UNIVERSITY OF COPENHAGEN

Optimization of hot-air drying conditions on the physicochemical characteristics of torch ginger (Etlingera elatior)

Juhari, Nurul Hanisah Binti; Lasekan, Ola; Muhammad, Kharidah; Karim, Shahrim

Published in:
Journal of Food, Agriculture & Environment (JFAE)

Publication date:
2012

Document version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Juhari, N. H. B., Lasekan, O., Muhammad, K., & Karim, S. (2012). Optimization of hot-air drying conditions on the physicochemical characteristics of torch ginger (Etlingera elatior). *Journal of Food, Agriculture & Environment (JFAE)*, *10*(2), 64-72. [2].

Download date: 19. sep.. 2020

WFL Publisher
Science and Technology

Meri-Rastilantie 3 B, FI-00980
Helsinki, Finland
e-mail: info@world-food.net

Journal of Food, Agriculture & Environment Vol.10 (2): 64-72. 2012

www.world-food.net

Optimization of hot-air drying conditions on the physicochemical characteristics of torch ginger (*Etlingera elatior*)

N. H. Juhari [1], O. Lasekan [2]*, M. Kharidah [3] and S. Ab Karim [1]

[1] Department of Food Service and Management, Faculty of Food Science and Technology, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia. [2] Department of Food Technology, Faculty of Food Science and Technology, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia. [3] Department of Food Science, Faculty of Food Science and Technology, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia.
**e-mail: lasekan@food.upm.edu.my, nurulhanisah.juhari@gmail.com*

Received 12 January 2012, accepted 30 April 2012.

Abstract

Response surface methodology (RSM) was used to determine the effect of hot-air drying on physicochemical characteristics of torch ginger (*Etlingera elatior*). Three independent variables were time (3-5 hours), temperature (40-80°C) and loading capacity (0.5-2 kg/m^2). In this research, 20 treatments were assigned based on central composite design (CCD) containing 8 factorial points, 6 centre points and 6 axial points. The quality of dried Torch ginger produced was evaluated by determining moisture content, water activity, Hunter L, a, b values and texture (brittleness). The results revealed that the linear terms exhibited significant ($P<0.05$) effect on moisture content. The quadratic terms showed significant ($P<0.05$) effect on water activity, texture (brittleness), colour L and colour b values; while for colour a values, the interaction terms of drying condition was the most significant ($P<0.05$) factor. A satisfactory coefficient of determination (R^2) at 0.523, 0.807 and 0.953 was obtained for the response variables studied namely texture, moisture content and water activity, respectively. However, there are an unsatisfactory coefficient of determination (R^2) for colour-L, colour-a and colour-b. No significant ($p>0.05$) lack of fit was indicated for the reduced models, except for the models fitted for texture. The optimization results indicated that the best response, within the range studied, was reached when the drying time was 4.1 h, the drying temperature 79°C and loading capacity 0.7kg/m^2, respectively. No significant ($p>0.05$) difference was found between the experimental and predicted values, thus ensuring the adequacy of the response surface models employed for describing the effects of hot-air drying on physicochemical properties of Torch ginger.

Key words: Torch ginger, hot-air drying, physicochemical properties, *Etlingera elatior*, response surface methodology, optimization, herb and spices, drying, central composite design, ginger flower.

Introduction

Herbs and spices have been used for many centuries for flavouring and food preservation as well as medicinal purposes [1]. Currently, the spice production levels and supplies have increased, with an attendant widespread usage among population [1, 2]. In addition, the use of spices had increased significantly due to renew interest in dishes that use a variety of spices and to the ability of the spices to act as antioxidants in addition to their seasoning properties [3]. Apart from being used in food seasoning, dried herbs are also used in various applications such as seasoning of foods, in the beverage industry, pharmaceutical, perfumery and in cosmetic products.

Torch ginger (*Etlingera elatior* Jack) is also known as 'Kantan' in Malaysia [4, 5]. It is also synonymous with *Phaeomoria speciosa* (Blume), *Phaemoria magnifica* (Roscoe) or *Nicolaia speciosa* (Blume). Torch ginger is native of Sumatra, Indonesia, and it has been found in many places throughout Southeast Asia. There are at least 20 genera and 300 species found in Malaysia out of 50 genera and 1500 species known in the world [4, 6]. The plant of etlingera is widely grown for both flavouring and medicinal purposes. It can be consumed as condiment, eaten raw or cooked [7]. Normally, the young and tight flower buds of etlingera are widely used for culinary purposes because they give spice and colour to curries, fish soups, stir-fried veggies and salads [8], as well as to flavour local dishes like 'nasi ulam', 'laksa asam', 'kerabu' [9], 'laksa' or 'asam pedas'. The different tones of pink and red colours of the flowers make etlingera species very attractive among others [10]. Jaafar *et al.* [6] revealed that the essential oils of the flowers contained major compounds such as 1,1-dodecanediol diacetate (24.38%) and cyclododecane (47.28%). Besides that, these plants exhibit antimicrobial activity and cytotoxic effects to hela cells [11] and antitumor-promoting activity [12].

The leafy spices are highly perishable in nature and, therefore, they have very short shelf-life. Usually, they deteriorate rapidly after harvesting which leads to loss of flavour and quality. So, drying is an important technology for preserving the product's quality and to prevent the spoilage of the product during storage, as well as to facilitate its packaging and distribution. According to Maroulis and Saravacos [13], food drying is a traditional method of food preservation, which is also used for the production of special foods and food ingredients. The term 'drying' always refers to the removal of a relatively small amount of moisture from a solid or nearly solid material by evaporation [14], which assures microbial stability and guarantees expected shelf-life of the product [15]. Most of the drying methods used application of heat on the products to remove moisture. Moreover, good drying technique can enhance the quality of the product significantly [16]. However, different drying conditions and techniques can create diverse food structure [17, 18]. Previous studies revealed that numerous methods of drying have been applied to food materials, especially herbs and spices. Hot-air drying is still the most widely used method to produce dried products, because of their lower cost. In addition, air drying of aromatic herbs can be an effective method of preservation that inhibits growth of microorganisms and delays some biochemical reactions in the final product [19].

Recently, many studies have been conducted on the effect of drying condition on different plants. Doymaz *et al.* [20] determined the effect of drying air temperature on the drying time and drying characteristic of dill and parsley. Derya and Ozcan [21] determined sun, oven and microwave drying characteristics of rosemary leaves and compared traditional sun drying and conventional oven drying methods to the microwave drying method. Demir *et al.* [22] determined optimum conventional drying conditions for bay leaves. The conditions studied included colour, shape, drying time and essential oil. Sakhale *et al.* [23] studied the effect of magnesium oxide on curry leaves dried under different drying methods such as sun drying, shade drying and tray drying; the leaves were subsequently analyzed for their nutritional and organoleptic qualities. Balladin and Headly [24] evaluated solar dried thyme and compared with oven and microwave methods. Ozcan *et al.* [25] observed the effect of oven and sun drying on the mineral content of basil herbs. Also, Mohamed *et al.* [26] investigated the effects of drying air temperature and air flow rate on the drying kinetics of *Citrus aurantium* leaves. However, there is very little published work on dried torch ginger.

Response Surface Methodology (RSM) is a valuable tool used to determine the optimum levels of two or more treatment variables, the aim is to optimize the responses. RSM has been successfully used to model food ingredients [27, 28], to optimize food process variables [29, 30] and to optimize orange beverage emulsion [31]. It has important applications in the design, development and also formulation of new products, as well as in the improvement of existing product design. It defines the effect of independent variables, alone or in combination, on the processes. In addition to analyzing the effects of independent variables, this experimental methodology generates a mathematical model which describes the chemical or biochemical processes [28].

Thus, this study aimed to examine the effect of hot-air drying conditions on the physicochemical characteristics of torch ginger (*E. elatior*). After that, to find the optimum conditions for drying and production of high quality dried material that could be used for a high food grade spicing material.

Materials and Methods

Fresh torch ginger (*Etlingera elatior*) samples were obtained from the same local supplier to avoid variation. The samples were separated from stalks and stem and washed thoroughly under running water to remove dirt, and weighed. The excess water was drained and kept in cold storage at -60°C. Prior to drying experiment, the samples were taken out of storage and thawed at room temperature. They were dried under different drying conditions. After drying, the samples were placed into moisture permeable plastic bags and stored at room temperature until further analysis. Each sample was evaluated for its physicochemical characteristics.

Drying equipment: A programmable oven with 400W (Smoke Master Model SMA-112, Japan) was used. The drying oven is equipped with a temperature control function that allows the user to select the required drying temperature and also to adjust the time of processing. The hot-air drying experiments were performed using a drying tray (52 cm× 41 cm). Air was circulated from above and the bottom of the perforated drying tray.

Drying procedure: Fresh herbs with different loading capacity (0.5-2 kg/m^2) were dried in a drying oven (Smoke Master Model SMA-112, Japan) under different drying temperatures (40-80°C) and drying time (3-5 h) and prepared for optimization procedure based on a central composite design (CCD) (Table 1). The term of loading capacity can be defined as a specified amount of weight per square foot that is allowed to be placed on a given platform (tray). During drying process, samples were turned over every 30 min for evenly distribution of heat among samples. The oven was switched on for 1 h before the drying process to equilibrate the temperature.

Determination of moisture content: The moisture content of samples was determined (in triplicate) using hot-air oven method at 105°C for 5 h [32]. Prior to moisture content analysis, samples were ground into coarse powder and mixed thoroughly. Crucibles and lids were dried in oven (Memmert Model 500 ULM, Schwabach, Germany) at 105°C for 1 h. Crucibles were weighed without lid after attained room temperature. Samples (2 g) were placed in crucible and dried in the oven at 105°C for 5 h. After that, the crucibles were transferred directly and cooled in the desiccators. Soon after attaining room temperature, the weights of crucible were measured. The loss on drying (LD) was reported as the moisture content (%).

$$\%\ (w/w)\ LD = \%\ (w/w)\ moisture = 100 \times \frac{\text{wt loss on dying (g)}}{\text{wt test portion}}$$

Determination of water activity: Water activity of dried samples was measured using a water activity meter (Aqualab Series 3 TE, Decagon Device, Inc., Pullman, WA, USA) as reported by Yousif *et al.* [19]. Initially, the water activity meter was warmed up before measurement. The chamber of this device was opened and the samples were filled into the cup to ¾ levels before it was returned into the chamber and sealed. The results were read on the meter screen [33].

Table 1. Levels of independent variable for hot-air oven drying established according to the central composite design (CCD).

Variable	Independent variable levels				
Independent variables	Low	Centre	High	Axial (-α)	Axial (+α)
Time (hour)	3	4	5	2.37	5.63
Temperature (°C)	40	60	80	27.34	92.66
Loading capacity (kg/m^2)	0.5	1.25	2.0	0.03	2.47

Texture analysis: Textures of dried herbs were evaluated using instrumental method. A TA.XT2 i plus Texture Analyser (Stable Micro Systems, Godalming, UK) was used for force/

displacement measurement with a 5 kg load cell, using a 2 mm cylinder spherical stainless probe SMS (P/2) to measure the force required to penetrate an individual dried torch ginger placed on the centre of corresponding platform with 10 mm diameter. The test settings were test speed 0.5 mm/s, trigger force 10 g and travel distance of the probe 8 mm. The value of rupture strength and brittleness reported were the mean of 15 measurements.

Colour analysis: All dried herbs were analyzed using Hunter Lab colorimeter (Hunter Lab D65 Spectrocolorimeter Ultrascan PRO, Reston, VA) as reported by Yousif *et al.* [19]. Five g of each treatment samples were ground (in triplicate) for 10 s to produce a powder of a uniform colour. The samples were transferred to a 10 cm glass cuvette and read by a Hunter Lab Scan II Spectrocolorimeter. The instrument, equipped with a D_{65} illuminant and 2° observer optical position, was calibrated using a black plate and standard white plate (X = 79.8, Y = 84.67, Z = 91.23). The results were expressed as Hunter Lab *L* (whiteness/darkness), *a* (red/green) and *b* (yellow/blue) values on the screen of colorimeter and were recorded. Each reading gave three different coordinates *L*, *a* and *b*.

Experimental design and data analyses: The effect of three independent variables; X_1 (time), X_2 (temperature) and X_3 (loading capacity), on six response variables (Y_1-Y_6, namely moisture content, water activity, texture, colour L, colour a and colour b) were evaluated by using RSM. A central composite design (CCD) (Table 1) was employed to study the main and combined effects of main drying conditions on the physicochemical properties of dried torch ginger, to create models between the variables and to use these variables to optimize the drying conditions for the production of high quality food grade spicing material. As shown in Table 2, 20 treatments were assigned based on the second-order CCD with three independent variables. The three independent variables ranges studied for hot-air oven drying were time (3-5 h), temperature (40-80°C) and loading capacity (0.5-2 kg/m^2) as shown in Table 1. The experiments were randomized in order to minimize the effects of unexplained variability in the actual responses due to extraneous factors. The centre points were repeated six times to calculate the repeatability of the method [34]. The matrix of the CCD, including the values corresponding to the levels of factors and the treatments, is shown in Table 2. The arrangement of CCD presented was in such a way that it allowed the development of the appropriate empirical equations [35, 36].

Statistical analyses: Analysis of variance (ANOVA) and regression surface analysis was conducted to determine regression coefficients and statistical significance of model terms and to fit the mathematical models to the experimental data, aiming at an overall optimal region for the response variables [36]. The generalized response surface model for describing the variation in response variables is as follows:

$$Y = \beta_o + \Sigma\beta_i x_i + \Sigma\beta_{ii} x^2_i + \Sigma\beta_{ij} x_i x_j \quad (1)$$

where *Y* is the response value predicted by the model; β_o is an offset value; β_i, β_{ii} and β_{ij} are main (linear), quadratic and interaction regression coefficients, respectively. The adequacy of the models was determined using model analysis, lack-of-fit test and coefficient of determination (R^2) analysis [37, 38]. It is suggested that for a good fitness of a response model, R^2 should be at least 0.80 [39]. Atkinson and Donev [40] indicated that the corresponding variables were more significant (P<0.05) if the absolute *t* value becomes larger and *p* value becomes smaller. The terms statistically found non-significant (P>0.05) were dropped from the initial models and the experimental data refitted only to significant (P<0.05) independent variable effects in order to obtain the final reduced model. It should be noted that some variables were kept in the reduced model despite non-significance. For example, linear term containing the variables was also kept in the model if a quadratic or interaction term containing the variable was significant (P<0.05) [36]. The experimental design matrix, data analysis and optimization procedure were carried out using Minitab, version 14, statistical package (Minitab Inc., PA, USA).

Optimization procedure: In this study, both multiple graphical and numerical optimization procedures were applied to determine the optimum different hot-air drying conditions on the physicochemical properties of dried torch ginger. For graphical optimization procedure, the final reduced models were expressed as three-dimensional (3D) response surface plot to better visualize the interaction effect of main drying conditions on the physicochemical properties of dried torch ginger. The 3D plots were drawn by keeping one variable constant at the centre point and varying the other two variables within the experimental range in order to show how each response variable related to two continuous design variables. For numerical multiple optimizations, the response optimizer was carried out by using the Minitab software for determining the exact optimum level of independent variables leading to individual and overall response goals. Response optimizer allows us to compromise a single response or a set of responses. This numerical response optimization allows us to interactively change the input variable settings to perform sensitive analyses and possibly improve the initial solution [31].

Verification of models: Both practical and theoretical methods can be applied for validation. For practical method, the experimental data were run again by using optimum point obtained by each factor. The model is validated practically if obtained data are close to predicted data. For theoretical method, the experimental data were compared with predicted values in order to verify the adequacy of final reduced models by using 2-sample t-test. Close agreement and no significant difference must exist between the experimental data and predicted values [31].

Results and Discussion

Fitting the response surface models: In this study, multiple regression analyses were performed using response surface analysis to determine regression coefficients and statistical significance of model terms and fitting the mathematical models to the experimental data, aiming at and overall optimal region for the response variables [36]. The response surface analysis allowed the development of an empirical relationship where each response (Y_i) was assessed as a function of time (X_1), temperature (X_2) and loading capacity (X_3) and predicted as the sum of constant (b_o), three first-order effects (linear terms in X_1, X_2 and X_3), three interaction effects (interactive terms in X_1X_2, X_1X_3 and X_2X_3) and three second-order effects (quadratic terms in X_1^2, X_2^2 and X_3^2) [41]. The estimated regression coefficient of response surface models with the corresponding R^2 values and lack of fit test are reported in Table 3. The

Table 2. The matrix of central composite design (CCD) and experimental data obtained for the response variables studied (Y_1-Y_6) (mean ±SD).

Treatment runs	Blocks	Independent variables: Time (hour) (X_1)	Temperature (°C) (X_2)	Loading capacity (kg/m^2) (X_3)	Response variables: Moisture content (%) (Y_1)	Water activity (Aw) (Y_2)	Texture (brittleness) (mm) (Y_3)	Colour (powder-coarsely ground form): L (Y_4)	a (Y_5)	b (Y_6)
4	1	3.00	40.00	0.50	86.83 ± 0.26	0.990 ± 0.002	4.13 ± 1.13	62.10 ± 0.51	10.86 ± 0.16	10.13 ± 0.24
5	1	5.00	80.00	0.50	6.82 ± 0.13	0.442 ± 0.01	6.66 ± 0.66	51.97 ± 0.29	10.31 ± 0.08	11.25 ± 0.40
3	1	5.00	40.00	2.00	85.60 ± 0.21	0.992 ± 0.002	4.70 ± 0.96	50.98 ± 0.94	10.36 ± 0.15	11.31 ± 0.10
1	1	3.00	80.00	2.00	77.00 ± 0.30	0.988 ± 0.001	4.73 ± 1.17	57.50 ± 0.81	10.93 ± 0.30	10.13 ± 0.23
6 (C)	1	4.00	60.00	1.25	70.71 ± 0.28	0.982 ± 0.001	3.75 ± 0.94	66.47 ± 0.21	11.97 ± 0.84	13.61 ± 0.97
2 (C)	1	4.00	60.00	1.25	49.61 ± 0.07	0.968 ± 0.002	3.75 ± 0.94	64.46 ± 0.72	9.40 ± 0.41	10.09 ± 0.45
17	2	5.00	40.00	0.50	36.19 ± 1.35	0.955 ± 0.001	2.80 ± 1.03	66.26 ± 0.13	8.95 ± 0.64	9.86 ± 0.66
20	2	3.00	80.00	0.50	9.30 ± 0.14	0.557 ± 0.002	5.89 ± 0.85	64.03 ± 0.90	10.20 ± 0.25	9.56 ± 0.30
16	2	3.00	40.00	2.00	88.04 ± 0.21	0.996 ± 0.002	5.47 ±0.57	54.58 ± 0.70	8.72 ± 0.38	11.23 ± 0.19
19	2	5.00	80.00	2.00	49.94 ± 0.08	0.969 ± 0.000	4.06 ± 0.49	66.05 ± 1.57	7.46 ± 0.48	11.09 ± 0.12
15 (C)	2	4.00	60.00	1.25	73.92 ± 0.24	0.994 ± 0.005	2.76 ± 1.30	60.59 ± 0.79	7.95 ± 0.23	11.72 ± 0.08
18 (C)	2	4.00	60.00	1.25	78.46 ± 0.14	1.001 ± 0.002	2.80 ± 0.90	61.37 ± 0.57	8.63 ± 0.06	10.62 ± 0.07
10	3	2.37	60.00	1.25	78.42 ± 0.33	0.993 ± 0.000	4.32 ± 0.68	58.36 ± 0.24	11.89 ± 0.32	9.27 ± 0.26
7	3	5.63	60.00	1.25	20.93 ± 0.23	0.860 ± 0.010	4.74 ± 0.37	67.09 ± 0.89	9.03 ± 0.51	8.79 ± 0.30
12	3	4.00	27.34	1.25	86.26 ± 0.19	0.996 ± 0.002	5.76 ± 0.38	54.65 ± 1.16	8.92 ± 0.48	10.89 ± 0.19
14	3	4.00	92.66	1.25	7.13 ± 0.30	0.498 ± 0.013	6.70 ± 0.49	64.90 ± 0.46	9.29 ± 0.43	9.88 ± 0.27
8	3	4.00	60.00	0.03	8.79 ±0.16	0.539 ± 0.042	8.17 ± 0.71	61.07 ± 1.90	9.51 ± 0.35	9.95 ± 0.57
11	3	4.00	60.00	2.47	81.00 ± 0.08	0.990 ± 0.000	2.92 ± 1.45	56.73 ± 0.98	10.84 ± 0.20	10.44 ± 0.17
9 (C)	3	4.00	60.00	1.25	37.55 ± 0.50	0.960 ± 0.011	4.87 ± 0.40	68.18 ± 0.25	7.32 ± 0.33	11.47 ± 0.33
13 (C)	3	4.00	60.00	1.25	53.47 ± 0.42	0.969 ± 0.003	5.00 ± 0.67	68.45 ± 0.61	7.66 ± 0.16	11.17 ± 0.17

(C): Centre point.

R^2 values for these response variables were between 0.289 and 0.97. The results showed that the regression models for the response variables were significant by the test at the 5% confidence level (P<0.05). The results exhibited that the final reduced models were significantly (P<0.05) fitted for the three response variables studied; namely moisture content, water activity and texture (brittleness) with R^2, ranging from 0.523 to 0.970 (Table 3). However, the results also indicated that the final reduced models were not significantly (P>0.05) fitted for the other three response variables studied, *i.e.* colours, L, a and b with R^2, ranging from 0.289 to 0.337 (Table 3). The results demonstrated that there was a significant (P<0.05) lack of fit for the regression models fitted for texture (brittleness). This may be as a result of the wide range of independent factors being considered in the study [42, 43].

The results obtained were then analyzed by ANOVA to assess the 'goodness of fit'. Only terms found significant (P<0.05) were included in the final reduced model. Eq. 2 to 7 showed that the models obtained for predicting the response variables explained the main quadratic and interaction effects of factors affecting the response variables. The sign and magnitude of the coefficients indicate the effect of the variables on the response (Table 3). A negative coefficient means a decrease in response when the level of the variable increased, whereas a positive coefficient indicates an increase in the response. Furthermore, a significant interaction suggests that the level of one of the interactive variables may increase while that of the other may decrease for a constant value of the response [35, 27]. The lack of fit, which is used to measure the fitness of models, exhibited no significant F value (P>0.05) in terms of the response variable studied. This indicated that the models were accurate for predicting those response variations. The following response surface models (Eq. 2-7) were obtained:

Moisture content:

$$Y_1=135.963-13.238X_1-1.061X_2+27.936X_3 \quad (2)$$

Water activity:

$$Y_2=0.9178+0.005X_2+0.002X_3-0.000X_2^2-0.114X_3^2+0.008X_2X_3 \quad (3)$$

Texture:

$$Y_3=5.795-0.108X_2+2.591X_3+0.002X_2^2-0.058X_2X_3 \quad (4)$$

Colour, L:

$$Y_4=78.018-0.232X_2-17.209X_3+0.253X_2X_3 \quad (5)$$

Colour, a:

$$Y_5=21.384-4.936X_1-0.007X_2-1.989X_3+0.53X_1^2+0.0001X_2^2+0.769X_3^2 \quad (6)$$

Colour, b:

$$Y_6=-0.138+5.478X_1-0.669X_1^2 \quad (7)$$

Effect of different drying variables on physicochemical characteristics (moisture content, water activity, texture and colour) of torch ginger (Etlingera elatior):

Moisture content: The effect of three independent variables on the moisture content was examined by the coefficient of the second-order polynomial regression equations (Table 4). A surface plot which displays a three-dimensional view and provides a clearer picture of the effect of independent variables (drying time, drying temperature and loading capacity) on the moisture content of

Table 3. Regression summary and analysis of variance for moisture content, water activity, texture, colour *L*, colour *a* and colour *b* in uncoded form of process variable.

Regression coefficient	Responses					
	Moisture content	Water activity	Texture	Colour L	Colour a	Colour b
b_o	135.963	0.918	5.795	78.018	21.384	-0.138
b_1	-13.238	-	-	-	-4.936	5.478
b_2	-1.061	0.005	-0.108	-0.232	-0.007	-
b_3	27.936	0.002	2.591	-17.409	-1.989	-
b_1^2	-	-	-	-	0.539	-0.669
b_2^2	-	-0.000	0.002	-	0.000	-
b_3^2	-	-0.114	-	-	0.769	-
b_{12}	-	-	-	-	-	-
b_{13}	-	-	-	-	-	-
b_{23}	-	0.008	-0.058	0.253	-	-
R^2	0.807	0.970	0.523	0.337	0.306	0.289
R^2(adj)	0.771	0.953	0.396	0.212	0.000	0.205
Regression (P value)	0.000 *	0.000 *	0.019 *	0.080 **	0.490 **	0.055 **
Lack of fit (F value)	0.730	0.740	4.520	1.430	0.450	0.580
Lack of fit (P value)	0.692 **	0.654 **	0.021 *	0.288 **	0.848 **	0.571 **

b_o: The estimated regression coefficient for the main linear effect.
b_1: The estimated regression coefficient for quadratic effect.
b_2: The estimated regression coefficient for the interaction effects.
(1): Time. (2): Temperature. (3): Loading capacity.
*Significant (P<0.05).
**Not significant (P>0.05).

dried torch ginger is shown in Fig. 1. As shown in Eq. 2, a linear term was fitted for predicting the moisture content value. The moisture content was significantly (P<0.05) influenced by the linear effect of drying time, drying temperature and loading capacity (Table 4). The optimum moisture content (*i.e.* the lowest value Y_1= 7.59%±0.11 dry basis) was predicted to be obtained at 4.1 h drying time, 79°C drying temperature and 0.7 kg/m^2 loading capacity using response surface plots and response optimizer. These results were in agreement with Spice Qualities and Specifications listed by Muggeridge [44] where the moisture content (after drying) that is required for spices or similar products in the market is 12% maximum. Fig. 1 illustrates the surface plot where moisture content decreases with an increase in the drying temperature, drying time and loading capacity. This behaviour may be caused by excitation of molecules, where molecules are in increased state of excitation increase when temperature increased, thus rising their distance reduces the attractive force between them [45].

The results indicated that drying time and drying temperature had significant (P<0.05) negative effect on moisture content (Table 4). This may be because of the wide variation in the drying time, which ranged from 2.45 to 20 h [23]. Similar results were also reported by Doymaz [46], Abalone *et al.* [47] and Vega *et al.* [48] for hot-air drying of okra, amaranth seeds and aloe vera, respectively. The results exhibited that drying temperature had significant (P<0.05) negative effect on moisture content. It can be seen that moisture content of dried torch ginger was much lower at high temperature as compared to low temperature of drying (Table 2). The time required for hot-air drying of torch ginger was much higher when lower temperature was used.

The influence of loading capacity on the moisture content of torch ginger samples as influenced by loading capacity are shown in Fig. 1. Obviously, as the loading capacity of sample increased, the moisture content increased. These results were in agreement with previous literature studies [49, 50]. It has been also described by other researches that almost all of the drying of biological products takes place in the falling rate period [50]. Higher loading capacity also led to higher thickness of the samples during drying process. The other possibility, as Yahya *et al.* [51] stated, were methods of drying and biological nature of the plant.

Besides that, air in the oven is saturated, by the time, the loading

Table 4. ANOVA and regression coefficients of the first- and second-order polynomial models.

Variables	Main effects X_1	Main effects X_2	Main effects X_3	Quadratic effects X_1^2	Quadratic effects X_2^2	Quadratic effects X_3^2	Interaction effects X_1X_2	Interaction effects X_1X_3	Interaction effects X_2X_3
Moisture content									
P value	0.003*	0.000*	0.000*	-	-	-	-	-	-
F ratio	13.155	33.768	32.948	-	-	-	-	-	-
Water activity									
P value	0.898**	0.051**	0.317**	0.650**	0.000*	0.000*	0.274**	0.155**	0.000*
F ratio	0.017	5.244	1.141	0.222	81.288	66.961	1.376	2.462	127.713
Texture									
P value	0.637**	0.191**	0.698**	0.809**	0.043*	0.162**	0.489**	0.779**	0.050*
F ratio	0.240	2.039	0.162	0.063	5.808	2.372	0.526	0.084	5.327
Colour L									
P value	0.519**	0.355**	0.241**	0.444**	0.127**	0.084**	0.756**	0.340**	0.043*
F ratio	0.454	0.964	1.605	0.648	2.900	3.877	0.104	1.030	5.750
Colour a									
P value	0.064**	0.940**	0.177**	0.097**	0.919**	0.174**	-	-	-
F ratio	4.239	0.001	2.079	3.291	0.011	2.114	-	-	-
Colour b									
P value	0.104**	0.996**	0.326**	0.038*	0.516**	0.378**	0.355**	0.899**	0.480**
F ratio	3.353	0.000	1.094	6.180	0.461	0.870	0.964	0.017	0.548

Values of P value and F ratio less than 0.050 indicate model terms are significant Values of P value and F ratio greater than 0.100 indicate model terms are not significant
*Significant (p<0.05) **Not significant (p>0.05)

capacity is increased and it forms a thick film around the food that would prevent effective separation of the evaporated moisture from the food. This may be the reason for the existence of a constant rate period in their study. Then, all the samples tended to dry slowly at higher loading capacity resulting in low transport rate of water and prolonged drying time [52]. The yield of dried torch ginger was found very different in quantity after being dried at different drying time. This result is similar to that reported by Sakhale *et al.*[23], who demonstrated that variations in the yield were basically due to higher moisture content in the sample itself.

Water activity: In contrast with moisture content, water activity was significantly (P<0.05) affected by the quadratic terms (Table 4). Surface plot of the effect of drying temperature and loading capacity on the water activity of torch ginger is shown in Fig. 2. Table 4 revealed that water activity was significantly (P<0.05) influenced by the quadratic effect of drying temperature and loading capacity, followed by the interaction terms. The linear effect has no significant (P>0.05) effect on the water activity. The optimum water activity (Y_2= 0.45±0.01) was obtained at 4.1 h drying time, 79°C drying temperature and 0.7 kg/m^2 loading capacity. Fig. 2 demonstrates the surface plot where water activity decreased with an increase in drying temperature and decrease in loading capacity.

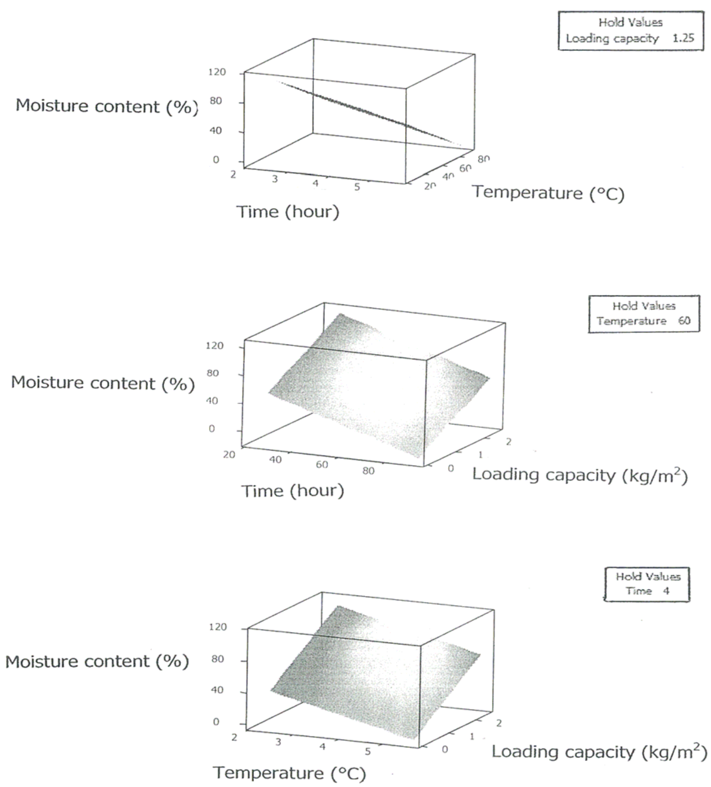

Figure 1. Effect of hot-air drying (drying time, temperature and loading capacity) on the moisture content of torch ginger.

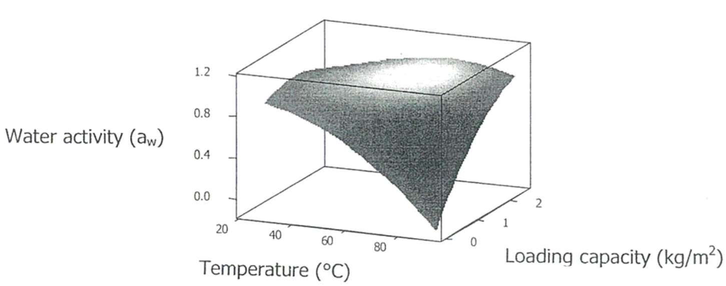

Figure 2. Effect of hot-air drying conditions (temperature and loading capacity) on the water activity of dried torch ginger.

Texture: Similar to water activity, texture (brittleness) of dried torch ginger was significantly (P<0.05) affected by the quadratic terms of drying temperature and the interaction effects of temperature and loading capacity, respectively (Table 4). A surface plot displays the effect of drying temperature and loading capacity on the texture (Fig. 3). As observed in Eq. 4, a quadratic term was fitted for predicting the texture value. The optimum texture (Y_3= 6.18±0.83) was predicted to be obtained when drying time was 4.1 h, the drying temperature, 79°C and loading capacity, 0.7 kg/m^2 respectively. The graphical result from surface plot revealed an increase in texture with an increase in drying temperature and a decrease in loading capacity.

Moreover, the surface plot also shows that the highest texture is obtained when loading capacity is low and temperature is high (Fig. 3). The texture of torch ginger that have been dried at low temperature (40°C) was softer than that dried at high temperature (80°C). Besides that, it took a longer time to fracture the dried samples because during drying, liquid diffuses to the surface of the torch ginger from the interior and carries solute with it. As the moisture evaporates, solutes concentrate and precipitate, leaving a hard and dry skin [53]. From my observation, the samples that have been dried at higher temperature resulted in very dry skin compared to low temperature drying.

Vegetable tissues undergo some degree of shrinkage during drying process. This statement is supported by the fact that usually in the early stage of drying, at low rates, the amount of shrinkage bears a simple relationship to the amount of moisture removed. Towards the end of drying, shrinkage is slowly reduced so that the final size and shape of the material is fixed before drying is completed [54]. Previous researchers also reported that shrinkage of foodstuffs during drying may influence their drying rates due to the changes in drying surface area and the setting up of pressure gradients within the material[55].

Colour (L, a and b): For measurement of the colour of dried torch ginger, the value of L (lightness), a (redness) and b (yellowness) were measured. The quadratic terms showed no significant (P>0.05) effect on L and a values; while for b values, the quadratic terms and the linear effect were the most significant (P<0.05) factor. As shown in Eq. 5 and 7, quadratic terms were fitted for predicting the L and b values; while linear interaction was fitted for predicting the a values. Table 4 exhibited that L value was significantly (P<0.05) influenced by the interaction terms and the linear effect of loading capacity. The optimum value for L, a and b were Y_4= 55.39±0.23, Y_5= 8.69±0.24 and Y_6= 8.94±0.07, respectively. The L value revealed an inverse relationship with the drying temperature, and a direct relationship with the loading capacity (Fig. 4). Preferred colours are those closest to the original colour of fresh torch ginger. The original colour of fresh torch ginger was L (49.36 ± 0.87), a (11.52 ± 0.30), b (10.32 ± 0.12). The results showed that drying caused a decrease in lightness (L value). Higher temperature in hot-air drying resulted in a darker colour (lower *L* value) of dried torch ginger. This result is similar to that reported by Therdthai and Zou [56] who demonstrated that the lightness of dried mint leaves was decreased after hot-air. This may be due to the discolouration during drying which may also be related to non-enzymatic browning [57] and longer time of drying. In addition, the degree of colour change also depends on drying temperature, drying time and oxygen level [58]. Fig. 5 indicates the surface plots where a value decreases with an increase in drying time and loading capacity as well as a decrease in drying temperature.

Also, there were no significant differences (P>0.05) in *a* values for samples dried with hot-air. The effect of drying conditions on colour *a* value is shown in Fig. 5. The *a* value increases with increase in temperature. However, the drying time and loading capacity exhibited a concave relationship with *a* value. This result is in agreement with the report of Bondaruk *et al.* [59] who stated that due to relatively small absolute values of *a*, it can be assumed that the redness (*a* value) did not affect the overall colour evaluation of dried torch ginger. The increase in *a* value denotes a redder chroma, which is indicative of browning reaction [60]. Redness of dehydrated products increases as drying temperature increases and relative humidity decreases for all yellow materials. The effect of temperature on changes of redness during conventional drying seems to be more intense than the effect of air relative humidity for all materials. Colour changes may be associated to Maillard reactions [61].

Similar to the behaviour of chroma parameter *a*, is the increase of value of chroma parameter *b* (yellowness). Krokida[60] also reported that this value increased fast for air dried samples, as air drying goes beyond 70°C. Furthermore, yellowness (*b*) of dehydrated materials is strongly affected by temperature and air relative humidity.

Optimization and validation procedures: Both multiple graphical and numerical optimization were carried out to determine the exact optimum point of different hot-air drying conditions on the physicochemical properties of dried torch ginger leading to the desirable response goals. For graphical optimization procedure, the final reduced models were expressed as three-dimensional (3D) response surface plot to better visualize the interaction effect of main drying conditions on the physicochemical dried torch ginger properties [31]. The optimum drying process performed at 4.1 h, 79°C and 0.7 kg/m^2 were recommended to provide dried torch ginger with optimum quality. The predicted response values for moisture content, water activity, texture (brittleness), colour *L*, colour *a* and colour *b* were found to be 7.59, 0.45, 6.18, 55.39, 8.69 and 8.94, respectively.

All response models were verified theoretically. The experimental data were compared with predicted values in order to verify adequacy of final reduced models by using 2-sample T-test (Table 5). Also, close agreement and no significant different existed between experimental and predicted values, thus indicating the adequacy of final reduced models fitted by RSM.

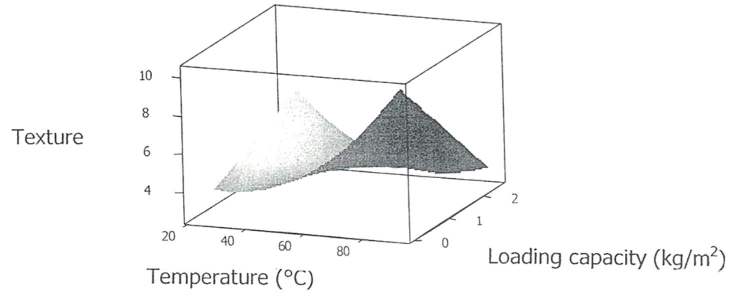

Figure 3. Effect of hot-air drying conditions (temperature and loading capacity) on the texture of dried torch ginger.

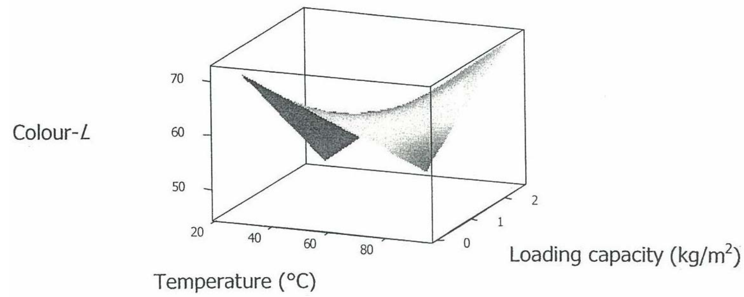

Figure 4. Effect of hot-air drying conditions (temperature and loading capacity) on the colour *L* of dried torch ginger.

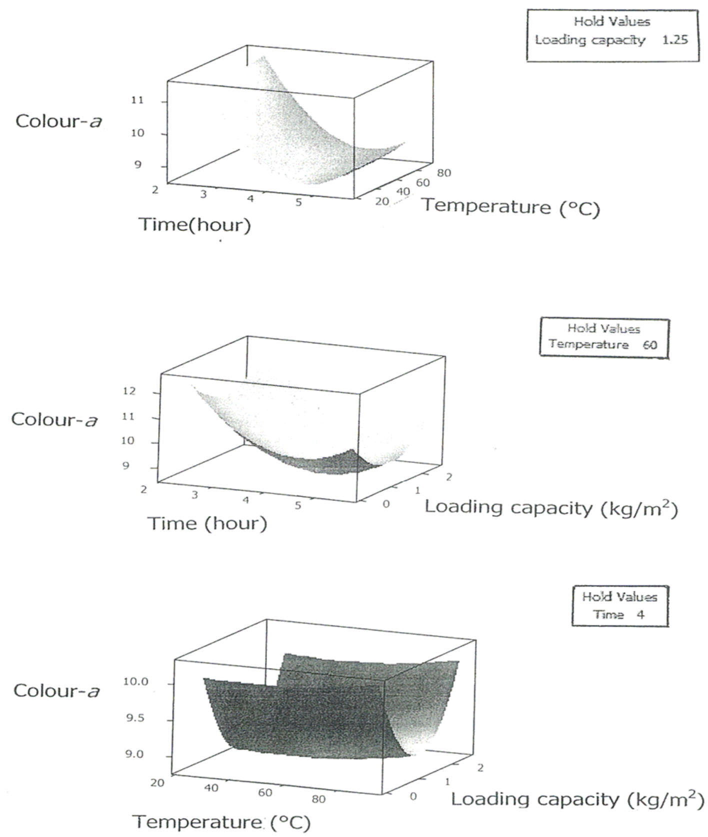

Figure 5. Effect of hot-air drying (drying time, temperature and loading capacity) on the colour *a* of torch ginger.

Table 5. Experimental and predicted values for the response variables studied.

Run	Moisture content			Water activity			Texture			Colour L			Colour a			Colour b		
	Y_o	Y_1	Y_o-Y_1	Y_o	Y_1	Y_o-Y_1	Y_o	Y_1	Y_o-Y_1	Y_o	Y_1	Y_o-Y_1	Y_o	Y_1	Y_o-Y_1	Y_o	Y_1	Y_o-Y_1
1	77.00	67.277	9.723	0.988	0.959	0.029	4.73	3.800	0.930	57.50	65.086	-7.586	10.93	11.590	-0.66	10.13	10.274	-0.144
2	49.61	54.299	-4.689	0.968	0.984	-0.016	3.75	4.248	-0.498	64.46	61.29	3.17	9.40	9.970	-0.57	10.09	11.069	-0.979
3	85.6	83.224	2.376	0.992	0.999	-0.007	4.70	4.684	0.016	50.98	54.143	-3.163	10.36	10.253	0.107	11.31	10.526	0.784
4	86.83	67.796	19.034	0.990	0.967	0.023	4.13	4.298	-0.168	62.10	65.081	-2.981	10.86	11.600	-0.74	10.13	10.274	-0.144
5	6.82	-1.102	7.922	0.442	0.470	-0.028	6.66	6.914	-0.254	51.97	60.849	-8.879	10.31	10.447	-0.137	11.25	10.526	0.724
6	70.71	54.299	16.411	0.982	0.984	-0.002	3.75	4.248	-0.498	66.47	61.29	5.18	11.97	9.970	2.00	13.61	11.069	2.541
7	20.93	32.682	-11.752	0.860	0.941	-0.081	4.74	4.248	0.492	67.09	61.29	5.8	9.03	9.060	-0.03	8.79	9.490	-0.700
8	8.79	20.084	-11.294	0.539	0.557	-0.018	8.17	5.362	2.808	61.07	64.025	-2.955	9.51	9.875	-0.365	9.95	11.069	-1.119
9	37.55	54.299	-16.749	0.960	0.941	0.019	4.87	4.248	0.622	68.18	61.29	6.89	7.32	8.639	-1.319	11.47	11.069	0.401
10	78.42	75.915	2.505	0.993	0.941	0.052	4.32	4.248	0.072	58.36	61.29	-2.93	11.89	11.094	0.796	9.27	9.080	0.190
11	81.00	88.513	-7.513	0.990	0.982	0.008	2.92	3.135	-0.215	56.73	58.554	-1.824	10.84	9.709	1.131	10.44	11.069	-0.629
12	86.26	88.937	-2.677	0.996	0.971	0.025	5.76	5.344	0.416	54.65	58.55	-3.9	8.92	8.647	0.273	10.89	11.069	-0.179
13	53.47	54.299	-0.829	0.969	0.941	0.028	5.00	4.248	0.752	68.45	61.29	7.16	7.66	8.639	-0.979	11.17	11.069	0.101
14	7.13	19.66	-12.53	0.498	0.533	-0.035	6.70	6.758	-0.058	64.90	64.029	0.871	9.29	8.797	0.493	9.88	11.069	-1.189
15	73.92	54.299	19.621	0.994	1.002	-0.008	2.76	4.248	-1.488	60.59	61.29	-0.7	7.95	7.983	-0.033	11.72	11.069	0.651
16	88.04	109.699	-21.659	0.996	1.017	-0.021	5.47	4.684	0.786	54.58	54.143	0.437	8.72	9.511	-0.791	11.23	10.274	0.956
17	36.19	41.320	-5.13	0.955	0.985	-0.03	2.80	4.298	-1.498	66.26	65.081	1.179	8.95	8.368	0.582	9.86	10.526	-0.666
18	78.46	54.299	24.161	1.001	1.002	-0.001	2.80	4.248	-1.448	61.37	61.29	0.08	8.63	7.983	0.647	10.62	11.069	-0.449
19	49.94	40.801	9.139	0.969	0.977	-0.008	4.06	3.800	0.260	66.05	65.086	0.964	7.46	8.358	-0.898	11.09	10.526	0.564
20	9.30	25.373	-16.073	0.557	0.488	0.069	5.89	6.914	-1.024	64.03	60.849	3.181	10.20	9.705	0.495	9.56	10.274	-0.714

(Y_o): Experimental value; (Y_1): Predicted value; (Y_o–Y_1): Residue.
[a]No significant (P>0.05) difference between experimental and predicted values.

Conclusions

RSM was employed to optimize the optimum different drying conditions leading to desirable quality of physicochemical characteristic of dried torch ginger. The response surface analysis showed significant (P<0.05) relationship between the independent variables and the response variables, with R^2 values, ranging from 0.289 to 0.970. The optimization results indicated that the best response, within the range studied, was reached when the drying time was 4.1 h, the drying temperature 79°C and loading capacity 0.7 kg/m^2, respectively. Under the optimum condition, the corresponding predicted response values for moisture content, water activity, texture (brittleness), colour *L*, colour *a* and colour *b* were found to be 7.59, 0.45, 6.18, 55.39, 8.69 and 8.94, respectively.

Acknowledgements

The authors are grateful to Universiti Putra Malaysia and the Ministry of Higher Education for financial support.

References

[1]Kaefer, C. M. and Milner, J. A. 2008. The role of herbs and spices in cancer prevention. J. Nutr. Bio. **19**:347-361.

[2]McCormick 2007. The history of spices. Available at http://www.mccommick.com/content.cfm?HD=1011&StatusCD=P on 6/8/2010.

[3]Risch, S. J. 1997. Spices: Sources, processing and chemistry. In Risch, S. J. and Ho, C. T. (eds). Spices Flavour Chemistry and Antioxidant Properties. American Chemical Society, Washington DC, pp. 2-6.

[4]Habsah, M., Ali, A. M., Lajis, N. H., Sukari, M. A., Yap, Y. H., Kikuzaki, H. and Nakatani, N. 2005. Antitumor promoting and cytotoxic constituents of *Etlingera eliator*. Malaysian J. Med. Sci. **12**:6-12.

[5]Habsah, M., Lajis, N. H., Abas, F. and Ali, A. M. 2005. Antioxidative constituents of *Etlingera eliator.* J. Nat. Prod. **68**(2):285-288.

[6]Jaafar, F. M., Osman, C. P., Ismail, N. H. and Awang, K. 2007. Analysis of essential oils of leaves, stems, flowers and rhizomes of *Etlingera eliator* (Jack) R. M. Smith. The Malaysian J. Anal. Sci. **11**(1):269-273.

[7]Noweg, T., Abdullah, A. R. and Nidang, D. 2003. Forest plants as vegetables for communities bordering the Crocker Range National Park. ASEAN Review of Biodiversity and Environmental Conservation (ARBEC) January-March, pp. 1-18.

[8]Ibrahim, H. and Setyowati, F. M. 1999. *Etlingera*. In De Guzman, C. C. and Siemonsma, J. S. (eds). Plant Resources of South-east Asia. Pudoc,Wageningen, **13**:123-126.

[9]Larsen, K., Ibrahim, H., Khaw, S. H. and Saw, L. G. 1999. Gingers of Peninsular Malaysia and Singapore. Natural History Publications (Borneo), Kota Kinabalu, 135 p.

[10]Lim, C. K. 2001. Taxonomic notes on *Etlingera giseke* (Zingiberaceae) in Peninsular Malaysia: The 'chasma' taxa and supplementary notes on the 'Nicolaia' taxa. Folia Malaysiana **2**:141-178.

[11]MacKeen, M. M., Ali, A. M., El Sharkawy, S. H., Manap, M. Y., Salleh, K. M., Lajis, N. H. and Kawazu, K. 1997. Antimicrobial and cytotoxic properties of some Malaysian traditional vegetables (Ulam). Pharmaceut. Biol. **35**(3):174-178.

[12]Murakami, A., Ali, A. M., Mat Salleh, K., Koshimizu, K. and Ohigashi, H. B. 2000. Screening for *in-vitro* antitumour promoting activities of edible plants from Malaysia. Biosci. Biotechnol. Biochem. **64**:9-16.

[13]Maroulis, Z. B and Saravacos, G. D. 2003. Food Process Design. Marcel Dekker, New York, pp. 243-244.

[14]Aghbashlo, M., Kianmehr, M. H. and Samimi Akhijahani, H. 2008. Influence of drying conditions on the effective moisture diffusivity, energy of activation and energy consumption during the thin-layer drying of berberis fruit (Berberidaceae). Energ. Convers. Manage. **49**:2865-2871.

[15]Lewicki, P. P. 2006. Design of hot-air drying for better foods. Trends in

Food Sci. Tech. **17**:153-163.
[16]Garg, H. P. and Kumar, R. 2001. Developments in solar drying. Proceedings of the 2nd Asian-Oceania Drying Conference (ADC 2001). Batu Feringhi, Pulau Pinang, Malaysia, pp. 297-319.
[17]Atkinson, A. C. and Donev, A. N. 1992. Optimum Experimental Designs. Oxford University Press, Oxford, pp. 132-189.
[18]Mujumdar, A. S. 2000. Drying Technology in Agriculture and Food Science. Science Publishers Inc., Enfield (NH), USA.
[19]Yousif, A. N., Durance, T. D., Scaman, C. H. and Girard, B. 2000. Headspace volatiles and physical characteristics of vacuum-microwave, air and freeze-dried oregano (*Lippia berlandieri* Schauer). J. Food Sci. **65**(6):926-930.
[20]Doymaz, I., Tugrul, N. and Pala, M. 2006. Drying characteristic of dill and parsley leaves. J. Food Eng. **77**:559-565.
[21]Derya, A. and Ozcan, M. M. 2008. Evaluation of drying methods with respect to drying kinetics, mineral content and colour characteristics of rosemary leaves. Energ. Convers. Manage. **49**(5):1258-1264.
[22]Demir, V., Gunthan, T., Yagcioglu, A. K. and Degirmencioglu, A. 2004. Mathematical modeling and the determination of some quality parameters of air-dried bay leaves. Biosyst. Eng. **88**(3):325-335.
[23]Sakhale, B. K., Nandane, A. S., Tapre, A. R. and Ranveer, R. C. 2007. Studies on dehydration of curry leaves. ADIT J. Eng. **4**(1):62-64.
[24]Balladin, D. A. and Headley, O. 1999. Evaluation of solar dried thyme (*Thymus vulgaris* Linne) herbs. Renew Energ. **17**:523-531.
[25]Ozcan, M., Arslan, D. and Unver, A. 2005. Effect of drying on the mineral content of basil (*Ocimum basilicum* L.). J. Food Eng. **69**:375-379.
[26]Mohamed, L. A., Kouhila, M., Jamali, A., Lahsasni, S., Kechaou, N. and Mahrouz, M. 2005. Single layer during behavior of *Citrus aurantium* leaves under forced convention. Energ. Convers. Manage. **46**:1473-1483.
[27]Lasekan, O., Salva, J. T. and Abbas, K. 2010. Effect of malting conditions and quality characteristics of malt and roasted malt extract from 'Acha' grains (*Digitaria exilis* Stapf). J. Sci. Food and Agr. **90**:850-860.
[28]Gallagher, E., O'Brien, C. M., Scannell, A. G. M. and Arendt, E. K. 2003. Use of response surface methodology to produce functional short dough biscuits. J. Food Eng. **56**:269-271.
[29]Senanayake, S. P. J. and Shahidi, F. 1999. Enzyme assisted acidolysis of borage (*Borage officinalis*) and evening primrose (*Oenothera biennis* L.) oils: Incorporation of x-3 poly unsaturated fatty acids. J. Agr. Food Chem. **47**:3105-3112.
[30]Telez Luis, S. J., Moldes, A. B., Alonso, J. L. and Vázquez, M. 2003. Optimization of lactic acid production by *Lactobacillus delbrueckii* through response surface methodology. J. Food Sci. **68**:1454-1458.
[31]Mirhosseini, H., Tan, C. P., Hamid, N. S. A., Yusof, S. and Boo, H. C. 2009. Characterization of the influence of main emulsion components on the physicochemical properties of beverage emulsion using response surface methodology. Food Hydrocolloid. **23**:271-280.
[32]AOAC 1990. Official Methods of Analysis of AOAC International. 15th edn. Williams, S. (ed.), AOAC, Virginia.
[33]AOAC 1995. Official Methods of Analysis of AOAC International. 16th edn. AOAC International, Airlington, VA, 42 p.
[34]Montgomery, D. C. 2001. Design and Analysis of Experiments. 5th edn. Wiley, New York.
[35]Montgomery, D. C., Runger, G. C. and Hubele, N. F. 2001. Engineering Statistics. Wiley, Hoboken.
[36]Mirhosseini, H., Tan, C. P., Hamid, N. S. A. and Yusof, S. 2008. Optimization of the contents of Arabic gum, xanthan gum and orange oil affecting turbidity, average particle size, polydispersity index and density in orange beverage emulsion. Food Hydrocolloid. **22**:1212-1223.
[37]Lee, J., Ye, L., Landen, W. O. and Eitenmiller, R. R. 2000. Optimization of an extraction procedure for the quantification of vitamin E in tomato and broccoli using response surface methodology. J. Food Compos. Anal. **13**:45-47.
[38]Weng, W., Liu, W. and Lin, W. 2001. Studies on the optimum models of the dairy product Kou Woan Liao using response surface methodology. Asian-Aust. J. Anim. Sci. **14**:1470-1476.
[39]Joglekar, A. M. and May, A. T. 1987. Product excellence through design of experiments. Cereal Foods World **32**:857-868.
[40]Attansio, G., Cinquanta, L. and Matteo, M. D. 2004. Effect of drying temperature on physico-chemical properties of dried and rehydrate chestnuts (*Castanea sativa*). Food Chem. **88**:583-590.
[41]Lasekan, O. and Abbas, K. 2010. Investigation of the roasting conditions with minimal acrylamide generation in tropical almond (*Terminalia catappa*) nuts by response surface methodology. Food Chem. **125**:713-718.
[42]Capanza, M. V. and Buckle, K. A. 1997. Optimization of germinations with response surface methodology of a high amylase rice (*Oryza sativa*) cultivar. Lebensm.-Wiss. Technol. **30**:155-163.
[43]Kok Whye, C., Tan, C. P., Hameh, M., Nazimah, S. A. H., Azizah, O. and Mahiran, B. 2010. Equilibrium headspace analysis of volatile flavor compounds extracted from soursop (*Annona muricata*) using solid-phase microextraction. Food Res. Int. **43**(5):1267-1276.
[44]Muggeridge, M., Foods, L. and Clay, M. 2001. Quality specifications for herbs and spices. In Peter, K. V. (ed.). Handbook of Herbs and Spices. Woodhead Publishing Limited, Cambridge.
[45]Jamali, A., Kouhila, M., Mohamed, L. A. and Idlimam, A. 2006. Moisture adsorption-desorption isotherms of *Citrus reticulata* leaves at three temperatures. J. Food Eng. **77**:71-8.
[46]Doymaz, I. 2005. Drying characteristics and kinetics of okra. J. Food Eng. **69**:275-279.
[47]Abalone, R., Gaston, A., Cassinera, A. and Lara, M. A. 2006. Thin-layer of amaranth seed. Biosyst. Eng. **93**:179-188.
[48]Vega, A., Uribe, E., Lemus, R. and Miranda, M. 2007. Hot-air drying characteristics of aloe vera (*Aloe barbadensis* Miller) and influence of temperature on kinetic parameters. Lebensm.-Wiss. Technol. **40**:1698-1707.
[49]Maskan, M. and Ibanoglu, S. 1998. Drying behavior of infrared dried tarhana dough. Proceedings of The Food Engineering Congress. Gaziantep, Turkey, pp. 171-177.
[50]Madamba, P. S., Driscoll, R. H. and Buckle, K. A. 1996. The thin-layer drying characteristics of garlic slices. J. Food Eng. **29**:283-293.
[51]Yahya, F., Lu, T., Santos, R. C. D., Fryer, P. J. and Bakalis, S. 2010. Supercritial carbon dioxide and solvent extraction of 2-acetyl-1-pyrroline from pandan leaf: The effect of pre-treatment. J. Supercrit. Fluids **55**:200-207.
[52]Kostaropoulos, A. E. and Saravacos, G. D. 1995. Microwave pre-treatment for sun-dried raisins. J. Food Sci. **60**:344-347.
[53]Lin, T. M., Durance, T. D. and Scaman, C. H. 1998. Characterization of vacuum microwave, air and freeze dried carrot slices. Food Res. Int. **31**(2):111-117.
[54]Brennan, J. G., Butters, J. R., Cowell, N. D. and Lilley, A. E. V. 1990. Food Engineering Operations. 3rd edn. Elsevier Applied Science, UK, 383 p.
[55]Charm, S. E. 1978. The Fundamentals of Food Engineering. 3rd edn. AVI, Connecticut.
[56]Therdthai, N. and Zou, W. 2009. Characterization of microwave vacuum drying and hot air drying of mint leaves (*Mentha cordifolia* Opiz ex. Fresen). J. Food Eng. **91**:482-489.
[57]Feng, H. and Tang, J. 1998. Microwave finish drying of diced apples in a spouted bed. J. Food Sci. **63**:679-683.
[58]Rudra, S. G., Sigh, H., Basu, S. and Shivhare, U. S. 2008. Enthalpy entropy compensation during thermal degradation of chlorophyll in mint and coriander puree. J. Food Eng. **86**:379-387.
[59]Bondaruk, J., Markowski, M. and Blaszczak, W. 2007. Effect of drying conditions on the quality of vacuum-microwave dried potato cubes. J. Food Eng. **81**:306-312.
[60]Krokida, M. K. and Maroulis, Z. B. 1997. Effect of drying method on shrinkage and porosity. Dry Technol. **10**(15):1145-1155.
[61]Hodge, J. E. 1953. Dehydrated foods, chemistry of browning reactions in model systems. J. Agr. Food Chem. **1**(15):928-943.