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Research Article
Effect of Edible Coating on Antioxidants and Certain Properties of Dried Jerusalem Artichoke

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Abstract

Background and Objective: Most food industries try to solve the problem of dried food quality by using optimum pre-treatments before subjecting to hot air drying. The edible coating is considerably extended shelf-life of dried foods. The objectives of this research were to investigate the effect of edible coating agents (modified cassava starch and sodium caseinate) on properties of dried Jerusalem artichoke (JA) slices. **Materials and Methods:** Pieces of the sample were coated by dipping in the coating solution for 10 min both for atmospheric coating (AC) and vacuum coating (VC). The weight ratio of the sample to the solution was 1:2. The VC was conducted in a closed desiccator connected to a vacuum pump with a residual pressure of 150 m bar controlled during 10 min of dipping. **Results:** The coating agents resulted in improvements in product qualities. Browning and shrinkage were reduced significantly ($p<0.05$). The antioxidant properties were similar between a hot air-dried product and a freeze-dried product. There was no observed benefit of using vacuum pressure rather than atmospheric pressure. Sensory acceptance of coated products was similar to that of an uncoated product. **Conclusion:** The edible coating with modified cassava starch or sodium caseinate was, therefore, an efficient pre-treatment and could be applied with conventional drying to produce healthy fruit and vegetable snacks by using a simple and inexpensive method.

Key words: Antioxidant, coating agent, drying, healthy snack, sensory, vacuum

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Nowadays, consumer requirements include greater product quality providing a health benefit. For the production of fruit and vegetable snacks, various drying methods including hot air drying, vacuum drying, microwave-assisted hot air drying and freeze-drying have been used instead of frying. However, sensory and nutritional properties of the products may decrease by long duration of contact with heated air. Most fruits and vegetables are generally dried convectively with 50-80°C drying temperature. The impact of hot air drying on the degradation of certain components in fruits has been widely reviewed[1,2]. However, to achieve crispiness of snacks, moisture content and water activity should be decreased rapidly while the shrinkage rate is not advanced. Nowadays, most food industries solve the problem of dried food quality by using optimum pre-treatments prior to hot air drying to achieve product qualities comparable with freeze-dried products. The application of edible coatings as pre-treatments of fruits and vegetables prior to drying has been continuously developed.

Filming and coating have been used as a pre-treatment for minimally processed foods and cereal food products. Edible coating agents including polysaccharide based (modified starch, maltodextrin, carboxymethyl cellulose, gums, etc.) and protein-based (sodium caseinate, whey, gluten, gelatin, protein isolates, etc.) types are generally used. The fine layers of the edible coating provide a good barrier film that protects the product from environmental effects. Therefore, oxygen diffusion into the food matrix is minimized. Consequently, during a drying process, loss of aroma, color, nutritional and antioxidant substances might be reduced[3]. Modified cassava starch (MCS) stands out as a potential biopolymer matrix, which is currently used in food industry as a food stabilizer and as biodegradable films and coatings. The remarkable characteristics, including high paste viscosity, high paste clarity and consistency and high freeze-thaw stability are some of the advantages to many industries. Sodium caseinate (NaCAS) is a water-soluble polymer obtained by the acid precipitation of casein. Due to the structure and amino acid sequence of casein, it appears that the mechanism of film formation involves hydrogen bonding, electrostatic interactions and hydrophobic forces. NaCAS film is widely used as coating material for some food products, such as cheese, vegetables and fruits, because of its transparent, flexible and bland nature. The advantages of edible coating in fruit, vegetable and cereal products were retention of color, acid, sugar, flavor and nutritional components and also shelf-life extension[4,5]. The good carotenoid retention determined in the samples covered with starch solution with high viscosity, applied at high temperature, might suggest that the coating worked as an efficient barrier against oxygen[3].The efficiency of soaking in maltodextrin solution to maintain phenolic and antioxidant activity of dried goji berries depended on temperature and contact time[6].

A dipping method is a simple method used to coat fruit and vegetable surface with dipping time of 2-10 min. Vacuum impregnation has been reported in mass transfer promotion of osmotic dehydration. The advantages of using vacuum pressure on water/solute diffusion applied in soaking using viscous medium have been reported[7,8]. Jerusalem Artichoke, *Helianthus tuberosus* L. (JA) is a good source of nutrient and functional substances, including carbohydrate, vitamins, minerals, fiber, antioxidants and accumulates high levels of inulin and fructo-oligosaccharides (FOS)[9].

The objective of this research was to improve the qualities of dried JA by using coating techniques to achieve a healthy snack using low cost production methods. The effect of the carbohydrate and protein-based agents (CMS and NaCAS) on color, texture, antioxidants and sensory acceptance of the dried JA were analyzed. Analysis of the superior benefit of vacuum-assisted coating compared to atmospheric pressure was performed.

MATERIALS AND METHODS

Preparation of JA slices and coating solutions: This study was carried out at Department of Food Technology, Faculty of Technology, Mahasarakham University, Thailand (2017-2018). Fresh JA tubers were purchased from a supplier in Thailand. Fresh JA tubers, approximately 5,000 g were used for each treatment. JA tubers of uniform size and weight were chosen, peeled and soaked in water with citric acid added (1.5 g citric acid/100 mL water) in order to retard enzymatic browning. The tubers were then cut transversely into pieces 1.0-1.5 mm thick, 30.0-32.0 mm diameter. The sample pieces were again soaked in water with citric acid and calcium chloride added (1.0 g $CaCl_2$/100 mL water) for 30 min and then drained for 5 min. The purpose of soaking in $CaCl_2$ solution was to achieve a crunchy texture.

The coating solutions were prepared from cassava-modified starch (MCS) and sodium caseinate (NaCAS) which were purchased from Thai Food and Chemical Co., LTD., Thailand. MCS solution (4 g/100 g distilled water) was prepared from a mixture of MCS and glycerol with 1:0.25 weight ratio. It was heated for 5 min at 80°C to achieve a viscous and transparent solution. NaCAS solution (4 g/100 g distilled water) was prepared from a mixture of NaCAS and glycerol with 1:0.25 weight ratio. In the 1st step, NaCAS was dispersed in distilled water at room temperature using a rotor-stator homogenizer (IKA T-25 ULTRA-TURRAX) at 10,000 rpm for 1 h. In the 2nd step, glycerol was added and the mixture was homogenized at 15,000 rpm for 10 min. All solutions were cooled (30+1°C) before applying the coating step.

Coating and drying of JA samples: Two methods of coating, atmospheric coating (AC) and vacuum coating (VC). Pieces of sample were coated by dipping in the coating solution for 10 min both for AC and VC. The weight ratio of sample to solution was 1:2. VC was conducted in a closed desiccator connected to a vacuum pump with residual pressure of 150 m bar controlled during 10 min of dipping. The weight of consumed solutions was recorded in order to approximately control the film thickness. After the coating step, the samples were drained and left at room temperature for 30 min. The samples were placed as a single layer on a drying tray and then dried by using hot air at 80°C (HD) or freeze drying (FD) until the a_w value of the dried sample was approximately 0.3-0.4 to obtain a crunchy texture. The snack samples were kept in a laminated film pouch.

Measurement of color and texture characteristics: Color measurement of the products was performed using a Minolta color meter (CR-300, Japan). The coordinates of the color CIE-of the sample surface were obtained by reflection. L*, a* and b* represent the lightness, redness and yellowness values, respectively. The total color change (ΔE*) was calculated as follows[10]:

$$\Delta E^* = \left[\left(L_o^* - L_t^*\right)^2 + \left(a_o^* - a_t^*\right)^2 + \left(b_o^* - b_t^*\right)^2\right]^{1/2} \quad (1)$$

where, L*, a* and b* represent the lightness, redness and yellowness values of fresh (o) or dried sample (t), respectively.

The Browning index (BI) value was calculated as follows[11]:

$$BI = \frac{\left[100\left(x - 0.31\right)\right]}{0.17} \quad (2)$$

$$x = \frac{\left(a + 1.75L^*\right)}{5.645L^* + a^* - 3.012b^*} \quad (3)$$

Texture measurement was performed by using a TA. XT2i texture analyzer (Stable Micro System, UK). The puncture force passed through the samples was determined. A cylinder probe of 5 mm diameter was used. The test speed was 1 mm sec^{-1}. The distance between the two brackets was 2.7 cm. Six pieces of sample were used in each measurement. The force values of the highest peak of penetration were recorded as hardness value (N). Each result was an average of 3 replications of the experiment. Shrinkage (%) was calculated after determining the volume of the JA piece, before and after drying using the solid displacement method and calculated using the following equation[12]:

$$\text{Shrinkage} = \frac{V_0 - V}{V_0} \times 100 \quad (4)$$

where, V (cm^3) is volume of the sample after drying and V_0 (cm^3) is volume of the sample before drying.

Measurement of antioxidant properties: Two gram of dried JA samples were extracted in 100 mL of methanol. The Folin-Ciocalteu method that slightly modified from Bae and Suh[13] was used to determine phenolic content of the methanolic extract. The absorbance values were measured at 750 nm using a UV-VIS spectrophotometer. The result was expressed as μg Gallic acid equivalents mL^{-1} (μg GAE mL^{-1}). The antioxidant activity of dried JA snack was determined using 2, 2-diphenyl-1picrylhydrazyl (DPPH) (Sigma Chemical Co. St. Louis, MO) as a free radical. The absorbance was determined at 517 nm. The antioxidant activity value expressing as percentage inhibition was calculated as follows[14]:

$$\text{Inhibition (\%)} = \frac{\text{Absorbance}_{\text{blank}} - \text{Absorbance}_{\text{sample}}}{\text{Absorbance}_{\text{blank}}} \times 100$$

Sensory evaluation of JA snack: The sensory acceptance of JA snacks was evaluated by using 9-point Hedonic scale (dislike extremely-like extremely). The evaluation parameters were appearance, color, flavor, hardness and overall acceptability and were obtained from 30 panelists.

Statistical analysis: All experiments were conducted in triplicate. The statistical analysis was performed using analysis of variance (ANOVA). The significant difference between experimental means was determined by using Duncan's new multiple range tests ($p<0.05$). An uncoated sample served as a control sample.

RESULTS

The effects of coating agents were observed on a* and b* parameters. All samples from FD had insignificantly different color parameters (Table 1). In a comparison between HD and FD, the L* value of FD sample was higher than those of HD samples because FD was performed under vacuum pressure and lower temperature. Sublimation of ice crystal contributed to porous structure resulting in increased lightness. Coating with NaCAS showed high a* and low b* values while the L* value was similar to that found using CMS. HD was carried out at high temperature (to obtain a crunchy structure), the conditions induced a browning reaction, particularly with the coating using NaCAS. In this study, using color parameters like L*, a*, b* might have been insufficient to interpret the effects of the process variables on color changes.

Analysis of variance of ΔE* and BI influenced by the coating method was examined (Table 2). ΔE* and BI and were good indicators in browning comparison. Among coating treatment, ΔE* and BI were affected by coating agent and pressure. Highest ΔE* and BI values were clearly shown in samples coated by NaCAS+VC method.

The appearance and color of dried JA were affected by coating treatments (Fig. 1). The highest shrinkage and browning were shown at an uncoated sample (HD), which the ΔE* and BI values were averagely 12.07±2.35 and 25.56±4.95, respectively. The color of dried JA samples varied from creamy white to brown depending on the type of coating agents and drying methods. Reduction of shrinkage and browning was clearly shown when compared to an uncoated sample. NaCAS+VC seem to bring about browning and shrinkage.

Table 3 shows texture properties of coated dried-JA. For uncoated samples, the average hardness values were

Table 1: Color parameters of the dried JA samples

	Coatings				
Drying methods	Agents	Pressure	L*	a*	b*
HD	CMS	AC	73.55±2.31[a]	-1.40±0.34[b]	15.01±1.28[a]
	CMS	VC	73.70±1.52[a]	-2.17±0.26[a]	17.08±0.39[ab]
	NaCAS	AC	71.13±2.99[a]	-0.87±0.41[c]	15.96±0.67[a]
	NaCAS	VC	70.09±2.61[a]	-1.00±0.23[c]	19.31±0.59[b]
FD	CMS	AC	88.26±0.92[a]	-0.53±0.15[a]	12.41±2.68[a]
	CMS	VC	90.75±0.89[a]	-0.50±0.11[a]	11.43±1.93[a]
	NaCAS	AC	89.22±1.47[a]	-0.79±0.28[a]	13.57±1.45[a]
	NaCAS	VC	86.81±3.15[a]	-0.66±0.39[a]	13.80±1.47[a]

Different letters in the same column for each drying method show significant differences ($p<0.05$) by using the DMRT, CMS: Cassava modified starch, NaCAS: Sodium caseinate, HD: Hot air drying, FD: Freeze drying

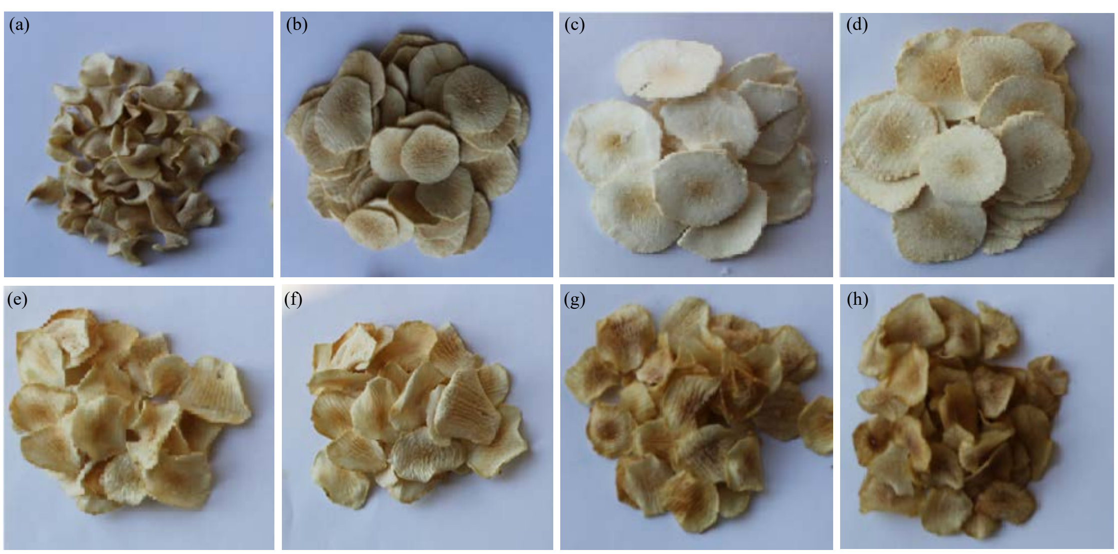

Fig. 1(a-h): Appearance and color of the dried JA samples, (a) Uncoated HD, (b) Uncoated FD, (c) CMS, AC, FD, (d) NaCAS, VC, FD, (e) CMS, AC, HD, (f) CMS, VC, HD, (g) NaCAS, AC, HD and (h) NaCAS, VC, HD

CMS: Cassava modified starch, NaCAS: Sodium caseinate, HD: Hot air drying, FD: Freeze drying

Table 2: Total color change and browning index of the dried JA samples

Drying methods	Coatings Agents	Pressure	ΔE	Browning index
HD	CMS	AC	11.17±2.15[a]	20.61±4.28[a]
	CMS	VC	10.97±1.33[a]	23.18±0.19[b]
	NaCAS	AC	14.43±2.31[b]	23.92±2.22[b]
	NaCAS	VC	16.57±2.89[b]	34.05±4.55[c]
FD	CMS	AC	6.60±1.37[a]	14.41±3.51[a]
	CMS	VC	8.60±1.01[a]	12.75±2.29[a]
	NaCAS	AC	6.83±1.01[a]	15.49±2.35[a]
	NaCAS	VC	5.57±2.14[a]	19.41±1.61[b]

Different letters in the same column for each drying method show significant differences (p<0.05) by using the DMRT, CMS: Cassava modified starch, NaCAS: Sodium caseinate, HD: Hot air drying, FD: Freeze drying

Table 3: Hardness and shrinkage of dried JA samples

Drying methods	Coatings Agents	Pressure	Hardness (N)	Shrinkage (%)
HD	CMS	AC	1.34±0.16[a]	18.18±1.59[b]
	CMS	VC	1.27±0.08[a]	12.05±2.34[a]
	NaCAS	AC	1.67±0.13[b]	16.33±2.63[ab]
	NaCAS	VC	1.40±0.05[a]	20.76±4.50[b]
FD	CMS	AC	0.84±0.03[a]	4.30±1.25[a]
	CMS	VC	0.63±0.06[a]	5.10±1.50[a]
	NaCAS	AC	0.89±0.15[a]	8.33±2.88[b]
	NaCAS	VC	0.64±0.06[a]	6.67±2.88[ab]

Different letters in the same column for each drying method show significant differences (p<0.05) by using the DMRT, CMS: Cassava modified starch, NaCAS: Sodium caseinate, HD: Hot air drying, FD: Freeze drying

Table 4: Phenolic content and antioxidant activity of dried JA samples

Drying methods	Coatings Agents	Pressure	Phenolic content (μg GAE mL^{-1})	Inhibition (%)
HD	CMS	AC	70.15±1.22[a]	53.72±5.91[a]
	CMS	VC	72.54±1.56[ab]	54.39±5.91[a]
	NaCAS	AC	80.16±2.65[ab]	63.88±2.10[ab]
	NaCAS	VC	82.56±2.15[b]	68.54±5.55[b]
FD	CMS	AC	74.23±1.43[a]	67.20±5.55[a]
	CMS	VC	79.56±1.31[a]	62.56±5.77[a]
	NaCAS	AC	73.24±7.12[a]	66.63±7.22[a]
	NaCAS	VC	72.51±5.45[a]	66.21±6.33[a]

Different letters in the same column for each drying method show significant differences (p<0.05) by using the DMRT, CMS: Cassava modified starch, NaCAS: Sodium caseinate, HD: Hot air drying, FD: Freeze drying

0.41±0.05 N for FD sample and 1.98±0.15 N for HD sample. Shrinkage values were 10±1.00% for FD sample and 29.98±9.06% for HD sample. Coating treatments could reduce shrinkage of both the FD and HD samples but did not improve harness characteristic. Hardness of coated ones were close to uncoated samples (0.41-1.98 N), while shrinkage was reduced around 1.2-fold (FD) to 2.5-fold (HD).

Even though, the coatings provide reduction of shrinkage of HD samples (ca.1.2-2.5-fold compared with uncoated samples), shrinkage values of HD samples were more than 2 times those of FD samples (Table 3). The ice sublimation in FD increases the formation of pores and cavities. Therefore, freeze-dried foods were less shrunken and more fragile structures than hot-air dried foods. In the present work, reduction of shrinkage was found in all coated samples, particularly HD samples. Among coated samples, the slight effect of coating on shrinkage could be observed in HD samples (Table 3). The highest shrinkage was shown at NaCAS+VC and CMS+AC. These beneficial results were involved structure protection during a high rate of drying at 80°C.

Phenolic content in coated samples was increased approximately 1.6-1.8 times (HD) and 1.4-1.5 times (FD) as compared to the uncoated samples (43.55 μg GAE mL^{-1} (HD), 50.23 μg GAE mL^{-1} (FD). High retention of phenolics and antioxidant activity was caused by coating agents, while vacuum effects were insignificant (Table 4). Damage due to heat and oxygen may be reduced by covering with a film layer. During JA drying, the coating film also became drier, resulting in a protective effect at the surface which reduced thermal damage and oxidation. The antioxidant activity of coated samples was also higher than those of uncoated ones. In addition, antioxidant activity could be related to phenolic content in dried JA. The advantage of coating and vacuum application on the infusion of antioxidants into the food matrix has been reported.

The sensory score of all JA snacks obtained from a conventional drying (HD) was in the range of 5-6, indicating slightly like perceptions (Table 5). Sensory acceptability scores of coated snacks were close to those of uncoated ones, indicating that coating didn't affect any sensory attributes of dried JA except in the NaCAS+VC sample. All sensory scores of NaCAS+VC sample were lower than 6, indicating unacceptable just. Appearance and color scores lower than those in other samples and could be related to the color and texture results that measured by the objective methods (Table 2, 3). Therefore, high BI and shrinkage might cause unacceptable just score of JA snacks. Overall acceptability of all dried JA was similar, possibly due to hardness and flavor scores being insignificantly different. Numerous studies have focused on flavor development during baking. The reactive carbonyl group of the sugar reacts with the nucleophilic amino group of the amino acid and forms a complex mixture of poorly characterized molecules responsible for specific aromas and flavors. The development of color also happens over the last stages of the baking process because of complex processes of Maillard reaction. An optimum level of brown color related to rich flavor in baked goods has been reported.

Table 5: Sensory scores of dried JA samples

Snacks	Appearance	Color	Hardness[ns]	Flavor[ns]	Overall acceptability
Uncoated	6.53±1.09[b]	6.23±1.07[b]	5.95±1.38	5.62±1.39	6.08±1.27[ab]
CMS	6.25±1.34[ab]	6.32±1.31[b]	5.65±1.25	5.77±1.54	5.99±1.25[a]
CMS	6.32±0.94[b]	6.23±1.10[b]	5.88±1.22	6.03±1.35	6.27±1.24[ab]
NaCAS	6.27±1.40[ab]	6.43±1.28[b]	5.58±1.15	6.23±1.33	6.57±1.11[b]
NaCAS	5.73±1.26[a]	5.65±1.21[a]	5.47±1.26	5.70±1.38	5.58±1.34[a]

Different letters in the same column for each drying method show significant differences (p<0.05) by using the DMRT, CMS: Cassava modified starch, NaCAS: Sodium caseinate, [ns]Non-significant

DISCUSSION

NaCAS+VC brings about more browning and shrinkage in the dried JA when compared to CMS treatments. Vacuum pressure possibly damaged tissue of fresh JA slices (1.35±0.12 mm thickness) during coating and increased oxygen diffusion into the tissue during drying. Moreover, the interaction effects of protein-based agent and vacuum pressure might induce browning reaction namely Maillard reaction, while coating with CMS was not found this impact because of less protein remaining in starch. The Maillard reaction usually occurs when foods containing reducing sugars and amino groups are concentrated by heat and exhibits rate maxima at intermediate to high a_w values (0.6-0.8). Therefore, in this presenting results, the advanced glycosylation end products of the Maillard reaction causing by caseinate and reducing sugar might be induced by both vacuum pressure and drying temperature effects. Generally, polysaccharides have been used as coating agent for foods because of their protective effect and relatively low cost. Coating with carbohydrate such as 2% carboxymethyl cellulose (CMC) could reduce the total color change of osmotically dehydrated apple when a 60% sugar syrup was used as a soaking medium[8,15]. Even though a high drying temperature was avoided for protein-based products such as dried meat and fish in order to avoid case-hardening and deterioration of protein, reducing drying time and shrinkage by using a high temperature (70-80°C) is necessary for production of a crunchy vegetable snack[3,16-18].

Vacuum pressure induced shrinkage in NaCAS coated samples, possibly due to insufficient adhesion and strength of NaCAS gel. It was not enough to decrease a structure collapse caused by vacuum pressure and dehydration. In our study, the average solution viscosity of CMS and NaCAS film solutions were different, 0.54±0.032 and 0.031±0.020 Pa. s (at 150 sec^{-1}) for the CMS and NaCAS solutions respectively. In addition, a difference in adhesion capacity (mass gain after coating), 23.36±2.88 and 15.25±1.98 for the CMS and NaCAS solutions, respectively was found. The CMS gel strength from high amylose content and cross-linked structure was largely responsible for film formation and morphological protection of dried foods.

In this study, although coating with NaCAS showed higher browning and shrinkage than coating with CMS but antioxidant properties particularly in dried samples from HD were increased, possibly due to its oxygen-proof properties of the protein-based film. This resulted in enhancing antioxidant stability of dried products during drying and storage. NaCAS has good film-forming properties and coating capabilities because of the random coil structure and molecular interaction derived from hydrogen bonds, electrostatic force and hydrophobic bonds[13]. NaCAS has good properties in moisture and oxygen-proof for cereals during the storage that reported by Talens *et al.*[19]. Coating with CMS seems to be less protective when compared with NaCAS. Generally, films made from polysaccharides are brittle because of retrogradation phenomena. Amylose content and structure modification are responsible for the film-forming capacity of the starches. Therefore, the use of a single film from CMS had some limitations for antioxidant protection. Starch-based films have been improved by the blending of polysaccharides and proteins due to the establishment of polymer interaction providing mechanical and barrier property improvement[20,21]. The future recommendation for drying of JA or similar property is that raw materials with the blending of CMS, NaCAS or another protein based-agent used in order to increase at least 2 benefits, oxygen-proof and cost reduction.

CONCLUSION

Although NaCAS caused browning, but also enhanced antioxidant properties as compared to MCS. Moreover, antioxidant properties were similar between a hot air-dried product and a freeze-dried product. Therefore, NaCAS and MCS were potentially useful for edible coatings for conventional drying in order to make healthy fruit and vegetable snacks by using a simple and inexpensive method.

SIGNIFICANCE STATEMENT

This study discovers the advantages of edible coating with MCS or NaCAS prior to drying which provided a significant reduction of browning and shrinkage and did not affect sensory acceptance. This study will help the food industry to uncover the simple processes for healthy product production that many entrepreneurs were not able to explore.

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