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FULL LENGTH ARTICLE

Enhancement of shelf life of *Coriandrum sativum* leaves using vacuum drying process: Modeling and optimization

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KEYWORDS

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Optimization

Abstract A vacuum drying process was employed to deal with the moisture removal, Vitamin C content and total dietary fiber from coriander leaves (dhania). Box–Behnken design (BBD) and response surface methodology (RSM) were applied to evaluate and optimize the three key drying parameters, namely temperature (*A*), loading rate (*B*) and vacuum (*C*). This approach provided statistically significant quadratic model, which was adequate to predict response and to carry out optimization under the conditions studied. It was demonstrated that the interaction between all the drying parameters has a significant effect on the moisture removal. The optimal conditions were found to be temperature of 75 °C, loading rate of 0.63 kg/m^2 and vacuum = 28 mm Hg. Under these conditions, 95% moisture removal, 527 mg/100 g Vitamin C content and 13 g/100 g total dietary fiber were obtained. Finally, product quality was also examined.

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1. Introduction

The market for dehydrated vegetables and leaves is important for most countries worldwide due to their medicinal and antioxidant activities. Particularly, in many Asian countries has stimulated increasing demand for high-quality dehydrated products (Bobic et al., 2002). This trend is expected to continue and even accelerate over the next decade in all emerging economies of the world. Dehydration offers a means of preserving samples in a stable and safe condition as it reduces water activity and extends shelf-life much longer than that of fresh vegetables and leaves. The removal of moisture from the food materials prevents the growth and reproduction of spoilage microorganisms, slows down the action of enzymes and minimizes many of the moisture mediated deteriorative reactions. Many conventional thermal methods, including airflow drying, microwave drying, and freeze-drying, result in low drying rates as well as the long drying loading rates at relatively high temperatures often lead to undesirable thermal degradation of the finished products (Prakash Maran et al., 2014). Nowadays, vacuum drying offers opportunities to shorten the drying load-

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Table 1 Process variables and their ranges.

Level	−1	0	1
Temperature (oC)	50	70	90
Loading rate (kg/m^2)	0.25	0.50	0.75
Vacuum (mm [Hg])	20	40	60

ing rate and improves the final quality of the dried products compared to other conventional drying methods.

Coriander leaves (*Coriandrum sativum* L.) are one of the most popularly used plants for culinary and medicinal purposes in India. It is very rich in various food elements and vitamins, such as protein, fat, fiber, carbohydrates, water, Vitamins C, calcium, phosphorus, iron, thiamine, riboflavin, and oxalic acid. It is also a very valuable herb as it strengthens the stomach and promotes digestion, increases secretion and discharge of urine and reduces fever (Thirugnanasambandham et al., 2014a). Meanwhile, coriander leaves are an important market leaves of Asia and have a very limited shelf life for freshness. Therefore, there is a critical need to develop a technically and economically viable drying method to reduce the moisture content of coriander leaves without affecting its quality. An extensive literature shows that there is none of article is available regarding drying of coriander leaves using vacuum drying method (Ahn et al., 2004). In order to evaluate the practicability of vacuum drying for improving the quality of dried coriander leaves, it is necessary to carry out research on the vacuum drying characteristics of coriander leaves. Moreover, the drying parameters in vacuum drying process such as temperature, loading rate and vacuum have the significant effect on the drying efficiency and optimization of these variables shows enhanced performance of vacuum drying method.

In recent years, multivariate statistical techniques namely response surface methodology (RSM) coupled with Box–Behnken design (BBD) have been preferred to optimize and investigate the drying process parameters, which are not possible to identify using the univariate method (Jerkovic et al., 2001). In addition, these techniques are very useful tools to reduce the loading rate and cost of studies. Box–Behnken design (BBD) is one of the RSM tools in which the response function largely depends on the nature of the relationship between the response and the independent variables and it has been used for the optimization of various drying process. However, to our best knowledge, no publications are available on the drying of coriander leaves using vacuum dryer via RSM. Hence, the main objective of the present study has been made to investigate and optimize the individual and interactive effect of drying parameters such as temperature, loading rate and vacuum on the maximum moisture removal from coriander leaves based on Box–Behnken response surface design coupled with derringer's desired function methodology.

2. Materials and methods

2.1. Raw materials

Fresh coriander leaves (*C. sativum L.*) were obtained from Pungamuthur, Udumalpet Taluk, Tamil Nadu, India. The samples were washed and stored at 4 °C before the experiments. In order to determine the initial moisture content (dry basis) of the leaves, they were separated from the stems and dried in an oven at 105 °C for 24 h and an average value was determined.

2.2. Vacuum drying process

In order to carry out the drying experiments, 25 g of leaves was weighed using a digital balance (Sartorius GP3202, India) with a precision of 0.01 g. One sample was placed on the wire netting basket and dried in each run, its weight was continuously recorded at intervals of 5 min using the data acquisition system throughout the drying process. Different temperature, loading rate and vacuum were used to dry the samples and three replications were performed to confirm the reproducibility. Each drying process was applied until the initial moisture ratio reduced to 0.1 g dry base. Moisture loss was determined by weighing the plate using digital balance (Sartorious EX 2000A, Canada) with 0.01 g precision.

Table 2 BBD with corresponding results.

S. no	*A*	*B*	*C*	Y_1	Y_2	Y_3
1	90	0.5	20	55	509.54	9.28
2	70	0.75	20	42	499.48	7.85
3	70	0.25	20	49	503.43	8.55
4	70	0.5	40	95	549.55	13.08
5	70	0.75	60	88	542.28	12.38
6	50	0.5	20	28	482.34	6.54
7	50	0.5	60	83	537.48	11.45
8	90	0.75	40	68	522.48	10.42
9	90	0.25	40	88	542.65	12.42
10	70	0.5	40	95	549.35	13.08
11	70	0.25	60	90	544.52	12.86
12	50	0.25	40	72	526.48	10.33
13	70	0.5	40	95	549.42	13.08
14	90	0.5	60	80	534.12	11.55
15	50	0.75	40	44	498.44	7.87
16	70	0.5	40	95	549.36	13.08
17	70	0.5	40	95	549.48	13.08

Table 3 Sequential sum of squares.

Source	Sum of Squares	Df	Mean Square	F Value	Prob > F	Remarks
Sequential model sum of squares for Y_1						
Mean	93684.94	1.00	93684.94			
Linear	4404.25	3.00	1468.08	5.26	0.0136	
2FI	247.25	3.00	82.42	0.24	0.8640	
Quadratic	3155.31	3.00	1051.77	32.26	0.0002	Suggested
Cubic	228.25	3.00	76.08	63660000.00	< 0.0001	Aliased
Residual	0.00	4.00	0.00			
Total	101720.00	17.00	5983.53			
Sequential model sum of squares for Y_2						
Mean	4754546.60	1.00	4754546.60			
Linear	4228.75	3.00	1409.58	5.06	0.0154	
2FI	249.69	3.00	83.23	0.25	0.8619	
Quadratic	3117.66	3.00	1039.22	28.37	0.0003	Suggested
Cubic	256.38	3.00	85.46	12087.73	< 0.0001	Aliased
Residual	0.03	4.00	0.01			
Total	4762399.11	17.00	280141.12			
Sequential model sum of squares for Y_3						
Mean	2054.80	1.00	2054.80			
Linear	43.05	3.00	14.35	5.21	0.0140	
2FI	1.81	3.00	0.60	0.18	0.9095	
Quadratic	31.92	3.00	10.64	35.57	0.0001	Suggested
Cubic	2.09	3.00	0.70	63660000.00	< 0.0001	Aliased
Residual	0.00	4.00	0.00			
Total	2133.67	17.00	125.51			

Table 4 Model Summery statistics.

Model	Model summary statistics					
	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	Press	Remarks
Y_1						
Linear	16.7121	0.5481	0.4439	0.3129	5521.2	
2FI	18.3945	0.5789	0.3262	−0.0879	8741.4	
Quadratic	5.7103	0.9716	0.9351	0.5455	3652.0000	Suggested
Cubic	0.0000	1.0000	1.0000		+	Aliased
Y_2						
Linear	16.6958	0.5385	0.4320	0.2942	5542.3	
2FI	18.3687	0.5703	0.3125	−0.1259	8841.5	
Quadratic	6.0523	0.9673	0.9254	0.4776	4102.1366	Suggested
Cubic	0.0841	1.0000	1.0000		+	Aliased
Y_3						
Linear	1.6600	0.5458	0.4410	0.3152	54.0	
2FI	1.8444	0.5687	0.3100	−0.1101	87.6	
Quadratic	0.5470	0.9734	0.9393	0.5752	33.5080	Suggested
Cubic	0.0000	1.0000	1.0000		+	Aliased

2.3. Analytical methods

Carbohydrate, Fat, Sugar, Vitamin C, Phosphorus and Calcium were measured according to standard methods described by American Public Health Association (APHA) (Thirugnanasambandham et al., 2014c). The moisture removal efficiency was calculated as follows (Chaieb et al., 2007):

$$R = \frac{Y_0 - Y}{Y_0} \times 100 \tag{1}$$

Where, R is removal efficiency (%), Y_0 and Y were initial and final moisture value of the sample.

2.4. Experimental design

The Design Expert Software (8.0.7.1) was used for the experimental design and data analysis. In this study, the BBD coupled with the response surface methodology (RSM) for data analysis was applied to optimize the three major operating factors: temperature, loading rate, vacuum. Table 1 shows the factor levels in this experiment. In order to evaluate the performance of the vacuum drying process, moisture removal was selected as response variable. A total number of 17 experiments were carried out in this work in triplicates to assess the effects of the independent variables on the response. Second order polynomial equation (Eq. (2)) was used to fit the

Table 5 ANOVA results for moisture removal.

Source	Y_1		Y_2		Y_3	
	F value	*P* value	*F* value	*P* value	*F* value	*P* value
Model	26.60	0.0001	23.0416	0.0002	28.515	0.0001
A	15.70	0.0054	13.9995	0.0072	23.3767	0.0019
B	12.46	0.0096	10.0989	0.0155	13.2904	0.0082
CV	106.91	< 0.0001	91.347	< 0.0001	107.227	< 0.0001
AB	0.49	0.5062	0.42272	0.5363	0.17682	0.6867
AC	6.90	0.0341	6.37399	0.0395	5.82395	0.0465
BC	0.19	0.6747	0.01996	0.8916	0.04044	0.8463
A2	34.62	0.0006	32.2058	0.0008	43.7184	0.0003
B2	14.58	0.0066	11.9147	0.0107	15.7386	0.0054
C2	37.87	0.0005	32.5337	0.0007	36.5936	0.0005
CV	7.69		5.58		6.85	
AP	15.95		13.24		17.54	
Press	3652.00		4425.00		3333.25	

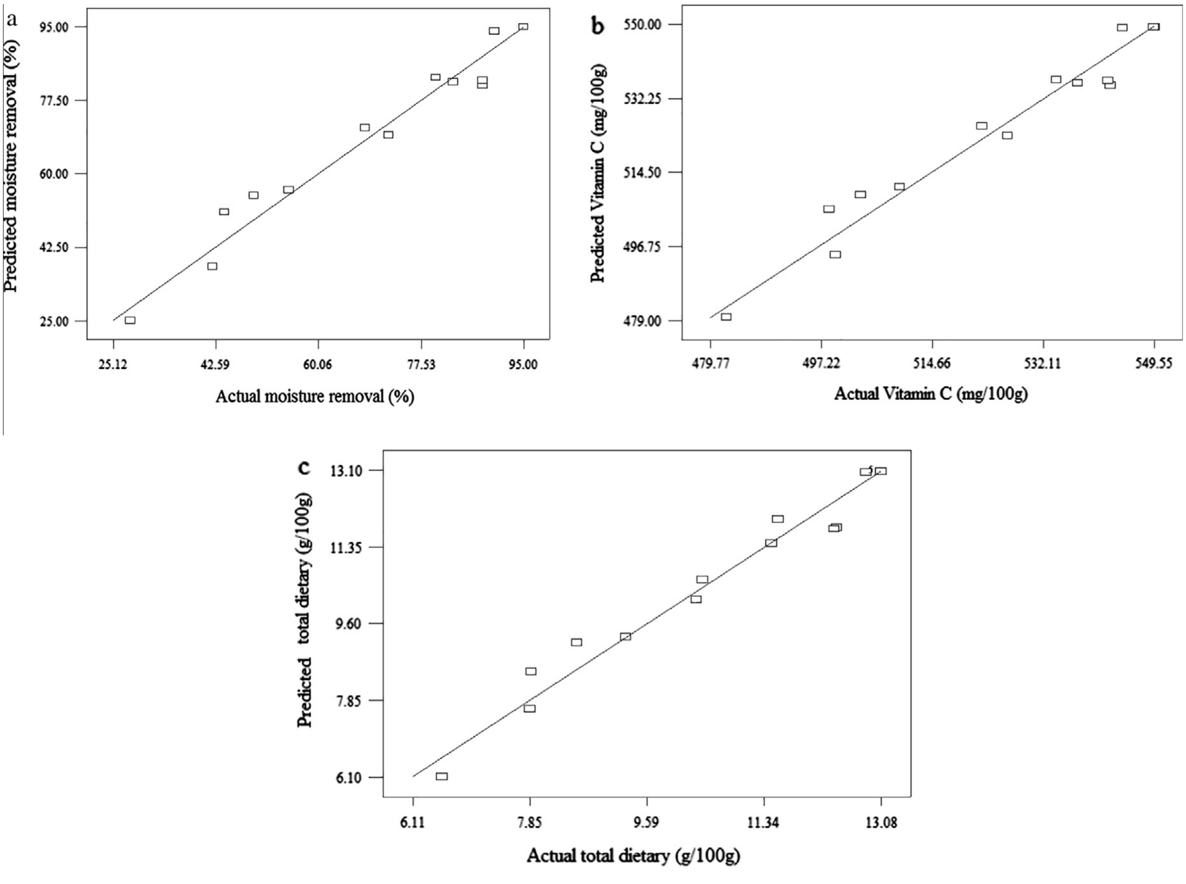

Fig. 1 Predicted versus actual plot for drying process.

experimental data and the general form of mathematical quadratic response equation was given as follows (Kingsly et al., 2007):

$$Y = \beta_0 + \sum_{j=1}^{k}\beta_j X_j + \sum_{j=1}^{k}\beta_{jj} X_j^2 + \sum_{i}\sum_{<j=2}^{k}\beta_{ij} X_i X_j + e_i \tag{2}$$

where, Y is the response; X_i and X_j are variables (i and j range from 1 to k); β_0 is the model intercept coefficient; β_j, β_{jj} and β_{ij} are interaction coefficients of linear, quadratic and the second-order terms, respectively; k is the number of independent parameters ($k = 3$ in this study); and e_i is the error. The obtained results were completely analyzed by using the analysis of variance (ANOVA) and the model terms were analyzed based on the *P*-value with a 95% confidence level. Three-dimensional plots (3D) and their respective contour plots generated and were used to evaluate the interaction between the two factors (chosen from the significant interaction terms) on the response variable. The optimum drying conditions were also identified based on the Derringer's desired function methodology (Pajohi et al., 2011).

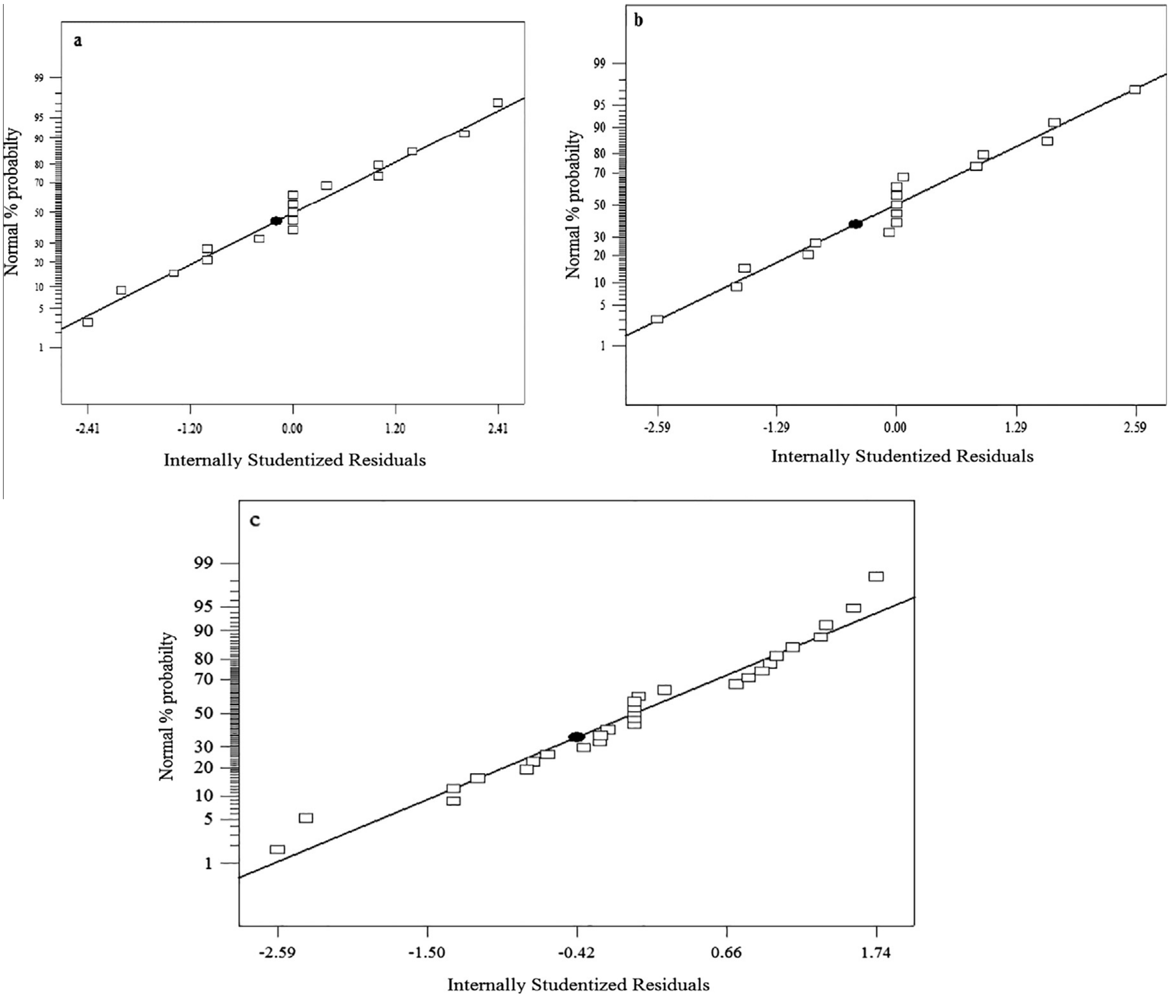

Fig. 2 Normal % probability versus residual error plot for drying process.

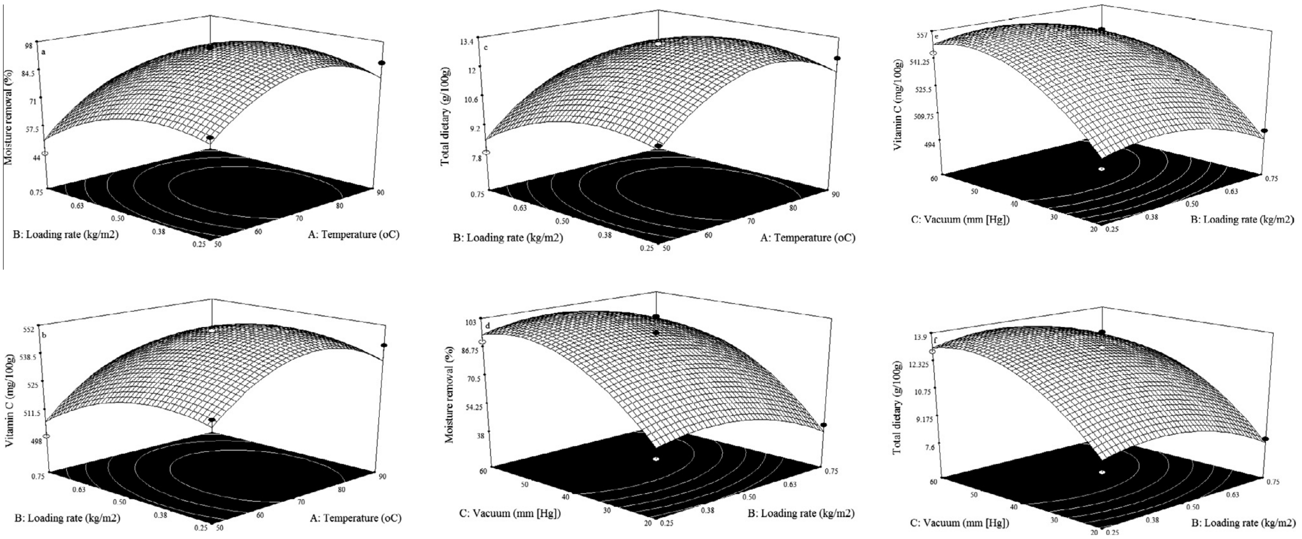

Fig. 3 Response surface plots representing the effect of process variables on the drying method.

3. Results and discussion

3.1. Experimental results

The relationships between moisture removal and three independent variables (temperature, loading rate and vacuum) were studied using vacuum drying method. The experimental design listed in Table 2 also provides the moisture removal for each experimental run. Then, these data were analyzed by different response functions such as linear, interactive, quadratic and cubic models using multiregression analysis namely sequential model sum of squares (Table 3) and model summary statistics (Table 4). Results indicated that the quadratic model provided the best fit to experimental data with the lowest standard deviation, the highest correlation coefficient (R^2), adjusted R^2, predicted R^2 values, and the lowest P value. Therefore, the quadratic model was chosen for further analysis. Then, the response obtained in Table 2 was correlated with the three independent variables using a polynomial equation, Eq. (2) and the best fit model in terms of coded factors is given below:

$$Y_1 = 95 + 8.00A - 7.12B + 20.88C + 2.00AB - 7.50AC + 1.25BC - 16.38A^2 - 10.63B^2 - 17.12C^2 \quad (3)$$

$$Y_2 = 549.43 + 8.01A - 6.80B + 20.45C + 1.97AB - 7.64AC + 0.43BC - 16.74A^2 - 10.18B^2 - 16.82C^2 \quad (4)$$

$$Y_3 = 13.08 + 0.93A - 0.71B + 2.00C + 0.12AB - 0.66AC + 0.055BC - 1.76A^2 - 1.06B^2 - 1.61C^2 \quad (5)$$

where, Y_1 is the moisture removal (%), Y_2 is Vitamin C content(mg/100 g) and Y_3 is total dietary fiber (g/100 g). Adequacy and fitness of the developed mathematical model was tested by analysis of variance (ANOVA). As can be seen in Table 5, the probability value (P-value) for models is less than 0.05 (<0.0001), and F-value is larger than 0.05, implying that the model obtained is statistically reasonable. The coefficient of variation (CV), defined as the percent ratio between the standard error of the estimate and the mean value of the observed response is a measure of the reproducibility of the model. Generally, model can be considered reasonably reproducible if its CV is not larger than 10% and the low CV value in the model indicated a good reproducibility. Adequate precision (AP) is a measure of the range in predicted response relative to its associated error or, in other words, a signal-to-noise ratio. Its desired value is 4 or greater and the AP value of the present study demonstrate that the developed mathematical model is reliable to describe the vacuum drying process. In order to acquire a better understanding of results, diagnostic plots such as predicted versus actual (Fig. 1) and normal % probability versus residual error plots (Fig. 2) are used to evaluate the model suitability. The obtained results indicate an adequate signal and confirm that developed mathematical model can be used to navigate the design space (Thirugnanasambandham et al., 2014b).

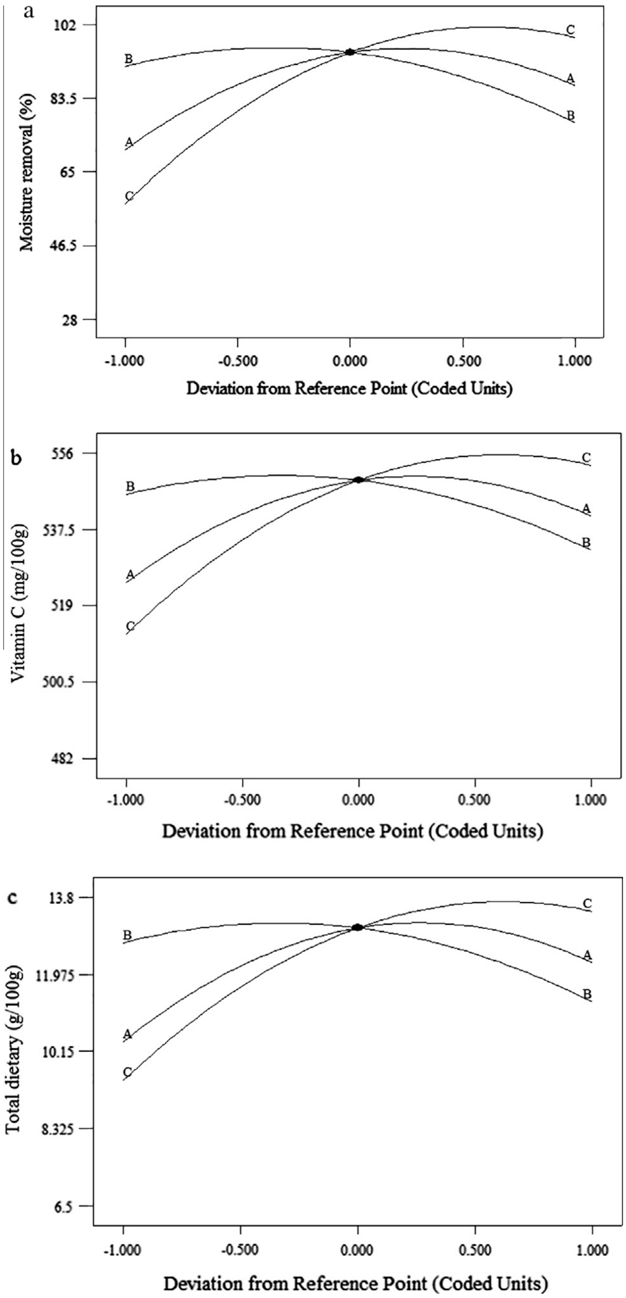

Fig. 4 Perturbation plot for drying process.

3.2. Effect of process variables on drying process

The three dimensional (3D) surface response and contour plots of the quadratic model with one variable kept at central level and the other two varying within the experimental ranges are shown in Fig. 3.

3.2.1. Influence of temperature

Temperature is one of the crucial parameters which influences the drying process of coriander leaves appreciably. In order to investigate the effect of temperature on drying process, the experiments were carried out at various temperatures (50–80 °C) and the results are illustrated in Fig. 3a–c,which shows that moisture removal was increased with increasing temperature up to 80 °C, thereafter there is a negligible effect on the drying process (Bakhara et al., 2009).

3.2.2. Influence of loading rate

Drying loading rate is also one of the important parameter in moisture removal from coriander leaves. In order to investigate the effect of loading rate on drying process, the experiments were carried out at various loading rates (25–75 min) and the results are shown in Fig. 3a–c. From the results, it is found that the percentage removal of moisture, Vitamin C content and total dietary fiber are increased with increasing loading rate up to 65 min. Beyond that, drying efficiency shows ignorable effect (Senadeera et al., 2003).

3.2.3. Influence of vacuum

Vacuum is one of the most significant parameter that affects the drying process significantly. To examine the optimum vacuum for the maximum moisture removal experiments were carried out in various vacuums in the range of 20 to 60 mm [Hg] and results are shown graphically in Fig. 3 d–f. From the results, it is found that the moisture removal, Vitamin C content and total dietary fiber are increased with increasing vacuum up to 50 mm [Hg]. Thereafter, there is an insignificant effect on moisture removal. Perturbation plot for drying process is shown in Fig. 4 which also gives the significance of the process variables on the drying of coriander leaves using vacuum drying process (Maskan et al., 2002; Thirugnanasambandham et al., 2014d).

3.3. Optimization

Simultaneous optimization of the multiple responses was carried out using Derringer's desired function methodology on BBD results and optimal drying conditions. The optimal conditions were found to be temperature of 75 °C, loading rate of 0.63 kg/m^2 and vacuum = 28 mm [Hg]. Under these conditions, 95% moisture removal, 527 mg/100 g Vitamin C content and 13 g/100 g total dietary fiber were obtained. Finally, the Characteristics of coriander leaves after and before drying confirm the effectiveness of vacuum drying process for coriander leaves without affecting quality (Mongpraneet et al., 2002).

4. Conclusion

The Box–Behnken design (BBD) was used to examine and optimize the process parameters (temperature, loading rate and vacuum) that gives maximum moisture removal from coriander leaves using vacuum drying process. From the results, it is revealed that all the process variables significantly affected the drying process and the developed second order polynomial equation was found to be good fit. 3D response surface graphs clearly illustrate the combined effect of process parameters on the drying efficiency. ANOVA was used to examine the adequacy of developed mathematical model and the optimal drying conditions were determined by desired function methodology. The optimal conditions were found to be temperature of 75 °C, loading rate of 0.63 kg/m^2 and vacuum = 28 mm [Hg]. Under these conditions, 95% moisture removal, 527 mg/100 g Vitamin C content and 13 g/100 g total dietary fiber were obtained. These results show that drying process using vacuum is an effective method to enhance moisture removal from coriander leaves.

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