THE INTERNATIONAL JOURNAL OF SCIENCE & TECHNOLEDGE

Optimization of Convective Hot Air Drying of Okra Slices Using Response Surface Methodology

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Abstract:
In this study, response surface methodology was applied to optimize the drying conditions of okra during convective drying in a designed and fabricated cabinet dryer. The output variables of interest were the moisture content (Y_M), protein (Y_P), carbohydrate (Y_C) and total plate count (Y_T) which were evaluated based on the effect of four independent variables, namely; air velocity (X_1), humidity (X_2), drying temperature (X_3) and drying time (X_4). Analysis of variance (ANOVA) showed that all individual factors (air velocity, drying temperature and drying time except relative humidity for moisture response were highly significant with p values $\leqslant$0.005. Interactive effect of the process variables such as relative humidity and time, and air velocity and time were highly significant ($p < 0.001$). The response surface plots revealed the combined effect of air velocity, drying time, temperature and humidity on moisture content, protein, carbohydrate, total plate count, TPL and moisture. Optimal drying conditions were found to be 3.98 m^3/s, 348 seconds, 52.2 ^0C and 60.40% respectively while the output was 1.116% H_2O, 10.02 protein, 66.94% H and 2.88 x 10^{-3} TPL.

Keywords: *Response Surface, Optimize, moisture content, protein Content, Carbohydrates content, Total Plate Count, Analysis of Variance (ANOVA).*

1. Introduction

The okra plant (*Abelmoschus esculentus L. Moench*) is a tropical dicotyledonous plant grown throughout the tropics and warm temperature regions for its immature pods used as vegetable, food ingredient as well as traditional medicine (Purseglove, 1987; Sengk *et al*, 2009). Okra is commonly grown in Nigeria and are harvested during the peak periods of raining season. Loss of the vegetable is unavoidable since drying immediately after harvest often proves difficult because of the rains and little or no sunlight required for traditional sun drying for preservation. Spoilt and/or rotten vegetables are usually dumped in villages and major cities as waste (Itodo, *et al*, 2002; Bala, *et al*, 2003). Rehydration of the crops during cloudy weather and at nights results to poor dehydrated products for storage (Ayensu, 1997). Solar drying was an improvement over the sun drying method. Unfortunately, there are several other disadvantages and problems associated with those dryers. Firstly, solar dryers lack the mechanism to control the drying conditions. Secondly, the drying process is very slow and can be interrupted by unfavourable weather conditions. Thirdly, they also require constant supervision of the drying process since the produce has to be protected from rain and predators. That is, they are all weather dependent.

Processing of agricultural produce does not only contribute to food preservation but also offers better opportunity for product utilization and value addition drying is one of the most effective means of preserving agricultural proceeds especially fruits and vegetables that have limited storage properties. Drying provides solution to maintaining quality and storability of the products (Daniel, 1996).

In most developing countries, dehydration of agricultural produce such as pepper, yam, plantain, okra, cassava, and others using the sun (natural drying) is a very common practice. Here, the materials are spread on the floors such as the rock surfaces, soil (clay) grounds, cemented pavements, raise mesh tray, and other devices. (Jeon, and Halos, 1991). This method is time consuming and it could take four to six days for the product to get dried. Product quality suffers because of prolonged drying which makes the product susceptible to contamination. Losses are also incurred due to repeated handling and direct consumption by animals.

Drying is removing a large portion of the moisture content contained in a product in order to considerably reduce the reactions which lead to the deterioration of the products. The removal of moisture arrests the growth and the reproduction of microorganism that would cause decay and minimizes many of the moisture-mediated deterioration reactions. This can be done by simultaneous heat and mass transfer and is a classical method of food preservation that provides longer shelf life, reduce weight and volume (Malaisamy, and Sabanayagam, 2014).

The use of solar dryers as an improved means of natural drying using the sun's energy is gradually gaining popularity and replacing the direct sun drying. Solar dryers produce better quality products within a relatively shorter period. Odogala,(1991) observed that the natural convection solar dryer in clear and sunny weather produces mold-free chips when dried between two to three days up to 12-13% moisture content. Drying using solar dryer or direct sun drying depends mainly on the weather and, therefore, not reliable and quite unattractive during the rainy season or wet weather (Ajayeoba, *et al*, 2014,).

Hot air cabinet dryer does not have the negative tendencies mentioned above. It is more efficient, permits closer control of the drying operations, produce quality products and does not depend on the weather (Daniel, 1996). Cabinet dyer produces uniformity in air temperature and velocity throughout the chamber (Amanlou and Zomorodian, 2010). Airflow shutters are provided for uniform air distribution to all the trays inside the drying chamber, and very compact to reduce the material cost. Often digital temperature controller is attached to ensure that the drying temperature is kept constant throughout the drying process (Bolaji, *et al*, 2008).

Drying has to occur rapidly (to avoid products going mouldy) but not too rapidly (otherwise, a crust could then form on the surface) or too high a temperature (that can char the product, spoils or blacken it). For efficient drying, the characteristics of the fresh product have to be taken into account (for instance, fatty fish/meat is not to be dried in the same way as leafy vegetables), and must compare favourably with same properties in the final product; such as texture, colour, and specific taste (Bolaji, *et al*, 2008, Brenan, 2006).

Response surface method (RSM) is a statistical experimental design that enables simultaneneous varying of process variables, unlike what obtains in the conventional experimentation. Thereby eliciting the interaction between such variables. It is a faster and more economical method of gathering research results than the classic one variable at a time or full factor experimentation (Krishnaiah *et al*, 2015). It also provides a model equation relating the response parameter to the process variables and optimization of the same. It is a veritable tool that has been deployed in wide range of fields, such as drying operation (Krishnaiah *et al*, 2015), Carrgreenan production (Bono *et al, 2014*), transesterification (Betiku *et al*,2015), solvent extraction (Rai *et al*,2016, Mohammadi *et al*,2016), adsorption (Ahmed and Treydan, 2016) and Fenton process (Kumar and Pal, 2012).

The aim of this study therefore is to analyze effects of interactive process variables on the drying using response surface method (RSM) and investigate optimum conditions for the drying of okra.

2. Materials and Methods

2.1. Sample Collection

The fresh okra samples were purchased from local suppliers at Idi-Oro, Lagos, South-West Nigeria. The selected samples were sorted, cleaned with brushes and then weighed. The samples were kept in for some hours to achieve equilibrium temperature with the environment before usage. This is because; the sample temperature could be higher than the temperature of the environment. This practice gives better result.

2.2. Cabinet Dryer Design Consideration

A forced air circulation with a diffusion method was selected to obtain the uniformity in distribution of air velocity and temperature. The design requirement for the airflow distribution unit is to: (i) provide uniform distribution to all the trays inside the drying chamber. (ii) compact dryer in order to reduce the material cost.

2.3. Drying Procedure

The experiments were carried out using fresh okra and unripe plantain with average moisture content of 84.997%, 86.037%, 62.04% respectively. The materials were cleaned with soft brushes to remove any form of dirty, no pre-treatment was done. The materials were cut into 2mm thick. The slices materials were weighed and loaded into each of the three trays, considering that weight on each tray was 1000gm (1kg)

The dryer was cleaned and heated up to the required drying temperature before the trays were put in the dryer. The temperature level in the dryer was set at 40 ^{0}C, 50 ^{0}C, 60 ^{0}C and 70 ^{0}Cand was regulated by temperature controllers for each of the above temperature. The hot air velocity and the relative humidity were initially constant at 3 m^3/s and 60% respectively for the testing of the equipment (dryer).

The drying process was monitored at every 30 minutes intervals. The second stage of drying the temperature was kept constant at 70 ^{0}Cwhile the hot air velocity and humidity were varied at 0.49 m^3/s, 1.89 m^3/s, 2.49 m^3/s, 3.58 m^3/s, and 3.88 m^3/s and 60%, 65%, 70%, 75%, and 80% respectively. The drying process was monitored 30 minutes interval until a constant weight was obtained in any of the experiment. The reading (experiment) was terminated at the equilibrium weight.

The Response Surface methodology was used to evaluate the optimum drying conditions (Central Composite Design. A factorial design (4th) four level parameters was used to analyse the dried okra quality as a function of air temperature, air velocity and humidity and time.

2.7. Statistical Data Analysis

Analysis of variance (ANOVA) was used for the analyses of the data obtained from batch experiments. The interactions between the process variables and the responses of different regression models developed for okra were investigated. The quality of the fit polynomial model was expressed by the coefficient of determinationR^2, and its statistical significance was checked by the Fisher's F-test implemented within the space of Design Expert version 6.0.3. Model terms were evaluated by the p-value (probability). Three-dimensional surface plots and their respective contour plots were obtained for four responses on the effects of the four factors as indicated from the design table.

2.8. Experimental Design

The effect of four independent variables volumetric air velocity (X_1), relative humidity (X_2), drying temperature (X_3) and drying time (X_4) on five response variables namely, moisture content (Y_M), protein (Y_P), carbohydrate (Y_C) and total plate count (Y_T) were evaluated using the surface response methodology (RSM). Experimental data were fitted to a second order polynomial model and the regression coefficients were obtained. The generalized second order polynomial model proposed for predicting the response variables is given as:
The regression models obtained for the process are:

$$Y_M = +197.02844 - 27.63760 X_1 + 7.24901X_2 - 9.76305X_3 - 0.80247X_4 - 0.38001X_1^2 - 0.048746X_2^2 + 0.051180X_3^2 + 8.38746E\text{-}004X_4^2 - 5.71304E\text{-}003X_1X_2 + 0.35462X_1X_3 + 0.016601X_1X_4 + 7.66296E\text{-}003X_2X_3 - 2.46676E\text{-}003X_2X_4 + 7.72408E\text{-}003X_3X_4 \quad (1)$$

$$Y_P = -5.865 + 1.135X_1 - 0.10180^* X_2 - 0.027X_3 + 0.083X_4 + 0.11584X_1^2 - 8.04398E\text{-}006X_2^2 - 8.93678E\text{-}004X_3^2 - 2.18355E\text{-}005X_4^2 + 2.12326E\text{-}003X_1X_2 - 5.54948E\text{-}003X_1X_3 - 2.65885E\text{-}003X_1X_4 + 3.85365E\text{-}003X_2X_3 - 6.32195E\text{-}004X_2X_4 - 7.75174E\text{-}005X_3X_4 \quad (2)$$

$$Y_C = -361.41460 + 39.125X_1 - 1.437X_2 + 7.921X_3 + 0.927X_4 + 2.001X_1^2 + 0.019X_2^2 - 0.034X_3^2 - 4.04660E\text{-}004X_4^2 - 0.30104X_1X_2 - 0.20490X_1X_3 - 0.03728X_1X_4 - 2.14583E\text{-}003X_2X_3 - 5.78704E\text{-}005X_2X_4 - 8.78588E\text{-}003X_3X_4 \quad (3)$$

$$Y_T = -56320.569 - 1348.926X_1 + 2980.163X_2 - 134.713X_3 - 229.878X_4 - 600.976X_1^2 - 21.312X_2^2 + 1.087X_3^2 + 0.163X_4^2 + 23.493X_1X_2 - 15.473X_1X_3 + 10.5138X_1X_4 - 4.2600X_2X_3 + 0.79537X_2X_4 + 0.5536X_3X_4 \quad (4)$$

The Design Expert 6.0.3 was used for the experimental design matrix, data analysis and optimization procedure. A functional relationship between response and the set of independent variables was found according to Montgomery (2001).

3. Results and Discussion

3.1. Analysis of Variance (ANOVA) for Okra Drying Response

Source	Sum of Squares	DF	Mean Square	F Value	Prob >F		
Model	3760.536	14	268.6097	48.96243	<0.0001	Significant	
X_1	346.2554	1	346.2554	63.11577	<0.0001		
X_2	25.67602	1	25.67602	4.68025	0.0471		
X_3	202.2762	1	202.2762	36.8711	<0.0001		
X_4	127.124	1	127.124	23.17228	0.0002		
X_1^2	3.96079	1	3.96079	0.721977	0.4089		
X_2^2	40.73473	1	40.73473	7.425166	0.0157		
X_3^2	718.4603	1	718.4603	130.9616	<0.0001		
X_4^2	1266.002	1	1266.002	230.7681	<0.0001		
X_1X_2	0.013056	1	0.013056	0.00238	0.9617		
X_1X_3	201.2057	1	201.2057	36.67597	<0.0001		
X_1X_4	35.71503	1	35.71503	6.510169	0.0221		
X_2X_3	2.348836	1	2.348836	0.428148	0.5228		
X_2X_4	19.71505	1	19.71505	3.593678	0.0774		
X_3X_4	773.2127	1	773.2127	140.942	<0.0001		
Lack of Fit	52.72184	10	5.272184	0.891514	0.5916	not significant	

Table 1: ANOVA for Okra Drying Regression Model of Moisture Content Response

From Table 1, it was observed that all individual factors (air velocity, drying temperature and drying time except relative humidity for moisture response were highly significant with p values 0.005. The quadratic terms for drying temperature and time in equation 1 are also statistically significant as indicated in Table 1. However, interaction between the parameters of air velocity and drying temperature is highly significant (confidence level = 99%) in Table 1. Moreover, the interaction between other parameters like operating time and temperature was also significant with confidential level > 97%. Apart from the interaction, effect of individual parameters like air velocity, temperature and drying time are significant with good confidence level as indicated in the Table 1.

Source	**Sum of** Squares	DF	**Mean** Square	**F** Value	Prob > F		
Model	102.5209	14	7.322922	46.07445	<0.0001	significant	
X_1	11.63066	1	11.63066	73.17794	<0.0001		
X_2	0.873434	1	0.873434	5.49548	0.0332		
X_3	25.42699	1	25.42699	159.9818	<0.0001		
X_4	60.04226	1	60.04226	377.7746	<0.0001		
X_1^2	0.368065	1	0.368065	2.315796	0.1489		
X_2^2	1.11E-06	1	1.11E-06	6.98E-06	0.9979		
X_3^2	0.219061	1	0.219061	1.37829	0.2587		
X_4^2	0.858026	1	0.858026	5.39854	0.0346		
X_1X_2	0.001803	1	0.001803	0.011346	0.9166		
X_1X_3	0.049275	1	0.049275	0.310027	0.5859		
X_1X_4	0.916208	1	0.916208	5.764608	0.0298		
X_2X_3	0.594023	1	0.594023	3.737484	0.0723		
X_2X_4	1.294933	1	1.294933	8.147477	0.0121		
X_3X_4	0.077876	1	0.077876	0.48998	0.4947		
Residual	2.384051	15	0.158937				
Lack of Fit	2.126601	10	0.21266	4.130122	0.0655	not significant	

Table 2: ANOVA for Okra Drying Regression Model of Protein Response

The result of second-order response surface model for okra drying with the input variable of volumetric air velocity (X_1), relative humidity (X_2), drying temperature (X_3) and drying time (X_4) and protein as response in Eqn. (2) in form of ANOVA is shown in Tables 2. The significance of each parameter was also determined by F-values and P-values. The parameters for the main effects such as air velocity, drying temperature and time are significant in Table 2.

Quadratic terms of all the drying process for protein response were found to be insignificant. Interactive effect of the process variables such as relative humidity and time, and air velocity and time were highly significant ($p < 0.001$) with relatively high F-values for okra drying with protein content as response. Low probability values ($P < 0.0001$) with the corresponding high F-values in the Table 2 demonstrates high influence of the factors on protein content of dried okra.

Source	**Sum of** Squares	DF	**Mean** Square	**F** Value	Prob > F		
Model	6210.55	14	443.6107	21.58538	<0.0001	significant	
X_1	328.3134	1	328.3134	15.9752	0.0012		
X_2	138.8407	1	138.8407	6.755763	0.0201		
X_3	1596.722	1	1596.722	77.69393	<0.0001		
X_4	2054.746	1	2054.746	99.98064	<0.0001		
X_1^2	109.866	1	109.866	5.345901	0.0354		
X_2^2	6.21103	1	6.21103	0.302219	0.5906		
X_3^2	331.8476	1	331.8476	16.14717	0.0011		
X_4^2	294.6816	1	294.6816	14.33873	0.0018		
X_1X_2	36.25043	1	36.25043	1.763888	0.2040		
X_1X_3	67.17168	1	67.17168	3.268466	0.0907		
X_1X_4	180.1188	1	180.1188	8.76429	0.0097		
X_2X_3	0.184184	1	0.184184	0.008962	0.9258		
X_2X_4	0.010851	1	0.010851	0.000528	0.9820		
X_3X_4	1000.404	1	1000.404	48.67806	<0.0001		
Residual	308.2716	15	20.55144				
Lack of Fit	152.5516	10	15.25516	0.489826	0.8424	not significant	

Table 3: ANOVA for Okra Drying Regression Model of Carbohydrate Response

Table 3 shows ANOVA for Okra Drying Regression Model of Carbohydrate as Response. All individual factors in Table 3 except humidity and air velocity show high level of significance, with p value $<$ 0.0001. This implies that air velocity, drying temperature and time have influence on carbohydrate content during okra drying process. Furthermore, it was noticed that quadratic terms of drying temperature and time were significant based on p and F values in Table 3. The interaction between air velocity and operating time as well as temperature and time influenced carbohydrate content of okra during drying process as indicated from the values of p and F in Table 3.

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F		
Model	3.74E+08	14	26690198	145.9516	<0.0001	Significant	
X_1	939945.4	1	939945.4	5.13996	0.0386		
X_2	4235.672	1	4235.672	0.023162	0.8811		
X_3	81119148	1	81119148	443.5887	<0.0001		
X_4	1.93E+08	1	1.93E+08	1054.585	<0.0001		
X_1^2	9906456	1	9906456	54.17207	<0.0001		
X_2^2	7786111	1	7786111	42.57726	<0.0001		
X_3^2	324533	1	324533	1.774663	0.2027		
X_4^2	48292222	1	48292222	264.0793	<0.0001		
X_1X_2	220786.6	1	220786.6	1.207341	0.2892		
X_1X_3	383068.9	1	383068.9	2.094759	0.1684		
X_1X_4	14326161	1	14326161	78.34061	<0.0001		
X_2X_3	725908.7	1	725908.7	3.96953	0.0649		
X_2X_4	2049647	1	2049647	11.20821	0.0044		
X_3X_4	3972519	1	3972519	21.72316	0.0003		
Residual	2743053	15	182870.2				
Lack of Fit	2313505	10	231350.5	2.692951	0.1429	not significant	

Table 4: ANOVA for Okra Drying Regression Model of TPC Response

Table 4 shows analysis of variance for Okra Drying Regression Model with respect to Total Plate Count (TPC) as Response. It was observed from Table 4, based on p and F value that all operating variables affect TPC of okra during drying process except Humidity and air velocity. Moreover, it was noticed that all quadratic terms except operating temperature were significant according to p and F values in Table 4. The interaction between air velocity and operating time, relative humidity and time, and temperature and time influenced TPC of okra during drying process as indicated in Table 4.

The goodness of the fit of the models (Eqns 1 - 4) was also checked by the correlation coefficients (R^2). 0.978, 0.977, 0.952 and 0.992 are R^2 valuesfor Eqn 1 - 4 which revealed that the regression models are statistically reliable, dependable and significant. For a model to be adequate, R^2 must not be less than 0.75 (Le-Man *et al,* 2010). The values of predicted multiple correlation coefficients for the models (pred.R^2 = 0.909, 0.879, 0.830 and 0.962) are in reasonable agreement with the value of the adjusted multiple correlation coefficients (adj.R^2 = 0.958, 0.956, 0.908 and 0.985). according to Rai *et al*, 2016, experimental and predicted R^2 must be within 20%, to be significant. The non-significant value of lack of fit in Tables 1 - 4 showed that the quadratic models were valid for okra drying process using fabricated dryer. Adequate Precision measures the signal to noise ratio of the data in the model. A ratio greater than 4 is desirable. The ratios for the models are 25.488, 24.816, 18.138 and 25.11; indicating an adequate and reliable regression models.

3.2. Interactive Effect of Process Variables on Okra Drying Process

To investigate the interactive effect of the factors on drying process, the contour and response surface plots were drawn in RSM and used to analyze the interactive effect between two independent variables on the dependent variables (% moisture content, protein, carbohydrate and TPC). Contour plot is the projection of the response surface as a two-dimensional plane. This analysis gives a better understanding of the influence of variables and their interaction on the response.

The three-dimensional response surface and contour plot obtained from RSM in Design Expert for second order polynomial equations are shown in Figures 1- 3. The combined process factors that affect % moisture content during okra drying was obtained by analysing the response surface plots in Figures 1- 3. The response surface plots revealed the combined effect of air velocity and drying temperature on moisture content at constant relative humidity of 70% and drying time of 270 mins as depicted in Figure 1. It was noticed that at 2m^3/s and 40^{o}C, the % moisture content for okra drying achieved 51.2%. As temperature increases to 60^{o}C and flow rate of 4 m^3/s, % moisture content drastically reduced to 1.04%. Therefore, high temperature and high air velocity flow rate favours the reduction in moisture content. Figure 2 shows the interactive effect of volumetric flow rate and time on the %moisture content, keeping relative humidity and temperature constant. At low drying time of 90 mins, %moisture reduces from 56.9% to 1.2% as flow rate increases. At 450 mins and coupled with an increase in flow rate from 0 – 4 m^3/s, %moisture content curve tends towards linearity.

Figure 3 shows the effect of temperature and time combination at constant flow rate of 2m^3/s and relative humidity of 70%, on the %moisture content. Increase in temperature from low time of 90 mins resulted in high reduction of moisture from 63.04% to nil at high time of 450 mins, moisture content decreases drastically with increase in temperature.

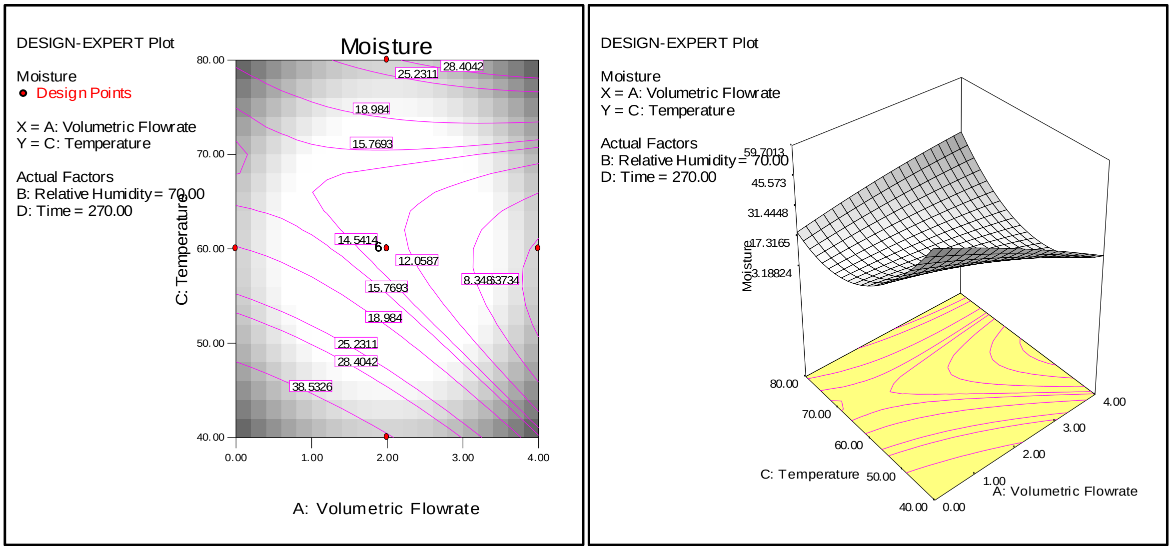

Figure 1: Response surface plots of Temperature and Volumetric flow rate on %Moisture

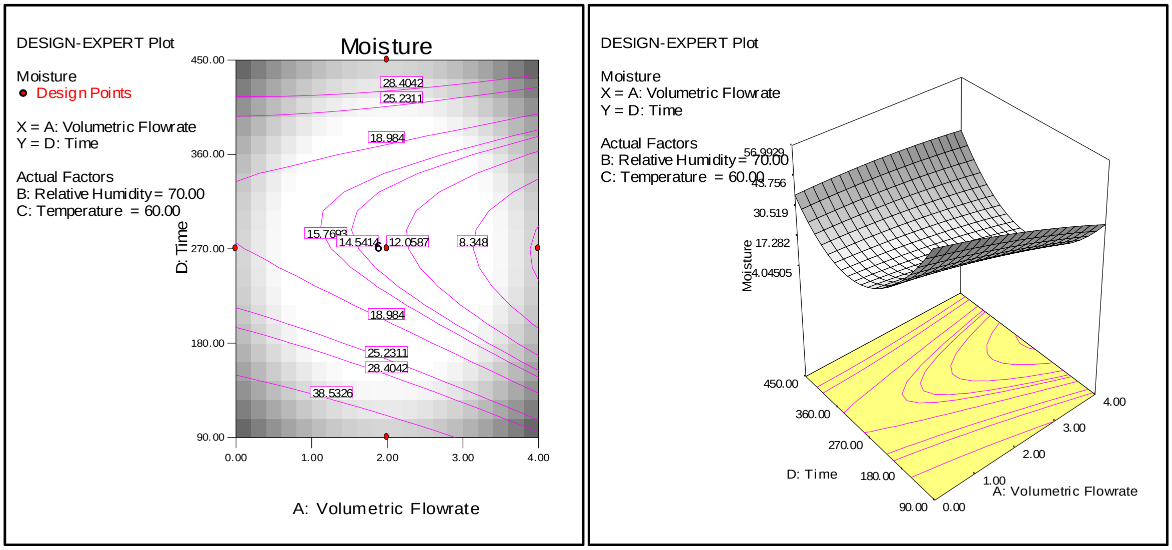

Figure 2: Response surface plots of Time and Volumetric flow rate on %Moisture

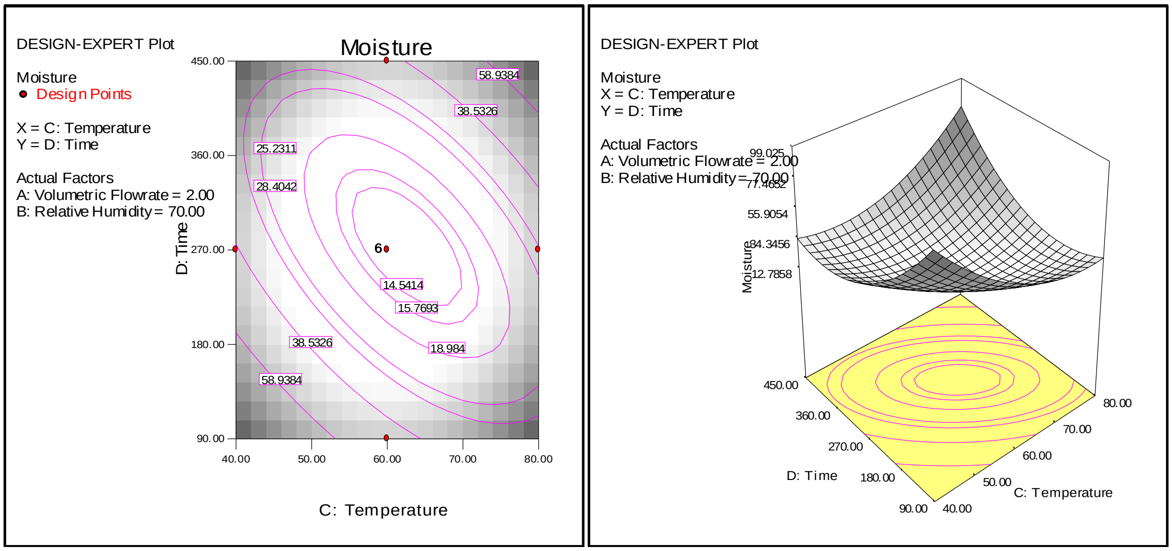

Figure 3: Response surface plots of Time and Temperature on %Moisture

The combined process factors that significantly affect Protein content during okra drying was obtained by analysing the response surface plots in Figures 4 and 5. The interactive effect of volumetric flow rate and time on protein content at constant relative humidity of 70% and temperature of 60^{o}C was shown in Figure 4. % Protein was slightly increased from 1.2% to 5.9% as time increases and across the increment in flow rate. The highest %Protein of 9.3 was achieved at a time of 450 mins and air velocity of $4m^{3}/s$. Figure 5 shows the effect of relative humidity and time on Protein content, keeping volumetric flow rate and temperature constant at $2m^{3}/s$ and 60^{o}C. % protein was low at a low time of 90mins with increase in relative humidity while a reverse behaviour was observed at high time of 450mins while still drying at a constant temperature of 60^{0}C

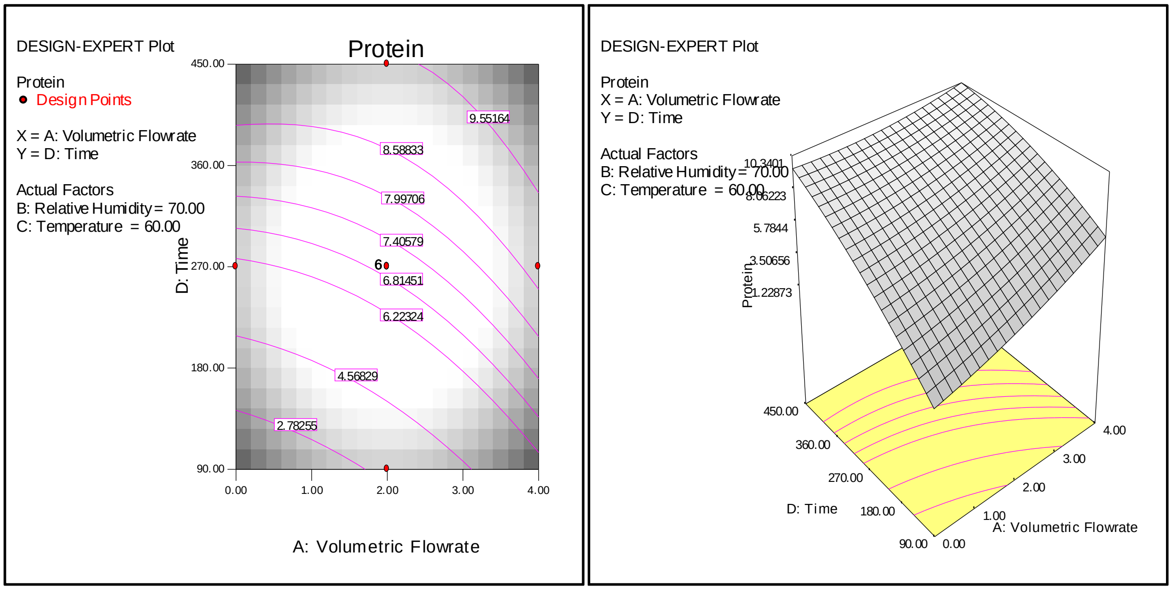

Figure 4: Response surface plots of Time and Volumetric flow rate on %Protein

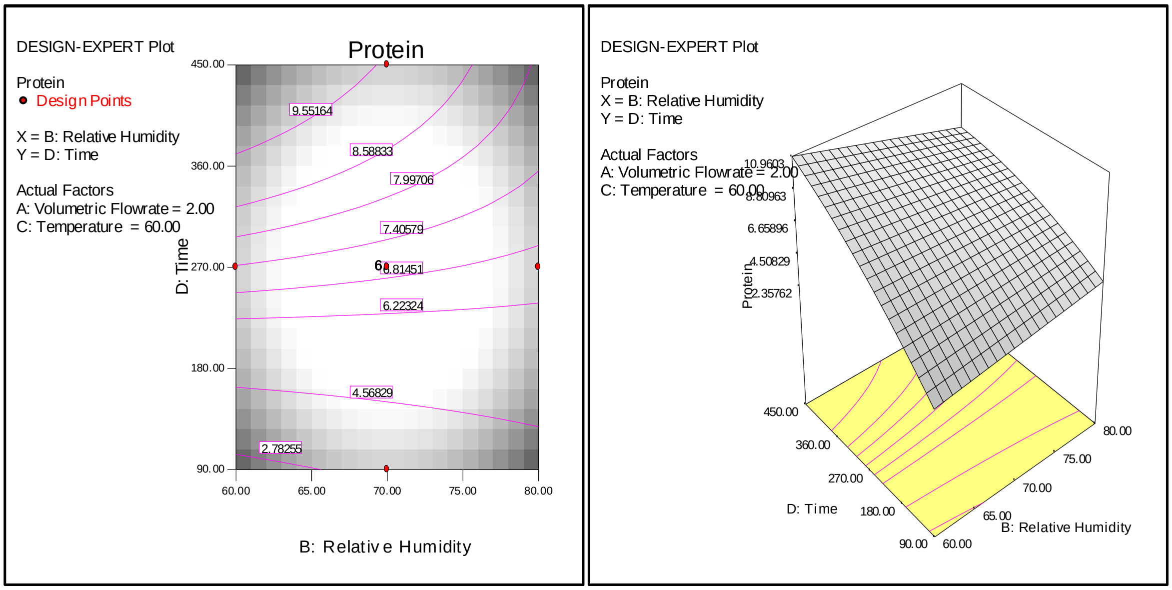

Figure 5: Response surface plots of Time and Relative Humidity on %Protein

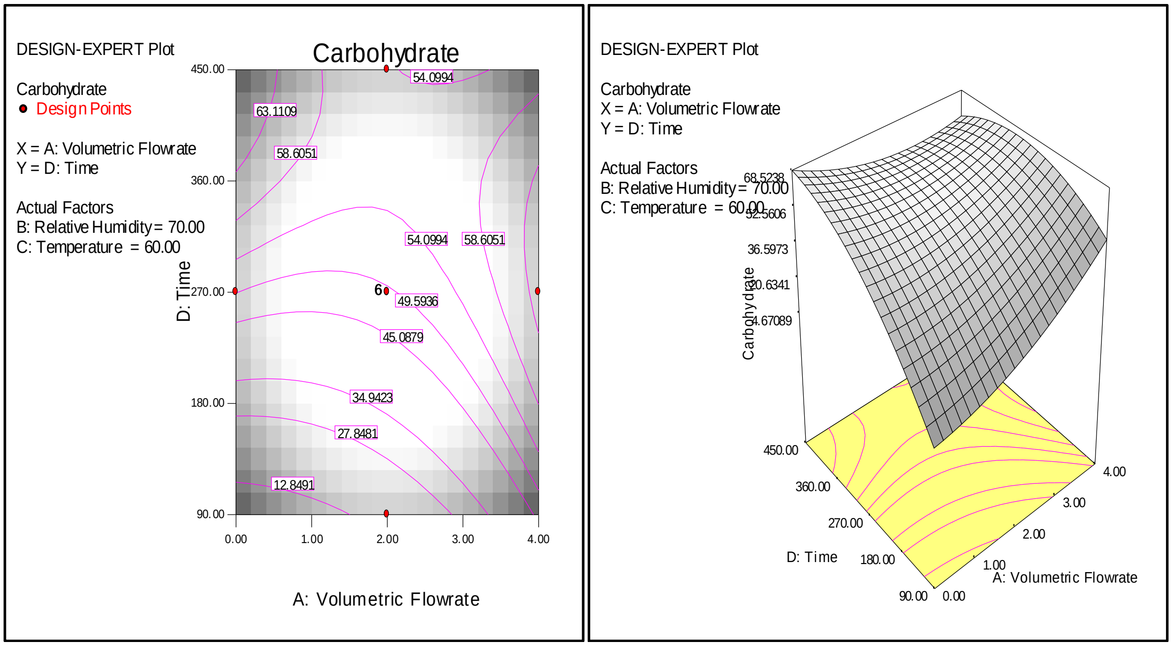

Figure 6: Response surface plots of volumetric flow rate and time against %Carbohydrate

The response surface plots to determine the effects of factor interaction for %Carbohydrate of Okra drying process are shown in Figure 6 - 7. Figure 6 shows the synergetic effect of time and air volumetric flow rate on %Carbohydrate, keeping relative humidity and temperature constant at 70% and 60^{o}C respectively. At 2m^{3}/s and time 90 mins, the observed %Carbohydrate was 10.5 but increases to 60.9 drying at a time of 450mins and air velocity of 2m^{3}/s. The highest value of carbohydrate content was achieved at low flow rate and high time. % Carbohydrate increases at 450 mins as air velocity increases.

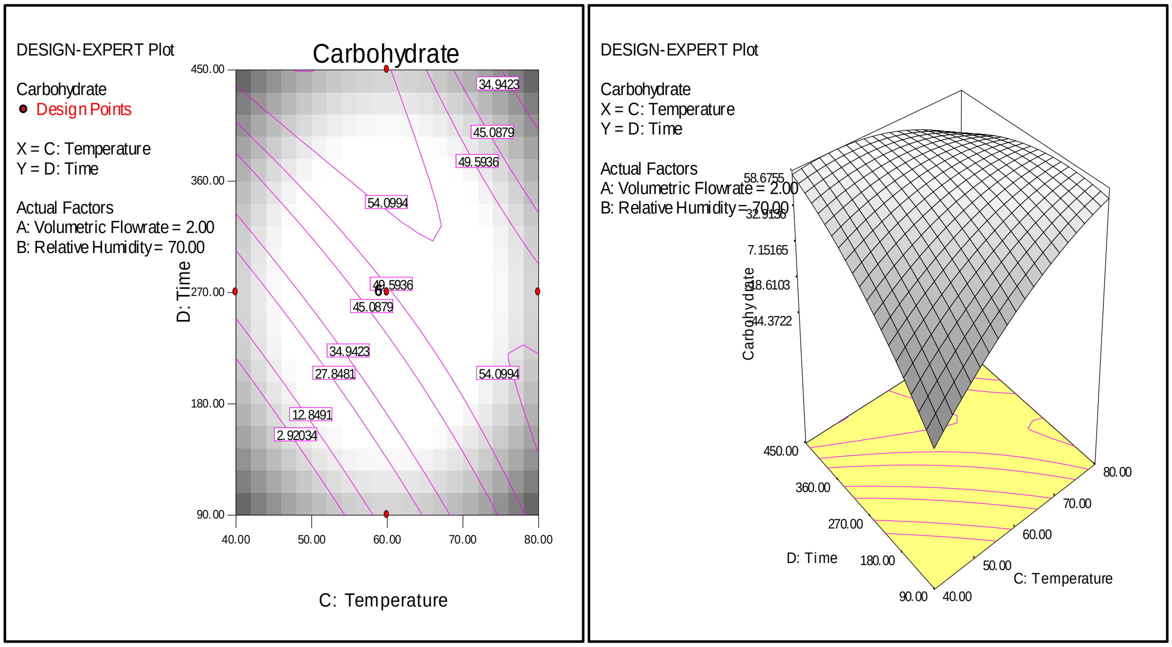

Figure 7: Response surface plots of temperature and time against %Carbohydrate

The interactive effects of temperature and time on the % Carbohydrate at constant flow rate of 2m^{3}/s and relative humidity of 70% was shown in Figure 7. %Carbohydrate increases with increase in temperature at low time of 90mins. The highest carbohydrate content of 60.9% was achieved at maximum time of 450 mins and temperature of 60^{o}C.

The combined process factors that affect total plate count during okra drying was obtained by analysing the response surface plots in Figures 8 - 10.

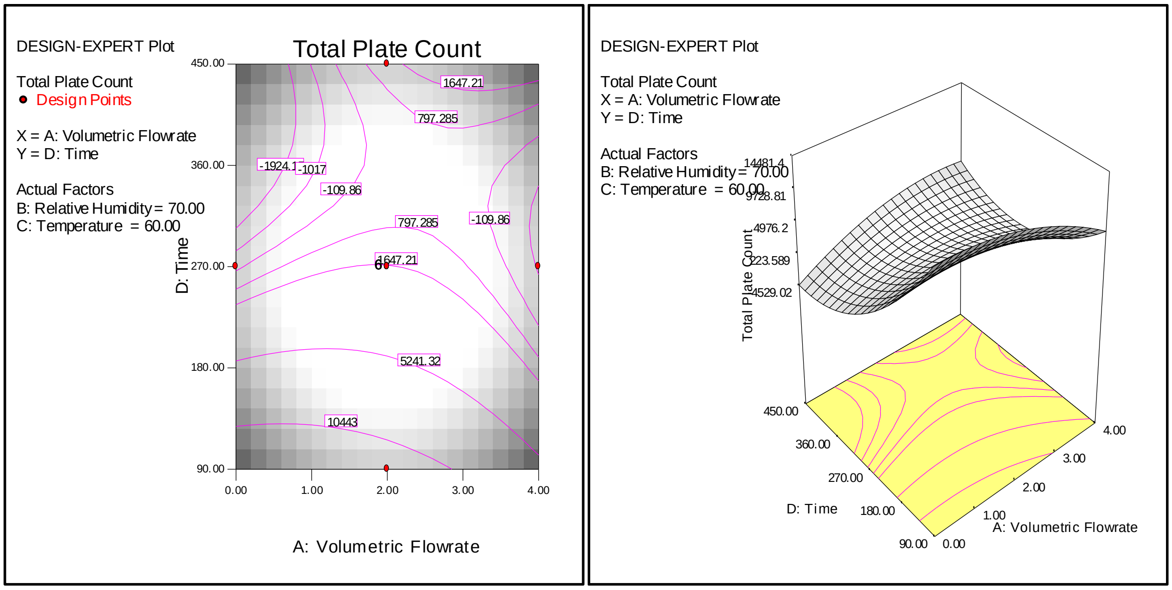

Figure 8: Response surface plots of volumetric flow rate and time against Total Plate count

The response surface plots show the combined effect of volumetric flow rate and drying time on total plate count at constant relative humidity of 70% and drying temperature of 60^{o}C as depicted in Figure 8. It was observed that at a volumetric flow rate of 2m^{3}/s and a time 270 mins, the total plate count for okra drying achieved 140 cfu. At low time of 90 mins, plate count reduced from 14442 cfu to 2800 cfu as flow rate increases. At high time of 450 mins and flow rate of 4 m^{3}/s, total plate count was observed to be 1.0 cfu.

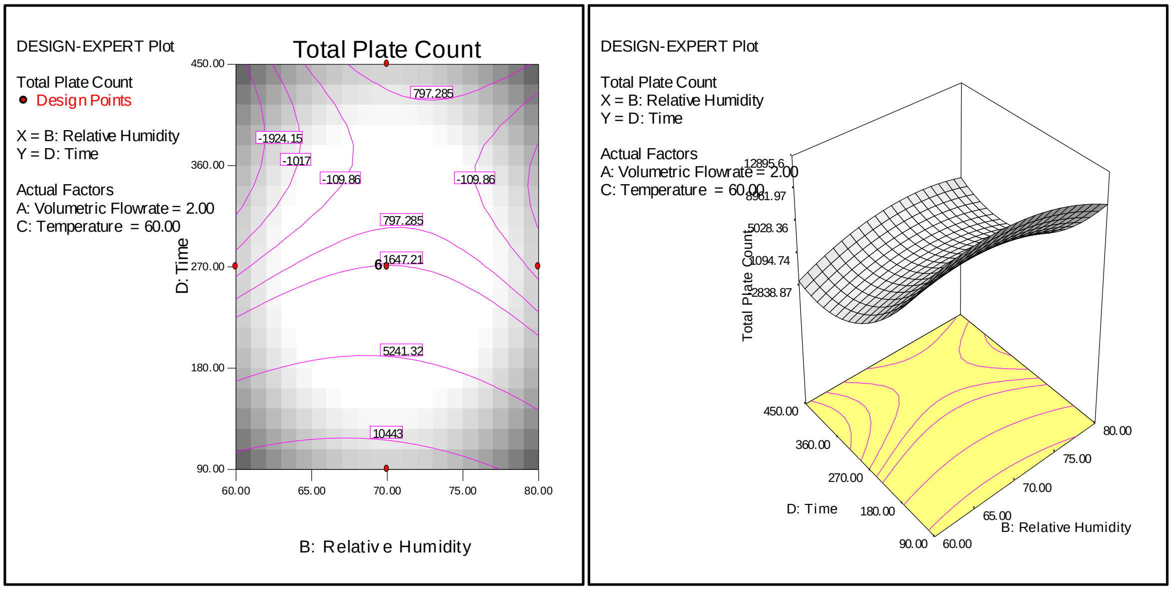

Figure 9: Response surface plots of Relative Humidity and time against Total Plate count

Figure 9 shows the interactive effect of time and relative humidity on the total plate count, keeping flow rate constant at 2m^{3}/s and temperature at 60^{o}C. Plate count was observed to be 150 cfu at a time of 270 mins and relative humidity of 80%. High value of plate count was obtained at low time of 90 mins and humidity of 70%, and the most desirable value was achieved at a higher drying time and at a higher temperature of 70^{0}C.

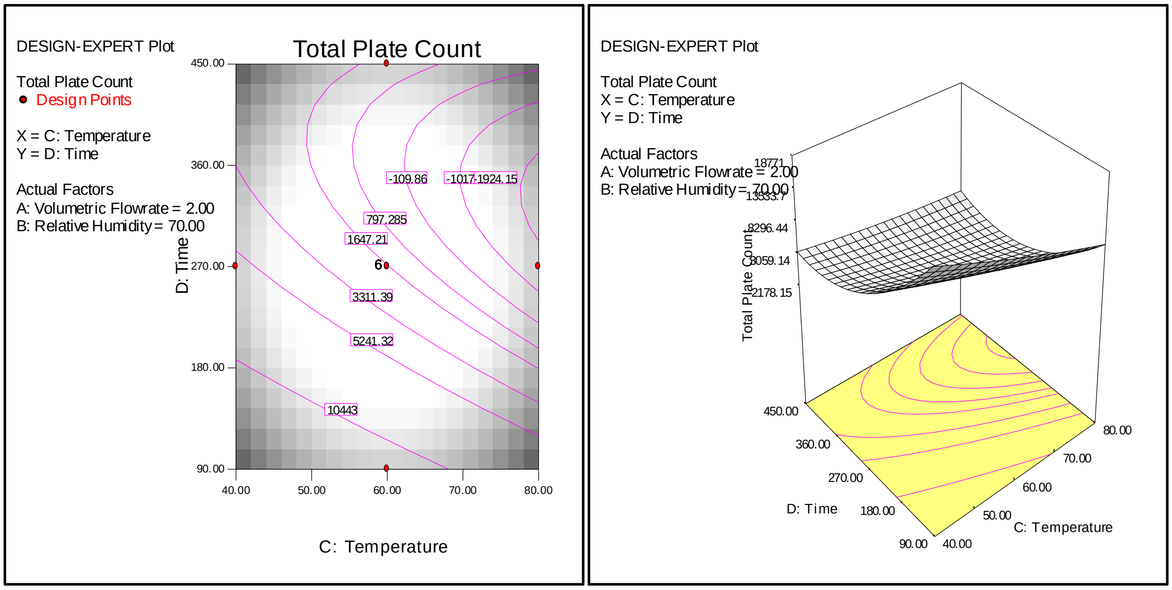

Figure 10: Response surface plots of Temperature and time against Total Plate count

Figure 10 shows the synergetic effect of temperature and time on the total plate count at constant flow rate of 2m^3/s and relative humidity of 70%. Total plate count was observed to reduce drastically at 90mins across the increase in temperature. The lowest plate count of 0 cfu (nil) was observed at 450 mins and 80^{o}C.

3.3. Numerical Optimization of Okra Drying Process Variables

The numerical optimization technique performed on the drying process variables is shown in Table 5. All process variables were kept in range while %moisture was set to be minimized, %Protein to be maximized, %Carbohydrate to be maximized and plate count to be minimized according to the objective of this research. On the other hand, Figure 11 shows the result of the optimization process. At desirability of 1, the optimum values for the responses are 1.116%, 10.02%, 66.94% and -2878cfu for %moisture, %protein, %carbohydrate and total plate count respectively. Considering the optimization technique as a batch process, the optimum point for all the process variables are 3.98m^3/s, 60.40%, 52.42^{o}C and 348.2mins for volumetric flowrate, relative humidity, temperature and time respectively.

		Lower	**Upper**	**Lower**	**Upper**	
Name	Goal	Limit	Limit	Weight	Weight	Importance
Volumetric Flow rate	is in range	0	4	1	1	3
Relative Humidity	is in range	60	80	1	1	3
Temperature	is in range	40	80	1	1	3
Time	is in range	90	450	1	1	3
Moisture	minimize	4.7	47.40312	1	1	3
Protein	maximize	2.8	10.01722	1	1	3
Carbohydrate	maximize	9.65	61	1	1	3

Table 5: Numerical Optimization Constraints

Total plate count TPC

Total Plate Count	minimize	-2845.33	12154.3	1	1	3

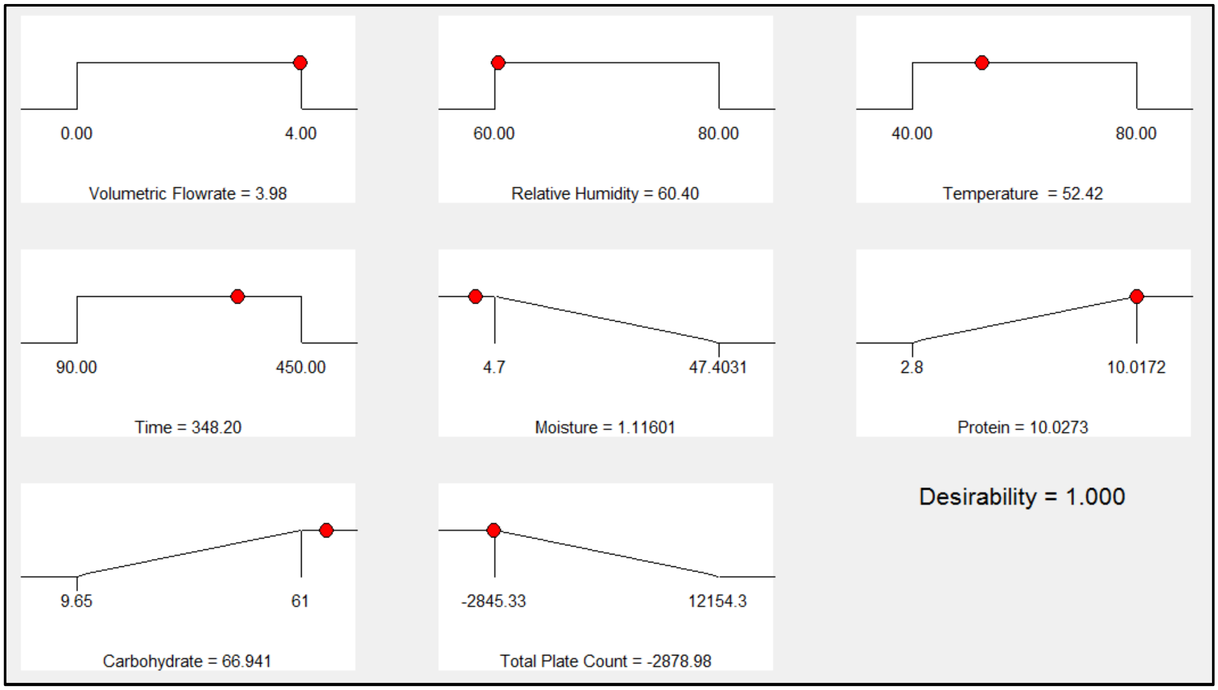

Figure 11: Ramps of optimized responses for Okra drying process

4. Conclusion

The individual and combined effects of the four processing parameters (temperature, humidity, air velocity and time) on the drying of okra were studied using Central Composite Design (CCD) of surface response method (RSM). The responses considered were moisture, protein, carbohydrate and total plate count.

Based on the profile of responses, drying at higher hot air temperature and longer time, higher air velocity lowers the moisture content and total plate count while the protein and carbohydrate contents increased. The quadratic regression models were adequate based on ANOVA test.

The results of numerical optimization show that at a desirability of 1, the optimum combination of process variables were: 3.98 m^3/s, 60.40%, 52.42 ^{0}C and 348 seconds to give the optimum value of responses of 1.116%, 10.02%, 66.94% and 2.88 x 10^{-3} for moisture, protein, carbohydrate and total plate count respectively.

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