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Effect of Blanching and Microwave Power on Drying Behavior of Green Peas

Krishna Murthy T.P.*, Harish A., Rashmi M., Blessy B. Mathew and Monisha J.
Research and Development Centre, Department of Biotechnology, Sapathagiri College of Engineering, Bangalore-560057, INDIA

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Abstract

The effect of pretreatment (blanching temperature and blanching time) and microwave power on drying kinetics of green peas were investigated. Response surface methodology was employed to study the effect of process conditions on drying time, drying rate, and effective moisture diffusivity and rehydration ratio. The drying experiments were performed using a Box-Bhenken for three variables: blanching temperature (85-100 ^{o}C), blanching time (2 to 5 min) and microwave power (180-900W). ANOVA analysis indicated that microwave power significantly affected by drying time but and drying rate were significantly affected by the microwave power and interaction between microwave power and blanching time. Effective moisture diffusivity also affected by microwave power and blanching time. Blanching temperature was not significantly affected the selected responses such as drying time, drying rate and effective moisture diffusivity. Rehydration ratio which reflects the quality of dried green peas was not affected by any of the process parameters. Midilli et.al model was used to describe the drying kinetics of the untreated green peas.

Keywords - Green peas, blanching, drying time, drying rate, effective moisture diffusivity, rehydration ration, microwave power.

Introduction

Pea (*Pisum sativum*) belonging to Leguminosae family is one of the oldest domesticated crops and is the second largest cultivated grain legume. It originated in the Middle East and was later widely grown in temperate regions of the world, among them China, India, United States, France and Egypt are its major producers. Pea seeds consist of 23-25% of protein, 50% starch, 5% soluble sugars including fiber, minerals, vitamins and phytochemicals in minor quantities. The minerals and vitamins offer disease prevention whereas the pea cell wall cotyledons and the seed coat contain fibers which help in better gastrointestinal activity[1]. But peas are prone to perish fast and they must be preserved well for later consumption and usage, so drying of peas is becoming a preferred method to extend its shelf life and consumability[2,3].

Drying is one of the oldest unit operation processes to remove free moisture content due to simultaneous heat and mass transfer, and it is also most traditional methods of food preservation. Due to removal of moisture content in agricultural materials having high moisture content, the microbiological spoilage and deteriorative chemical reaction are greatly minimized[4,5]. On the other hand reduction in size that enables saving in transportation and storage needs and avoidance of the need to use expensive cooling systems for preservation[6]. Drying of food products not only affects the water content of the food product, but also alters other physical, chemical and biological properties, such as enzyme activity, microbial spoilage, viscosity, hardness, aroma, flavor and palatability[7,8]. The most common method widely used for drying is sun drying and hot air drying. The disadvantage of sun dying include long drying times due to slower drying rates because of uncertainty of the weather and contamination with dust, insects etc. in drying environment. In case of hot air drying also longer drying time during falling rate period and elevated temperature results in undesirable thermal degradation of finished foodstuffs and consume higher amount of energy and yields low drying efficiency[9,10].

Microwave drying has gained popularity in recent years since it helps to cut down the time required for drying, homogeneous energy distribution and improves the final quality of the dried products. Microwave heating is a result of dipolar interaction of water molecules inside the food materials. The polar water molecule tend to align themselves according to change in electrical field and heat is produced due to friction between oscillating molecules. This rapid internal energy generation causes the pressure build up and results in rapid evaporation of water[11-14]. However, the quality of dried products depends not only on the drying process but also on the various steps preceding the drying process. Pretreatment of agricultural products can reduce some of the undesirable changes such as color and textural changes by inactivating enzymes and also reduce the drying time by relaxing tissue structure and can yield a good quality dried products which reflects in reducing energy requirement. Blanching of fruits and vegetables either by steam or hot water is a common pretreatment process which involves heat treatment for a short period of time that inactivate the enzyme responsible for commercially unacceptable darkening and off flavors[15-18].

The most important aspect of drying technology is process modeling, simulation for the design of drying equipment and to establish optimal operating conditions to increase the efficiency of drying facility[8,19]. Among various mathematical equations that describe drying phenomena, thin layer drying models are clearly of significant practical value to engineers for the preliminary evaluation of potential drying operation. The simple mathematical correlations with the characteristic namely drying constant, providing a combined, but sufficiently informative, measure of transport properties such as moisture and thermal diffusivity[20,21]. Response surface methodology is a series of experimental design, analysis and optimization technique to determine the interrelation among the test variables in the response. In addition to analyzing the effect of the independent variables, this experimental methodology develops a mathematical model which describes drying process[6,22].

Present investigation aimed at (a) studying the effect of different blanching conditions and microwave power on the drying time, drying rate, drying rate constant, effective moisture diffusivity and rehydration ratio (b) to find possible relations between drying parameters on drying kinetics.

Material and Methods

Sample Preparation: Fresh samples of green peas (Pisum sativa) were procured from a local market, Yeshwanthapur, Bangalore, India. Immature, dry and damaged pods were removed manually by visual inspection. The pods were shelled manually and stored in a refrigerator at 4±1 ºC until taken for further processing. Three 50 g of green peas were dried in hot air oven (Neha scientific international, Model no. SI 101A) at 105 ºC for 24 hr to determine initial moisture content and is given on dry basis (kg H_2O.kg db^{-1}). The average initial moisture content of the green peas was 2.895 kg H_2O.kg db^{-1}. Before dehydration, the green peas were blanched at 70, 85 and 100^{o}C for 0, 2.5 and 5 min and samples were cooled to room temperature under running cold water for at least 5 min and finally drained. Untreated sample was used as control.

Drying Experiments: Drying experiments were carried out in household digital microwave oven (LG, India; Model MC-8087ABR). The microwave oven has the capability of operating at five different microwave powers, 180, 360, 540, 720 and 900 Watts. The time and power level required for microwave processing were adjusted with the help of digital control present on microwave oven. 50g of green peas were used to perform the complete experiment. Green peas were arranged on the rotatable plate fitted inside the microwave oven cabin in the form of a thin layer. The rotatable plate helps the microwave radiations to distribute equally among the sample. Box-Bhenken design was preferred to perform the drying experiment. A digital weighing balance (CAS; Model MW-11-200 series) with accuracy 0.01g was used to note down the loss of weight of green peas at regular intervals of time. The process of microwave drying was continued until initial moisture content reduced to 95%. The microwave drying experiments were carried out in triplicates and the average values were noted.

Mathematical Modeling: The experimental moisture content data was converted to dimensionless Moisture ration using Equation 1

$$MR = \frac{X_t - X_e}{X_0 - X_e} \qquad (1)$$

Where X_o is the initial moisture content, X_t is the moisture content at time t and X_e is the equilibrium moisture content[23,24]. Equation 1 can be further simplified to MR= X_t/X_o as the values of X_e is relatively small compared to X_o and X_t for long drying time[25-29].

The drying rate during the experiments was calculated using the following Equation 2:

$$\text{Rate of drying} = \frac{dX}{dt} = \frac{X_{t+dt} - X_t}{dt} \qquad (2)$$

Where X_{t+dt} is the moisture content at time t+dt and X_t is the moisture content at time t and t is the drying time[30]. The experimental data of dimensionless moisture ratio vs drying time were fitted to a semi empirical Midilli et.al model (Equation3) which is widely used to describe the drying behavior of agricultural materials to find the kinetic rate constant.

$$MR = a \exp(-kt^n) + bt \qquad (3)$$

Where k is kinetic rate constant (s^{-1}) and a, b, n are model parameters respective

Determination of effective moisture diffusivity: The effective moisture diffusivity of green peas during microwave dying was calculated by Ficks second law of diffusion with the assumptions of moisture migration being by diffusion, negligible shrinkage and constant effective moisture diffusivity and negligible external resistance:

$$MR = \frac{X_t - X_e}{X_o - X_e} = \frac{6}{\pi}\sum_{n=0}^{\infty}\frac{1}{n^2}.\exp\left(-n^2\pi^2\frac{D_{eff}\,t}{r^2}\right) \qquad (4)$$

Where D_{eff} is the moisture dependent diffusivity (m^2/s), r is the radius (m) of the green peas and t is the drying time (s). For long drying periods (n=1), Equation4 can be further simplified to only the first term of series.

$$MR = \frac{X_t - X_e}{X_o - X_e} = \frac{6}{\pi^2}\exp\left(-\frac{\pi^2 D_{eff}}{r^2}t\right) \qquad (5)$$

Equation 5 could be further simplified to a straight line equation as given below:

$$\ln(MR) = \ln\left(\frac{6}{\pi^2}\right) - \left(\frac{D_{eff}.\pi^2}{r^2}t\right) \qquad (6)$$

A graph of ln (MR) Vs drying time was plotted and the slope ($\pi^2 D_{eff}/ r^2$) obtained from it was used to determine the effective moisture diffusivity.

Effective moisture diffusivity was typically determined by plotting experimental drying data in terms of ln (MR) Vs drying time and found from the slope ($\pi^2 D_{eff}/ r^2$) according to Equation 6. [7,31].

Design of Experiments and Statistical analysis: A Box-Bhenken Response surface method was used to estimate the effects of the process variables on drying rate, drying time, drying rate constant, effective moisture diffusivity and rehydration ratio during the microwave drying of blanched green peas at different blanching conditions. Blanching time, blanching temperature and microwave power were selected as independent variables[32]. RSM and ANOVA were done using Design Expert 8.0 statistical analysis software with a value of $p<0.05$. The experimental data were fitted to the following second-order polynomial model (Equation 7) and regression coefficients were obtained.

$$DTorDR\ or\ k\ or\ D_{eff}\ or\ RR = A_0 + A_1 * MW + A_2 * BT + A_3 * Bt + A_4 * MW^2 + A_5 * BT^2 + A_8 * Bt^2 + A_7 * MW * Bt + A_8 * MW * Bt + A_9 * BT * Bt \qquad (7)$$

Where DT is drying time, DR is average drying rate, k is kinetic rate constant, D_{eff} is effective moisture diffusivity, RR is rehydration ratio, MW is microwave power and BT is Blanching Temperature and Bt is Blanching time. A_0 - A_5 are the coefficients of the mode[33].

Rehydration Capacity: Dried green peas were rehydrated by immersing in distilled water at room temperature. About 5 g of dried samples were placed in glass beakers containing water in the ratio 1:25 (w/w) for 8 hr. Samples were drained, blotted with tissue paper and weighed. The rehydration capacity was calculated as follows

$$\text{Rehydration ratio} = \frac{W_r}{W_d} \qquad (8)$$

Where W_r and W_d are weight after the rehydration and weight before rehydration respectively[34].

Results and Discussion

Effect of microwave power on drying kinetics: Green peas were dried under three different microwave power (900, 540 and 180 W) to study its effect on drying time, drying rate, effective moisture diffusivity and moisture content. The effect of microwave power on moisture ration was illustrated in figure- 1. As can been seen from this figure, the moisture removal rate is significantly increasing with increase in microwave power due to increase in drying rate. This is due to rapid mass transfer within sample during high microwave power because more heat generates at higher microwave powers and significant vapor pressure difference between the centre and the surface of product. The illustration of drying rate versus drying time is given in figure- 2. Conversely increase in microwave power decreases the drying time. There is no constant drying rate observed during the microwave drying of green peas. Maximum moisture loss took place in the falling rate period with the short accelerating phase at initial stages as shown in figure- 3. The effect of microwave power on drying kinetics of green peas was described using semi empirical Midilli et.al model. The experimental Moisture Ratio (MR) data was regressed against time according to the Equation3. The coefficient of determination (R^2) values for fitted data was greater than 0.98. The effect of microwave power on kinetic rate constant was shown in figure-4.

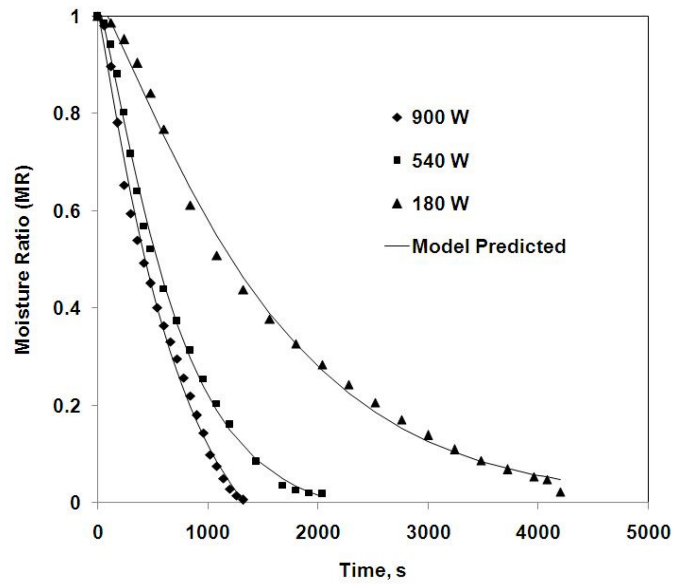

Figure-1
Moisture ratio vs. drying time at various microwave powers

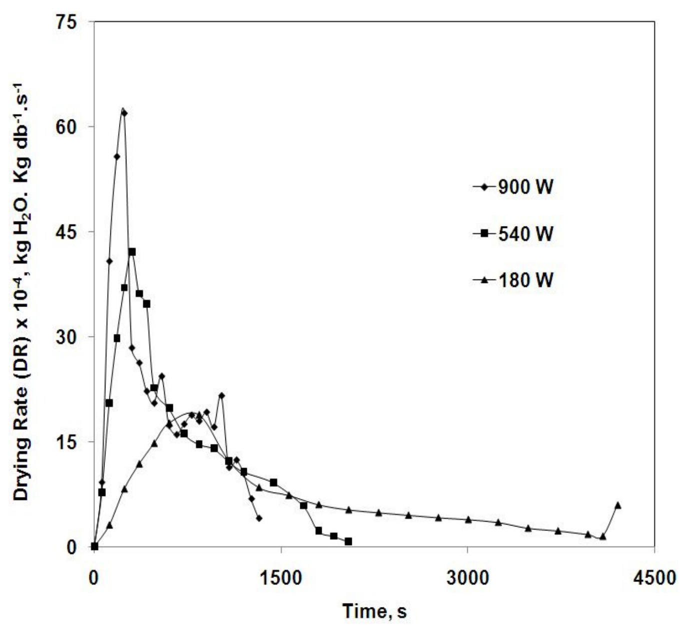

Figure-2
Drying rate versus drying time at different microwave power levels

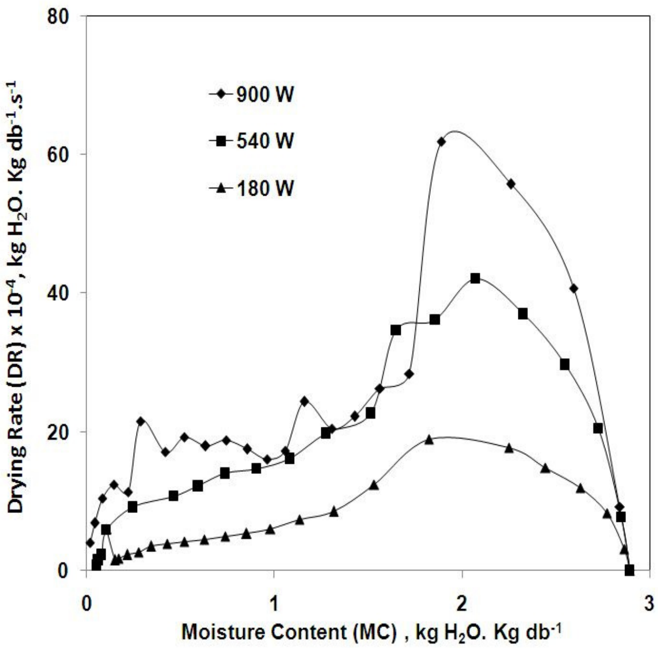

Figure-3
Drying rate vs. moisture content at different microwave power levels

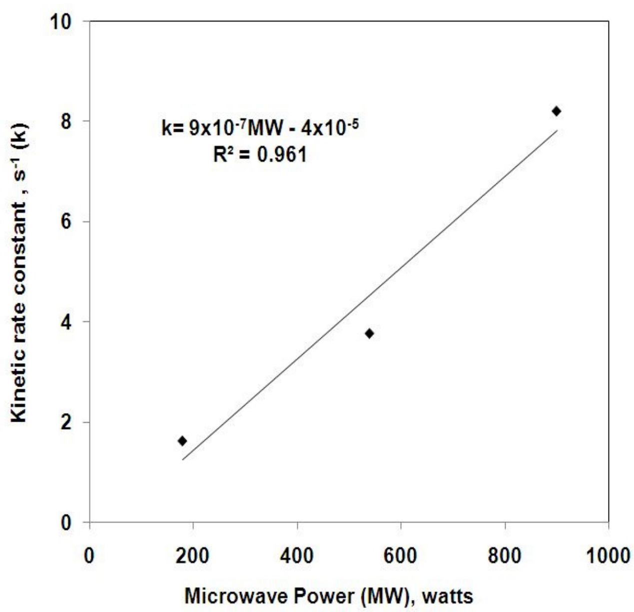

Figure-4
Effect of microwave power on kinetic rate constant

Effect of microwave power, blanching temperature and blanching time on drying rate and drying time: The effect of microwave power, blanching temperature and blanching time on the drying rate and drying time was studied by fitting the experimental data to second order polynomial equation (Equation7). The experimental data were in good agreement with polynomial regression models as per Box-Behnken design. The variables with a confidence level of 95% were used to build the models. The model was found to be highly significant, as is evident from the high Fischer ratio obtained from analysis of variance (ANOVA) for drying rate and drying time. The value of coefficients of correlation (R) for drying rate and drying time was found to be 0.99 which indicates a high degree of association between observed and predicted values therefore representing adequacy of the fitted models. Figure-5 and figure-6 shows the effect of MW, BT and Bt on the Drying time and drying rate (table 1). From table.2 and 3, the microwave power in the linear terms of the model was found to be highly significant ($P<0.00001$) on drying time and blanching temperature and blanching time were not significant. Even square term of Microwave power in the quadratic terms is significant. Remaining all other terms in model was not significant. Increase in microwave power decreased drying time but blanching temperature and blanching time have no effect on the drying time. The model used to study the effect of dying conditions on drying rate was also significant from high Fischer ratio. Microwave power in linear term and quadratic term of the model is significant as the P value is less than 0.0001. The interaction between microwave power and blanching time is also significant. The positive sign of coefficient indicates that an increase in microwave power and blanching time can increase the drying rate. The model equation coefficients for drying time and drying date are given in Table.3.

Effect of microwave power, blanching temperature and blanching time on effective moisture diffusivity: The effect of microwave power, blanching temperature and blanching time on effective moisture diffusivity was studied (table.1). The experimental data was fitted to second order polynomial equation with 95% confidence level. ANOVA results show that model is significant. From table.2 the coefficient of determination 0.968 for effective moisture diffusivity indicates a high degree of correlation between observed and predicted values thus indicating adequacy of the fitted models. Figure- 7 shows the effect of MW, BT and BT on effective moisture diffusivity. From table 3, the microwave power in the linear terms of the model was found to be significant ($P<0.05$) on effective moisture diffusivity and blanching temperature and blanching time were not significant. Interaction between blanching temperature and blanching time shows effect on effective moisture diffusivity. Remaining all other terms in model was not significant.

Effect of microwave power, blanching temperature and blanching time on rehydration ratio: The effect of microwave power, blanching temperature and blanching time on rehydration ratio was studied. The experimental data was fitted to second order polynomial equation with 95% confidence level. ANOVA results show that model is significant. The coefficient of determination 0.9067 (table.2) for Rehydration ratio specifies a high degree of correlation between observed and predicted values as a result indicating adequacy of the fitted models (figure-8).

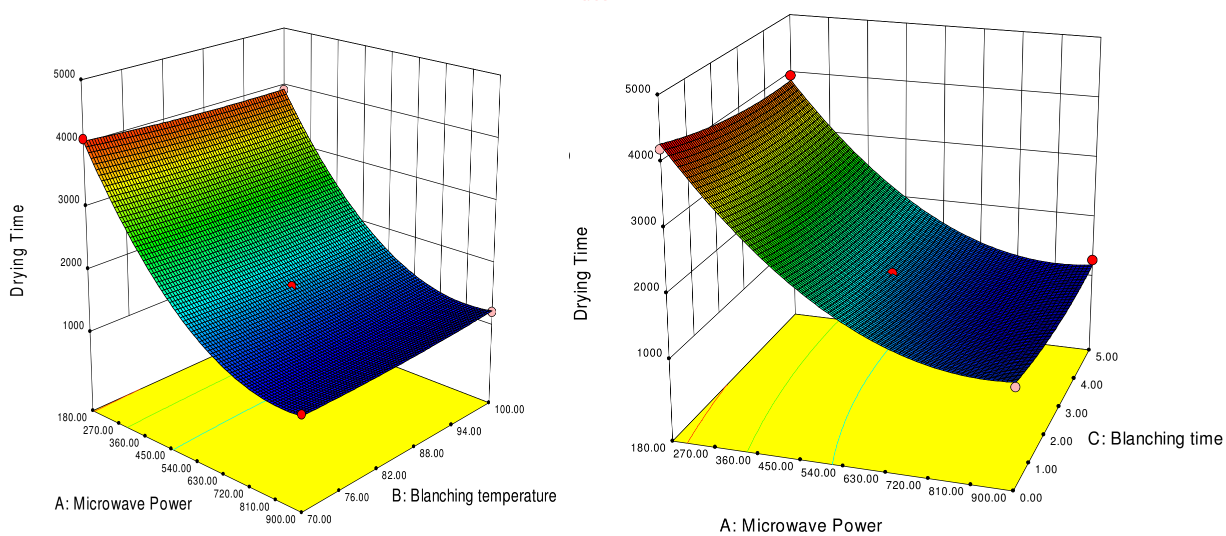

Figure-5

Response surface plots for drying time with respect to microwave power, blanching time and blanching temperature

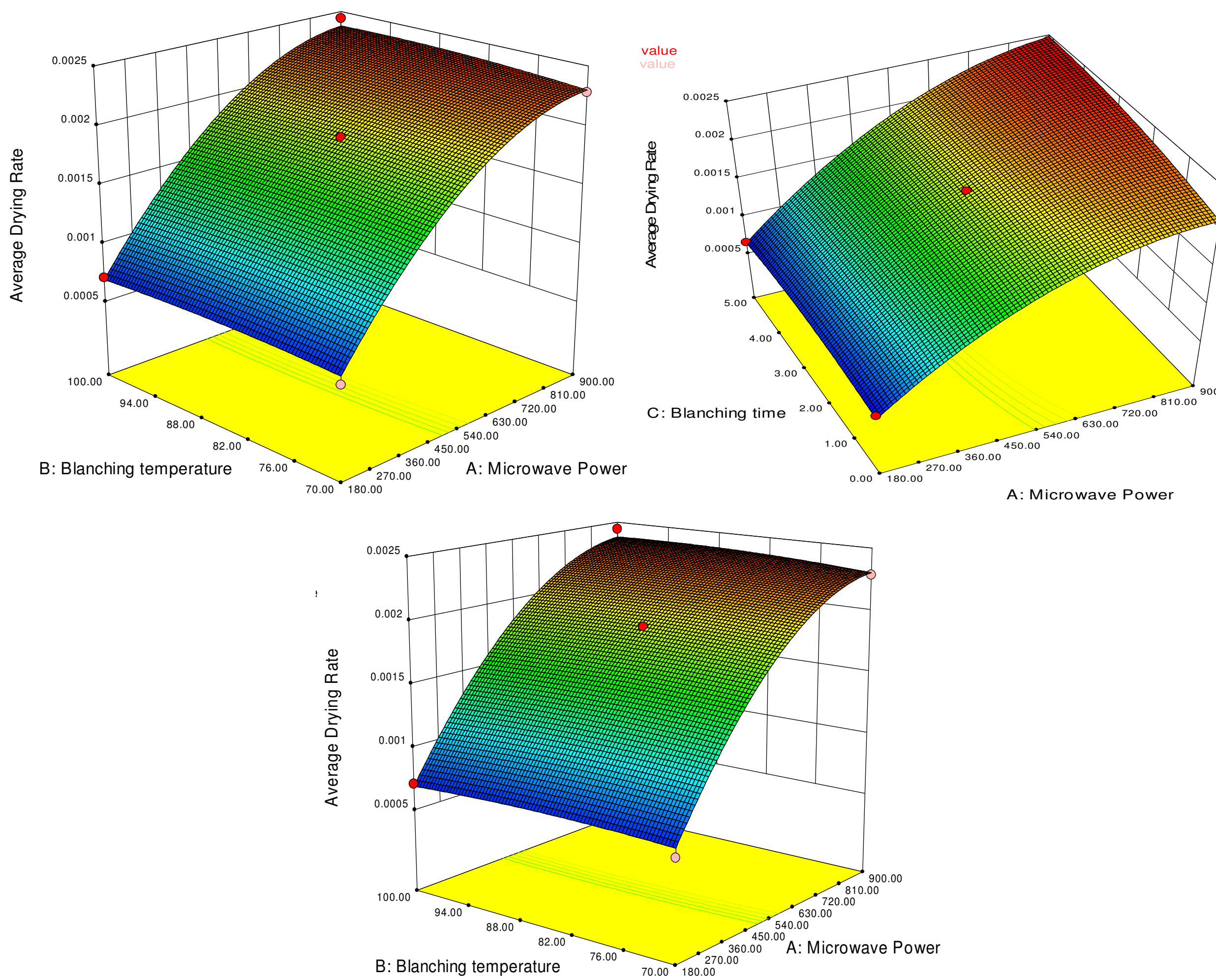

Figure-6

Response surface plots for average drying rate with respect to microwave power, blanching time and blanching temperature

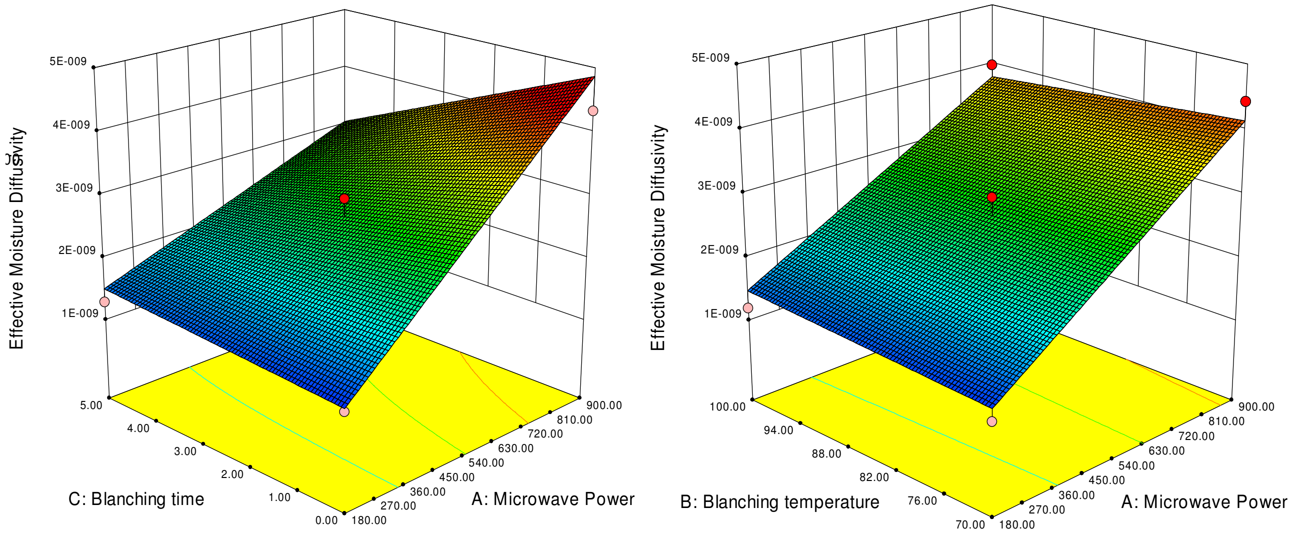

Figure-7

Response surface plots for effective moisture diffusivity with respect to microwave power, blanching time and blanching temperature

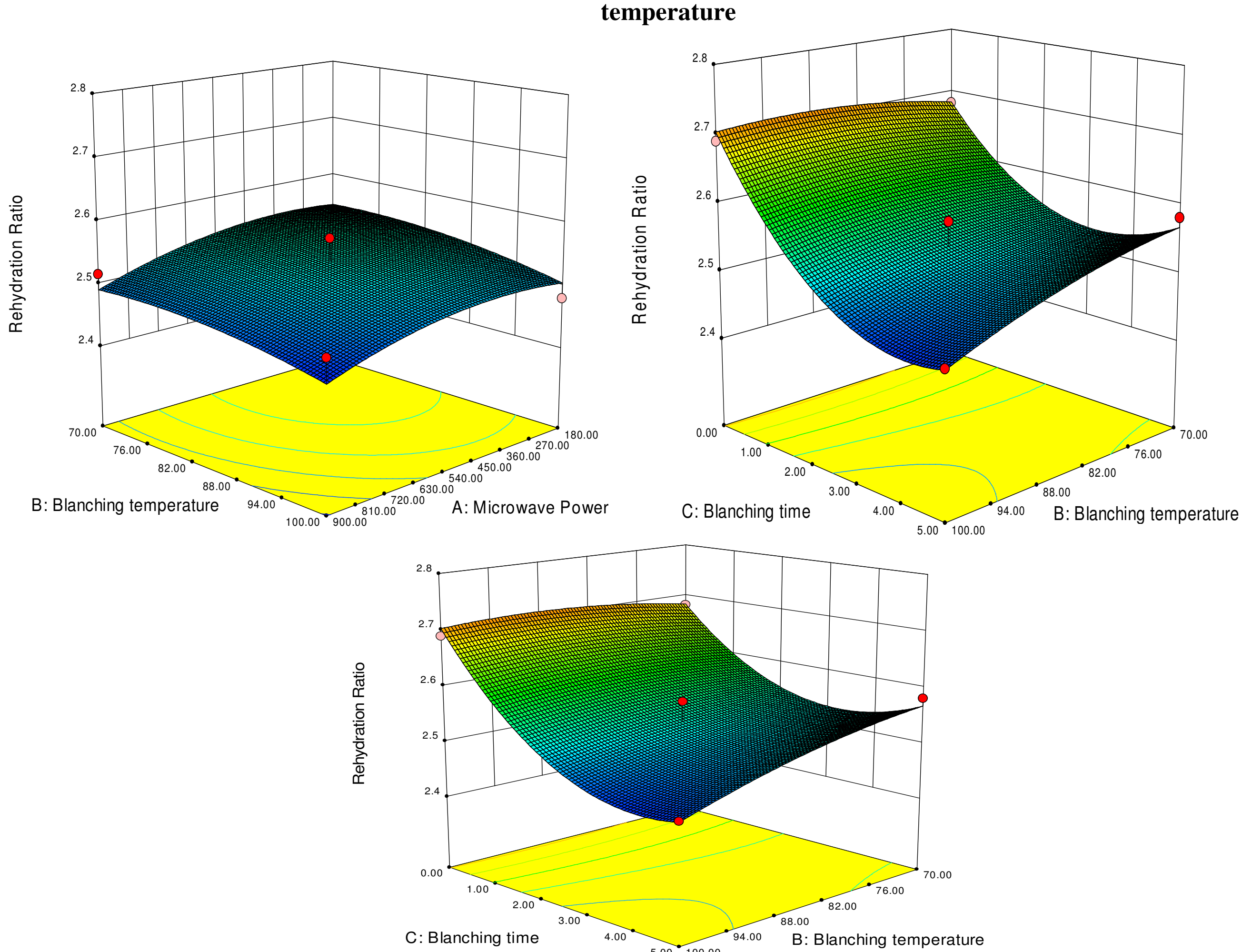

Figure-8

Response surface plots for rehydration ratio with respect to microwave power, blanching time and blanching temperature

Table-1
Levels of process variables according to Box-Bhenken design and values of responses

	Coded Values			Un Coded Values			Response			
Sl no	**M W**	**Blanching Temp**	**Blanchin g time**	**M W**	**Blanching Temp**	**Blanching time**	**Drying time**	**Drying rate**	**D_{eff}**	**RR**
1	-1	1	0	180	100	2.5	3920	7.09E-04	1.189E-09	2.480
2	0	-1	1	540	70	5	1560	1.98E-03	2.525E-09	2.581
3	-1	0	-1	180	85	0	4200	6.80E-04	1.206E-09	2.755
4	0	1	1	540	100	5	1700	1.86E-03	2.545E-09	2.473
5	1	0	-1	900	85	0	1260	2.09E-03	4.337E-09	2.627
6	0	1	-1	540	100	0	2040	1.69E-03	3.141E-09	2.690
7	-1	-1	0	180	70	2.5	4080	6.27E-04	1.094E-09	2.511
8	0	0	0	540	85	2.5	1620	1.91E-03	2.964E-09	2.518
9	0	0	0	540	85	2.5	1680	1.91E-03	2.964E-09	2.523
10	0	0	0	540	85	2.5	1740	1.91E-03	2.962E-09	2.574
11	0	-1	-1	540	70	0	2100	1.69E-03	3.140E-09	2.682
12	1	0	1	900	85	5	1260	2.43E-03	2.365E-09	2.451
13	-1	0	1	180	85	5	3960	6.54E-04	1.285E-09	2.552
14	1	1	0	900	100	2.5	1200	2.44E-03	3.983E-09	2.496
15	1	-1	0	900	70	2.5	1140	2.29E-03	4.435E-09	2.516

Table-2
Statistical values of the selected model

	Drying Time	Drying Rate	D_{eff}	RR
Multiple R	0.9985	0.9981	0.9842	0.9522
R Square	0.9971	0.9962	0.9686	0.9067
Adjusted R Square	0.9918	0.9894	0.9122	0.7388
Standard Error	105.1665	0.0001	0.0000	0.0458

Table-3
Model coefficients and p-values for drying time, average drying rate, effective moisture diffusivity and rehydration ratio

	Drying time		Average drying rate		Effective moisture diffusivity		Rehydration ratio	
	Coefficients	**P-value**	**Coefficients**	**P-value**	**Coefficients**	**P-value**	**Coefficients**	**P-value**
Intercept	8226.60	0.0065	-0.00122	0.35126	2.6E-09	0.6688	2.218775	0.0392
Microwave Power(MW)	-12.1435	0.0001	4.81E-06	0.00057	1.06E-11	0.0167	6.71E-05	0.8791
Blanching Temperature (BT)	-41.1111	0.3716	2.3E-05	0.43237	-8.5E-11	0.5467	0.010972	0.5740
Blanching time (Bt)	-307.3333	0.0669	0.000112	0.24297	3.43E-10	0.4416	-0.03818	0.5351
MW^2	0.0067	0.00001	-2.8E-09	0.00014	-3.2E-15	0.0600	-1.9E-07	0.3600
BT^2	0.1889	0.4726	-1.3E-07	0.44829	5.59E-13	0.4945	-6.2E-05	0.5828
Bt^2	20.4000	0.0672	-1.3E-05	0.06982	-4E-11	0.2011	0.01311	0.0185
MW*BT	0.0102	0.3435	3.27E-09	0.62418	-2.5E-14	0.4437	5.06E-07	0.9098
MW*Bt	0.0667	0.3055	1.04E-07	0.04018	-5.7E-13	0.0261	7.21E-06	0.7883
BT*Bt	1.3333	0.3853	-7.5E-07	0.44204	1.21E-13	0.9790	-0.00078	0.2590

Conclusion

Response surface methodology was successfully used to study the effect of microwave power and blanching conditions on the drying rate, drying time, effective moisture diffusivity and rehydration ratio. Microwave power and blanching time found to be having significant effect on the selected responses. The responses are not affected by blanching temperature. Microwave power dominated the blanching effect on the drying kinetics.

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