Study of optimum conditions for vacuum frying carambolas

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The effects of various frying parameters on the quality of vacuum-fried carambolas were investigated. The three-variable three-level fractional factorial design response surface methodology was used to combine the operation conditions, and process variables including syrup-soaking time, frying temperature and frying time. The response variables were based on the overall acceptability determined through sensory evaluation; the highest overall acceptability was obtained by the combination of syrup-soaking at 30° Brix for 1 hour, and then vacuum frying at 108°C for 46 min. Model functions were verified as being adequate, using an optimum combination of syrup-soaking time, frying temperature and frying time. The result showed that vacuum-fried carambolas have good quality.

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The carambola (*Averrhoa carambola*. L) is also called star fruit, owing to its star shape. The fruit is juicy, has a strong flavor, and is very favorable in tropical areas, such as in the Southern Asia, Southern American, Hawaii, and Australia; in Taiwan, fresh carambolas can be supplied over 8 months. Thus, they are economically important in the region.

Snack foods are very popular among the young generation. Most traditional snack foods are made from cereals. Recently, vacuum-fried fruits have become popular hot snack foods. With for the diversity of carambola products, the vacuum frying of carambolas should be developed to obtain products that are crispy, and non oily, and have a good color retention. In this study, we surveyed the optimum conditions for vacuum frying carambolas.

The operation conditions were combined using the three-variable three-level fractional-factor designed response surface methodology (RSM). By RSM, the effect of response on multiple factors by simple experimental design, mathematic deduction and systematic analysis, the process variables including syrup-soaking time, frying temperature and frying time, and the response variables for overall acceptability of sensory evaluation can be determined. Frying temperature and frying time are the most significant factors in yielding study of vacuum frying. Syrup soaking can remove some

water from the raw material, yielding a crispy product. Thus, syrup soaking time is also used as a variable factor in this study.

Materials and Method

1. Materials

- Carambolas were purchased from Mr. Lee's garden in Pingtung, Taiwan.
- Palm oil was purchased from Macro Wholesale Market.
- Sugar was from Taiwan Sugar Company.
- CaCl₂ was from Nacalai Tesque, Inc. (Japan).
- Ethyl ether was from Tedia Company, Inc. (Germany).

2. Equipment

- The vacuum fryer used was purchased from Big John Factory (Mini-S 1 Type, Taipei, Taiwan).
- Moisture content was measured using ZR water nets (FD-600-2 Type, Kett Electric Laboratory, Japan).
- The Colorimeter used was from Juki Co., Ltd. (JP 7100 F, Japan).
- Instron: Instron, 4464 Model, USA

3. Processing procedure

Raw materials were washed and cut horizontally into about 1-cm-thick pieces and, soaked in 2 % sodium chloride and then in syrup with 2 % calcium chloride for 1 hour. The samples were frozen at -20°C in a freezer overnight after

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syruping, and then fried in vacuum and de oiled by centrifugation (3,000 rpm) for 5 min. The processing procedure is shown in Fig.1.

4. Experimental Method

According to Box *et al.*, the combination of the concentration of the soaking syrup, frying temperature and frying time constitutes a three-level design for the study of 3 variables, by represented X_1 , X_2 and, X_3 . Each variable had three levels, - 1, 0, and + 1 representing the standard values of the code number. Soaking in 30° Brix syrup for 1 hour, and frying at 100°C for 45 min are regarded as the central point in the experimental design. The experimental values of each factor are decided by the results of the pretest. The distribution experiment is shown Table 1. The moisture content, oil content, color, texture and sensory evaluation parameters were measured for each sample. The results of the sensory evaluation were analyzed by Response Surface Regression (RS REG) using SAS (Statistic Analysis System). Soaking syrup concentration (X_1), frying temperature (X_2) and frying time (X_3) were used as variable factors obtained during operation. The optimum conditions are based on the overall acceptability by sensory evaluation.

5. Qualitative Analysis of Products

(1) **Moisture content determination** Five grams of sample was ground using an osterizer blender (USA), placed in a water meter at 105°C for 60

Fig.1 Procedure of processing vacuum-fried carambolas

Table 1 Qualitative characteristics of vacuum-fried carambolas following different treatments

Treat- ment	Soaking syrup (° Brix)	Frying temperature (°C)	Frying time (min)	Moisture content (%)	Perforation (kg)	Oil content (%)	Color (Whiteness)
1	40	110	45	11.73	0.4003	29.468	33.73
2	20	110	45	15.47	0.5023	28.274	34.47
3	40	90	45	24.63	0.8776	23.486	49.73
4	20	90	45	29.5	0.9390	22.069	49.37
5	40	100	50	17.57	0.5233	28.124	40.10
6	20	100	50	19.43	0.5930	27.919	41.39
7	40	100	40	21.53	0.6723	25.781	44.30
8	20	100	40	24.76	0.7030	25.118	43.49
9	30	110	50	10.73	0.3997	30.590	30.10
10	30	110	40	15.66	0.4860	27.878	37.86
11	30	90	50	23.6	0.7880	25.563	46.72
12	30	90	40	26.9	0.9456	21.462	50.61
13	30	100	45	20.3	0.6140	26.947	41.71
14	30	100	45	20.98	0.6027	26.491	42.29
15	30	100	45	20.56	0.5900	27.014	41.98

minutes, and then read of its moisture content.

(2) **Oil content determination** A Soxhlet-type extractor was used to extract oil with ether.

(3) **Color measurement** The color of each sample was determined using a color and color difference meter by determining the Hunter parameters "L", "a" and "b" were read. The meter was calibrated using a standard white plate ($X = 93.80$, $Y = 95.64$, $Z = 113.70$) with

$$\text{Hunter's whiteness} = 100 - \sqrt{(100 - L)^2 + (a^2 + b^2)}$$

(4) **Texture analysis** Instron was used in texture analysis. Probe model: 2830-005; 2.95mm in diameter.

(5) **Sensory evaluation** The sample was evaluated by 15 panelists using a 9-score system. The score was evaluated by differential test, and sensory evaluation. Its overall performance was determined. Color, greasiness, flavor, and crispiness were used as individual sensory evaluation parameters. The overall performance was based on the evaluation Vacuum-fried carambolas by the panelists, the mine-score system was as follows: 1, was dislike very much. 5, acceptable; and 9, like very much.

6. Statistical Analysis and Determination Search of Optimum Conditions

SAS statistical analysis was used to execute the variable analysis of the results of the sensory evaluation of each sample, and the significance of difference between the samples was determined using Duncan's Multiple Range Test (DMRT).

The overall acceptability of sensory evaluation was analyzed using the RSEZG equation in SAS. A multiple equation was drawn to describe the response surface figure. A homogeneity curve plotted using Excel and the optimum conditions were analyzed using the Figure Reconfirmation Test.

The triple sensory evaluation was carried out with the optimum combined conditions, the value evaluated using the equation under the optimum combined conditions was compared with the sensory value. The equation was considered feasible when there was no significant difference between these values.

Result and Discussion

The quality characteristics of vacuum-fried carambolas were determined. A three-variable and three-level fractional-factor design was decided through a pretest. Moisture content, perforation force, oil content, color, sensory characteristics were measured

to determine the quality of the product. The quality characteristics of the product are shown as follows:

1. Moisture content

As shown in Table 1, the lowest moisture content (10.73%) was obtained in the 9th test; at this moisture content, the frying temperature the frying time were 110°C and 50 minutes respectively. Thus, the higher the frying temperature and the longer the frying time, the lower the moisture content is. The moisture content was 15.66% during frying at 110°C for 40 minutes. At a fixed temperature, when the frying time was increased to 45 minutes, the moisture content decreased to 11.73%; it decreased to 10.73% when the frying time was increased to 45 minutes. This phenomenon is similar to the falling rate drying period. The rate of dehydration decreased because moisture diffused from the inside to the outside. Another reason is that the high temperature induces the surface of the carambolas to form a hard film; this film prevents the diffusion of water from the inside.

2. Perforation force

In the test on perforation force, all the samples were perforated using the same probe, and the perforation speed (150 mm/min) was the same. The perforated pressure was high for the probe diameter used and the surface was small. The following equation was used.

$$P = F/A$$

Perforation force was shown as a measure of crispiness. The lower the perforation force, the better the crispiness was. The sample fried at 110°C for 50 minutes showed the lowest perforation force. This indicates that this sample was the best in crispiness; in contrast, the sample fried at 90°C for 40 minutes showed the highest perforation force, maybe because the frying temperature was low and the frying time is short, so that most of the moisture was retained in the sample. The perforation force was larger for a softer texture and the probe was hard to perforate. In general, the lower the moisture content, the better, the crispiness was.

3. Oil content

In table 1, the oil content of vacuum-fried carambolas increased with frying temperature and frying time.

The increases in frying temperature and frying time induced the surface of the carambolas to rapidly form a gradient diffusion. The interval

moisture turned to steam and evaporated from the surface by diffusion, and oil easily to penetrated the hydrophobic interval space of the carambolas. Thus, the lower the moisture content, the higher the oil content of the carambolas is.

4. Color

The higher the frying temperature and the longer the frying time, the darker the color, or the lower the whiteness is, as shown in Table 1. The whiteness was 50.61 when the product was fried at 90 (C for 40 minutes, while it decreased to 30.10 when the product was fried at 110 (C for 50 minutes; the difference was significant. The product showed a dark color when the frying temperature was more than 110 (C and the frying time was longer than 50 minutes. Thus, the optimum conditions for frying carambolas were a frying temperature of less than 110 (C and a frying time of less than 50 minutes.

5. Sensory Evaluation

Color, greasiness, flavor, crispiness and overall acceptability were used as sensory evaluation parameters. The higher the frying temperature and the longer the frying time, the darker the color, the higher the greasiness and the better the flavor of the product were. There was a higher evaluation on crispiness and overall acceptability when the product was fried at 100 (C for 45 minutes. There was a good relationship of crispiness with the overall acceptability. Thus, in judging the overall

acceptability of vacuum-fried carambolas, crispiness was seen to be the most important factor.

6. Optimum Conditions for Vacuum Frying Carambolas

The analysis of the optimum conditions for vacuum frying carambolas was based on the data of the overall acceptability obtained by sensory evaluation, because the overall acceptability could be regarded as a measure of the preference of consumers.

The data of the overall acceptability was treated by SAS is using data regression. The regression coefficient of the overall acceptability shown in Table 3. The data could be shown in with layers of equation in three variables as follows:

Table 3 Regression coefficients and overall acceptabilities

Regression	Overall acceptability
A_0	6.680
A_1	0.406
A_2	0.625
A_3	0.454
A_{12}	0.283
A_{13}	-0.120
A_{23}	-0.458
A_{11}	-1.430
A_{22}	-0.868
A_{33}	-0.635

Table 2 Sensory evaluation values of vacuum-fried carambolas following different treatments

Treat- ment	Soaking syrup (°Brix)	Frying temperature (°C)	Frying time (min)	Color	Greasiness	Flavor	Crispi- ness	Overall acceptability
1	40	110	45	8.00 ab	5.33 c	6.87 a	6.47 b	5.59 c
2	20	110	45	7.73 b	6.33 b	6.87 a	5.60 c	4.58 e
3	40	90	45	3.93 f	3.33 f	5.20 b	3.47 e	3.62 fg
4	20	90	45	3.67 f	3.33 f	4.13 c	3.20 e	3.74 f
5	40	100	50	6.87 c	5.20 c	5.20 b	6.53 b	5.60 c
6	20	100	50	6.87 c	4.33 de	5.20 b	6.53 b	4.66 e
7	40	100	40	4.53 e	3.27 f	4.20 c	4.53 d	4.81 e
8	20	100	40	4.60 e	3.27 f	4.00 c	4.27 d	3.39 g
9	30	110	50	8.40 a	7.33 a	3.00 b	5.53 c	5.66 c
10	30	110	40	6.53 c	6.33 b	5.80 b	4.53 d	5.79 c
11	30	90	50	4.80 e	4.27 de	3.00 d	2.60 f	5.48 d
12	30	90	40	2.67 g	2.27 g	3.27 d	1.20 g	3.78 f
13	30	100	45	5.40 d	4.67 d	5.27	6.53 b	6.55 ab
14	30	100	45	5.53 d	4.13 e	5.47 b	6.80 b	6.90 a
15	30	100	45	5.53 d	5.60 c	5.47 b	7.47 a	6.59 ab

Y : Response type

X_i : variable

The results of the variable analysis are shown in Table 4. The model, lack of fit and R^2 were the most common indexes of results obtained by regression analysis.

(1) **Model regression** The model represented the fitness response to the model developed

(2) **Lack of fit** The lack of fit indicated the fit of the regression equation to the surface response.

(3) **R^2** R^2 represented correlation of the prediction by determining the regression equation value to the real value. The nearer R^2 is to 100%, the better the result is.

From Table 4, the regression of the model indicated a significant difference. This showed that the model was fit to study the response state response. The lack of fit was not significantly different, the regression equation is fit to the reality of the response surface, with a value of 97.69%. Thus the regression model is fit to the fact. The response surface figure and the homogeneity curve could be drawn from the regression equation.

Table 4 Variable analysis of overall acceptabilities of vacuum-fried carambolas

Source	df	Sum of squares of overall acceptability
Model	14	273.48 ⁽¹⁾
Linear	3	6.092
Quadratic	3	10.510
Cross product	3	1.214
Total regress	9	17.816
Lack-of-fit	3	0.348 ⁽²⁾
Pure error	2	0.073
Total error	5	0.422
% Variability explained (R^2)		97.69

(1) It was significant difference at 1 % level.

(2) It was no significant difference at 5 % level.

Table 5 Variable analysis of integral of total function from sum of overall acceptability of variance

Process variable	df	Sum of overall acceptability
Syrup concentration (X 1)	4	9.248 ⁽¹⁾
Frying temperature (X 2)	4	7.060 ⁽¹⁾
Frying time (X 3)	4	4.031 ⁽²⁾

(1) Significantly different at 1 % level.

(2) Not significant different at 5 % level.

The integrated total function of overall acceptability from the triple variance of the procedure is shown in Table 5. There were significant differences in the integrated total function of syrup concentration, frying temperature and frying time. These factors were the temperate variance on the product.

In general, frying temperature and frying time are the control points parameters of vacuum-fried products, to improve product quality. Syrup concentration was also used as variance. -1, 0, and 1 were used to represent the step codes of syrup concentration. These codes were introduced to the regression multi equation. the equation describing the response character is expressed as follows.

For $\times 1 = -1$,

$$Y = 4.88 + 0.342 \times 2 + 0.574 \times 3 - 0.458 \times 2 \times 3 - 0.868 \times 2^2 - 0.635 \times 3^2$$

For $\times 1 = 0$,

$$Y = 6.680 + 0.625 \times 2 + 0.454 \times 3 - 0.458 \times 2 \times 3 - 0.868 \times 2^2 - 0.635 \times 3^2$$

For $\times 1 = 1$,

$$Y = 5.656 + 0.908 \times 2 + 0.334 \times 3 - 0.458 \times 2 \times 3 - 0.868 \times 2^2 - 0.635 \times 3^2$$

The response surface figure and homogeneity curve could be drawn from the above three regressions as Fig.2 A.

From the response figure, the sample soaked in 30° Brix has a higher overall acceptability; this shows that consumers would like the product soaked in 30° Brix syrup concentration, and fried at 103°C, 46 minutes, it was found that frying at 104°C for 41 minutes showed the higher overall acceptability. This result might have led to the variation of the panel test. Thus, the optimum conditions for vacuum frying carambolas were a 30° Brix syrup concentration, a 108°C frying temperature and a 46 min in frying time.

Reconfirmation

A reconfirmation test was carried out to support the panel test of the product prepared under optimum conditions. The experimental overall acceptability is shown in Table 6, the predicted values obtained using the equation of the step code transferred under the optimum conditions are also shown in Table 6. There was no significant difference between the experimental and predicted values, so the experimental equation and optimum

Fig. 2 A Overall acceptability of response surface and homogeneity curve at 20° Brix ($x_1 = -1$) syrup concentration

Fig. 2 B Overall acceptability of response surface and homogeneity curve at 30° Brix ($x_1 = 0$) syrup concentration

Fig. 2 C Overall acceptability of response surface and homogeneity curve at 40° Brix ($x_1 = 1$) syrup concentration

Table 6 Comparison of predicted value and experimental value

	Experimental value	Predicted value	Difference (%)
Overall acceptability	7.78	7.84	0.771

conditions could be fit to improving the procedure of vacuum frying.

Conclusions

The optimum conditions for the vacuum frying carambolas was achieved by the response surface method, and the conditions were also reconfirmed by a test : 30° Brix syrup concentration, 103°C frying temperature and 46 min frying time. There was no significant difference between consumer acceptability and the predicted value. Moisture content was the most important factor affecting the quality of vacuum-fried carambolas.

There was large difference between fresh carambolas and vacuum-fried carambolas in terms of appearance, texture, flavor, and commercial aspects as a snack food. The quality vacuum-fried carambolas was affected by the conditions of pretreatment and processing. Thus, it was difficult to make good-quality vacuum-fried carambolas. RSM was used in this experiment to determine the optimum conditions for processing vacuum-fried carambolas successfully. Other new product developments were obtained under the optimum conditions also by RSM.

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ゴレイシをバキューム・フライにする 最適条件に関する研究

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本研究ではゴレイシを、いくつかの条件の下でバキューム・フライにする際の、製品品質に及ぼす影響を調べた。3段階式反応表面法の製造工程において、シラップに漬け込む時間や、バキューム・フライの温度や時間などを変えた場合の、品質への影響をパネル・テストを行って調べた。評価がもっともよかったものは原料を30° Brixのシラップに漬け込んで1時間後に108°Cで46分間バキューム・フライにしたものであった。モデル式で検証してみると、最適漬込み時間、最適バキューム・フライ温度および時間の組み合わせで、もっともよい品質の製品が得られ、それは110ネルテスト、一致した。

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