

*Research Article*

## **Comparative study on drying of osmotic treated carrot slices**

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### **Abstract**

This research work was aimed at comparing the quality of dried carrot slice from freeze drying, microwave drying and hot air drying. Osmotic treatment of carrot slice in glycerol:sucrose:glucose syrup solution was undertaken before drying to improve texture and final appearance. Carrot slices were freeze dried for 8 hr, microwave dried at 240 W for 25 minutes and hot air dried at 60°C for 6 hr. Chemical, physical, microbial and sensory (by 9-point hedonic scale test) qualities of the dried samples were determined. Sorption isotherms were also analyzed. Freeze drying produced the sample with the lowest moisture content and  $a_w$ , and the highest cutting force and L value ( $p \leq 0.05$ ). The highest total carotenoid and beta-carotene contents (0.14 and 0.17 mg/g solids, respectively) were found in microwave dried carrot. All samples had microbial counts less than 10 cfu/g. Microwave dried and hot air dried samples were slightly and moderately liked (sensory scores of 6.18 and 7.0), respectively, while the freeze dried sample was disliked (sensory score of 3.24). All samples had similar sorption isotherms, however, the freeze dried carrot was more hygroscopic and had higher sorption isotherms. Moisture sorption isotherm data were fitted with GAB model.

**Keywords:** freeze drying, microwave vacuum drying, hot air drying, chemical, physical, sensory qualities, sorption isotherm, Thailand.

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### **Introduction**

Carrot is rich in dietary fibre, vitamins and minerals. It is also known as a good source of carotenoids. In Thailand, carrots are generally produced in large quantities and sold at a cheap price. Conversion of fresh carrot into other products, such as dried form, adds market value, generates consumer convenience and extends the shelf life of the material. Drying, which is a

common technique in food preservation, can be used to produce a new form of carrot. Shelf life extension of the dried product is due to moisture removal and hence a reduction in water activity to the level at which microbiological and physico-chemical deterioration are retarded or limited. Consumers generally expect the dried product to have properties close to those of the original material. Various drying techniques have been widely studied in order to obtain the best quality dried food products.

Osmotic dehydration is a non-thermal treatment, the aim of which is to modify the composition of food material by partially removing water and impregnating it with solutes, without affecting the material's structural integrity [1]. The chemical composition and organoleptic characteristics of osmodehydrated fruit and vegetables result in high quality products that can undergo subsequent freezing, dehydrofreezing, air drying or vacuum drying. Using osmotic dehydration combined with subsequent drying, products with good organoleptic quality can be obtained. Energy savings are obtained in the complementary heated air drying. The raw material is placed into concentrated solutions of soluble solids having higher osmotic pressure and lower water activity. Simultaneous water and solute diffusion processes are caused by the water and solute activity gradients across the cell membrane, the cell wall and the surface of the tissue. The complex cellular structure of food acts as a semipermeable surface. Since these compartments are only partially selective, there is always some solute diffusion into the food. The water transfer is generally accompanied by natural substances (vitamins, flavours, fruit acids, pigments, saccharides, minerals). As a consequence of this exchange, the product loses weight and shrinks. Osmotic dehydration as a pretreatment to many processes improves nutritional, sensorial and functional properties of food without changing its integrity. It is effective even at ambient temperature, so heat damage to texture, colour and flavour of food is minimized [2]. If the solutes are correctly chosen, and the ratio of water removal to solute impregnation is controlled, the natural flavour of fruit products and colour retention can be enhanced. The nature of the osmo-active solute determines its capacity for lowering the water activity of the osmotic solution, affecting the driving force responsible for the mass transport and the kinetics of water removal and solute uptake. By increasing the molecular weight of the solutes, a decrease of solid gain and an increase of water loss is obtained, so favouring weight loss and dehydration [1]. The most commonly used solutes for osmotic treatments are sugars (mainly with fruit) and salts (with vegetables, fish, meat and cheese) with relevance for sucrose and sodium chloride. Another osmo-active solute used in osmotic treatment is glycerol, a food additive that improves the texture of food (plasticizer) [3]. It can also protect the food from microorganisms [4].

Convective drying is widely practiced in the food industry due to its operation simplicity and relatively inexpensive technology. This technique employs a flow of heated air stream to supply heat to the food and remove its moisture. Depending on the nature of the food, drying time can be extensive. During drying, the food contacts with oxygen in the air and may be exposed to high temperature for a long time. Such exposure reduces the content of some valuable components which readily undergo oxidation at elevated temperature. Product shrinkage, which affects drying behaviour and physical quality of the food, may be experienced in convective drying [5]. To overcome several disadvantages of the convective system, non-convective methods such as freeze drying and microwave vacuum drying have been employed. Freeze drying involves moisture removal by ice sublimation at sub-freezing temperature. This method provides for excellent quality of the final product. Colour, flavour, chemical composition and shape undergo only slight changes. It is, however, a very

expensive method and time-consuming. Microwave vacuum drying is a method that can operate at low temperature in the absence of oxygen. This method is able to dry the product in a shorter time. The microwaves penetrate into the interior of the product being dried and cause the water to boil at a comparatively low temperature, owing to the reduced pressure in the drying chamber. It is due to the water boiling inside the material that the relative difference in the pressure between the interior and the environment of the material provides for extremely quick water vapour removal and produces favourable conditions for the occurrence of the puffing phenomenon, which considerably limits the drying shrinkage effect [6].

In this study, combinations of osmotic pretreatment with different drying methods (hot air, freeze drying and microwave vacuum drying) were studied in order to compare their effects on physico-chemical, microbial and sensory qualities of the final product.

## **Materials and Methods**

### ***Material preparation and osmotic pretreatment***

Uniform shaped carrots were selected, cleaned and peeled. The carrots were sliced to 5 mm thickness immediately followed by blanching at near boiling point for 3 minutes [7] and cooled in ice water immediately. The blanched carrot slices were soaked in osmotic solution (40°Bx) consisting of glycerol (40% w/w), sucrose (40% w/w) and glucose syrup (40% w/w). The ratio of carrot:solution of 1.0:1.5 and treatment time of 6 hr at ambient temperature were used.

### ***Drying process***

The osmotic treated carrot was divided for drying using 3 methods, namely hot air drying, freeze drying and microwave vacuum drying. Hot air drying was carried out at 60°C for 6 hr [8] in a hot air oven (Likhitchewan Co., Ltd., Chiang Mai, Thailand). Freeze drying was conducted at  $133 \times 10^{-3}$  mbar for 8 hr using a freeze dryer (Dura-Dry II MP, Science Engineering International Co., Ltd., Thailand). Microwave vacuum drying was done at 240 W for 25 min using a microwave vacuum dryer (March Cool Co., Ltd., Thailand). The experiment was carried out in triplicate in a complete randomised design. The dried samples were kept sealed in polyethylene bags for further analysis.

### ***Quality analysis***

The dried samples were analyzed for colour ( $L^*$ ,  $a^*$  and  $b^*$  values) by a chromameter (Minolta Co., Ltd, Osaka, Japan), water activity by Aqualab water activity meter (model series 3, Decagon Device Inc., Pullman, USA.). AOAC methods were used for determination of moisture content, total solids, total carotenoids and beta-carotene by spectrophotometric method [9]. The maximum force required to cut the carrot slice was determined by a texture analyzer (TA-XT<sub>2</sub> Plus, Stablemicrosystems Co. Ltd., Surrey, UK) using a knife and blade set probe. The total microbial, yeast and mould count were determined using AOAC methods [9]. Sensory evaluation was conducted by a 9-point hedonic scale test using 50 panelists.

### ***Determination of sorption isotherm***

Sorption isotherms of the samples were determined by a gravimetric method following the method stated by Bell and Labuza [10]. The dried samples were equilibrated with saturated salt solutions (LiCl, CH<sub>3</sub>COOK, MgCl<sub>2</sub>, K<sub>2</sub>CO<sub>3</sub>, Mg(NO<sub>3</sub>)<sub>2</sub>, KI, NaCl, KCl, KNO<sub>3</sub>, pure water) to obtain water activity in the range of 0.11-1.00. After equilibrium was reached, the

samples were analyzed for moisture content [9], and the sorption isotherm was constructed from moisture content and water activity data. The experiment was conducted in triplicate.

### ***Statistical analysis***

The experimental data was subjected to analysis of variance and mean comparison by Duncan's multiple range tests, in order to determine any significance of the differences in the data.

## **Results and Discussion**

### ***Physico-chemical, microbial and sensory qualities***

Qualities of the dried carrot samples are shown in Table 1. The moisture contents of the samples from different drying methods were significantly different ( $p \leq 0.05$ ). Freeze drying gave the lowest wet basis moisture content (8.47%), whereas microwave vacuum drying gave the highest value of 30.62%. Water activity of the samples corresponded to the moisture content. The dried samples had  $a_w$  in the range of 0.15-0.49, which are within the recommended level for safe storage (0.60). The freeze dried sample had the lowest  $a_w$  due to its lower moisture content. The highest  $a_w$  was found in the microwave vacuum dried sample. Microwave vacuum drying is generally used in combination with other drying techniques to reduce cost and energy consumption. The total solids content was significantly different ( $p \leq 0.05$ ), ranging from 69.38 to 91.53%w/w, which negatively corresponded with the moisture content of the samples.

The cutting force required to cut carrot slices depended on moisture content and structural collapse. The cutting force for the freeze dried sample was the highest at 142.38 N. The freeze dried carrot had the least moisture which caused a tougher texture. The microwave vacuum dried sample contained much higher moisture and had puffing characteristics (which may damage cell structure of the carrot), which may contribute to a softer texture (cutting force of 47.02 N). Higher cutting force of the hot air dried sample (61.56 N) may be due to shrinkage of the sample during drying, resulting in a more compact and stronger structure. In addition, high sugar content in the osmosed carrot may contribute to phase transition during drying, giving rise to a tougher and more elastic texture. Hence this may increase the cutting force. Cui, *et al.* [11] found that hot air dried carrot had the highest cutting force, followed by microwave vacuum dried and freeze dried samples. Disagreement between the results from this work and the literature may be due to pretreatment of the carrot before drying, different moisture content (7% in the literature) and drying time.

**Table 1. Physico-chemical, microbial and sensory qualities of dried carrot.**

Property	Drying Method		
	Hot air drying	Freeze drying	Microwave vacuum drying
<b>Chemical properties</b>			
a <sub>w</sub>	0.34 <sup>b</sup> ± 0.05	0.15 <sup>a</sup> ± 0.00	0.49 <sup>c</sup> ± 0.00
Moisture (%w/w)	15.46 <sup>b</sup> ± 0.79	8.47 <sup>a</sup> ± 0.35	30.62 <sup>c</sup> ± 0.57
Solids (%w/w)	84.54 <sup>b</sup> ± 0.79	91.53 <sup>c</sup> ± 0.35	69.38 <sup>a</sup> ± 0.57
<b>Physical properties</b>			
Cutting force (N)	61.57 <sup>b</sup> ± 2.88	142.38 <sup>c</sup> ± 11.14	47.02 <sup>a</sup> ± 1.64
L*	52.62 <sup>a</sup> ± 1.21	61.77 <sup>b</sup> ± 6.05	50.84 <sup>a</sup> ± 3.42
a*	26.71 <sup>ab</sup> ± 1.66	24.91 <sup>a</sup> ± 1.09	29.03 <sup>b</sup> ± 0.86
b*	30.69 <sup>ns</sup> ± 4.31	35.33 <sup>ns</sup> ± 2.48	36.00 <sup>ns</sup> ± 3.07
<b>Microbial count</b>			
Total microbiology (CFU/g)	< 10 <sup>ns</sup>	< 10 <sup>ns</sup>	< 10 <sup>ns</sup>
Total yeast and mould (CFU/g)	< 10 <sup>ns</sup>	< 10 <sup>ns</sup>	< 10 <sup>ns</sup>
<b>Sensory acceptance score</b>			
Colour	6.47 <sup>b</sup> ± 1.81	3.06 <sup>a</sup> ± 1.82	7.59 <sup>b</sup> ± 1.33
Flavour	5.59 <sup>b</sup> ± 1.06	3.29 <sup>a</sup> ± 1.69	6.12 <sup>b</sup> ± 1.27
Sweetness	5.88 <sup>b</sup> ± 1.17	4.00 <sup>a</sup> ± 1.32	5.94 <sup>b</sup> ± 1.20
Texture	6.12 <sup>b</sup> ± 0.99	3.53 <sup>a</sup> ± 1.62	6.53 <sup>b</sup> ± 1.28
Overall acceptability	6.18 <sup>b</sup> ± 1.01	3.24 <sup>a</sup> ± 1.25	7.00 <sup>c</sup> ± 1.22

Lightness value (L\*) of the samples significantly different (p≤0.05).

The freeze dried sample was the brightest sample due to porosity formation during sublimation of ice from the slice matrix. Porous material can absorb more light, and hence, give a brighter colour. The microwave vacuum dried carrot had the darkest colour. This may be due to shrinkage and structural collapse of the carrot during the high rate of water removal [11]. Also hot air drying caused shrinkage of the carrot, resulting in a darker colour, similar to the microwave vacuum dried sample. There was a significant difference ( $p \leq 0.05$ ) between a\* values of freeze dried and microwave vacuum dried samples. A positive a\* value signifies redness of the sample, whereas a negative value represents green colour. The microwave vacuum and hot air dried samples had higher a\* values, indicating that the samples were more red than the freeze dried sample. It may be possible in cases of high temperature treatment that the orange colour in carrot deteriorates. However, it may not be the case in this study. The differences in redness may result from an optical property change due to structural collapse or compaction which reduces reflection of white light. Therefore, more redness was detected in the microwave vacuum dried and hot air dried samples. In order for the colour change due to carotene degradation to occur, the sample has to be exposed to temperatures above 70°C for more than 5.5 hr [12]. There was no significant difference between the b\* values for all samples ( $p > 0.05$ ).

The microbial analysis showed that all carrot samples did not contain any microorganisms, as there was no growth detected during the analysis. However, due to the standard reporting

format, it was reported that the microbial count was less than 10 cfu/g. This indicates that the preparation and processing of the dried carrot did not have any contamination.

The sensory evaluation revealed that taste panelists liked (overall acceptability score of 7.00) carrot from microwave vacuum dried sample more than other samples. The panelists disliked the freeze dried sample (overall acceptability score of 3.24). Acceptability scores for all attributes (colour, flavour, sweetness and texture) for hot air and microwave vacuum dried samples were not significantly different ( $p>0.05$ ). The highest acceptability scores were given to colour attributes, whereas the lowest scores were given to sweetness attributes for both samples. When acceptability scores were related to the instrumental values, it was found that the panelists liked the samples with darker colour, softer texture and relatively moist.

#### ***Effect of drying technique on total carotenoid and beta-carotene***

Carotenoid content is an important indicator of final quality. Carotenoids are sensitive to heat, oxygen, light and enzymes. From Table 2, the total carotenoid and beta-carotene contents in all dried samples significantly decreased ( $p\leq 0.05$ ) when compared with the fresh carrot. Amongst the dried samples, microwave vacuum dried carrot contained the highest total carotenoids and  $\beta$ -carotene. Similar results were found by Lin *et al.* [13]. These results also agree with those reported by Cui *et al.* [11], who stated that freeze dried and hot air dried samples retained less carotenoids than microwave-vacuum dried. However, the current study's results show much lesser retention of carotenoids than in Cui *et al.* [11, 14], due to carotenoid degradation during blanching, whereas Cui *et al.* [14] did not blanch the carrot before drying. Regier *et al.* [12] found that carotenoid content was reduced by 20% when dried in microwave-vacuum at 400-600 W for 45-75 min. For hot air drying, they found that carotenoid retention was not significantly reduced when dried at temperatures below 70°C after drying for 5.5 hr. This was due to oxygen control at below 0.04% during drying. Because microwave vacuum drying provides a uniform heat distribution over the sample in a vacuum, the effect of oxidation on carotene is reduced [15]. Also quick moisture removal at low temperature due to low pressure was achieved [11]. Many studies have found highest retention of carotenoids (>90%) during freeze drying [13, 12]. Low carotenoid retention found in the current study may be due to loss during osmotic dehydration. Pan *et al.* [16] found that carotenoid content loss was related to the loss of moisture and exponentially related to the treatment time during osmotic dehydration. Up to 50% loss was found during 4 hr of osmotic dehydration.

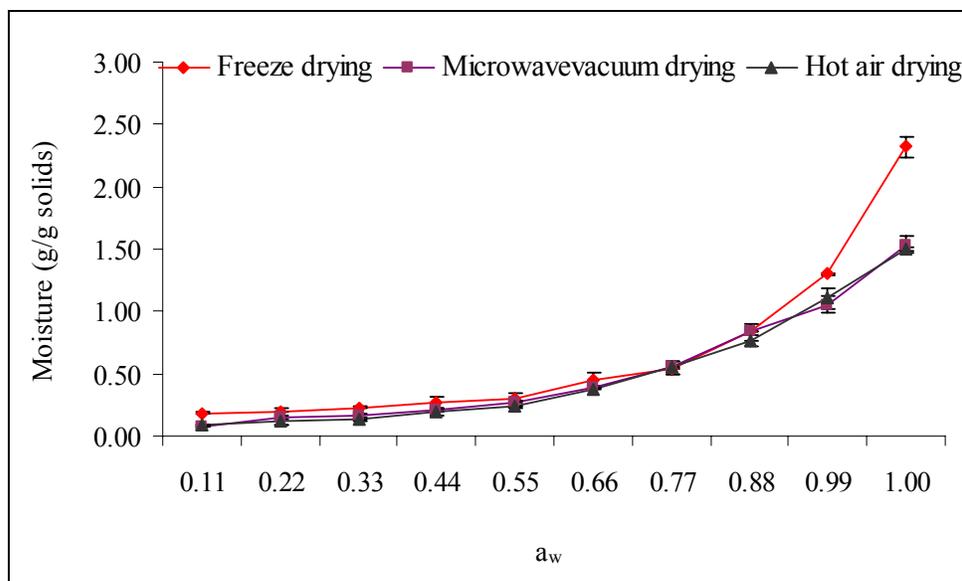
**Table 2. Total carotenoid and beta-carotene content of carrot samples.**

Sample	Total carotenoid (mg/g solid)	$\beta$ -carotene (mg/g solid)
Fresh carrot	3.14 <sup>a</sup> ± 0.14	3.31 <sup>a</sup> ± 0.11
Hot air dried	0.11 <sup>b</sup> ± 0.01	0.11 <sup>b</sup> ± 0.01
Freeze dried	0.11 <sup>b</sup> ± 0.01	0.11 <sup>b</sup> ± 0.01
Microwave vacuum dried	0.14 <sup>b</sup> ± 0.01	0.17 <sup>b</sup> ± 0.01

#### ***Sorption isotherms of dried carrots***

Sorption isotherms of the dried carrot samples are shown in Figure 1. Similar shape of the isotherms were found for all samples. There was no significant difference between the isotherm of microwave vacuum and hot air dried samples ( $p>0.05$ ). This may be due to a similar

cell structure change during drying. The sorption isotherm of the freeze dried sample lies above the other two counterparts. This was due to the porous structure of the sample generated during ice sublimation. High porosity facilitates a quicker vapour sorption into the food structure. Therefore, at the same equilibrium condition, freeze dried samples adsorbed higher moisture. Similar sorption isotherms were found in other food products, such as in tomato [17], garlic mushroom, pumpkin and onion powders [18].



**Figure 1. Adsorption isotherms of osmosed carrot dried by different methods.**

The Guggenheim-Anderson-de Boer (GAB) model (Equation 1) was fitted with the sorption isotherm data of the dried carrot in order to provide a predictive model for future use.  $M$  is moisture content (g/g dry solids),  $M_0$  is monolayer moisture content (g/g dry solids),  $C$  is the Guggenheim constant and  $k$  is a molecule multilayer factor. The monolayer moisture,  $C$  and  $k$  values were determined for the sample from each drying method. The results are shown in Table 3. It can be seen that the freeze dried carrot has higher constant  $C$  and  $k$  values, which corresponds to a higher adsorption behaviour of the sample. These values are much higher than the sorption of untreated freeze dried carrot which had the  $M_0$ ,  $C$  and  $k$  values of 0.066 g/g dry solids, 3.6 and 1.04, respectively [19]. All dried samples had higher monolayer moisture contents than the literature [19] due to the effect of osmotic pretreatment in which moisture was bound to the solute in the sample. The standard errors of prediction using the GAB model was in the range of 0.044-0.093 (less than 10% error), indicating that the model can be used to predict the isotherm with minimal error.

$$M = \frac{M_0 C k a_w}{(1 - k a_w)(1 - k a_w + C k a_w)} \quad (1)$$

**Table 3. GAB parameters for dried carrots.**

Sample	GAB parameter			Std Error
	M <sub>0</sub> (g/g solids)	C	k	
Freeze dried	0.250	5.657	0.895	0.055
Microwave vacuum dried	0.613	0.804	0.728	0.044
Hot air dried	0.193	-2.49*10 <sup>8</sup>	0.877	0.093

### Conclusion

Osmotic pretreatment was used to improve physico-chemical and sensory properties of carrot. Drying of the carrot using freeze drying, microwave vacuum and hot air drying yielded samples with low water activity. Microwave vacuum drying gave higher moisture, darker, more red colour and softer texture. Sensory panelists accepted the microwave vacuum dried carrot with the highest score of 7.00. It also contained the highest total carotenoid and  $\beta$ -carotene contents as compared to the other samples. The microwave vacuum and hot air dried samples had similar sorption isotherms with the monolayer moisture contents of 0.613 and 0.193 g/g dry solids, respectively. The freeze dried sample was more hygroscopic and adsorbed higher moisture, resulting in a sorption isotherm curve above the other samples. The GAB model can be used to predict sorption isotherms of osmotic treated-dried carrot with standard error of less than 10%.

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