Effect of starch osmo-coating on carotenoids, colour and microstructure of dehydrated pumpkin slices

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Abstract Carotenoids in pumpkins are extremely unstable during industrial drying, to avoid the carotenoid degradation, starch osmo-coating was subjected to the pretreatment process for dehydrated pumpkin slices. The results showed that starch osmo-coating reduced the dehydration rate of pumpkin slices. When coated with corn starch, the retention rates of lutein, α -carotene and β -carotene in dehydrated pumpkin slices significantly increased by 11.3, 9.0 and 7.7%, respectively, and the provitamin A activity increased by 9.5%. 1% (w/v) modified corn osmo-coating gave highest retention rate of total carotenoids (95.5%), while provitamin A activity reached 4148 μ g RAE/100 g. In addition, the colour parameters ΔE and a^* values reduced, but L^* , b^* and H values increased with coated samples. Pearson correlation analysis showed that lutein, α -carotene and β -carotene were significantly positive correlated with L^* , and exhibited negative correlations with ΔE . The SEM indicated starch granules was attached to tissue gap and caused the film formation of oxygen barrier. It could be concluded that modified corn coating effectively improved the quality of final product.

Keywords Pumpkin · Starch osmo-coating · Dehydration · Carotenoids

Introduction

Carotenoids are pigments widely distributed in nature and responsible for the bright yellow to dark red colour of vegetal products. Many epidemiological studies have shown carotenoid intake associates with reduction in risk of developing degenerative diseases such as age-related macular degeneration (AMD), cataracts, cardiovascular disease (CVD), and specific cancers (Basu et al. 2001). Pumpkin (*Cucurbita moschata*) pulp contains large amounts of carotenoids, mainly β - and α -carotene, lutein, β -cryptoxanthin and zeaxanthin. It has been a potential source of pro-vitamin A (de Carvalho et al. 2012).

Drying or dehydration is frequently required to prolong shelf-life of perishable food for further use. However, nearly all drying techniques, including hot-air drying, microwave drying, microwave-vacuum drying and combining drying, etc., destroy or change the quality of final products with little hope of it being completely restored, especially for heat-sensitive fruits and vegetables (Nawirska et al. 2009). Hence it urgently needs to develop alternative pretreatment procedures that uttermost retain bioactive compounds such as carotenoids. Pretreatments of vegetables, fruits or other plant roots, stems, and leaves have been reported to significantly reduce carotenoid degradation (Dutta et al. 2005; Song et al. 2010).

Recent studies have suggested that the edible coating applied to crispy chips of fruits and vegetables prior to drying is a pretreatment technology that can improve the nutritional and sensory qualities of dehydrated products. Regarding fruit quality, the coating applied to papaya slices

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before drying enhanced vitamin C retention in comparison to papaya dried without coating, showing that pectin coating efficiently prevented oxidation of this bioactive compound (Garcia et al. 2014). Zhao and Chang (1995) and Sra et al. (2014) verified that edible coatings applied to carrots before hot air drying prevented oxidation of the carotenes, which was attributed to the reduced contact between oxygen and the tissue pigments. Coatings formed from polysaccharide materials, such as low-methoxylated pectin, cellulose and alginate etc., present good oxygen barrier properties due to their tightly packed, ordered, hydrogen-bonded network structure (Kou et al. 2014), especially under low moisture conditions (McHugh and Krochta 1994). Hence a polysaccharide coating applied to the food surface can be useful as a pretreatment for drying, since it prevents the oxidation of nutritional compounds, thereby improving the quality of the dried product.

Starch-based coatings are often utilized for fresh fruits and vegetables. There have been very few studies about the effect of starch osmo-coating on quality of dehydrated fruits and vegetables. Lenart and Piotrowski (2001) reported that coating with starch and pectin solutions significantly blocked the penetration of solute inside apples but did not affect the water removal during osmotic dehydration of samples. Zhao and Chang (1995) reported starch-treated carrot samples had a slower rate of carotene loss, and retained more ($P < 0.05$) red color than did control and sulfite-treated samples. Recently, Lago-Vanzela et al. (2013) evaluated the effect of the presence of starch-based coatings on the carotenoid content of pumpkin slices dehydrated using hot air. Significant improvement of carotenoid content was observed for dehydrated slices that were previously coated with a native maize starch solution at 90 °C, as well as with a modified maize starch solution at 30 °C and also with a modified cassava starch solution at 90 °C. However, osmo-coating is affected by starch type, solute concentration, temperature, time, and tissue compactness of the material, etc. The technique of film preparation should be adapted to the characteristics of starch, and only carefully preselected starches with superior permeability properties could be successfully used to obtain a sufficiently homogeneous system.

The main objective of this work was further to optimize the starch coating pre-treatment, and investigate the influence on the drying efficiency, colour, and carotenoids degradation in pumpkin slices, as also the structural changes occurring in the samples, aiming to obtain feasible coating conditions.

Materials and methods

Sample preparation

Pumpkins were purchased on a local market in Nanjing, China and stored at 4 °C. Prior to the treatment, the pumpkins were thoroughly washed and peeled, then cut into slices with thickness of 10 mm using a chip cutter.

Commercially available cassava starch, corn starch, potato starch and modified corn starch (supplied by Changchun Dahua Starch Co., Ltd. China) were used as coating materials. Starch coating films were prepared according to the method of Rodríguez et al. (2006) with some modifications. Briefly, certain amounts of starch was added into 1000 mL distilled water, the dispersion was heated with continuous stirring until it was completely gelatinized at their individual gelatinization temperatures (GT), and finally cooled it to 30 ± 1 °C, then 2% glycerol was added and well stirred for 2 min. GT was 70, 74, 65 and 66 °C detected by DSC for cassava starch, corn starch, potato starch and modified corn starch, respectively.

Ultrasound osmo-pretreatment

Prior to dehydration, the fresh pumpkin slices were placed and kept submerged in starch coating solutions. The material to solution ratio was 1:10 (w/w). Osmo-pretreatment was carried out under ultrasound irradiation (45 kHz, 300 W) for 1 min. Each sample was tested in duplicate and mean values were used in calculation. Finally, the pumpkin slices were removed from coating solutions, washed with water and gently blotted to remove excessive water. The samples were weighed and analyzed.

Microwave drying

Microwave drying was performed with a microwave vacuum dryer (MVD-1, Nanjing Xiaoma Electromechanical Equipment Company, Nanjing, China). Pumpkin slices were evenly placed on the turntable in the vacuum vessel. Microwave drying under the microwave power of 8 W/g was intermittently conducted with 3 min heating-on followed by 1 min heating-off. The drying was done until a final moisture content had reached to approximately 5.0%.

Carotenoid analysis

Carotenoid extraction, saponification and analysis procedures by C30-HPLC–DAD–MS were done based on preliminary studies (Song et al. 2016a, b; Li et al. 2015) in our laboratories. Lutein, β -carotene and α -carotene were mainly identified and quantified.

Retention rate and provitamin A activity was calculated as follows:

$$\text{Retention rate of uncoated dehydrated pumpkin slices (\%)} \\ = 100C_1/C_0$$

$$\text{Retention rate of coated dehydrated pumpkin slices (\%)} \\ = 100C_2/C_0$$

where C_0 - carotenoid content in fresh pumpkin slices ($\mu\text{g/g}$ d.w.); C_1 - carotenoid content in uncoated dehydrated pumpkin slices ($\mu\text{g/g}$ d.w.); C_2 - carotenoid content in uncoated dehydrated pumpkin slices ($\mu\text{g/g}$ d.w.)

Provitamin A activity was in terms of retinol activity equivalent (RAE). One RAE is equal to 12 μg all trans β -carotene or 24 μg of other provitamin A carotenoids (α -carotene) (Trumbo et al. 2003).

Colour determination

Colour parameters were measured (Chroma index, L^* , a^* , b^* , ΔE). The colour measurements were made on the surface of fresh sliced pumpkin before and after drying and the average values were made for calculation and each treatment was representing by three replicates. Total colour change (ΔE), chroma (C), was calculated using equations described by previous reports (Song et al. 2016a, b; Giri and Prasad 2007).

$$C = \left[(a^*)^2 + (b^*)^2 \right]^{1/2}$$

As the hue angle, when $a^* > 0$, $b^* > 0$, $H = \tan^{-1}(b^*/a^*)$; when $a^* < 0$, $b^* < 0$, $H = 180 + \tan^{-1}(b^*/a^*)$

$$\Delta E = \sqrt{(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2}$$

where; subscript “0” refers to the colour reading of fresh pumpkin slices. Fresh pumpkin was used as a reference and a larger ΔE denotes greater colour change from the reference material.

Microstructure

Microstructural changes during drying were analysed by scanning electron microscopy (SEM). Small pieces were taken from the inner parts of the pumpkin slices and were coated with a very thin layer of gold under high vacuum conditions and were analysed using a scanning electron microscope (EVO LS10, Carl Zeiss, Jena, Germany).

Statistical analysis

Data presented are means and standard deviations calculated from three independent replicates. An Analysis of Variance (ANOVA) and Duncan's multiple range test at $P < 0.05$

were applied using SAS (SAS Ver. 8.0, SAS Institute Inc., Cary, NC, USA). For the correlation of carotenoids and colour, the Pearson correlation coefficient was used by SPSS (SPSS Ver.16.0, SPSS Inc., Chicago, IL, USA).

Results and discussion

Drying curves

Figure 1 shows the drying curves of dehydrated pumpkin slices with starch omso-coating. Initially, the moisture content decreased rapidly and then it decreased rather slowly until reaching equilibrium for moisture content. This occurred because moisture gradients within the samples differed in two falling rate periods. The Page model ($MR = \exp[-(kt)^n]$) was used to fit the curves in Fig. 1. The values of drying constant k reflected the rate at which water from the sample was removed and k ranged from 0.23 to 0.26 under different starch coatings. The difference in k can be attributed to the fact that different starch coatings changed the driving force of heat mass transfer (Mali et al. 2004).

After coating with starch, the moisture ratio of pumpkin slices was significantly higher than the control group, in the case of non-pretreated pumpkin slices, the drying time required to reduce the moisture ratio below 0.2 when using microwave drying was approximately 1.2 times less than that required for potato starch pretreated samples. Similar result is noted in other studies. It demonstrated starch osmo-coating partly reduced the dehydration rate of pumpkin slices. Different types of starch produced different effects, it related with water resistance characteristics of starch film (Zobel 1988). Since cassava starches show lower amylose content (about 17%) (Charles et al. 2005),

Fig. 1 Drying curves of pumpkin slices by coating treatment with different starches

and some hydroxyl groups of the cassava starch molecule interact with hydroxyl groups of glycerol, it is supposed to reduce the hydrogen-bonding between starch chain, increase starch molecules mobility and greatly decrease starch crystallinity, therefore, cassava starch film had a larger moisture permeability and was easy to get dehydrated during drying process. However, due to there being hydrophilic phosphoric acid functional groups in the potato starch which water molecules can easily bind (Yu and Xia 2005), it resulted in difficulty in dehydration.

Carotenoids

Qualitative analysis of carotenoids in fresh pumpkin pulp

There are good linear relationships between the concentrations in 0.1–7.5 µg/mL for lutein and 4–40 µg/mL for β -carotene, with correlation coefficients of 0.9993 and 0.9992, respectively. A typical chromatogram of pumpkin carotenoids is shown in supplementary Fig. 1. The method used provided high resolution and high signal intensity, and showed good chromatographic separation for carotenoids. According to their characteristic retention time of standards, peak 1 and peak 3 were identified as lutein and β -carotene, respectively. Peak 3 possesses three maximum absorption wavelengths of 420, 446 and 472 nm respectively, with a molecular ion peak of m/z 537.4 and fragment ion peaks of m/z 481.4 and 444.4 of mass spectroscopy, which showed chromatographic data and UV–visible absorption spectra similar to those described for α -carotene, as had already been noted in another study (Cortés et al. 2004), these three carotenoids are predominant in the pumpkin species, with several other compounds detected in low concentrations or traces. They can be better studied with the use of a mass spectrophotometer, however, the separation, identification, and quantification of those carotenoids were not the aim of this work.

The fresh pulp of the tested pumpkin variety ‘Miben’ with gold colour, dense succulent, and delicate taste is a popular vegetable in China, which has higher carotenoid contents than the common one. In this study, lutein, α -carotene, and β -carotene contents of the selected sample was 46.97 µg/g d.w., 388.33 µg/g d.w. and 319.35 µg/g d.w., respectively, which accounted for 97% of total carotenoids. The Miben pumpkin had a high provitamin A activity (retinol activity equivalents, RAE: 4279 µg/100 g), it was identical with those reported in literature (Murkovic et al. 2002).

Changes of carotenoids and provitamin A activity

It was shown in Table 1, corn starch coated and potato starch coated dehydrated pumpkin slices were found to

have significantly ($P < 0.05$) higher TC retentions as compared to control sample. Pumpkin slices coated with corn starch reached highest TC retention rate of 95.5%, of which, the retention rates of lutein, α -carotene and β -carotene increased by 11.3, 9.1 and 7.7%, respectively, however, no significant change was observed in cassava starch coated samples. Additionally, the tested fresh pumpkin had a provitamin A activity of 4279 µg RAE/100 g, while its activity significantly decreased after microwave drying ($P < 0.05$), uncoated samples lost more than 12.8%. Likewise, osmo-coating with starch could retain provitamin A activity of dehydrated pumpkin slices, and corn starch film performed best, followed by potato starch, the result of cassava starch osmo-coating was not obvious. This is consistent with prior studies (Zhao and Chang 1995; Lago-Vanzela et al. 2013). Through coating pretreatment with starch, the surface or inside surface of dehydrated pumpkin slices formed the oxygen barrier, which delayed carotenoid oxidation. Rindlav-Westling and Gatenholm (2003) reported the oxygen barrier characteristics of starch was affected by starch granule size, ratio of amylopectin and amylose and the organizational structure of starch granules.

As also shown in Table 2, the effect of different concentrations of corn starch film on TC was significant ($P < 0.05$), 2% corn starch coating performed excellently. While provitamin A activity in dehydrated pumpkin slices coated with corn starch didn’t change obviously, merely increased by 9.5% when the concentration of corn starch was 2%. In addition, both 1 and 2% modified corn starches could significantly increase the retention rates of α -carotene and β -carotene (above 95%), TC retention was improved by 9.0%. However, modified corn starch coating with tested concentrations increased provitamin A activity by 11.2, 8.4 and 1.9%, respectively, it illustrated modified corn starch at a low concentration was prone to maintain the provitamin A activity of dehydrated pumpkin slices.

Zhao and Chang (1995) also confirmed soaking with 2.5% corn starch could reduce carotenoid loss. In our study, cross-linked corn starch further improved carotenoid retention, this might be due to the reason that alcoholic hydroxyl groups of corn starch interacted with multifunctional groups of cross-linking agent, which led to the formation of ester bonds, the cross-linking could help two or more of the starch molecules bridge and shape firm multidimensional network structures, therefore cohesiveness of modified corn starch increased, the air permeability of coated dehydrated samples reduced, this effectively inhibited oxidative degradation of carotenoids (Rindlav-Westling and Gatenholm 2003; Singh et al. 2007). Interestingly, when the concentration was 3%, modified corn starch negatively affect the retention rate of carotenoids, it was speculated that high concentration impaired water

Table 1 Effect of different starch osmo-coatings on the carotenoid retention and provitamin A activity in dehydrated pumpkin slices

Osmo-coating	Lutein		α -carotene		β -carotene		Total carotenoids		Provitamin A activity ($\mu\text{g RAE}/100\text{ g}$)
	Content ($\mu\text{g/g d.w.}$)	Retention (%)	Content ($\mu\text{g/g d.w.}$)	Retention (%)	Content ($\mu\text{g/g d.w.}$)	Retention (%)	Content ($\mu\text{g/g d.w.}$)	Retention (%)	
Fresh	46.97 $\pm$ 0.92 ^a	–	388.33 $\pm$ 10.54 ^a	–	319.35 $\pm$ 8.27 ^a	–	754.65 $\pm$ 18.66 ^a	–	4279
Control	33.40 $\pm$ 0.85 ^d	71.1 $\pm$ 1.8 ^c	340.28 $\pm$ 9.83 ^d	87.6 $\pm$ 2.5 ^c	277.47 $\pm$ 5.39 ^e	86.9 $\pm$ 1.7 ^d	651.15 $\pm$ 10.28 ^e	86.6 $\pm$ 1.3 ^d	3730
Cassava starch	36.19 $\pm$ 1.33 ^c	77.1 $\pm$ 2.8 ^b	339.17 $\pm$ 9.60 ^d	87.3 $\pm$ 2.5 ^c	285.72 $\pm$ 8.20 ^{cd}	89.5 $\pm$ 2.5 ^{bc}	661.08 $\pm$ 19.09 ^{de}	87.9 $\pm$ 2.4 ^{cd}	3780
Corn starch	38.68 $\pm$ 2.60 ^b	82.4 $\pm$ 5.5 ^a	375.34 $\pm$ 6.58 ^b	96.7 $\pm$ 1.7 ^a	302.25 $\pm$ 4.97 ^b	94.6 $\pm$ 1.6 ^a	716.27 $\pm$ 9.55 ^b	95.5 $\pm$ 1.2 ^a	4083
Potato starch	36.92 $\pm$ 1.19 ^{bc}	78.6 $\pm$ 2.5 ^{ab}	357.07 $\pm$ 5.30 ^c	92.0 $\pm$ 1.4 ^b	290.93 $\pm$ 5.26 ^c	91.1 $\pm$ 1.6 ^b	684.92 $\pm$ 8.48 ^c	91.6 $\pm$ 1.1 ^b	3904

Data followed by different letters within the same column indicate significantly different

Table 2 Effect of corn starch and corn distarch phosphate coatings on the carotenoid retention and provitamin A activity in dehydrated pumpkin slices

Osmo-coating	Lutein		α -carotene		β -carotene		Total carotenoids		Provitamin A activity ($\mu\text{g RAE}/100\text{ g}$)
	Content ($\mu\text{g/g d.w.}$)	Retention (%)	Content ($\mu\text{g/g d.w.}$)	Retention (%)	Content ($\mu\text{g/g d.w.}$)	Retention (%)	Content ($\mu\text{g/g d.w.}$)	Retention (%)	
Control	33.40 $\pm$ 0.85 ^b	71.1 $\pm$ 1.8 ^b	340.28 $\pm$ 9.83 ^{bc}	87.6 $\pm$ 2.5 ^{bc}	277.47 $\pm$ 5.39 ^c	86.9 $\pm$ 1.7 ^c	651.15 $\pm$ 10.28 ^{bc}	86.6 $\pm$ 1.3 ^{bc}	3730
Corn starch	1%	26.60 $\pm$ 1.11 ^c	334.84 $\pm$ 8.40 ^c	86.2 $\pm$ 2.2 ^c	274.06 $\pm$ 7.22 ^c	85.8 $\pm$ 2.3 ^c	635.50 $\pm$ 16.11 ^c	84.6 $\pm$ 2.1 ^c	3679
	2%	38.68 $\pm$ 2.60 ^a	82.4 $\pm$ 5.5 ^a	375.34 $\pm$ 6.58 ^a	96.7 $\pm$ 1.7 ^a	302.25 $\pm$ 4.97 ^{ab}	716.27 $\pm$ 9.55 ^a	95.5 $\pm$ 1.2 ^a	4083
	3%	32.60 $\pm$ 1.82 ^b	69.4 $\pm$ 3.9 ^b	350.18 $\pm$ 8.60 ^b	90.2 $\pm$ 2.2 ^b	283.06 $\pm$ 7.27 ^c	665.84 $\pm$ 17.81 ^b	88.6 $\pm$ 2.3 ^b	3818
Modified corn starch	1%	33.81 $\pm$ 0.54 ^b	72.0 $\pm$ 1.2 ^b	374.86 $\pm$ 6.57 ^a	96.5 $\pm$ 1.7 ^a	310.29 $\pm$ 8.37 ^a	718.96 $\pm$ 15.09 ^a	95.6 $\pm$ 1.9 ^a	4148
	2%	33.69 $\pm$ 0.78 ^b	71.7 $\pm$ 1.7 ^b	369.95 $\pm$ 5.79 ^a	95.3 $\pm$ 1.5 ^a	300.08 $\pm$ 4.54 ^b	703.72 $\pm$ 9.60 ^a	93.6 $\pm$ 1.2 ^a	4042
	3%	32.37 $\pm$ 1.38 ^b	68.9 $\pm$ 2.9 ^b	347.01 $\pm$ 3.08 ^b	89.4 $\pm$ 0.8 ^b	282.73 $\pm$ 2.77 ^c	662.11 $\pm$ 7.22 ^b	87.9 $\pm$ 0.9 ^b	3802

Data followed by different letters within the same column indicate significantly different

evaporation during microwave drying (Garcia et al. 2006), which triggered sustained high temperature inside pumpkin slices, this caused thermal degradation of carotenoids.

Colour

Color coordinates L^* , a^* and b^* and other colour functions were studied in relation to the pigment change. Compared with fresh pumpkins (Supplementary Table 1), L^* (whiteness/darkness) decreased significantly ($P < 0.05$), it showed microwave drying caused the colour of pumpkin to darken. Moreover, it showed an increase in a^* value, and no significant change of the b^* value was observed during microwave drying, the change in ΔE value was also expected, and possibly due to browning caused from partial caramelisation of sugars at high microwave temperatures (Albanese et al. 2013). Coated with cassava starch, corn starch and potato starch, respectively, ΔE of dehydrated pumpkin slices all decreased and L^* increased compared with uncoated samples, of which corn starch and potato starch omso-coating groups both reached the significant levels ($P < 0.05$). Meanwhile, H , b^* (yellowness/blueness) and C (colour intensity) significantly increased, a^* (redness/greenness) decreased significantly ($P < 0.05$) for corn starch coated samples, no obvious changes were observed for cassava starch and potato starch coated samples. As a whole, corn starch coating had a positive influence on the degradation of carotenoids. Supplementary Table 2 shows changes in colour of dried pumpkin slices after different concentrations of corn starch and corn distarch phosphate coatings. 1% modified corn starch decreased ΔE value significantly, and the efficiency was superior to other concentrations of starch films. In the meantime, L^* and H values significantly increased, while a^* value significantly decreased ($P < 0.05$), no obvious changes were observed in b^* and C values, it translated that dehydrated pumpkin slices lost its redness and maintained its yellowness when coated with modified corn starch.

Table 3 shows the correlation between colour and carotenoids of dried pumpkin slices after coatings. Generally, there was a significantly positive correlation between lutein, α -carotene and β -carotene and L^* value ($P < 0.01$), but negatively related with ΔE . It demonstrated colour

properties (L^* and ΔE) of dehydrated pumpkin slices were largely related to the presence of lutein, α -carotene and β -carotene. It indicated that L^* and ΔE were good predictors of both lutein, α -carotene and β -carotene thermal degradation. These colour changes might be used to define adequate omso-coating conditions for maximizing the final product quality (Garcia et al. 2014; Baloch et al. 1986).

Microstructure

Scanning electron micrographies of dehydrated pumpkins obtained by different starch omso-coatings are shown in Fig. 2. For dehydrated samples, microwave drying led to an increase in the intercellular gaps. Middle lamella was affected by microwave energy, so cell walls were collapsed (Askari et al. 2006). Cellular puffing during the microwave drying was observed, but since the irradiation had expired, cellular walls could not preserve the induced volume and as a result, the cellular structure came back to its original state and consequently lost its fundamental cellular configuration (Fig. 2a). Samples coated with cassava starch had a scattered distribution of intercellular gaps similar to those coated with potato starch (Fig. 2b and c). It can be explained that hardening phenomena occurred (Mishra and Rai 2006). However, both corn starch and modified corn starch coatings induced a very thin superficial layer on the sample's surface showing good coating characteristics (Fig. 2d and e), therefore it was beneficial to reduce an undesirable oxygen exposure (Xie et al. 2009; López et al. 2010).

Conclusions

In this study, starch omso-coating can retard the colour change of pumpkin slices, reduce the loss of carotenoids and improve the quality of dehydrated pumpkin slices. 1% (w/v) modified corn omso-coating gave highest retention rate of total carotenoids (95.5%), while provitamin A activity reached 4148 $\mu\text{g RAE}/100\text{ g}$. In addition, lutein, α -carotene and β -carotene were significantly positive correlated with L^* , and exhibited negative correlations with ΔE of coated dehydrated samples. Thus, it could be used as

Table 3 The correlation between colour and carotenoids of dehydrated pumpkin slices after omso-coating

	Coefficient of correlation					
	L^*	a^*	b^*	C	H	ΔE
Lutein	0.903**	− 0.275	− 0.331	− 0.453	0.060	− 0.637
α -carotene	0.724*	− 0.398	− 0.239	− 0.236	0.292	− 0.930**
β -carotene	0.747*	− 0.464	− 0.280	− 0.252	0.353	− 0.901**

*Represented a significant correlation ($P < 0.05$); **Represented an extremely significant correlation ($P < 0.01$)

Fig. 2 The microstructure of dehydrated pumpkin slices coated with different starches (SEM, $\times 1000$)

a process marker. Also, the SEM indicated starch granules was attached to tissue gap and caused the film formation of oxygen barrier, which was the probable cause of the improved quality. Further study should be conducted on the uniformity, permeability and stability of the osmo-coating film. The dehydrated pumpkin slices investigated can be expected to be an alternative crisp food, starch osmo-coating could probably improve the quality of the final product.

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