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Process Optimization of Vacuum Fried Carrot Chips Using Central Composite Rotatable Design

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ABSTRACT

Carrot slices were blanched, immersed in fructose solution prior to frozen and vacuum fried to prepare carrot chips. The effects of immersing sugar concentration, vacuum frying temperature and time on the quality of fried carrot chips were studied with the central composite rotatable design (CCRD). Results showed that the moisture content, oil content, color quality, and breaking force of fried carrot chips were significantly related to immersing fructose concentration, frying temperature and time. The moisture content and breaking force of fried carrot chips were positively correlated with immersing fructose concentration, whereas the oil content and color quality of fried carrot chips were negatively correlated with immersing fructose concentration. Based on CCRD and contour plots, optimal processing conditions of vacuum fried carrot chips were: vacuum frying temperature of 100 - 105°C, vacuum frying time of 16 - 20 min, and immersing fructose concentration of 30 - 40%. The high R^2 correlation coefficients (above 0.90 except moisture content and ΔE value) indicated that the variables were adequately fitted to the regression equation which could highly predict the quality of vacuum fried carrot chips prepared from the frying conditions.

Key words: vacuum frying, carrot chips, processing conditions, central composite rotatable design

INTRODUCTION

The common drying methods used for fruits and vegetables are air drying, solar drying, vacuum drying and freeze drying[(1)]. Freeze drying is capable of producing the highest quality dried products and reducing weight with little reduction in bulk[(2)], however, it is more energy and time consuming than other drying methods[(3)]. Deep-fat frying is an alternative dehydration method. Fried foods are generally processed under atmospheric pressure at elevated temperature. Surface darkening may occur even before the food is fully cooked[(4)]. Dehydrated food produced by vacuum frying, can have crispy texture, good color and flavor[(5-8)]. Vacuum frying also has less adverse effects on oil quality[(9,10)]. Recently, vacuum frying has been tested as an option to produce fried potatoes with low oil content[(11)].

Carrots have the highest carotene content among vegetables and are consumed in large quantities. The main pigments in carrot are α- and β-carotene. Thus, carrots are important dietary source of provitamin A[(12)]. Carrots are commonly preserved by canning, freezing and dehydration. Among these processes, dehydration offers many advantages, such as reduced weight, inexpensive packaging and longer shelf-stability. Several processes have been used for carrot dehydration, however, these processes resulted in considerable loss of carotene during processing and poor product appearance. We have observed that carrot chips produced by vacuum frying have good retention of nutrients[(13)]. This process is therefore suggested to be a desirable process for preparing dehydrated fruit and vegetable products. Fan and others[(14)] have investigated the effect of the vacuum absolute pressure on the quality of carrot chips. In our earlier study with carrot chips it was found that the quality of vacuum-fried carrot chips was greatly influenced by pretreatment methods such as immersion in sugar solution and freezing[(8)].

This investigation was to develop and optimize a process for vacuum frying of carrot slices which would result in crispy texture, good color and flavor. Response surface methodology (RSM) was used to optimize the vacuum frying condition of carrot chips. Three independent variables investigated in this experiment were the concentration of immersing sugar solution, vacuum frying temperature and frying time.

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MATERIALS AND METHODS

I. *Materials*

Carrots, fructose and palm oil were purchased from a local market in Taiwan. The carrots (89.13% moisture content, 0.33% crude fat, 1.18% crude protein, 0.79% crude fiber, 0.75% ash and 7.82% N-free extract) were randomly selected at market. The palm oil (Olyco Co. Ltd, Sarawak, Malaysia) was imported from Malaysia. Palm oil is commonly used for deep fat frying of foods because it has good oxidative stability during frying(5,10,15). Whole carrots (*Daucus carrot* L.) were packaged in polyethylene (PE) bags and stored at 0°C prior to use.

II. *Preparation of Carrot Slices*

Washed, peeled and drained carrots were cut into 2 mm thick slices with a slicer (OMAS slicer, model VS250, Italy). The carrot slices were blanched in water at 95°C for 2 min, cooled, drained and then immersed in various concentrations of fructose solution at 50°C for 30 min. Drained slices were frozen at -30°C overnight.

III. *Vacuum Frying*

About 36 Kg of palm oil was placed into a vacuum fryer (Horng Yun Steel Factory, Yon Lin, Taiwan). A batch of 400 g frozen carrot slices were fried under vacuum (98.66 kPa) at various temperatures for various time intervals. After frying, the fried carrot chips were centrifuged at 600 ×g for 30 min to remove the frying oil, packed in PE bags and then stored at -30°C before analysis.

IV. *Experimental Design*

Central composite rotatable design (CCRD) is one kind of the response surface methodology. In this study, CCRD was employed to optimize the vacuum frying condition and a five-level three-variable design was adopted(16,17). The three independent variables investigated in this experiment were frying temperature, frying time and immersing fructose concentration, the codes of those variables were X_1, X_2 and X_3, respectively. Each independent variable has five levels which were -1.682, -1, 0, +1, and +1.682 (Table 1). A total number of 15 level combinations were generated for the 3 independent variables. The centre point (the level combination in which the value of each coded variable was 0) was repeated six times for the three-variable design (Table 2). Responses (dependent variables, Y_1 = moisture content, Y_2 = oil content, $Y_3 = \Delta E$ and Y_4 = breaking force) were represented mathematically by equations (or models) which were similar to the regression equations. The model for three independent variables is as follows:

$$Y_n = a_0 + a_1X_1 + a_2X_2 + a_3X_3 + a_{11}X_1^2 + a_{22}X_2^2 + a_{33}X_3^2 + a_{12}X_1X_2 + a_{13}X_1X_3 + a_{23}X_2X_3$$

V. *Analytical Methods*

Moisture content of carrot chips was measured in a vacuum oven by drying at 70°C. The ground samples (5 g) were dried to constant weight. Moisture content was calculated from the weight difference between the original and dried samples and expressed as percentage of original sample. Oil content of carrot chips was determined gravimetrically by Soxhlet extraction with ether(18).

The surface color of carrot chips was measured with a colorimeter (Nippon Denshoku Σ90 color difference meter, Japan) and expressed as Hunter *L* (lightness), *a* (redness) and *b* (yellowness) values. The colorimeter was standardized using a white tile (Y = 95.43, X = 93.49, Z = 113.21). Color difference (Hunter ΔE) was calculated according to the equation: $\Delta E = [(L-L_{ref})^2 + (a-a_{ref})^2 + (b-b_{ref})^2]^{1/2}$

where L_{ref}, a_{ref} and b_{ref} were the L, a, and b values of fresh carrot slices, respectively. The color of fresh carrot slice was used as reference.

A model TA-XT2 Texture Analyzer (Stable Micro Systems Co. Ltd, Godalming, Surrey, UK) was used for the breaking force determination. Each carrot chip was placed across the bridge of a 2” long piece of 3/4” aluminum channel and the probe (no. P/0.5S) was brought down in the middle of the bridge. All numerical results were expressed in grams.

VI. *Statistical Analysis*

All data were analyzed using the Statistical Analysis System(19) software package. Analyses of variance were performed by ANOVA procedure. Significant differences between the means were determined by Duncan’s multiple range test. Regression coefficients (a_0.....a_{23}) were used to generate contour plots for response variables (Y)(17).

Table 1. Values and corresponding coded variable of the processing conditions in the central composite rotatable design for vacuum fried carrot chips

	Variable level					
Processing conditions	-1.682	-1	0	+1	+1.682	Coded variable
Vacuum frying temp. (°C)	78.2	85	95	105	111.8	X_1
Vacuum frying time (min)	9.6	13	18	23	26.4	X_2
Immersing fructose conc.(%)	16.4	30	50	70	83.6	X_3

Table 2. Layout of the central composite rotatable design and corresponding quality values for vacuum fried carrot chips

Run	Coded variable[a]			Frying temp. (°C)	Frying time (min)	Immersing fructose conc. (%)	Moist. content (%)	Oil content (%)	*L* value	*a* value	*b* value	ΔE	Breaking force (g)
	X_1	X_2	X_3										
1	-1	-1	-1	85	13	30	3.77	23.28	43.28	28.73	23.06	11.11	1212
2	-1	-1	1	85	13	70	7.27	9.80	39.51	24.97	20.81	16.73	1904
3	-1	1	-1	85	23	30	2.19	25.97	43.13	27.43	23.01	11.94	841
4	-1	1	1	85	23	70	4.83	10.02	38.18	23.57	19.13	19.11	1618
5	0	0	0	95	18	50	3.05	12.12	38.52	22.27	19.60	19.43	662
6	0	0	0	95	18	50	3.75	10.08	39.82	24.82	20.09	16.88	694
7	1	-1	-1	105	13	30	1.18	26.16	34.58	21.11	16.52	24.15	602
8	1	-1	1	105	13	70	2.65	12.55	35.58	22.23	16.30	23.07	926
9	1	1	-1	105	23	30	0.72	30.63	34.68	18.23	16.40	25.42	383
10	1	1	1	105	23	70	1.55	13.36	34.58	21.11	16.52	25.15	716
11	0	0	0	95	18	50	3.01	12.73	39.07	24.18	19.01	18.26	735
12	0	0	0	95	18	50	4.84	13.91	37.08	22.29	17.53	21.26	772
13	1.682	0	0	112	18	50	0.34	14.72	35.01	17.67	154.47	25.92	536
14	-1.682	0	0	78	18	50	10.72	9.72	40.65	25.35	22.10	15.07	2082
15	0	1.682	0	95	26	50	1.47	15.14	36.33	22.27	18.03	21.59	513
16	0	-1.682	0	95	10	50	5.10	10.56	42.21	28.39	22.18	12.90	829
17	0	0	1.682	95	18	84	5.42	6.73	33.89	17.86	15.57	26.58	1830
18	0	0	-1.682	95	18	16	1.71	35.57	40.34	24.61	20.29	16.45	529
19	0	0	0	95	18	50	4.73	13.58	37.10	22.67	18.05	20.83	619
20	0	0	0	95	18	50	4.04	13.62	37.13	23.52	18.89	20.07	650

[a] X_1, frying temperature; X_2, frying time; X_3, immersing fructose concentration.

RESULTS AND DISCUSSION

In our previous study[8], it was found that pretreatment method and vacuum frying temperature and time greatly affected the quality of fried carrot chips. Therefore, attempts were made to optimize the processing conditions, and the central composite rotatable design (CCRD) was used in this study. According to the results of our previous work, a frying temperature of 95°C, a frying time of 18 min and an immersing fructose concentration of 50% were chosen as the centre points in the experimental design (Table 1). Table 2 shows the analytical data for moisture and oil contents, *L*, *a*, *b*, ΔE values and breaking force of each sample generated. Statistical Analysis System (SAS) was used to fit the second order polynomial equation (listed in the experimental design section) with experimental data shown in Table 2. The regression coefficient and analysis of variance for the dependent variables (moisture and oil contents, ΔE and breaking force) of fried carrot chips are presented in Table 3. No significant ($p > 0.05$) lack of fit implies this regression model was acceptable. The high R-square values (above 0.90 except moisture content and ΔE value) indicate that the variables are highly fitted to the regression equation.

I. *Moisture Content*

As shown in Table 3, the moisture content of carrot chips was significantly ($p < 0.05$) affected by frying temperature (X_1), frying time (X_2), and the concentration of immersing fructose solution (X_3). The contour plots of moisture content revealed that the moisture content of carrot chips increased with increasing fructose concentration and decreasing frying time (Figure 1A-C). However, as the frying temperature was above 95°C and the immersing fructose concentration was below 50%, the moisture content of carrot chips decreased to below 4% (Figure 1B). This indicated that the moisture content was affected by frying temperature more than by frying time, and the immersing fructose concentration played an important role in the moisture content of carrot chips.

II. *Oil Content*

As also evident from Table 3, the oil content of carrot chips was significantly ($p < 0.05$) affected by X_1 and X_3. The significant level ($p < 0.001$) on X_3^2 implied that the oil content was greatly affected by the concentration of immersing fructose solution. As shown in Figure 1D-E, the oil content of carrot chips decreased with increasing fructose

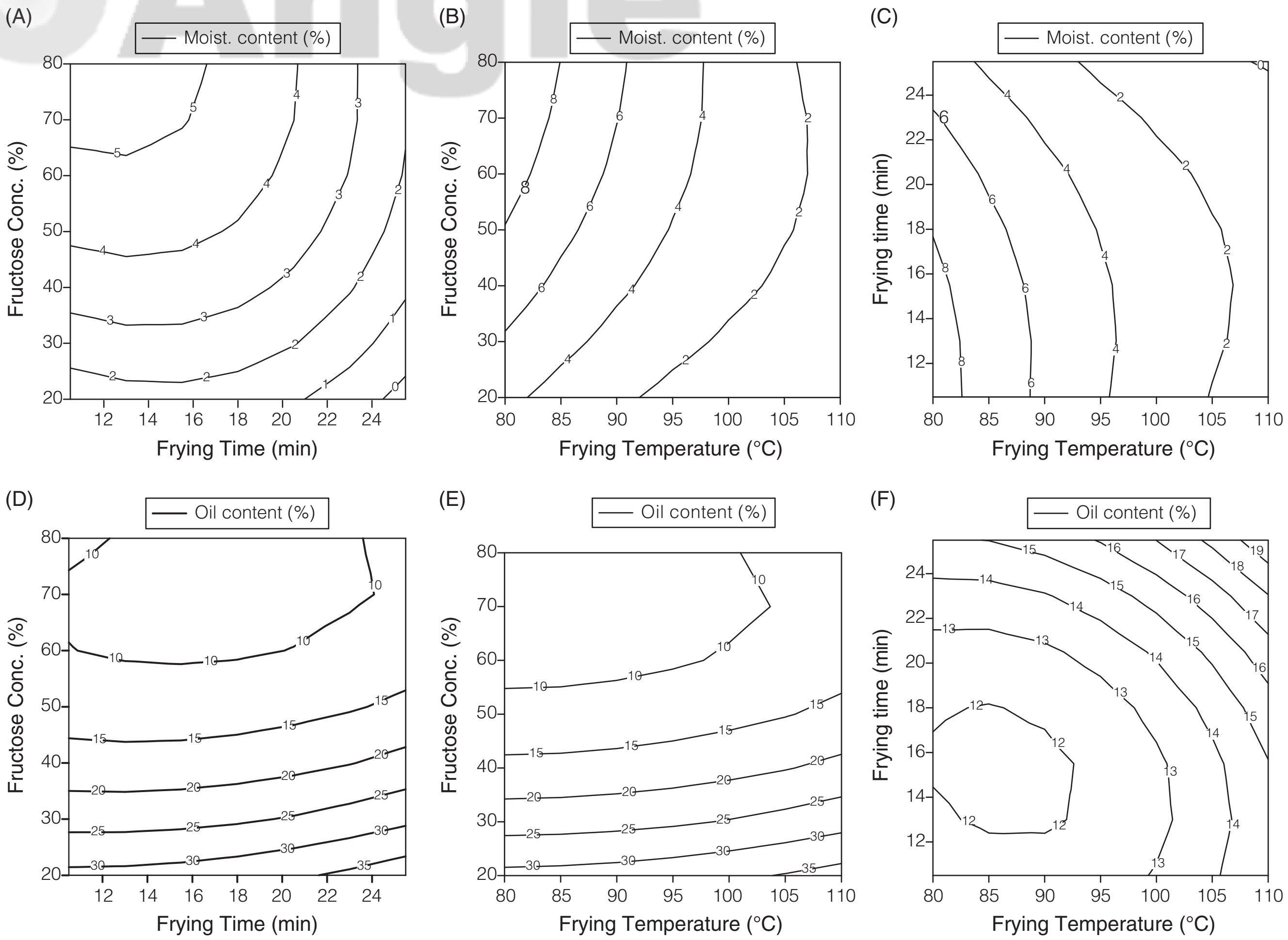

Figure 1. A-F. The contour plots of moisture content and oil content for vacuum fried carrot chips as affected by frying temperature, frying time, and concentration of immersing fructose solution.

concentration. The lowest oil content (< 10%) in carrot chips was obtained when an immersing fructose concentration of > 60% was used. Evidently, the oil content of carrot chips was less affected by the frying temperature (Figure 1D-F). These contour plots showed that the least oil content in carrot chips could be obtained when carrot slices were fried at a lower temperature (< 93°C) for 12 - 18 min.

III. *Color*

Table 3 also showed that the *L* values of carrot chips were significantly ($p < 0.05$) affected by X_1, X_2, X_3, and $X_1 \times X_3$. Statistical analysis indicated significant ($p < 0.001$) interaction between frying temperature (X_1) and immersing fructose concentration (X_3). The contour plots (data not shown) showed that the *L* values of carrot chips decreased with increasing fructose concentration and frying time. It could be assumed that the lightness of carrot chips was decreased due to low moisture content. As could be seen from Table 3, the *a* values of carrot chips were significantly ($p < 0.05$) affected by X_1, X_2, X_3, $X_1 \times X_3$, and X_2^2. Similar to *L* values, statistical analysis indicated significant ($p < 0.001$) interaction between frying temperature and immersing fructose concentration. The *a* values of carrot chips were also greatly affected by frying time. When carrot slices were immersed in fructose solution (> 50%) and fried at 95°C for up to 18 min, the *a* values could significantly decrease (data not shown). It could thus be speculated that some of carotenoids could be dissolved in the frying oil due to long frying time. In addition, the *b* values of carrot chips were significantly ($p < 0.05$) affected by X_1, X_2, and X_3 (Table 3). It was also shown that the *b* values of carrot chips were significantly ($p < 0.001$) affected by frying temperature more than the other two variables. Consequently, using a higher frying temperature would lower the *b* value of carrot chips.

Table 3 revealed that the color difference (Hunter ΔE) of carrot chips was significantly ($p < 0.05$) affected by X_1, X_2, X_3, and $X_1 \times X_3$. Statistical analysis indicated significant ($p < 0.05$) interaction between frying temperature and immersing fructose concentration. The contour plots (Figure 2A-C) of Hunter ΔE revealed that Hunter ΔE of carrot chips increased significantly ($p < 0.01$) as the frying temperature and immersing fructose concentration increased. This indicated that the higher Hunter ΔE, the lower color quality. It

Table 3. Regression coefficient and analysis of variance for dependent variables of vacuum fried carrot chips in the central composite rotatable design[a]

	Moist. content (%)	Oil content (%)	*L* value	*a* value	*b* value	ΔE	Breaking force (g)
Lack of fit	0.09	0.08	0.18	0.16	0.36	0.21	0.08
R-square	0.86	0.96	0.86	0.89	0.90	0.89	0.98
Intercept	3.98[a]	12.56[a]	38.12[a]	23.27[a]	18.86[a]	19.42[a]	683.63[a]
X_1	-2.15[a]	1.61[c]	-2.57[a]	-2.56[a]	-2.30[a]	4.11[a]	-406.25[a]
X_2	-0.86[c]	1.16	-0.90[c]	-1.24[b]	-0.63[c]	1.48[c]	-118.43[a]
X_3	1.08[c]	-7.97[a]	-1.44[a]	-1.10[c]	-1.04[b]	2.01[b]	315.89[a]
$X_1 \times X_1$	0.35	0.56	-0.13	-0.47	-0.02	0.32	211.04[a]
$X_2 \times X_1$	0.31	0.30	0.19	-0.16	0.23	-0.11	28.50
$X_2 \times X_2$	-0.44	0.78	0.38	0.88[c]	0.45	-0.83	-14.53
$X_3 \times X_1$	-0.48	-0.18	1.20[c]	1.45[c]	0.75	-1.89[c]	-101.50[c]
$X_3 \times X_2$	-0.19	-0.77	-0.17	0.21	-0.16	0.17	11.75
$X_3 \times X_3$	0.35	3.71[a]	-0.38	-0.57	-0.32	0.68	165.25[a]

[a] a, $p < 0.001$; b, $p < 0.01$; c, $p < 0.05$.

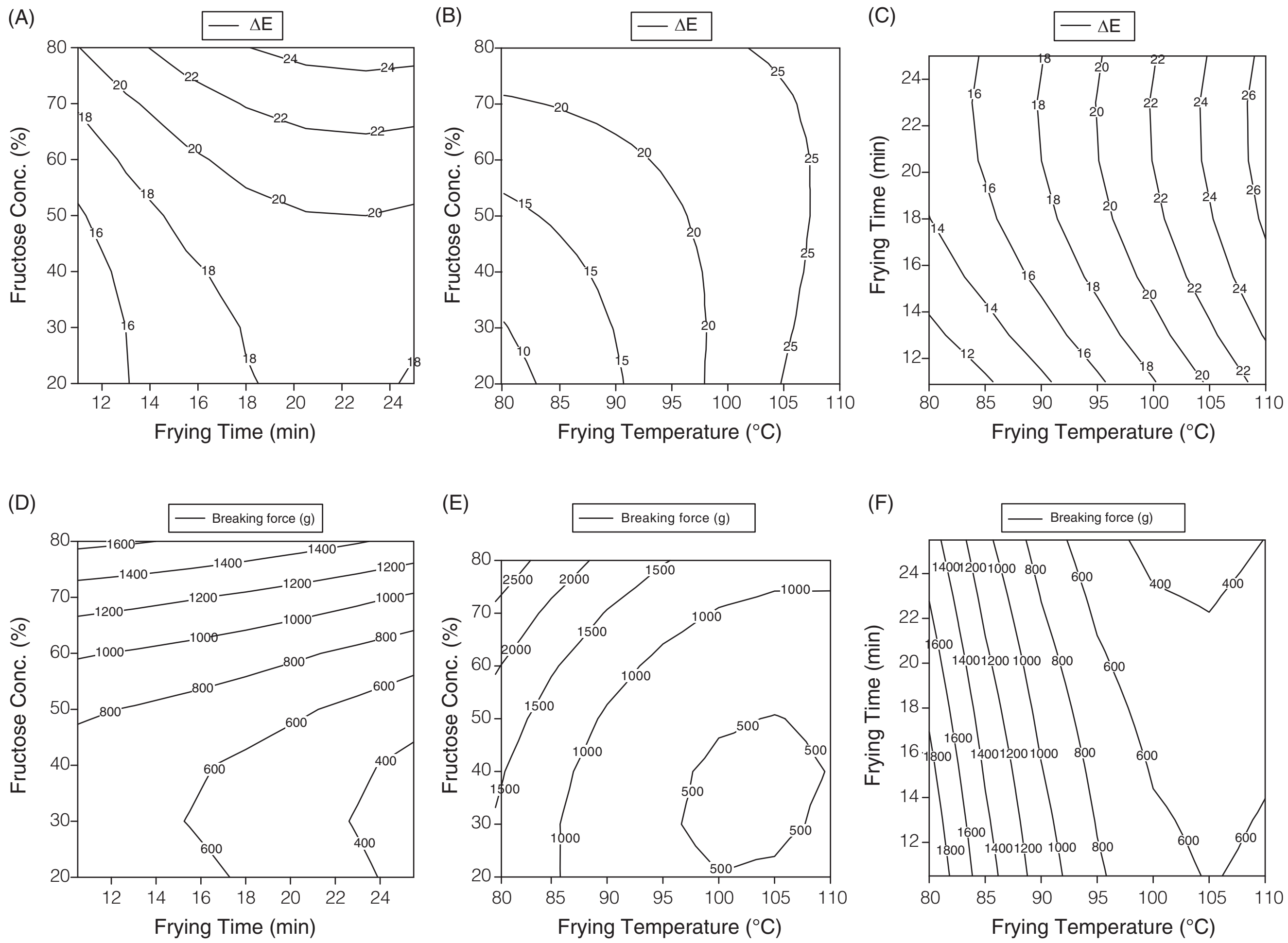

Figure 2. A-F. The contour plots of hunter ΔE and breaking force for vacuum fried carrot chips as affected by frying temperature, frying time, and concentration of immersing fructose solution.

might be assumed that heating could cause degradation of carotenoids in carrot slices, because carotenoids are unstable at elevated temperature[20,21]. In our previous report, we found that when carrot slices were fried under vacuum at 100°C for 20 min, the loss of α-carotene and β-carotene was 18% and 9%, respectively[13]. Also, it was possible that some of carotenoids could be dissolved in the frying oil due to long frying time.

IV. *Breaking Force*

The breaking force was used to measure the crispness of fried carrot chips in this study. A lower breaking force was considered to have a higher crispness. For carrot chips, a very crispy texture was expected since crispness was an indicator of freshness and high quality[22]. As shown in Table 3, the breaking force of carrot chips was significantly ($p < 0.001$) affected by frying temperature (X_1), frying time (X_2), and immersing fructose concentration (X_3) as well as the interaction between frying temperature and immersing fructose concentration ($X_1 \times X_3$). The contour plots (Figure 2D-F) revealed that the breaking force of carrot chips was reduced to below 600 g when the immersing fructose concentration was below 40% and the frying time was above 16 min. The least breaking force of carrot chips was reached when an immersing fructose concentration of 30 - 40% and the frying temperature of 100 - 105°C were used (Figure 2-E). Comparing the contour plots of breaking force (Figure 2D-F) to that of moisture content (Figure 1A-C), it was evident that breaking force of carrot chips decreased with decreasing moisture content. As the immersing fructose concentration was below 50%, carrot chip with breaking force lower than 600 g and moisture content of 3% could be achieved.

With breaking force as the main indicator of product quality, we found from the contour plots that the optimal processing conditions for vacuum fried carrot chips were: vacuum frying temperature of 100 - 105°C, vacuum frying time of 16 - 20 min, and immersing fructose concentration of 30 - 40%. This optimal processing condition was in agreement with our previous finding that immersion in fructose solution prior to vacuum frying at moderate temperature for 20 min could produce carrot chips with lower moisture and oil contents as well as good color and crispy texture[8]. Fan and others[14] reported that the optimum quality conditions of preparing vacuum fried carrot chips were a vacuum frying temperature of 100 - 110°C, a vacuum absolute pressure of 0.010 - 0.020 MPa and a frying time of 15 min. The conditions also fall within the range of our findings except absolute pressure (our absolute pressure is 0.00267Mpa). They, however, did not investigate the effect of immersion fructose concentration in their study. In this study, we found that the pretreatment of carrot slices in fructose solution and freezing prior to vacuum frying was the critical steps in obtaining vacuum fried chips with good flavor and texture[6,8].

The regression equation could highly predict the quality of vacuum fried carrot chips prepared from the frying conditions. Using the vacuum frying condition (100°C, 20 min) to prepare products, the predicted values of moisture and oil contents were 2.1% and 14.2%, respectively, while the experimental values of moisture and oil contents were 1.6% and 15.8%, respectively[8].

CONCLUSIONS

The results of response surface methodology (RSM) showed that the dependent variables including moisture content, oil content, color, and breaking force of carrot chips were significantly affected by the processing conditions such as frying temperature, frying time, and immersing fructose concentration. Among them, the immersing fructose concentration was the most important factor. The immersing fructose concentration was positively correlated with moisture content and breaking force of carrot chips but negatively correlated with the oil content and color of carrot chips. The optimal quality of fried carrot chips should possess a low moisture content, oil content and breaking force as well as slight color change. Based on CCRD and contour plots, the optimal processing conditions of vacuum fried carrot chips are: vacuum frying temperature of 100 - 105°C, vacuum frying time of 16 - 20 min, and immersing fructose concentration of 30 - 40%.

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