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Effect of sodium alginate coating on osmotic dehydration of pumpkin

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Abstract

The effect of coating blanched pumpkin cubes with sodium alginate (SA) on water loss (WL), solid gain (SG), physicochemical qualities and cell structure of osmotic dehydrated (OD) pumpkin was studied. Pumpkin samples coated with 1.0%, 2.0%, 3.0% SA (w/w), and samples without coating (control) were immersed in 70% (w/w) sucrose solution with a ratio of solution to sample of 4:1 for 12 h. The results showed that WL, hardness and reducing sugar of coated samples at the equilibrium point were higher than those of samples without coating significantly ($p<0.05$), while water activity, moisture content, SG and total sugar of coated samples were less than samples without coating significantly ($p<0.05$). Coating with 3.0% SA gave the highest process efficiency index (WL/SG) of 5.28.

Introduction

Pumpkin is a vegetable in the family Cucurbitaceae (Silva *et al*., 2011). It has high beta-carotene and essential nutrients e.g. C, E, B6, as well as minerals, e.g. potassium, phosphorus, magnesium, iron and selenium (Pękosławska and Lenart, 2009; Zawirska *et al*., 2009). Cell wall structure of vegetables and fruits will change according to the mutuality and has a direct effect on the rate of osmosis (Wanida, 2000). The diffusion of the solvent into the cell of immature pumpkin was higher than ripe pumpkin because the ripe pumpkin had high starch content resulting in strong structures and less porosity.

Osmotic dehydration (OD) is one of food preservation techniques in the processing of dehydrated foods, reducing the damage of heat to the flavor, color, inhibiting the browning of enzymes and decrease the energy costs (Alakali *et al*., 2006; Torres *et al*., 2006; Yuenyongputtakal and Maneepan, 2011; Khan, 2012). Osmotic dehydration is a drying method with the principle of osmosis, i.e., sugar in the syrup penetrates into products gradually. OD is widely used to remove water from fruits and vegetables by immersion in aqueous solution of sugars and/or salts at high concentration (İspir and Toğrul, 2009). This process results in weight loss and solid gain. It has been reported that osmotic dehydration reduced up to 50% weight of fresh vegetables and fruits (Rastogi and Raghavarao, 1997; Khan, 2012). Much research was conducted to investigate mass transfer during osmotic dehydration of fruits and vegetables by varying the concentration of sucrose solution in the range of 30-70% (Rastogi and Raghavarao, 1994; Khoyi and Hesari, 2007; Lee and Lim, 2011; Phisut, 2012; Yadav and Singh, 2014). Rastogi and Raghavarao (1996) was reported that an increase in concentration of the osmotic solution increased the rate of mass transfer up to a certain extent, above which undesirable changes in flavor, color and the texture of the product were observed. However, for the OD process, the concentration of sucrose solution should not be above 70%, otherwise the viscosity would be too high and thus reduce the mass transfer rate.

Silva *et al.* (2011) studied the osmotic dehydration process for low temperature blanched pumpkin and found that blanching affected the color of the pumpkin, whereas osmotic dehydration did not change it significantly. İspir and Toğrul (2009) studied the osmotic dehydration of apricot. They found that the increasing of temperature and concentration of osmotic medium caused increased water loss and solid gain. The water loss and solid gain were increased when the dimension of apricot was decreased. Jokić *et al.* (2007) studied the osmotic dehydration of sugar beet in combined aqueous solutions of sucrose and sodium chloride and found

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that WL was mainly affected by immersion time and sucrose concentration. Also it was found that addition of small quantities of sodium chloride led to higher dehydration rate without increase in SG.

Presently, consumers raise their concerns on health issues and prefer to consume products with low sugar. Thus, developing OD products with lower sugar content is an interesting research. Recently, edible semi-permeable membrane coating was applied to products before osmotic dehydration to reduce the amount of sugar absorbed.

Edible coatings are fine layers of digestible material added to a food product, which may be classified into three categories: polysaccharides, lipids and proteins (Lago-Vanzela *et al*., 2013). Lazarides *et al.* (2007) studied edible coating and counter-current product/solution contacting to monitor solids uptake during osmotic dehydration of a model food system. They found that counter-current product/solution contacting contributed to faster water loss and slower solids uptake. In both flow-types, initial solids had a significant impact on both water loss and solids uptake. Matuska *et al.* (2006) studied on the use of edible coatings to monitor osmotic dehydration kinetics for minimal solids uptake and reported that using edible coatings could increase water removal and prevent solute uptake. Among tested materials and coating procedures, double coating with a 0.5% sodium alginate (SA) solution gave the best results in terms of a high water loss (WL) to solid gain (SG) ratio (WL/SG), and single or double SA coating inhibited leakage losses upon freeze/thawing of osmotically treated strawberries. Lowering leakage losses was beneficial both in terms of higher product yield and in terms of marginally improved product texture. Singh *et al.* (2010) investigated the pre-treatment of edible coatings with 0.5% to 5.0% SA solution before OD of pineapple samples. Their results showed that the lowest SG and the highest performance ratio (WL/SG) were observed in the pineapple samples coated with 2% SA. They also reported that WL increased whereas SG decreased up to a certain concentration level of coating solution. Khin *et al.* (2007) studied the impact of process conditions and coatings with SA and low methoxyl pectinate (LMP) on the dehydration efficiency and cellular structure of apple tissue during osmotic dehydration. They found that higher performance ratio was found in the coated apples at high temperature of 55ºC. Better performance was obtained when sucrose was the osmotic agent as compared to dextrose. Better dehydration efficiency was found in the coated samples at higher temperatures than at low temperature. SEM results revealed that the cellular structure of the coated apples was better maintained than that of the non-coated samples, when osmotically dehydrated by sucrose solution at 55ºC. Garćia *et al*. (2010) studied the effects of chitosan coating on mass transfer during osmotic dehydration of papaya. They reported from their study that chitosan coatings improved the efficiency of osmotic dehydration process in both ripening stages, increasing the water loss and decreasing the solids gain. From the previous studies, sodium alginate (SA) is one of the edible coating materials in the coating because SA is a hydrocolloid, which is a polysaccharides obtained from the major structural carbohydrate in brown seaweeds. It is non-toxic, biodegradable and edible, and can be used for coating directly. So far there is no research on using SA for the coating before osmotic dehydration of pumpkin.

The aim of this work was to study the effect of SA coating before osmotic dehydration on water loss, solid gain, physicochemical qualities and cell structure of the non-coated and coated OD pumpkin samples. The appropriate level of SA coating was also determined for the OD process of pumpkin based on qualities and process efficiency index (WL/SG).

Materials and Methods

Sample preparation

Immature pumpkin (*Cucurbita* spp.) was purchased from a local market (Ying-Cha-Roen market), taking into account homogeneity in size, shape and ripeness. A manually operated vegetable dicer was used to prepare pumpkin cubes of dimensions 1×1×1 cm^3. The cubes were washed with water, soaked in 1% (w/w) CaC_{l2} solution for 30 min, blanched with steam for 10 min, and then cooling in cold water. Then, physicochemical characteristics of the pumpkin cubes were determined; color using Spectrophotometer (Minolta, CM-3500d, Japan), water activity (a_w) using Aqualab (Aw CX3TE), hardness determined using Lloyd (TA500), moisture content (%wet basis, wb) according to AOAC (2000), total sugar and reducing sugar by Lane and Eynon (1923).

Preparation of coating material with sodium alginate (SA)

In this study, 0% (control), 1%, 2% and 3% (w/w) sodium alginate (SA) were used as coating solution. The preparation of coating solution was prepared by dispersing SA in deionize water. The SA solution was heated to 70^{o}C and then was cooled to room temperature (Matuska *et al*., 2006).

Osmotic dehydration of non-coated pumpkin

Pumpkin cubes obtained from the preparation process were immersed in sucrose solution in 70% (w/w) concentration for 12 h. After 12 h, the OD process has already reached its equilibrium point. The osmotic solution to sample ratio was set at 4:1. Temperature of the osmotic solution was maintained at 30^{o}C.

Osmotic dehydration of coated pumpkin

In this study, samples with 1%, 2% and 3% SA coating were compared with non-coating samples. The coated pumpkin cubes were prepared by dipping in the coating material solution (1%, 2% and 3% SA, w/w) for 5 min. The coated pumpkin cubes were immersed in $CaCl_2$ solution (1% w/w) for 30 min (Khin, 2007). Then they were immersed in a sucrose solution with the same condition as the osmotic dehydration of pumpkin without coating.

Quality measurement of non-coated and coated pumpkin

Non-coated and coated pumpkin cubes were measured their qualities. All analyses were performed in triplicate. Moisture content (MC) and reducing sugar was measured. Total soluble solid was studied in terms of WL and SG after OD, according to the follow equations (Kaymak-Ertekin and Sultanoglu, 2000):

$$WL\ (\%) = [(M_O X_O^{W} - M_t X_t^{W}) / M_O] \times 100$$

$$SG\ (\%) = [(M_t X_t^{ts} - M_O X_O^{ts}) / M_O] \times 100$$

where M_O is initial weight of sample (g), M_t is weight of sample after osmotic dehydration (g), X_O^W is the initial moisture on wet basis of sample (g water/g sample), X_t^W is the moisture on wet basis of sample after osmotic dehydration (g water/g sample), X_O^{ts} is the initial solid content of sample (g total solids/g sample), and X_t^{ts} is the solid content of sample after osmotic dehydration (g total solids/g sample).

The process efficiency index (WL/SG) was used for evaluation of efficiency of the OD process due to it easy interpretation. If water loss and solid gain ratio increases, it means one of these three possibilities: 1. the process is favoring the water loss and solids gain, but mostly the water loss; 2. the process limits the solids gain; and 3. the process favors the water loss (Matuska, 2006; García, 2010).

Color of samples was measured in CIE system (L^*, a^*, b^*) by a colorimeter (Minolta Model CM-3500d, Japan). Hardness of samples was investigated by a texture analyzer (Lloyd, TA500, UK) with single hardness value. A ball probe (P/0.5) was used with 10 mm/min test speed and the deformation ratio was 50% (Nimmanpipug *et al*., 2013). The microstructure (internal and external structure) of OD samples was investigated by a scanning electron microscope (JEOL, JSM – 5410 LV, Japan) with an accelerating voltage of 15 kV. The total magnification was 350x for capturing the images. The preparation of samples for the scanning electron microscope (SEM) followed the instruction in Mukhopadhyay (2003). Water activity was measured by Aqua Lab (CX3TE, USA).

Statistical analysis

All experiments were conducted with three independent replications. Means of all treatments were analyzed using ANOVA (SPSS version 12.0, SPSS (Thailand) Co., Ltd., Bangkok, Thailand). Duncan's multiple range tests was used to identify differences at the 95% significance level.

Results and Discussion

Physicochemical qualities of fresh and blanched pumpkin

Physicochemical qualities of fresh and blanched pumpkin were presented in Table 1. From the results, aw of fresh and blanched pumpkin cubes were the same because fresh and blanched pumpkin cubes had high amount of water. Blanched pumpkin cubes had slightly higher moisture content than fresh pumpkin cubes since blanched pumpkin cubes had to pass the blanching and cooling process. By blanching, the lightness and redness of blanched pumpkin decreased whereas the yellowness increased due to browning reaction during the blanching process Even though there was an attempt to stop the browning reaction by immersing the samples in cool water right after the blanching process, the reaction still occurred. Moreover, the hardness values of blanched pumpkin were significantly lower than fresh pumpkin because blanching softened the texture of pumpkin cubes and also decreased the reducing sugar and total sugar contents of pumpkin cubes.

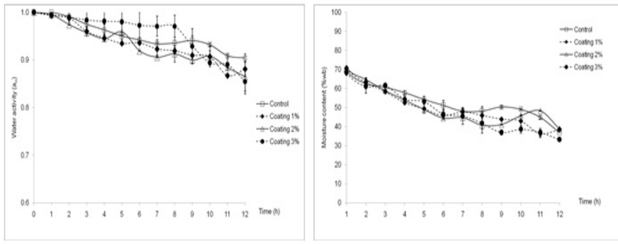
Physicochemical qualities of non-coated and coated OD pumpkin

MC and aw of non-coated and coated OD pumpkin are shown in Figure 1. A decrease in aw of coated pumpkin during OD was observed when immersion time was increased for all process conditions because of gradual diffusion of water out of the pumpkin pieces and diffusion of sugar into pumpkin pieces. Raoult's law reported that solute would reduce the vapor pressure of water in food resulting in decreased

Table 1. Total quality of fresh and blanched pumpkin cubes with steam

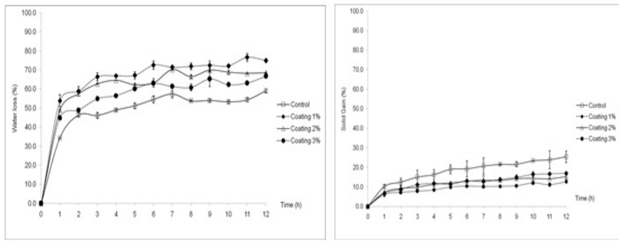
Chemical and Physical properties	Fresh	Blanched
a_w	1.00 ± 0^{a}	1.00 ± 0^{a}
Moisture content (%wb)	88.84 ± 1.59^{a}	89.35 ± 1.64^{a}
Lightness (L*)	66.28 ± 3.69^{b}	54.70 ± 4.31^{a}
Redness (a*)	10.96 ± 1.52^{a}	10.29 ± 1.19^{a}
Yellowness (b*)	56.36 ± 4.28^{a}	66.02 ± 3.94^{b}
Hardness (N)	44.11 ± 16.34^{b}	1.38 ± 1.40^{a}
Reducing sugar (%)	2.78 ± 0.28^{b}	2.13 ± 0.41^{a}
Total sugar (%)	3.97 ± 0.31^{b}	2.99 ± 0.60^{a}

Values were mean ± standard deviation. Values with different superscript letters within the same row were significantly different ($p<0.05$).



a b

Figure 1. a_w (a) and moisture content (b) of non-coated pumpkin and coated pumpkin with 1%, 2% and 3% sodium alginate during osmotic dehydration



a b

Figure 2. Water Loss (a) and Solid Gain (b) of non-coated pumpkin and coated pumpkin with 1%, 2% and 3% sodium alginate during osmotic dehydration

aw (Fennema, 1976). When samples was coated with 3% SA, aw was decreased slowly. SA coating thickness not only reduced the diffusion of sugar into the pumpkin cubes but it also reduced the diffusion of water from pumpkin cubes to the OD solution. The OD process of coated samples reached the equilibrium point slower than non-coated samples because non-coated samples had a better mass transfer of water from sample to the OD solution. However, aw of coated samples were significantly lower than aw of non-coated samples at the equilibrium point ($p<0.05$) because coating allowed water in pumpkin cubes diffuse to the osmotic solution but not allowing the solute to diffuse into the pumpkin cubes, or reducing the diffusion of substance into the pumpkin cubes. MC of pumpkin rapidly decreased during the first three hours of the OD. At the equilibrium point, MC of 1% and 2% SA coated samples were not significantly different than MC of non-coated sample, while MC of 3% SA coated sample was significantly lower than MC of non-coated sample ($p<0.05$). The reason might be because films developed by 1% and 2% SA coating were not thick enough to reduce the diffusion of sugar and water through the films between the pumpkin cubes and the OD solution. While 3% SA coating gave a thicker film, which allowed water in pumpkin cubes diffuse to the osmotic solution but reducing the solute to diffuse into the pumpkin cubes.

During the OD process, when immersion time increased, WL and SG increased as shown in Figure 2. WL and SG of non-coated samples increased rapidly during the first two hours of OD after that WL and SG increased gradually, while WL and SG of coated samples increased quickly during the first three hours and the first hour, respectively, and then WL and SG increased gradually. The results were corresponded with García *et al*. (2010) which found that the highest of WL occurred during the first three hours of the OD process of papaya. Pękosławska and Lenart (2009) also reported the osmotic dehydration of pumpkin in a starch syrup that the most intensive mass flow was observed at the beginning of the process for 60 and 180 min. This effect was possibly due to a higher difference in the chemical potential solutes between the sample and osmotic solution. WL is the flow of water from the material to the osmotic solution, and SG is the flow of sucrose from the solution to the material. WL and SG during the initial process increased very fast because the difference between mass concentration of tissue in fruit or vegetable and high concentrated osmotic solutions caused high osmotic pressure (Nutthanun, 2013). After that osmotic pressure was decreased until the equilibrium point of mass transfer; therefore WL and SG were slowly decreased.

At the equilibrium point, WL of non-coated and coated samples were significantly different ($p<0.05$). WL of the coated samples was higher than the non-coated sample, while SG of the coated samples was much lower than non-coated samples significantly ($p<0.05$). The lowest SG was found in the 3% coated sample, while the highest SG was found in the non-

Table 2. Quality measurement of non-coated and coated pumpkin cubes with sodium alginate at the equilibrium point of osmotic dehydration

Treatments	Control	Coating 1%	Coating 2%	Coating 3%
Lightness (L*)	46.16±2.18^{c}	46.23±1.58^{c}	44.94±0.21^{b}	40.21±0.37^{a}
Redness (a*)	12.43±0.74^{a}	15.44±0.22^{d}	13.88±0.04^{b}	14.54±0.45^{c}
Yellowness (b*)	51.80±0.06^{d}	47.19±3.90^{c}	41.70±0.58^{b}	35.51±0.07^{a}
Hardness (N)	1.06±0.16^{a}	2.58±0.43^{b}	3.4±0.18^{b}	3.74±0.86^{c}
Reducing sugar (%)	22.63±0.06^{a}	32.81±0.12^{c}	32.97±0.06^{c}	31.00±0.36^{b}
Total sugar (%)	38.33±0.16^{b}	38.72±0.40^{b}	38.53±0.23^{b}	35.76±0.88^{a}
WL/SG	2.32	4.42	4.49	5.28

Values were mean ± standard deviation.
$^{a-d}$ Means within the same row followed by different superscript letters were significantly different ($p<0.05$).

coated sample. The results showed that a higher percentage of SA coating produced a thicker film. This thicker film reduced a mass transfer of solute from the osmotic solution into the samples but increased a mass transfer of water from the samples to the osmotic solution. Therefore, the coating could reduce the permeability of sugar and inhibit solid (solute) uptake allowing a faster water removal (Matuska, 2006).

Quality measurement of non-coated and coated pumpkin at the equilibrium point

Table 2 showed the values of L^*, a^*, b^*, hardness, reducing sugar, total sugar, and WL/SG of non-coated and coated OD pumpkin at the equilibrium point of the OD process. It was found that coating with different percentage of SA affected the color of the samples. Coating pumpkin samples with higher percentage of SA resulted in decreasing L^* and b^* values but increasing in a* value after the OD process due to a thicker film. The pumpkin samples after the OD process had lower lightness and yellowness than the samples before the OD process since a browning reaction was induced in the samples with high sugar content (Wanida, 2000).

Coated samples had significantly higher hardness values than non-coated samples. The harness values also increased when the pumpkin samples were coated with a higher level of SA because a higher level of SA percentage developed a harder film around the samples. The reducing sugar of the control was lower than coated samples because the reducing sugar in the pumpkin samples could not pass through the coating material and cell membrane into the osmotic solution. For the total sugar content, the samples coated with 3% SA had significantly lower the total sugar content than other treatments ($p<0.05$). The 3% coated sample had the lowest level of total sugar because coating could substantially increase dehydration and decrease solid uptake rates (Matuska, 2006). Among all samples, the highest process efficiency index was founded for the coated with 3% SA, while the lowest process efficiency index was found in the non-coated or control.

Structure of OD non-coated and coated pumpkin

The internal and external structures of non-coated and coated OD pumpkin samples with SEM at the magnification of 350 were shown in Figure 3. The structure of cells and intercellular spaces of non-coated OD pumpkin samples in Figure 3 (a-b) was porous and well-arranged corresponding with the research of Wanida (2000). External and internal structure of coated samples showed in Figure 3 (c-h). The porosity of structure could not be observed when coating with a higher percentage of SA because a thick and rough film layer was formed, penetrated into the cellular structure and covered the pumpkin skin. The SEM images of the coated samples showed lower amount of solute uptake within cell wall. This SEM results were agreed with the better process efficiency index and the reduced SG and total sugar for the coated samples than those for the non-coated samples.

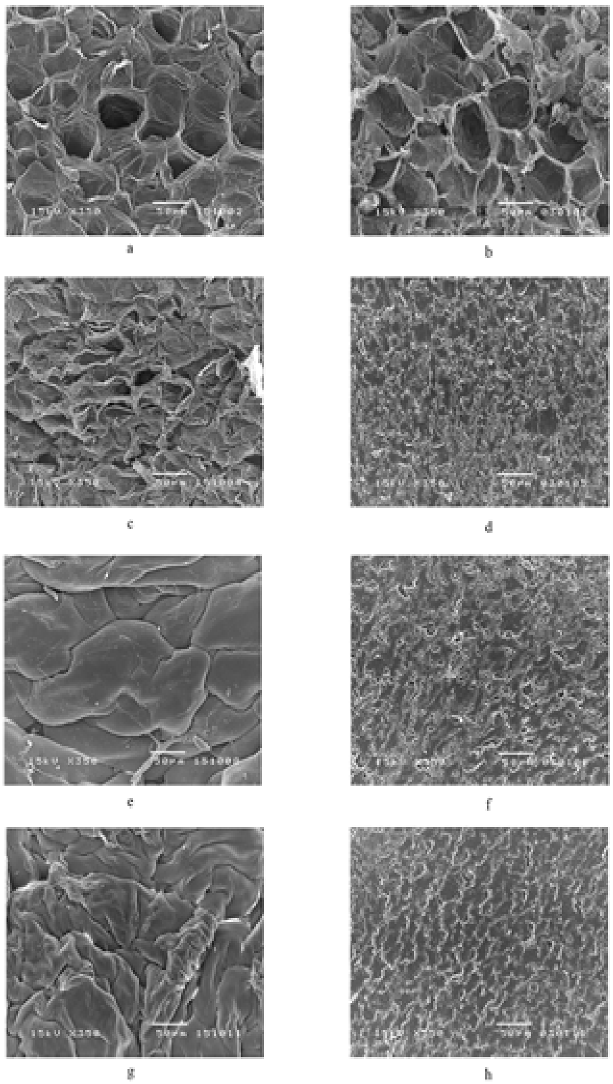


Figure 3. External (left) and internal (right) structure of non-coated pumpkin (a, b), 1% coated pumpkin (c, d), 2% coated pumpkin (e, f) and 3% coated pumpkin (g, h) by scanning electron microscope at the magnification of 350

Conclusion

This research showed that SA coating pre-treatment of pumpkin samples improved the OD process efficiency by increasing the water loss and decreasing the solid gain. Using a higher percentage of SA resulted in lower values of aw, moisture content, SG, color (a^*) and total sugar but higher values of WL, hardness and WL/SG. The pumpkin samples coated with 3% (w/w) had the highest process efficiency index (WL/SG=5.28) because the film from SA coating could better reduce the diffusion of solute in the OD solution into the pumpkin cubes. In addition, from using SEM to study cell structure, it was found that porosity of cell structure was covered with the SA film when coating with a high percentage of SA. The film helped to reduce the amount of solute uptake within the cell wall (Khin *et al*., 2007). This result was corresponded with the reduction in SG and total sugar and the highest process efficiency index of the 3% coated samples. Therefore, 3% SA was recommended for coating pumpkin samples.

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