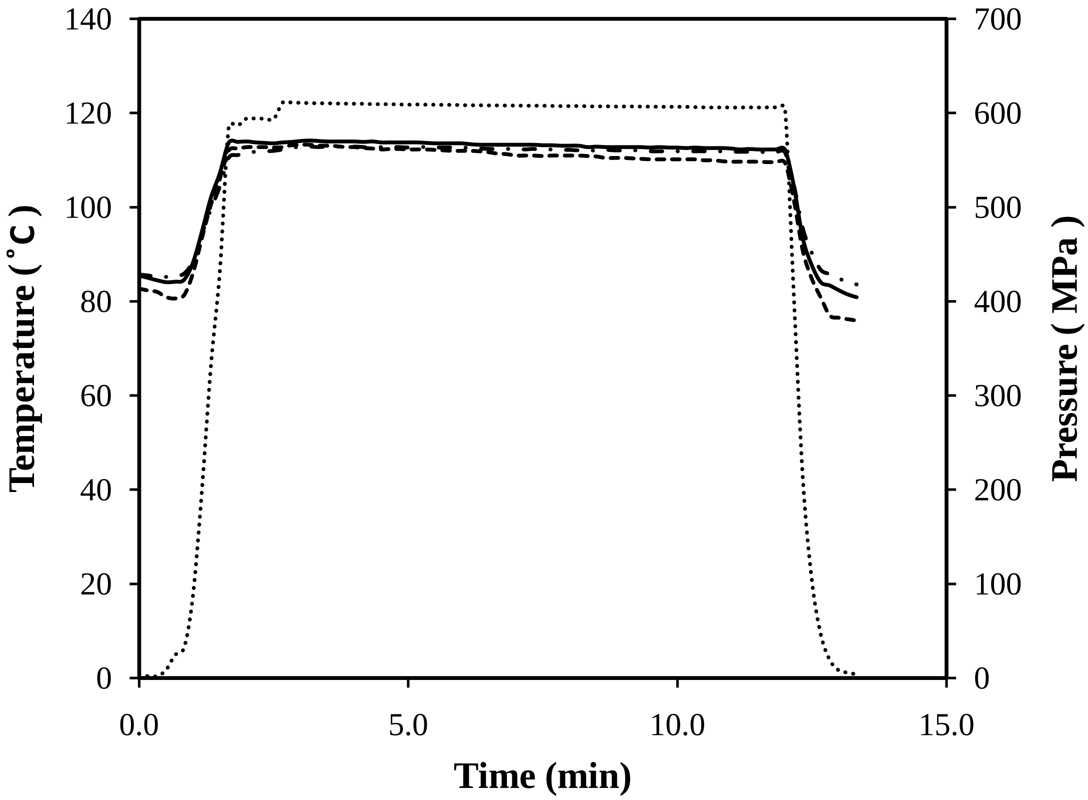

Figure 2. Sample temperature-pressure history for carrot samples processed at 600 MPa, 110 °C for 10 min. - - - - - , T $_{Bottom}$; ——— , T $_{Middle}$; – · – , T $_{Top}$; ········ , Pressure (MPa)

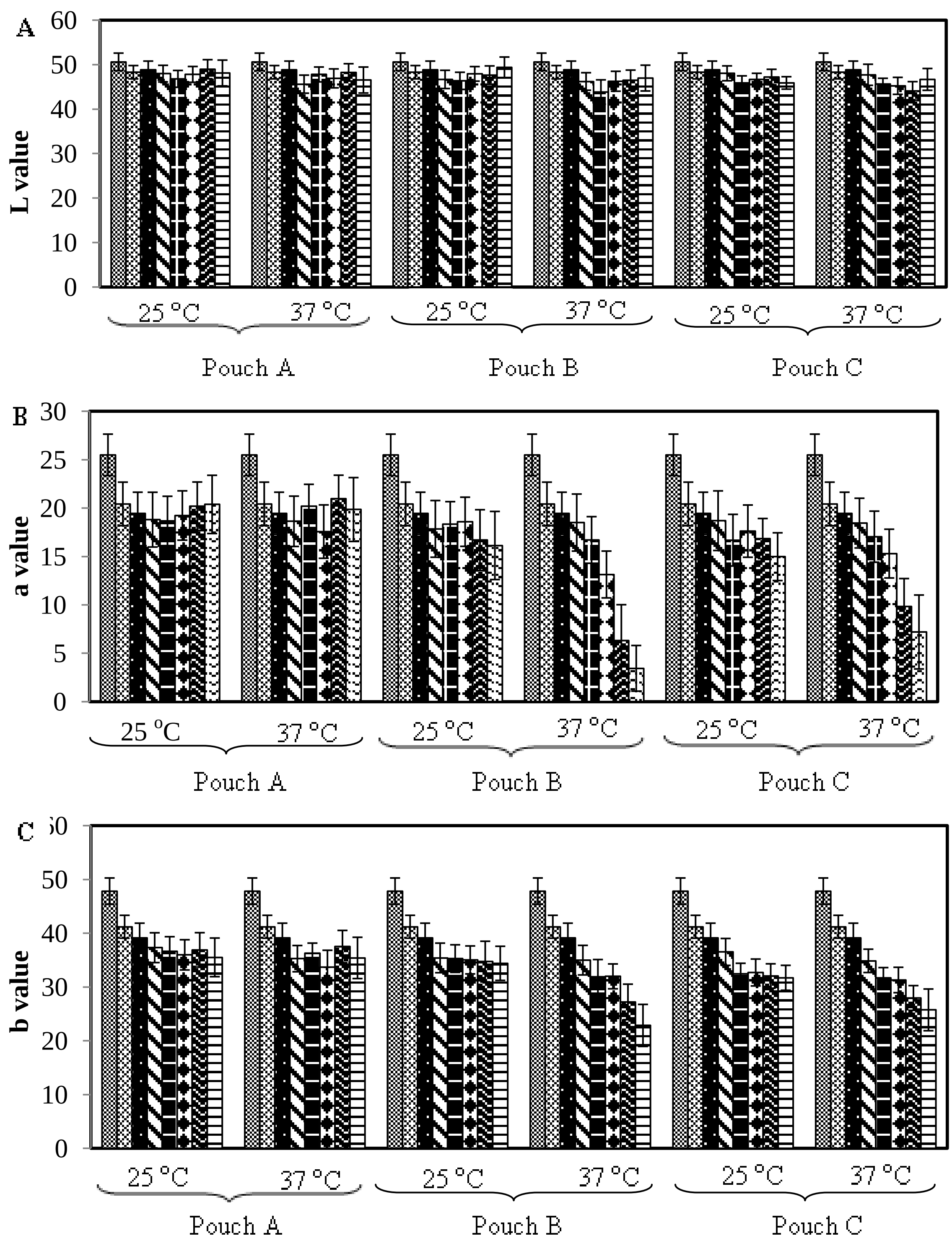

Figure 3. L, a and b values for carrots in different pouches and storage temperatures. A: Nylon / EVOH / EVA; B: Nylon / EVA; C: MetPET/PE. , raw carrot; , preheated; , 0 week; , 1st week; , 2nd week; , 4th week; , 8th week; , 12th week

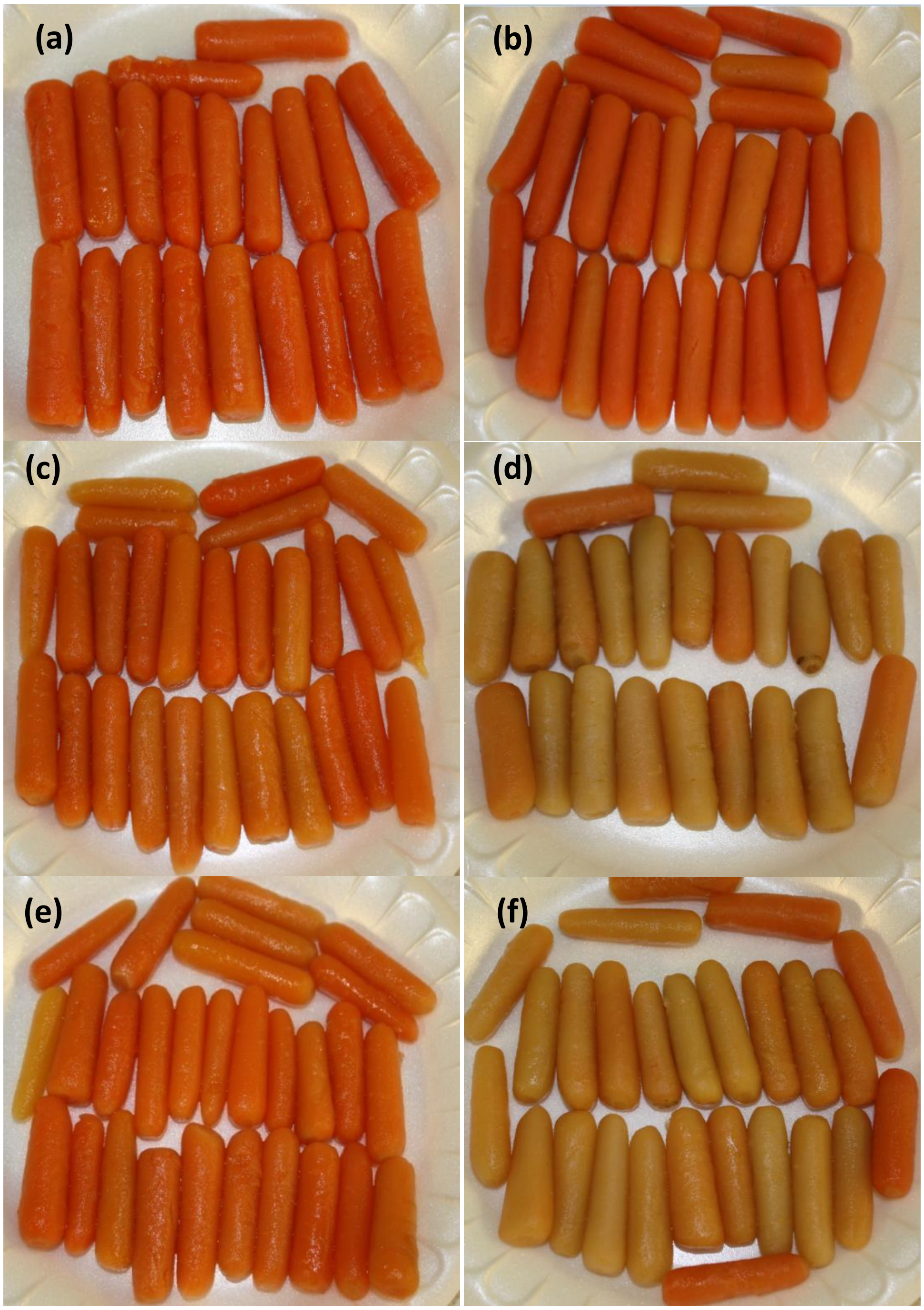

Figure 4. The color of carrots after PATP treatment and 12 weeks storage (a) Nylon/EVOH/EVA at 25 °C; (b) Nylon/EVOH/EVA at 37 °C; (c) Nylon/EVA at 25 °C; (d) Nylon/EVA at 37 °C; (e) MetPET/PE at 25 °C; (f) MetPET/PE at 37 °C.

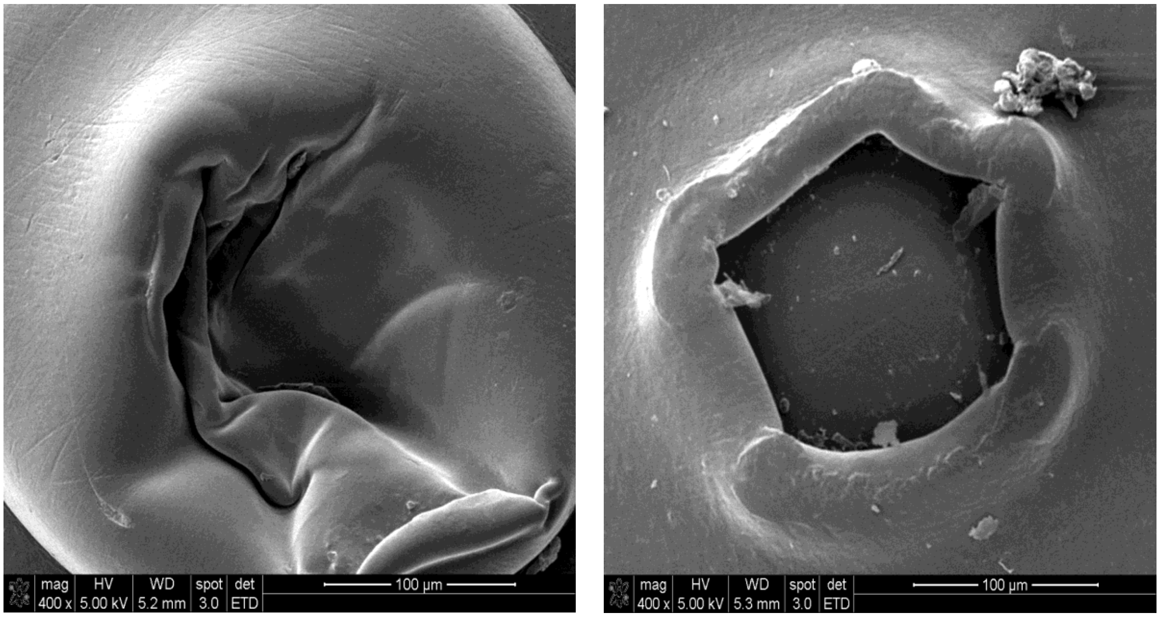

Figure 5. Scanning electron micrographs of Nylon/EVA pouch illustrating the pinholes a) PATP-treated only with no storage b) PATP-treated and stored at 25 °C for 12 weeks (magnification x400)