Jurnal Kejuruteraan 33(4) 2021: 903-914
https://doi.org/10.17576/jkukm-2021-33(4)-13

Process Variables Optimization for Heat Pump Drying of Roselle Calyx by Using Response Surface Methodology

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Received 07 September 2020, Received in revised form 04 February 2021
Accepted 04 March 2021, Available online 30 November 2021

ABSTRACT

Heat pump drying technology has been recognized for its capability to conserve energy consumption and product quality in drying process. Understanding the influence of drying conditions on product quality and optimisation are necessary to cut down the drying cost. In this study, the drying of Roselle calyx using heat pump dryer was optimized using response surface method where Central Composite Design (CCD) was employed to investigate the effects of independent variables: drying temperature (40-60°C) and sample mass (100-300 g), on the response variables (drying time, energy consumption and colour changes). The drying study aimed to achieve minimum drying time, energy consumption and total colour changes. It was discovered that temperature factor has dominant effect on drying time while sample mass on energy consumption and colour changes. The interplay between the variables was closely related to heat transfer and moisture evaporation rates of the sample. The optimum drying conditions as determined were at drying temperature of 60°C and sample mass of 100 g. Under these conditions, the drying time, energy consumption, and colour difference were 332.3 min, 27.05 kWh, and 4.29 ΔE, respectively. The optimization model was well validated since the difference between the predicted and experimental results was below 3%.

Keywords: Roselle; drying; heat pump; optimization; central composite design

INTRODUCTION

Roselle (*Hibiscus sabdariffa*) is a herb that is widely cultivated throughout the world. It currently emerges as a new commercial crop in Malaysia due to its huge potential to be utilized in food and pharmaceutical industries (Mohamad et al. 2018). Roselle calyces contain high amount of polyphenols and nutraceuticals with antioxidant property that provide health benefits such as antihypertensive, antihyperglycaemia, and antihyperlipidemia upon consumption (Si et al. 2017; Peng et al. 2011). Due to its beneficial effect on health, Roselle has been consumed raw as hot tea or juice, or it can also be processed into many food products, such as jams, syrup, refreshing drinks, and natural food colourants (Ifie et al., 2017). The moisture content of Roselle is quite high, reaching 88% wet basis, which shows that Roselle could not be kept fresh for a long period of time. Hence, the moisture content of Roselle has to be removed to a certain level to prevent pathogenic spoilage and to prolong its shelf life while minimizing physico-chemical alterations during storage (Tasirin et al. 2013).

Drying is one of the most common food processing techniques that could be employed to prolong the shelf life of fruits and vegetables through the removal of moisture content (Chong et al. 2014). Past studies have shown that Roselle can be dried via different methods, such as solar dryer, tray dryer, and hot air, where the bioactive compounds and vitamin C were reportedly preserved after the drying process (Saeed et al. 2008; Suherman et al. 2012; Tajudin et al. 2019). Moisture removal from natural products is an energy-intensive process since thermal energy is extensively used in various drying equipment. The drying process is thus being considered as one of the most energy intensive operations due to its high energy consumption nature (Motaveli et al. 2011). Hence, applying the right postharvest drying technology is vital to achieve minimum energy consumption while attaining maximum moisture removal and at the same time preserving the quality of dried products (Barati & Esfahani, 2010).

In this scenario, heat pump dryer that has been widely employed in food drying industry appears to be an attractive technology capable to meet the criteria mentioned previously. Past studies have reported that heat pump dryer offers the energy saving potential due to its capability to control both the drying temperature and air humidity. This enables the flexibility of adjusting the drying operating conditions without compromising the quality of the dried product (Claussen et al. 2007). Baysal et al. (2015) have demonstrated that using heat pump dryers managed to save up to 40% of energy consumption as compared to electrical-resistance dryers. This is due to heat pump dryer can extract and utilize the latent energy of the air and water vapour to dry the products (Fayose & Huan, 2016). On top of that, heat pump dryer is also competent to conserve the quality (in terms of colour, texture, and appearance) and preserve heat sensitive bioactive ingredients of fruits and vegetables after the drying process (Hii et al. 2013). This makes it an attractive drying process for various products such as apples, banana, kiwi, and herbs products (Jew's mallow, spearmint, and parsley) (Chong et al. 2014; Ceylan, 2009; Fatouh et al. 2006). Besides, heat pump dyrer is an environmentally friendly process due to its low emission of gases and fumes into the atmosphere (Baysal et al. 2015). Furthermore, the operation is unaffected by outside ambient weather conditions (Fayose & Huan 2016).

On one hand, the dried food products must contain high nutrition with high quality shelf-stable property to cater the demand from the consumers. On the other hand, the drying process must not only preserve the quality for the products, but also should not cause an economic constraint to the food industry. Hence, the design, modelling, and optimization of the drying process have to be done properly to meet the demands from both the consumer and industry sides (Fealekari & Chayjan, 2014). It is essential to select the optimal drying conditions in food processing for the effective operation of the systems and producing high quality of dried product while conserving the energy consumption (Cernisev, 2010). To understand the influence of operating conditions on the drying process and quality of the dried products, repeated experiments are normally required to be conducted. The conventional design of experiment is known as an arduous and highly disciplined process which needs proficient resources that could lead to high experimental cost due to enormous number of studies have to be conducted (Nalbant et al. 2007). In addition, the time required to complete the experiment is obviously long for investigating and evaluating large quantity of parameters that affect the desired quality aspects. The scenario is further complicated when experiment has to be repeated for several verification purpose until accurate and validated results are obtained (Tasirin et al. 2013).

Optimization tools such as Response Surface Methodology (RSM) could be employed to determine the optimal conditions for the drying process (Taheri-Garavand et al. 2017). RSM is a powerful tool for optimizing many engineering applications due to its high efficiency, simplicity, and comprehensive theory by using quantitative data obtained from the design of experiments to solve multivariate equations (Wang et al. 2014). It can save a lot of time and build models accurately and quickly in an optimization design (Nazghelichi et al. 2011). In general, RSM which includes the factorial design and also regression analysis are necessary to determine the effective factors and to build the models. From that, the interactions of the drying factors (e.g. temperature and airflow velocity) and the best optimum conditions of a desirable response (product quality and drying duration, time, and cost) can be evaluated (Rahman et al. 2013). This method has been widely tested in different drying studies of fruits and vegetables to show the correlation between the drying factors with the products quality (Chin & Law 2012).

Although heat pump dryer has been shown capable in drying Roselle calyx while preserving the quality in previous study, understanding the correlation and optimising the drying conditions are necessary to further support its advantages over the conventional drying process. Hence, this study aims to optimise the drying conditions of Roselle calyx by looking at the influence of drying factors (air temperature and sample mass) on drying time, energy consumption, and colour changes of the dried Roselle through RSM approach. Central Composite Design (CCD) was employed to identify the effects of operating conditions of heat pump dryer on the processing time, total energy consumption, and total colour differences using RSM.

METHODOLOGY

SAMPLE PREPARATION

Fresh Roselle (*Hibiscus sabdariffa*) of the Terengganu variety (UMKL-1) was obtained from the local supplier in Senggarang, Batu Pahat, Johor. The seed capsule was removed and the Roselle calyces were used in this experiment. Roselle were washed under running tap water and stored at a temperature of 4^{o}C before commencing the drying experiments to slow down the physiologal and chemical changes (Karaaslan & Tuncer, 2008). The initial moisture content of Roselle was determined to be 86% wet basis using standard hot air oven method at 105°C for 24 h (Abano et al. 2014).

DRYING PROCEDURE

Roselle was dried in a heat pump dryer (iLab LT1000; The University of Nottingham, Selangor, Malaysia) as showed in Figure 1. The drying process parameters considered in this study were temperature (40, 50, and 60°C) and mass samples (100, 200, and 300 g). Roselle were placed on a metal tray with opening square 1.0 x 1.0 cm in the middle of the drying chamber. Upon the drying process, the heated air from heater was supplied vertically from the bottom of the drying chamber via the mechanical blower. Subsequently, the heat from flowing hot air is transferred to the samples. The air velocity was measured using anemometer (Model 471 B Digital Thermo Anemometer, Dwyer, U.S.A.) and fixed at 2.5 ms^{-1}. Roselle were weighed at every 5 minutes interval for the first two hours and followed by 10 minutes interval until the mass reading remained constant towards the end of drying process. After completing the drying process, the samples were kept in Low Density Polyethylene (LDPE) bags at room temperature for further analysis. Moisture analyzer (AND MX-50, Muser Apac, Malaysia) was used to determine the moisture content of samples. The mass loss was recorded using analytical balance. Each condition set was replicated three times.

FIGURE 1. Heat pump dryer

Design of experiment and modeling (statistical)

TABLE 1. Factor levels of the CCD used in the RSM study of the drying parameters

Independent Variables	Symbols		Level	
	Natural	Coded	Natural	Coded
Temperature (°C)	T	A	40	-1
			50	0
			60	1
Sample mass (g)	M	B	100	-1
			200	0
			300	1

The CCD RSM was applied to design the experiment. The optimization was conducted with two independent variables: A (Temperature, °C) and B (mass, g) at three levels and three responses: drying time, total energy consumption, and total colour change. Table 1 shows the CCD RSM arrangement used for the drying experiments.

In this experimental design, the three coded levels for each variable (-1, 0, and +1) coincided to the low level, mid-level, and high level of each independent variable, respectively. With the two factors, a total of 13 experiments (with five replicates at the centre point) and single run for each of the other combinations were given by CCD as shown in Table 2.

TABLE 2. Central composite design for two factors and results of drying time, energy consumption and colour changes

	Actual values (coded values)			Experimental values of responses		
Standard Order	Run. no.	A	B	Drying time (min)	Energy consumption (kWh)	Colour changes (ΔE)
5	1	40 (-1)	200 (0)	960	35.01	10.3
6	2	60 (1)	200 (0)	390	31.31	7.98
4	3	60 (1)	300 (1)	420	33.72	10.41

continue...

...continued

13	4	50 (0)	200 (0)	640	38.28	9.45
12	5	50 (0)	200 (0)	640	38.28	8.00
7	6	50 (0)	100 (-1)	500	29.91	5.5
3	7	40 (-1)	300 (1)	1020	37.20	11.37
8	8	50 (0)	300 (1)	700	41.87	11.05
9	9	50 (0)	200 (0)	640	38.28	8.35
2	10	60 (1)	100 (-1)	350	28.1	4.36
1	11	40 (-1)	100 (-1)	840	30.64	8.59
11	12	50 (0)	200 (0)	640	38.28	9.7
10	13	50 (0)	200 (0)	640	38.28	8.79

Mathematical models describing the relationships among the process-dependent variable and the independent variables in a second-order equation were developed (Ekorong et al. 2015). The second order polynomial regression was applied to determine the dependent or response variable (Y) includes the linear, squared and interaction coefficients, respectiely as given in Eq.
(1). Experiment data were fitted to the equation and the regression coefficients were attained.

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum\sum_{i<j}^{k} \beta_{ij} x_i x_j \quad (1)$$

where, Y is the response, x_i and x_j are the variables, β_0 is the constant, β_i is the coefficient of the linear terms, β_{ii} and β_{ij} are the quadratic and interaction terms, respectively. Meanwhile, k is a number of variable (Cheng et al. 2012). The behaviour of the independent variables were expressed in mathematical models as shown in Eq. (2):

$$Y_r = \beta_0 + \beta_1 A + \beta_2 \mathrm{B} + \beta_3 \mathrm{A}^2 + \beta_4 \mathrm{B}^2 + \beta_5 \mathrm{AB} \quad (2)$$

where Y_r represent response or dependent variables (drying time, energy consumption and colour); A, B, are the coded values of the independent variables (drying temperature and mass sample), AB is the interaction term of drying temperature and sample mass; $\beta_0, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5$ are the regression coefficient where β_0 is a constant, β_1 and β_2 are linear, β_3 and β_4 are squared or quadratic, and, $\beta 5$ is an interaction.

ENERGY CONSUMPTION CALCULATION

The amount of energy consumed by the heat pump dryer for drying Roselle at different drying temperature and mass were calculated using the following Eq. (3) (Moteveli et al. 2011).

$$E_t = A.\ v.\ Pa.\ Ca\ .\Delta T.\ t \quad (3)$$

where E_t is total energy consumption in each drying cycle (kWh), A is the cross section area of the product tray (m^2), v is the air velocity (ms^{-1}), Pa is the density of air (kg/m^3), C_a is the specific heat of air (kJ/kg^{o}C), ΔT is the temperature difference (^{o}C), and t is the total drying time in min, required to reach a moisture content of 10% g/g. min (wet basis).

COLOUR MEASUREMENTS

Colour is an important feature judged by consumers in making their purchasing choices. The colour of the fresh and the dried Roselle were measured in a chroma meter CR-400/410 (Minolta Co., Osaka, Japan). Firstly, the colour analyzer was calibrated using a standard calibration plate with a white surface. After calibration, three colour parameters were characterized. Coordinate of L^* indicates degree of lightness, which ranges from 0 (black) to 100 (white). The chromaticity cooordinate (+60) of a^* is redness and (-60) is greenness, whereas (+60) b^* value denotes yellowness and (-60) is blueness. Such characterization was in accordance with the International Commisssion on Illuminant (Commission International I'Eclairage, CIE). The sample was prepared in a transparent Petri dish for measurement. Three readings at three different points of samples were measured to obtain an average data. Differences in L^*, a^*, and b^* were used to indicate the change in the colour parameters. Eq. (4) (Nonszi & Ramaswamy, 1998) was used to determine the total colour change. Subscript 0 shows initial value of fresh Roselle.

$$\Delta E^* = \sqrt{(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2} \quad (4)$$

Optimization of the drying process

Numerical optimization of the drying process was performed using Design Expert 11 statistical package software (Stat-Ease Inc, Minneapolis, USA). A multiple response method makes use of an objective function *D(X),* called the desirability function. This method was optimized synchronously through the use of a desirability function. It combines all the responses into one measurement (Eren & Kaymak-Ertekin, 2007). The following Eq. (5) defined the desirability function:

$$D(X) = (d_1 \text{ x } d_2 \text{ x } \ldots \text{x } d_n)^{1/n} = [\prod_{i-1}^{n} \text{di (Yi)}]^{1/} \quad (5)$$

where n is the total number of responses measured in the optimization process and $d_1, d_2..., d_n$ are responses. The di denotes the desirability index for each response variable. Numerical optimization method finds operating conditions (combination of independent variables) ranging between 0 and 1, with 0 being the least desirable, while 1 is the most desirable. The maximum value of desirability index value is the best condition of optimization process. The optimization process allowed the independent and dependent variables were selected as the best conditions. The desired optimum condition for each independent variable and response can be determined. For this study, the range for the independent variables within the selected levels of the design experiment. However, in the case of the response variables, the selected conditions were minimum value of energy consumption (E_t), drying time (min), and colour changes (ΔE).

STATISTICAL ANALYSIS

Response surface analysis of the experimental data in Table 2 was obtained using a statistical package software Design Expert version 11.0 (Stat-Ease Inc, Minineapolis, USA). Analysis of variance (ANOVA) and regression was carried out by fitting Eq. (1) to the experimental data to determine the regression coefficients and statistical significance of model terms assessed by F-ratio at a probability (p) of 0.05. Model adequacies were determined using model analysis, lack of fit test (>0.1), R^2 (>0.95), Adj-R^2, Pred-R^2 (>0.7), Adeq. Precision (>4) and coefficient of variation (C.V) values (<10%) (Erbay & Icier, 2009).

VALIDATION OF MODELS

The adequate of second order polynomial model (Eq. 2) for predicting the optimum condition values was verified by conducting experiments under the recommended optimum conditions. Response data of the experimental and predicted values obtained were compared in order to determine the verification of the models. The standard error between the experimental and predicted values is displayed in Eq. (6) (Chin & Law, 2012):

$$\sigma = \frac{\sqrt{\sum (Z_i - Z_i')^2}}{\sqrt{N}} \quad (6)$$

where, σ is the standard error, Z_i is a predicted value, Z_i' is an experimental value and N is the number of replication.

RESULTS AND DISCUSSION

MATHEMATICAL (STATISTICAL) MODELLING

Modelling of the influence of drying air temperature and sample mass on drying time, energy consumption and total colour difference were carried out by modelling the experimental design required for laboratory purposes (Table 2). Multiple linear regression analysis of experimental data yielded second order polynomial models for predicting drying time, energy consumption and total colour changes. The mathematical models obtained were as follows, respectively:

$$Y_{DT}\text{ (A,B)} = 635.17 - 275.00A + 76.67B + 51.90A^2 - 33.10B^2 - 30.00AB \quad (7)$$

$$Y_{Et}\text{ (A,B)} = 37.94 - 1.49A + 4.09B - 3.94A^2 - 1.81B^2 - 0.44AB \quad (8)$$

$$Y_{\Delta E}\text{ (A,B)} = 8.76 - 1.25A + 2.40B + 0.34A^2 - 0.52B^2 + 0.82AB \quad (9)$$

With Y_{DT} (A,B), Y_{Et} (A,B) and $Y_{\Delta E}$ (A,B) representing the mathematical order for drying time, energy consumption and total colour changes, respectively where coded A and B are denoted for each drying parameters for drying temperature (°C) and sample mass (g), respectively.

EFFECT OF DRYING PARAMETERS ON DRYING TIME

The accuracy and fitness of the model was studied based on the results of analysis of variance (ANOVA). By referring to the findings presented in Table 3, the statistical analysis reveals that drying time was significantly affected by linear terms of drying air temperature with the probability value (*p-value*) ($p<0.05$) and sample mass ($p<0.05$). The effect of drying air temperature on drying time was more predominant than sample mass with the larger value of coefficient estimate (βi). A positive sign (mass) of the coefficient (βi) in linear term represents a synergistic influence while a negative sign (temperature) indicates an antagonistic effect (Taheri-Garavand et al. 2017). Negative sign indicates that the increase of temperature factor will decrease the drying time, in contrast to positive sign which records the longer drying time with the increase of sample mass. Based on the values tabulated in Table 3, the interaction term of drying temperature and sample mass (AB) had significant effect (*$p<0.05$*) on drying time of Roselle calyx during heat pump drying process. Also, significant effect (*$p<0.05$*) were observed for the quadratic term of drying temperature (A^2) but insignificant effect ($p>0.05$) was obtained for the quadratic term of sample mass (B^2). This suggested that a short drying time could be obtained when the drying process was conducted at higher temperature and lower sample mass. These findings were supported with the study conducted by Gupta et al. (2013) where similar correlation between the effects of drying temperature on drying time of cauliflower was obtained.

TABLE 3. ANOVA results of the independent variables as linear, quadratic and interaction terms on each response variable and coefficients (βi)

Source	DF	Drying time (min)			Energy consumption (kWh)			Total colour changes (ΔE)		
		Bi	Sum of squares	p-value	*Bi*	Sum of squares	p-value	*Bi*	Sum of squares	p-value
Model	5	635.17	5.006E+005	< .0001*	37.94	192.66	0.003*	8.76	46.54	< 0.001*
A	1	-275.00	4.538E+005	< .0001*	-1.49	13.26	0.048*	-1.25	9.40	< 0.0007*
B	1	76.67	35266.67	0.0001*	4.09	100.37	0.0009*	2.40	34.46	0.0001*
A^2	1	51.90	7438.51	0.011*	-3.94	42.87	0.004*	0.34	0.32	0.375**
B^2	1	-33.10	3026.60	0.066**	-1.81	9.04	0.142**	-0.52	0.75	0.191**
AB	1	-30.00	3600.00	0.049*	-0.44	0.76	0.541**	0.82	2.67	0.025*
Residual	7	-	4478.16	-	-	23.12	-	-	2.52	-
Total	12	-	5.051E+005	-	-	215.78	-	-	49.88	-
R^2	-	0.9911	-	-	0.8929	-	-	0.9494	-	-
Adj-R^2	-	0.9848	-	-	0.8163	-	-	0.9133	-	-
Pred-R^2	-	0.9154	-	-	0.3816	-	-	0.8455	-	-
Adeq. Precision	-	40.931	-	-	10.668	-	-	17.887	-	-
C.V (%)	-	3.93	-	-	5.15	-	-	6.86	-	-

* Significant, ** Not Significant, Lack of fit is not significant at $p > 0.05$

Figure 2 shows the effects of air temperature and sample mass on drying time. It can be observed that an increase of temperature and decrease of mass led to a relatively shorter drying time for Roselle to achieve the desired final moisture content. Drying at higher temperature accelerated the moisture movement rate to travel from the interior of the Roselle calyx to the surface. This intensified the drying rate and subsequently led to a shorter drying time. Hii et al. (2009) also reported the same finding where the drying time of cocoa was shortened at a higher drying air temperature. On another note, a longer drying time was required when the sample mass was increased in the heat pump dryer. This could be attributed to the overlapping of Roselle sample on the product tray which hindered the air flow to dry the sample and to carry away the moisture from inner to surface and evaporate it (Mohammad et al. 2014).

By referring to Table 3, the coefficient of determination (R^2) value, Adj-R^2 value, and Pred-R^2 values obtained from the model were 0.9911, 0.9848, and 0.9154, respectively. The high R2 values could be translated into a high correlation between the observed and predicted values of drying time response. In addition, the values of C.V (<10%) and Adeq. Precision (>4) at 3.93 and 40.93, respectively showed that the model was acceptable to predict the response on processing time.

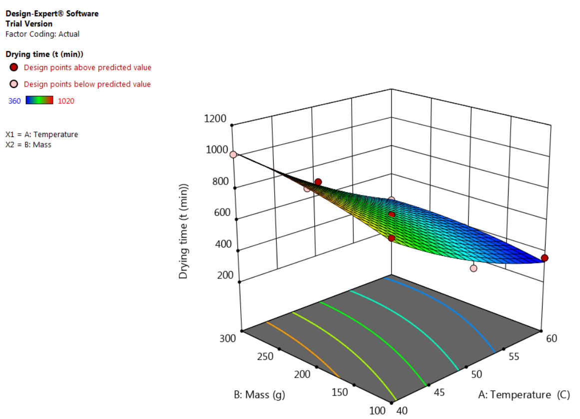

FIGURE 2. Effects of air temperature and sample mass on RSM for drying time

EFFECT OF DRYING CONDITION ON ENERGY CONSUMPTION

ANOVA results in Table 3 indicates that the energy consumption is significantly affected by all independent variables, namely temperature (A) and sample mass (B). The ANOVA analysis showed that there was a significant effect for the linear term of temperature and sample mass as well as the quadratic term of temperature (A^2) ($p<0.05$) as the function of energy consumption. It was also shown that the interaction term of temperature and mass (AB) and quadratic term of sample mass (B^2) did not have significant influence on the response of total energy consumption ($p>0.05$). Therefore, adjusting the drying air temperature and sample mass would have a huge impact on the cost of energy consumption. By referring to Table 3 (linear term), sample mass apparently was found to be the dominant factor as the coefficient estimate (βi) value obtained was 4.09 which was larger than the value of drying air temperature (1.49) on energy consumption. The significant ($p<0.05$) negative effect sign of linear term temperature (A) indicates that lower total energy consumption could be obtained when the temperature was increased. The obtained results were consistent with Tirawanichakul et al. (2011) who reported that high temperature led to a shorter drying duration and lower total energy consumption, as a result of the high heat transfer rate to the sample. It was opposite to the linear sample mass (B) which showed the significant positive effect sign that indicates the increase of total energy consumption with the increment of sample mass. It could be implied that the total energy consumption depends strongly on the sample mass more than the drying air temperature.

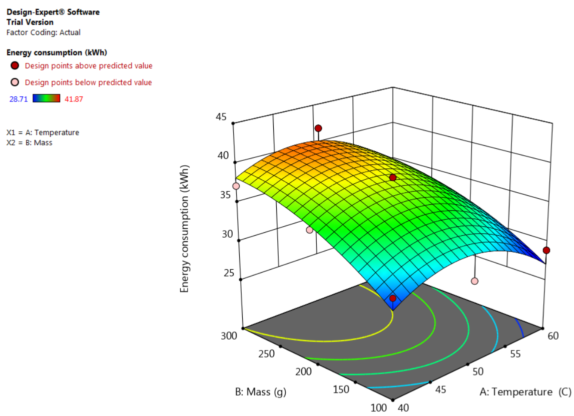

FIGURE 3. Effects of air temperature and sample mass on RSM for energy consumption

The negative and positive effects of linear and quadratic factors could be interpreted by referring to 3D surface plots in Figure 3. The linear effect of individual variables is represented by the trend of curves where increasing and decreasing patterns indicate positive and negative effects, respectively. Whereas, the trend of quadratic variables is indicated by the curve surface where concave surface represents positive effect while convex surface is negative effect. Figure 3 shows that the linear (A) and quadratic terms (A^2) of temperature have a negative effect to the response variables. Linear term of sample mass (B) has a positive effect while the quadratic term (B^2) has a negative effect on total energy consumption. Based on

Figure 3, it can be described that the lower energy consumption was obtained when a higher drying air temperature and lower sample mass were applied during the drying process as compared to lower drying temperature and higher sample mass. This could be due to the shorter drying process was obtained when the Roselle sample was exposed to higher drying temperature, which in turn cut down the energy consumption as compared to a lower drying temperature but longer drying time. Also, higher drying air temperature caused the reduction of vapour pressure which subsequently lowered the resistance to moisture evaporation from the Roselle calyx (faster removal of moisture). Meanwhile, the total energy consumption increased when the increase of sample mass due to the longer drying duration led to higher energy consumption cost. Similar finding has been reported by Darvishi (2017) where reduction of energy consumption for the drying of savory leaves using infrared-hot air dryer could be attributed to drying temperature and infrared power. Higher drying temperature and infrared power facilitated the moisture evaporation to occur at a faster pace and reduce the drying time considerably. This present work found that the lowest energy consumption could be achieved when Roselle calyx were dried at highest temperature of 60°C and lowest sample mass of 100 g.

From the ANOVA analysis as shown in Table 3, values of R^2, Adj-R^2, Adeq. Precision were 0.8929, 0.8163, and 10.668 (greater than 4), respectively. Meanwhile, the C.V value obtained was 5.15 which was less than 10 % and this indicated that the model is acceptable to predict the response of total energy consumption (Giri & Prasad, 2007). This shows the adequacies criteria of the model to predict the response of total energy consumption.

EFFECT OF DRYING CONDITION ON COLOUR CHANGES

Statistical analysis as shown in Table 3 revealed that the model was significant at $p<0.05$ on total colour changes. The sample mass had a dominant impact on the total colour change as compared to drying air temperature factor based on the larger value of sample mass (2.40) as compared to drying air temperature value (1.25) of linear term coefficient estimate (βi) values. The linear term of air temperature and sample mass had a significant effect ($p<0.05$) on the total colour changes. Also, the interaction term (AB) presented a significant effect ($p<0.05$) on colour changes. Nevertheless, it was found that the quadratic effect of all independent variables did not influence the total colour change significantly ($p>0.05$) as compared to linear term given in Table 3.

Drying air temperature exhibited a negative linear effect whereas sample mass exerted a positive linear effect to this response variable (Figure 4). Therefore, the total colour change for sample dried with the combination of higher drying temperature and lower sample mass could be better preserved. From previous section, an increase in sample mass resulted in a longer drying time to achieve the 10% final moisture content of the product. Longer drying process might reduce the sugar content of Roselle through the Maillard reaction and oxidation of ascorbic acid. The Maillard reaction occurred between reducing sugars and amino acids that causes the browning of colour and subsequently leads to more apparent colour changes (Chong et al. 2014). On the other hand, the higher temperature stimulated the drying rate and reduced the heat exposure time on samples, which in turn minimized the Maillard reaction and oxidation process (Chin et al. 2008). Similar results has also been observed by Abano et al., (2014) where the least total colour change of tomato dried in a laboratory tray dryer was obtained when dried at a higher drying air temperature (40–60°C).

The values of coefficient of determination (R^2), Adj-R^2, and Pred-R^2 were 0.9494, 0.9133, and 0.8455, respectively as given in Table 3. The Adeq. Precision value of the model was 17.887 showed that the value was greater than 4. In addition, the value of C.V obtained was less than 10 % (6.86). All of these observations indicated that the model can be used to predict the response on the total colour changes (Montgomery, 2001).

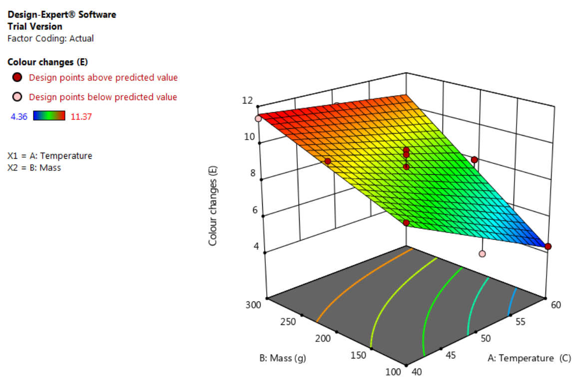

FIGURE 4. Effects of air temperature and sample mass on RSM for total colour changes

PROCESS OPTIMIZATION AND EXPERIMENTAL VALIDATION

In this study, the drying process was optimized to minimize the drying time, energy consumption, and total colour changes within the range of drying air temperature and sample mass. Two combinations of drying process conditions were achieved as shown in Table 4. The highest desirability value was selected as the best optimum conditions. Solution number one (1) gave the best solution of drying Roselle in a heat pump dryer. Although six (6) solutions acquired the same highest desirability value at 1.000, but the minimum criteria of drying time, energy consumption, and colour changes was obtained in solution number one (1). Hence, the best optimum conditions observed for the stated criteria were 60^{o}C (temperature) and 100 g (sample mass). At this point, drying time, energy consumption, and colour changes attained were 332.3 min, 27.05 kWh and 4.29 ΔE, respectively. Three experiments were conducted for the validation of the predicted models at the optimum process conditions. The results obtained from the verifications were 341.7 (± 2.9) min, 27.4 (± 0.2) kWh, 4.35 (± 0.07) (ΔE) for the mean of each response of drying time, energy consumption and total colour changes, respectively as given in Table 5. The results of the comparison between predicted and experimental values for each of the response were shown in Table 6. These difference values were relatively low and would be acceptable for practical application (Erbay et al. 2014). According to Zhang et al. (2007), percentage error between 10-15% was acceptable for standard error. Hence, the results obtained from the validation experiments were within the acceptable range for standard error.

TABLE 4. Result of optimization by desirability function of RSM

Number	Temperature (^{o}C)	Mass (g)	Drying time (min)	Energy consumption (kWh)	Colour changes (ΔE)	Desirability	
1	60.000	100.000	332.299	27.052	4.292	1.000	Selected
2	59.844	100.693	335.295	27.240	4.346	1.000	
3	59.945	100.758	333.934	27.156	4.328	1.000	
4	59.995	102.013	334.622	27.202	4.357	1.000	
5	59.754	100.505	336.384	27.306	4.359	1.000	
6	59.681	100.031	336.896	27.335	4.359	1.000	
7	59.464	100.001	340.023	27.520	4.403	0.998	
8	60.000	104.218	337.003	27.356	4.427	0.997	
9	60.000	104.983	337.842	27.410	4.452	0.996	
10	58.500	100.000	354.648	28.303	4.602	0.988	
11	60.000	110.662	343.958	27.807	4.635	0.987	
12	60.000	144.878	376.287	29.952	5.734	0.892	

TABLE 5. The predicted and experimental values for responses at optimum process conditions

Run	Drying time (min)	Energy consumption (kWh)	Total colour changes (ΔE)
1	345	27.7	4.43
2	340	27.3	4.31
3	340	27.3	4.31
Predicted values	332.3	27.05	4.29

TABLE 6. Results of optimization by desirability function and experimental validation

Response	Selected range	Predicted values	Experimental values[1]	SE[2]	Difference[3]	% error[4]
Drying time (min)	Minimum	332.3	341.7 (± 2.9)	7.2	- 9.4	2.75
Energy consumption (kWh)	Minimum	27.1	27.4 (± 0.2)	0.5	- 0.3	1.09
Total colour changes (ΔE)	Minimum	4.30	4.35 (± 0.07)	0.09	- 0.05	1.15

[1] Experimental values were expressed as mean ± standard deviation
[2] Mean standard error
[3](Pre – Exp)
[4]The % error = ($У_{exp}$ - $У_{pre}$/$У_{exp}$) x 100

CONCLUSION

Central Composite Design (CCD) experimental design in Response Surface Methodology (RSM) was employed to determine the effects of independent variables (air temperature and sample mass) on the response variables (drying time, energy consumption and colour changes) for the drying of Roselle calyx in a heat pump dryer. The shortest drying time was recorded at highest temperature (60^{o}C) and lowest sample mass (100 g). Also, the lowest energy consumption and the least total colour changes were obtained for the sample dried at temperature of 60^{o}C and 100 g sample mass. The ANOVA profile analysis showed that temperature factor has the strongest effect on drying time, while sample mass showed the dominant influence on energy consumption and colour changes. Results of numerical optimization presented that minimum drying time, energy consumption, and colour changes could be achieved at temperature 60^{o}C and sample mass 100 g for Roselle drying in heat pump dryer. Predicted values for the combination were 332.3 min, 27.05 kWh, and 4.29 ΔE, respectively for drying time, energy consumption, and colour changes. The optimization model was well validated since the difference between predicted and experimental results was quite low and within the acceptable range.

ACKNOWLEDGEMENTS

The authors are grateful for the financial support provided by Universiti Kebangsaan Malaysia and Ministry of Higher Education through research grant GGPM-2017-034 and FRGS/1/2017/TK02/UKM/02/5, respectively.

DECLARATION OF COMPETING INTEREST

None

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