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Response Surface Optimization of Fluidized Bed-Cum-Microwave Drying Process for Garlic Slices (*Allium Sativum* L.)

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ABSTRACT
Response surface methodology was used to investigate the effect of KMS concentration (0.1-0.5 %), drying air temperature (55-75^{0}C) and microwave power level (810-1350 W) on the drying time, hardness, rehydration ratio, shrinkage ratio, specific energy consumption, colour (L-value), non enzymatic browning and overall acceptability of garlic slices. The optimum process parameters obtained by computer generated response surface, canonical analysis and contour plots interpretation were: KMS concentration 0.1 %, drying air temperature 63.92^{0}C and microwave power level 810 W.

Keywords: Garlic slices, Optimization, Drying, Quality, Response surface methodology.

I. INTRODUCTION

Garlic (*Allium sativum* L.) is a bulbous perennial plant of the lily family lilliaceae. Garlic is a rich source of carbohydrates, proteins and phosphorous. The fresh peeled garlic cloves contains 60-65 % (wb) moisture, 6.30 % protein, 0.10% fat, 1% mineral matter, 0.80% fiber, 29 % carbohydrates, 0.03 % calcium, 0.31 % phosphorous, 0.001 % iron, 0.40 mg/100g nicotinic acid and 13 mg/100g vitamin C (Brondnitz et al. 1971). Hard neck, Soft neck and Creole varieties of garlic are grown worldwide. Hard neck varieties have fewer cloves and have little or no papery outer wrapper protecting the cloves. Soft neck varieties are white, papery skins and multiple cloves that are easily separated. There are two types of soft neck varieties: artichoke and silver skin. Creole variety has eight to twelve cloves per bulb arranged in a circular configuration. Garlic has been used 'time memorial, for the treatment of a wide variety of ailments, including hypertension, headache, bites worms, tumours etc. Hippocrates, Aristotle and Pliny cited numerous therapeutic uses for garlic.Although garlic have wide range of well-documented pharmacological effects; it's most important clinical uses are in the area infections, cancer prevention and cardiovascular disease (Lau1 et al. 1990).

Presently convective, fluidized bed and sun drying of garlic is in practice, which damages the sensory characteristics and nutritional properties due to the surface case hardening and the long drying duration. Main disadvantages of convective drying are long drying duration, damage to sensory characteristics and nutritional properties of foods and solute migration from interior of the food to the surface causing case hardening. Severe shrinkage during drying also reduces the rehydration capacity of the dehydrated products (McMinn and Magee 1999). Fluidized bed drying of garlic cloves has also been attempted but it was not effective in reducing the drying time and energy consumption appreciably in comparison to convective drying process.

Use of Microwave is considered as the fourth generation drying technology. Waves can penetrate directly into the material; heating is volumetric (from inside out) and provides fast and uniform heating throughout the entire product. The quick energy absorption by water molecules causes rapid water evaporation, creating an outward flux of rapidly escaping vapour. Microwaves penetrate the food from all direction. This facilitates steam escape and speed heating. In addition to improving the drying rate, this outward flux can help to prevent the shrinkage of tissue structure, which prevails in most conventional air drying techniques. Hence better rehydration characteristics may be expected in microwave dried products (Khraisheh et al. 1997; Prabhanjan 1995). Microwave processes offer a lot of advantages such as less start up time, faster heating, energy efficiency (most of the electromagnetic energy is converted to heat), space savings, precise process control and food product with better nutritional quality.Keeping in view the above aspects, the present study has been planed to study the effect of fluidized bed-cum-microwave drying on the quality of garlic slices and to optimize the fluidized bed-cum-microwave drying characterstics viz. KMS concentration, drying air temperature and microwave power level.

II. MATERIALS AND METHODS

2.1 Experimental design

The Box- Behnken design of 3 variables and 3 levels each with 3-centre point combination was used (Box and Behnken 1960). The design was selected as it fulfills most of the requirements needed for optimization of the hybrid drying process (fluidized bed-cum-microwave). In this design X_1, X_2, X_3 are the coded variables, which are related to un-coded variables using the following relation.

$$X_i = 2(\xi_i - \bar{\xi}_i)/d_i \tag{1}$$

Where, ξ_i is variables value in actual units of the ith observation, $\bar{\xi}_i$ is the mean of highest and lowest variables value of ξ_i and d_i is the difference between the highest and lowest variables of ξ_i.

The independent process variables were KMS concentration (C) (0.1- 0.5 %), drying air temperature (T) (55- 75^{0}C) and microwave power level (PL) (810-1350 W). A second order Box-Behnken design was conducted to work out the range of hybrid process variables for fluidized bed-cum-microwave drying of garlic slices are presented in table 1.

Table 1 Independent drying process variables and their levels for garlic slices

Independent variables	Symbol	Levels -1	0	+1
KMS Concentration (%)	X_1	0.1	0.3	0.5
Fluidized bed drying air temperature (° C)	X_2	55	65	75
Microwave Power level (Watt)	X_3	810	1080	1350

After coding the experiment region extended from -1 to +1 in term of X_i, the three level three factor experimental plans according to Box-Behnken design (1960) consists of 17 points of treatments combinations of the independent variables and are presented in Table 2. For each experiment, the known weight of dried garlic slices was formulated as per experimental combinations by varying KMS concentration (%), drying air temperature (^{0}C) and microwave power level (Watt) and quality attributes (colour, rehydration ratio, shrinkage ratio, texture(hardness), non enzymatic browning and overall acceptability) were measured by standard procedures.

Table 2 Experimental design with coded and actual levels of FCM drying process variables

Experiment /sample no.	KMS Concentration (X_1)		Fluidized bed drying air temperature (X_2)		Microwave power level (X_3)	
	Actual	Coded	Actual	Coded	Actual	Coded
1	0.1	-1	65	0	810	-1
2	0.5	1	75	1	1080	0
3	0.3	0	65	0	1080	0
4	0.1	-1	75	1	1080	0
5	0.3	0	55	-1	810	-1
6	0.5	1	55	-1	1080	0
7	0.3	0	65	0	1080	0
8	0.5	-1	65	0	1350	1
9	0.3	0	65	0	1080	0
10	0.3	0	55	-1	1350	1
11	0.3	0	65	0	1080	0
12	0.5	1	65	0	810	-1
13	0.1	-1	55	-1	1080	0
14	0.3	0	65	0	1080	0
15	0.3	0	75	1	1350	1
16	0.1	-1	65	0	1350	1
17	0.3	0	75	1	810	-1

2.2 Sample preparation

The fresh garlic was procured from local market, Ludhiana. The garlic bulbs were sorted for its uniform size and were peeled manually with the help of knives and then uniformly sliced (Avg. 3mm) with the help of garlic slicer. The colour and moisture content of fresh garlic slices were noted. The samples were pretreated with different concentrations of KMS (Abano et al. 2011).

2.3 Hybrid drying

The dryer selected (fluidized bed drying) were started half an hour before keeping the sample to achieve steady state conditions. The experimental set up for fluidized bed drying of garlic slices consists of three basic parts: a system for provision of air, a section for heating the air and a drying chamber. A 0.75 KW, 3 phase electric motor controlled by a simple general-purpose AC Drive (Model: VFD007L21A, Delta electronics, Inc. Taiwan) was used to drive the blower. Air flow can be controlled by varying the frequency of AC supply to motor. The velocity of air was kept constant 3.5 m/s for fluidized bed drying (shoba et al. 2012). 250 g of garlic slices were put into the drying bucket. The specific energy consumption was measured for fluidized bed/microwave drying with the help of attached energy meter. All the samples were recorded for their change in weight throughout drying process. The moisture content of each sample was reduced to 39 ±1 % (wb) by fluidized bed drying. The experimental set up for microwave drying of garlic slices by microwave dryer (Power range 0-1350 W and frequency 2450 MHz). It consists of a high voltage power source, transformer and a cooking chamber. The transformer passes the energy to the magnetron which converts high voltage electric energy to microwave radiations. The magnetron usually controls the direction of the microwaves with the help of microcontroller. The fluidized bed dried samples were further dried to 6 to 7 % (wb) by using microwave drying. The samples were allowed to come to room temperature, packed and stored.

2.4 Specific energy consumption

Specific energy consumption (SEC) is the ratio of total energy supplied (KWh) to dryer to the amount of water removed (g) from the garlic slices. Energy consumption is measured from energy meter which is attached to drier and amount of water removed is measured from moisture content of developed garlic flakes.

$$SEC = \frac{TES}{H_2O\ \text{Removed}} \tag{2}$$

Where,

TES = Total Energy Supplied (KWh)

H_2O Removed = Amount of H_2O removed in grams

2.5 Quality parameters

The dried samples were evaluated for rehydration ratio, shrinkage ratio, texture, colour, non enzymatic browning and overall acceptability and the procedure adopted are mentioned below:

2.5.1 Rehydration ratio: Rehydration ratio (RR) was evaluated by soaking known weight (5-10 g) of each sample in sufficient volume of water in a glass beaker (approximately 30 times the weight of sample) at 95°C for 20 minutes. After soaking, the excess water was removed with the help of filter paper and samples were weighed. In order to minimize the leaching losses, water bath was used for maintaining the defined temperature (Rangana 1986). Rehydration ratio (RR) of the samples was computed as follows:

$$\text{Rehydration ratio, } RR = \frac{W_r}{W_d} \tag{3}$$

Where,

W_r = Drained weight of rehydrated sample, g

W_d = Weight of dried sample used for rehydration, g

2.5.2 Shrinkage ratio: The shrinkage ratio (SR) of dried sample was measured by toluene displacement method. Shrinkage ratio was calculated as the percentage change from the initial apparent volume (Rangana 1986).

$$\text{Shrinkage ratio} = \frac{V_r}{V_0} \tag{4}$$

Where,

V_r= Volume displaced by rehydrated sample,

V_0 = Volume displaced by fresh sample, ml

2.5.3 Texture: The texture of the dried garlic slices was evaluated by using a texture analyzer (TA-XT2i) employing the method suggested by (Nouriyan et al. 2003). A dried garlic flakes sample were placed on a hollow planer base. A compressive force was applied to the sample by a 0.25 mm spherical probe at a constant speed of 0.5 mm/s until the sample is fractured. The maximum compressive force at rupture of each sample was to describe the sample texture in terms of hardness.

2.5.4 Colour: Colour is one of the important parameters, which is an indicative of the commercial value of the product. The basic purpose was to get an idea of the comparative change in colour of fresh, dried and rehydrated material. Colour was determined using Hunter Lab Miniscan XE Plus Colorimeter (Hunter 1975).

$$\text{Colour change } \Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \tag{5}$$

Where ΔL, Δa and Δb are deviations from L, a and b values of fresh sample.

ΔL = L dried sample – L fresh sample; + ΔL means sample is lighter than fresh, - ΔL means sample is darker than fresh.

Δa = a dried sample- a fresh sample, + Δa means sample is redder than standard, - Δa means sample is greener than standard
Δb = b dried sample –b fresh sample, + Δb means sample is yellower than standard, - Δb means sample is bluer than standard.

2.5.5 Non enzymatic browning: The dried garlic slices sample (5 g) was soaked in 15 mL of water and 30 mL of ethanol for 2 h. The soaked sample was ground with a pestle and mortar and "filtered through Whatman No. 1 "filter paper. The optical density of the filtrate was measured at 420 nm by using spectrophotometer and expressed as an index for non enzymatic browning (NEB) (Rangana 1986).

2.5.6 Overall acceptability: Organoleptic quality of developed product was conducted on a 9-point hedonic scale. Semi-trained panels of ten judges were selected for the evaluation. The samples were evaluated in terms of appearance (color), texture, odour and overall acceptability. Overall acceptability (OA) was evaluated as an average of appearance (color), odour and texture score and is expressed in percentage. The average scores of all the 10 panelists were computed for different characteristics.

2.6 Optimization of process parameter:

Response surface methodology (RSM) was applied to the experimental data using the package, Design-Expert version 8.0.4 (Statease Inc., Minneapolis, USA, Trial Version 2013). The same software was used for the generation of response surface plots, superimposition of contour plots and optimization of process variables (Dhingra and Paul 2005; Alam et al. 2010). In order to optimize the process variables, only those responses were selected for optimization, which were found to have non-significant lack of fit. The three dimensional plots and contour plots (graphical method) according to the fitted model and fixed variable were drawn. To localize an optimum condition, the superposition technique was employed for optimization of different process variables by response surface methodology. Desirability function was used to solve the problem as a constrained optimized problem. The optimization of hybrid drying process aimed at finding the levels of independent variables viz. C, T and PL which could give maximum RR, Colour (L-value) and OA ; and minimum SR, SEC, drying time, NEB, texture (hardness). Desirability, a mathematical model was used for selecting the optimum process values. For several responses and factors, all goals get combined into one desirability function. The numerical optimization finds a point that maximizes the desirability function.

III. Results and discussion

The value of various responses at different experimental combinations for coded variables is given in Table 3. A wide variation in all the responses was observed for different experimental combinations i.e. 48 to 72.17 min for drying time; 1495.68 to 2831.66 g for texture (hardness); 2.11 to 2.75 for (RR); 0.45 to 0.54 for (SR); 7.13 to 10.15 KWh/g for (SEC); 63.49 to 72.48 for color (L-value) and 5.3 to 7.3 for (OA). The maximum consumer acceptance was wittnessed for the sample exposed as experimental conditions of 0.1% KMS concentration followed by fludized bed drying at 63.92^{0}C drying air temperature and 810W microwave power level.

A data was analysed employing multiple regression technique to develop a response surface model. A linear model and a second order model with and without interaction terms were tested for their adequacies to describe the response surface and R ^{2} values were calculated. A second order polynomial of the following form was fitrted to the data of all the responses and results are given in Table 4 .

$$y_k = \beta_0 + \sum_{i=1}^{n} \beta_i x_i + \sum_{i=1}^{n} \beta_{ii} x_i^2 + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \beta_{ij} x_i x_j \qquad (6)$$

Where β_{ks} (β_{ko}, β_{ki}, β_{kii}, β_{kij}) are constant coefficients and x_i are the coded independent variables

Table 3 Experimental data of fluidized bed-cum-microwave (FCM) drying of garlic for response surface analysis

KMS Conc. X_1 (%)	Temperature X_2 (^oC)	Microwave power X_3 (watt)	Drying time (min)	Hardness (g)	RR	SR	SEC (KWh/g)	NEB	Color L-value	OA
0.5	65	810	61.5	2279.51	2.25	0.50	7.98	0.71	65.03	6.3
0.3	55	1350	70	1956.37	2.48	0.47	10.15	0.66	68.16	6.6
0.1	75	1080	49.16	2254.72	2.47	0.54	7.78	1.01	68.06	5.3
0.3	65	1080	60.14	1998.53	2.46	0.52	8.64	0.82	64.35	66
0.1	65	1350	59	1930.47	2.11	0.49	9.28	0.64	72.48	6.3
0.3	75	810	50.16	2285.01	2.42	0.53	7.13	0.99	65.08	5.6

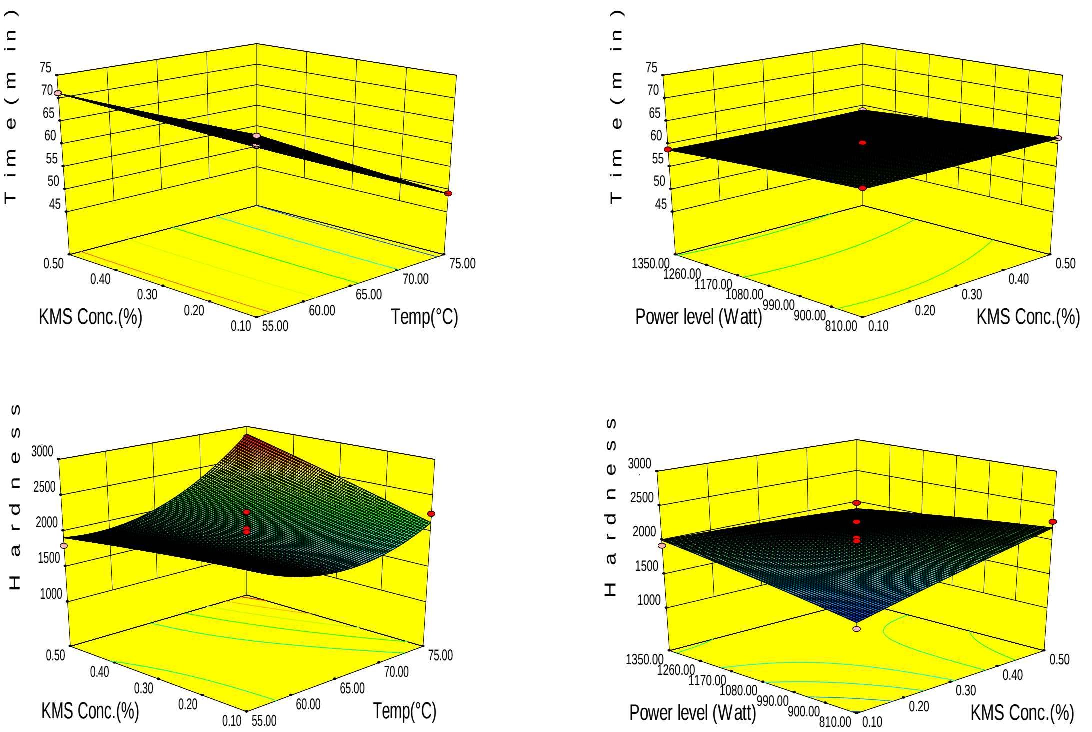
0.5	55	1080	71.16	1804.78	2.55	0.47	9.51	0.77	70.48	7.3
0.3	65	1080	59.87	2046.78	2.53	0.51	8.62	0.79	65.37	6
0.5	75	1080	50.16	2831.66	2.35	0.52	7.76	1.03	66.09	5.3
0.3	75	1350	48	2665.66	2.35	0.52	8.42	1.05	69.18	5.3
0.3	65	1080	60.28	2278.64	2.43	0.53	8.63	0.88	65.97	6.8
0.5	65	1350	59	1987.63	2.39	0.45	9.27	1.01	68.46	5.3
0.3	55	810	72.17	2213.6	2.44	0.49	8.86	0.69	69.98	6.6
0.1	55	1080	71.33	2238.36	2.75	0.54	9.51	0.68	71.26	7
0.3	65	1080	60.48	1843.56	2.46	0.49	8.65	0.98	65.94	6.6
0.1	65	810	61.33	1495.68	2.55	0.47	7.99	0.66	69.39	6.3
0.3	65	1080	60.33	1604.78	2.42	0.50	8.64	0.69	63.49	6

***** Fluidized bed drying at constant velocity of 3.5 m/s (Shoba et al. 2012).

All the eight models were tested for their adequecy using ANOVA techniques F-values for the lack of fit were found non significant ($p<0.05$) for all the models confirming the validity of the models . Further the analysis experimenatal values for responses revealed that drying time , color L-value, texture (hardness), shrinkage ratio , rehydration ratio , specific energy consumption(SEC), non-enzymatic browning and overall acceptability (OA) could be treated with 0.999, 0.887, 0.827, 0.848, 0.860, 0.999, 0.826 & 0.836 cofficient of determination , respectively.

Table 4 shows the combined effect of process variables was significant at linear, cross product and quadratic level ($p<0.05$) for the responses. Full second order model of the form was fitted to data and regression coefficients were computed the results of which are reported in Table 4. Significant interaction suggests that the level of of the interactive variables can be increased with the other decreased for constant value of the response (Montogomery 2004).

Effect of variables on all quality parameters is presented in Fig. 1 & 2. The minimum drying time (48 min)



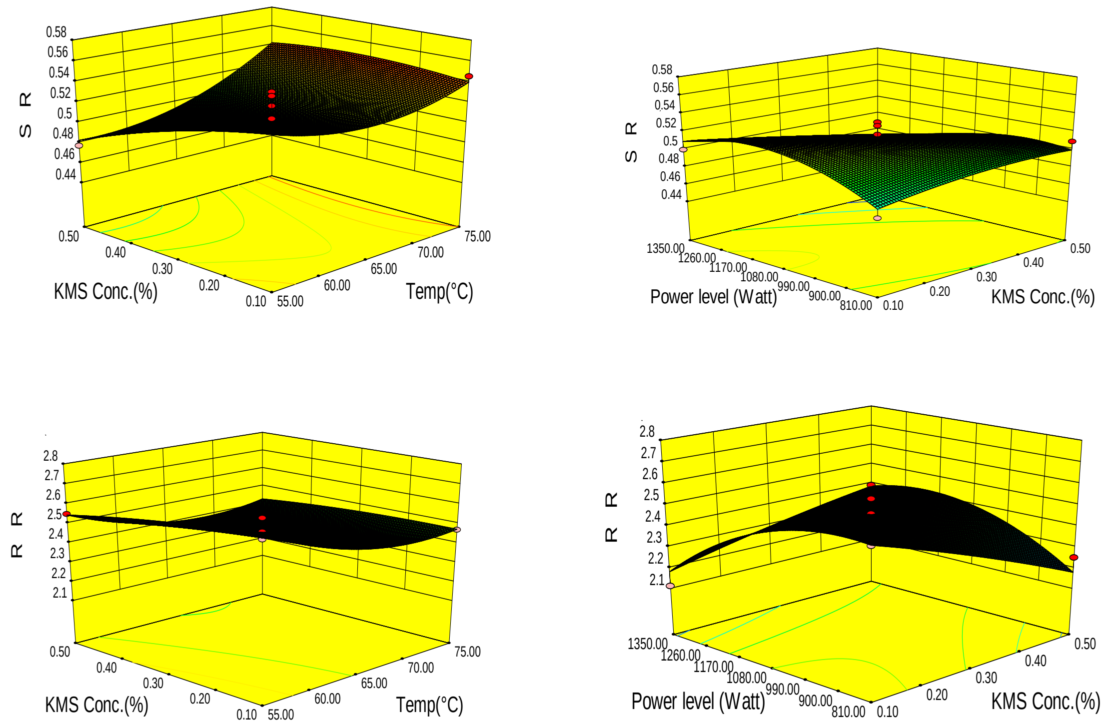
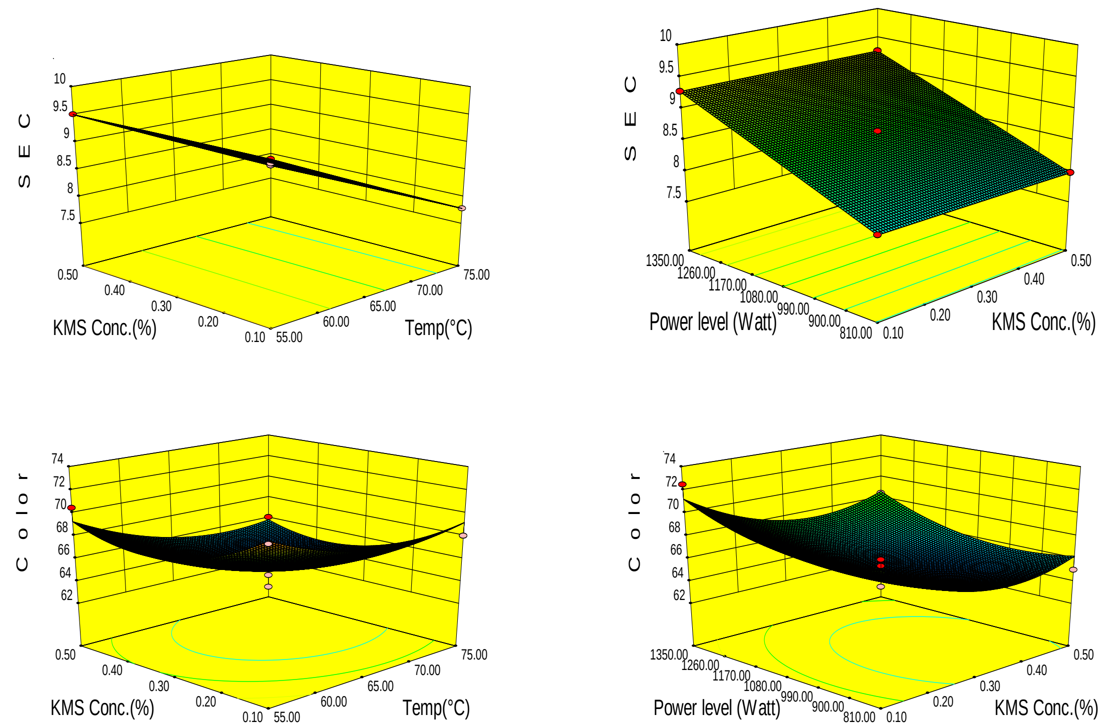


Fig. 1 Response surface plots for different quality parameters during hybrid drying of garlic slices



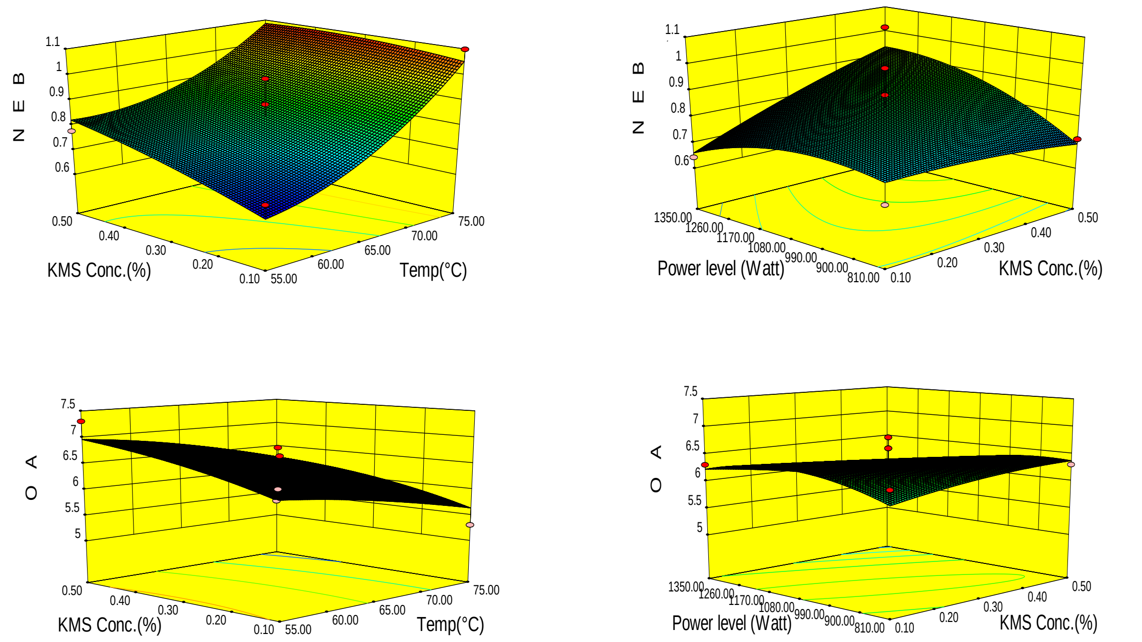


Fig. 2 Response surface plots for different quality parameters during hybrid drying of garlic slices

was noticed for 0.3 % KMS treated sample, dried at 75^{0}C fluidized bed drying air temperature followed by microwave drying at 1350W power level (Table 3). Drying time decreased with increase in T and PL while there is no significant effect of C on drying time. The linear term of T; PL and cross product term of T, C are significant (p<0.05) (Table 4).

Table 4 ANOVA table for quality responses of fluidized bed-cum-microwave drying

Source	RESPONSES (F-VALUES)							
	Time	Hardness	RR	SR	SEC	NEB	COLOUR	OA
Model	1936.47*	3.72*	4.79*	4.33*	12757.22*	3.70*	6.14*	3.96*
T	17224.32*	9.11*	8.39*	8.06*	73935.35*	22.52*	9.32*	29.23*
C	2.27^{NS}	2.65^{NS}	2.44^{NS}	5.29^{NS}	2.46^{NS}	2.45^{NS}	8.77*	0.40^{NS}
PL	190.15 *	0.19^{NS}	2.30^{NS}	2.09^{NS}	40872.63*	1.16^{NS}	5.49^{NS}	1.37^{NS}
TxC	6.20 *	5.59^{NS}	0.27^{NS}	3.19^{NS}	1.23^{NS}	0.66^{NS}	0.20^{NS}	0.15^{NS}
TxPL	0.12^{NS}	2.23^{NS}	0.51^{NS}	0.15^{NS}	0.00^{NS}	0.22^{NS}	4.96^{NS}	0.15^{NS}
CxPL	0.13^{NS}	2.89^{NS}	14.23*	5.96*	0.00^{NS}	2.53^{NS}	0.016^{NS}	1.62^{NS}
T^2	0.22^{NS}	10.81*	5.00^{NS}	4.89^{NS}	2.53^{NS}	2.39^{NS}	5.99*	0.27^{NS}
C^2	2.44^{NS}	0.019^{NS}	0.13^{NS}	0.62^{NS}	0.47^{NS}	0.095^{NS}	12.89*	0.15^{NS}
PL^2	2.79^{NS}	0.026^{NS}	10.47*	9.32*	0.47^{NS}	1.54^{NS}	5.03^{NS}	2.07^{NS}
Lack of fit	1.09	0.37	6.12	1.23	0.13	0.77	2.39	1.73
R^2	0.9996	0.8271	0.8602	0.8478	0.9999	0.8263	0.8876	0.8357
C.V (%)	0.39	10.17	3.16	3.09	0.10	12.21	1.97	6.34

* Significant at 5 % level ; NS-Not significant ;Where, T-Drying air temperature, C- KMS concentration & PL-Power level

The minimum hardness (1495.68) was noticed for 0.1 % KMS treated sample, dried at 65^{0}C fluidized bed drying air temperature followed by microwave drying at 810W power level (Table 3). Hardness decreased with increase in T & PL while there is slightly decrease in hardness with decrease in C. The linear term of T, PL and cross product term of T, C are significant (p<0.05) (Table 4).

The minimum SR (0.45) was noticed for 0.5 % KMS treated sample dried at 65^{0}C fluidized bed drying air temperature followed by microwave drying at 1350W power level (Table 3). SR decreased with increase in T & PL while there is increased in SR with increase in C. The linear term of T and cross product term of C, PL and quadratic term of PL are significant ($p<0.05$) (Table 4).

The maximum RR (2.75) was noticed for 0.1 % KMS treated sample dried at 55^0C fluidized bed drying air temperature followed by microwave drying at 1080W power level (Table 3). RR decreased with increase in T and PL while there is decrease in RR with increase in C. The linear term of T and cross product term of C, PL and quadratic term of PL are significant ($p<0.05$) (Table 4).

The minimum SEC (7.13) was noticed for 0.3 % KMS treated sample, dried at 75^0C fluidized bed drying air temperature followed by microwave drying at 810W power level (Table 3). SEC decreased with increase in T & PL while there is no significant effect of C on SEC. The linear term of T and PL are significant ($p<0.05$) (Table 4).

. The maximum colour (L-value) (72.48) was noticed for 0.1 % KMS treated sample dried at 65^0C fluidized bed drying air temperature followed by microwave drying at 1350W power level (Table 3). Colour (L-value) decreased with increase in T and slightly increase with increase in PL while there is increased in colour (L-value) with increase in C. The linear term of T, C and quadratic term of T, C are significant ($p<0.05$) (Table 4).

The minimum NEB (0.642) was noticed for 0.1% KMS treated dried at 65^0C fluidized bed drying air temperature followed by microwave drying at 1350W power level (Table 3). NEB increased with increase in T and decreased in NEB with increase in PL while there is decrease in NEB with increase in C. The linear term of drying air temperature are significant ($p<0.05$) (Table 4).

The maximum overall acceptability (7.3) was noticed for 0.5 % KMS treated, dried at 55^0C fluidized bed drying air temperature followed by microwave drying at 1080W power level (Table 3). OA decreased with increase in T and slightly decreased with increase in PL while there is slightly increased in OA with increase in C. The linear term of T, C and cross product term of C, PL and quadratic term of T are significant ($p<0.05$) (Table 4).

3.1 Optimization of fluidized bed-cum-microwave hybrid drying process

The process conditions for fluidized bed drying of garlic slices were optimized using numerical optimization technique. The main criteria for constraints optimization were maximum possible RR, colour (L-value) & OA and minimum SR, hardness, SEC & NEB (Themelin et al. 1997; Ade-Omowaye et al. 2002) and drying time in range .The response surface graphs for each response were generated for different interaction of any three independent variables. In order to optimize the process conditions for single layer drying of garlic by numerical optimization technique, equal importance of '3' was given to three process parameters (*viz.* C (%), T (^{0}C) and PL (Watt) and responses (i.e. time, hardness, RR SR, color (L-value) , NEB, SEC & OA). The optimum condition for fluidized bed-cum-microwave is 0.1 % KMS concentration (%), 63.92^0C drying air temperature and 810W power level. Corresponding to these values of process variables, the value of drying time, hardness, rehydration ratio, shrinkage ratio, specific energy consumption, non enzymatic browning , color and overall acceptability was 62.39 min, 1609.93g, 2.56, 0.49, 8.09 KWh/g, 0.73 ,69.53 and 6.12 respectively (Table 5). The overall desirability was 0.634.

Table 5 Optimum values of process parameters and responses

Process parameters	**Goal**	**Lower limit**	**Upper limit**	**Importance**	**Optimization level**	**Desirability**
C (%)	In range	0.1	0.5	3	0.10	
T (^{0}C)	In range	55	75	3	63.92	
PL (Watt)	In range	810	1350	3	810	
Responses					**Predicted value**	
Time (min)	Minimize	48	72.17	3	62.39	
Hardness (g)	Minimize	1495.68	2831.76	3	1609.93	
RR	Maximize	2.11	2.75	3	2.56	0.634
SR	Minimize	0.45	0.55	3	0.49	
SEC (KWh/g)	Minimize	7.13	10.15	3	8.09	
NEB	Minimize	0.64	1.09	3	0.73	
Colour (L-value)	Maximize	63.49	72.48	3	69.53	
OA	Maximize	5.3	7.3	3	6.12	

IV. Conclusion

The RSM was effective in optimizing process parameters for hybrid drying (Fluidized bed-cum-microwave) of garlic slices having KMS concentration in the range of 0.1 to 0.5 %, drying air temperature 55^0C to 75^0C and microwave power level 810 to 1350 W. The regression equations obtained can be used for optimum conditions for desired responses within the range of conditions applied in this study. Graphical techniques, in connection with RSM, aided in locating optimum operating conditions, which were experimentally verified and proven to be adequately reproducible. Optimum solutions by numerical optimization obtained were 0.1 % KMS concentration, 63.92^0C drying air temperature and 810 W microwave power level to get maximum rehydration ratio, colour (L-value) and overall acceptability, and minimum drying time, hardness, shrinkage ratio, specific energy consumption and non enzymatic browning .

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