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Optimization of Microwave-Vacuum Drying of Button Mushrooms Using Response-Surface Methodology

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Button mushrooms (*Agaricus bisporous*) were dried in a microwave-vacuum dryer up to a final moisture content of around 6% (d.b.). The effect of microwave power level (115 to 285 W), system pressure (6.5 to 23.5 kPa), and slice thickness (6 to 14 mm) on drying efficiency and some quality attributes (color, texture, rehydration ratio, and sensory attributes) of dehydrated mushrooms were analyzed by means of response surface methodology. A rotatable central composite design was used to develop models for the responses.Analysis of variance showed that a second-order polynomial model predicted well the experimental data. The system pressure strongly affected color, hardness, rehydration ratio, and sensory attributes of dehydrated mushrooms. A lower pressure during drying resulted in better quality products. Optimum drying conditions of 202 W microwave power level, 6.5 kPa pressure, and 7.7 mm slice thickness were established for microwave vacuum drying of button mushrooms. Separate validation experiment was conducted at the derived optimum conditions to verify the predictions and adequacy of the models.

Keywords Button mushroom; Hardness; Microwave-vacuum drying; Optimization; Rehydration ratio; Response surface methodology

INTRODUCTION

The drying process has been used worldwide for centuries to preserve different food and agricultural products. Drying is also an important unit operation in a wide variety of food industries. The consumption of dried vegetables in a variety of food formulations such as instant soups, sauces, snacks, pizzas, and meat and rice dishes has increased the demand of such dried vegetables as mushroom, tomato, and carrot. Mushrooms are edible fungi of commercial importance and their cultivation and consumption have increased substantially due to their nutritional value, delicacy, and flavor. The commercially available dehydrated mushrooms, which are dried by conventional methods, are not of prime quality in terms of color, rehydration ratio, and texture. In recent years, microwave-vacuum drying (MVD) has been investigated as a potential method for obtaining high-quality dehydrated food products.[1–6] Microwave-vacuum drying combines the advantages of both microwave heating and vacuum drying. The low temperature and fast mass transfer conferred by vacuum drying combined with rapid energy transfer by microwave heating generates very rapid, low-temperature drying and thus it has the potential to improve energy efficiency and product quality.

Drying is also a critical food processing operation in the sense that many undesirable changes occur during the drying process, which reduces the quality of the dried product. Optimization of any dehydration process is therefore performed to ensure rapid processing conditions yielding an acceptable quality product and a high throughput capacity. For dehydrated vegetables, the quality aspects may include the color parameters (L^*, a^*, and b^* values, hue, chroma, color difference), texture (hardness, crispness, etc.), rehydration ratio, nutritional value, and final moisture content. On the other hand, the process parameters to be optimized include temperature, relative humidity and flow rate of drying air, microwave power intensity, pressure, retention time, slice thickness, speed of machine, and many other related criteria for various methods of drying.

Response-surface methodology (RSM) is a useful technique for investigation of several input variables that influence the performance measures or quality characteristics of the product or process under investigation. It is also an effective and frequently used tool for optimization studies. Several authors have employed RSM to optimize various unit operation processes resulting in acceptable responses.[7–15]

The objective of the present work was to study the effect of microwave-vacuum drying parameters such as microwave power level, system pressure, and thickness of mushroom slices on certain product and process characteristics (instrumental color and texture values, rehydration ratio, sensory attributes, and drying efficiency) and to determine the optimum microwave-vacuum drying conditions for production of high-quality dried button mushrooms.

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MATERIAL AND METHODS

Fresh button mushrooms were obtained from market and kept in cold storage at 4–5°C. Prior to drying experiments, mushrooms were thoroughly washed to remove the dirt and graded by size to eliminate the variations in respect to exposed surface area. Moisture content of fresh mushrooms was determined by drying the samples to bone-dry conditions in a vacuum oven at 70°C for 14–16 h.[16] The initial moisture content of mushrooms ranged between 92 and 93% (w.b.). Slices of desired thickness were obtained by carefully cutting the mushrooms vertically with a vegetable slicer. The slices from middle portions with characteristic mushroom shape were used for drying experiments without any pretreatments.

Microwave Vacuum Drying

The experimental microwave-vacuum drying system used for drying studies is depicted in Fig. 1. The drying system consisted of a microwave oven (IFB Industries Ltd, Bangalore, India, Model Electron) of 600 W rated capacity at 2.45 GHz. The oven was modified to give variable power output (from 0 to 600 W) by incorporating a 230 V AC voltage variac in the circuit.[17] A container made of polycarbonate with provision to spread mushroom slices in a single layer was placed inside the microwave oven cavity. A vacuum pump with pressure-regulating valve was connected to the container for maintaining the desired level of pressure inside it. The extent of vacuum in the container was monitored with a vacuum gauge. An airtight condenser was also used in the vacuum line for condensing the water vapor released from the samples during drying.

About 50 g of mushrooms were taken for each microwave-vacuum drying experiment. Prior to the experiments, the microwave oven was run with water as load for about half an hour in order to warm up the magnetron and to achieve a steady input of microwave power. After keeping the samples inside the vacuum container and attaining the required vacuum, an appropriate level of microwave power was applied. The samples remained inside the vacuum chamber for a certain period while drying took place. The weight of the sample was recorded at 5-min intervals after switching off the microwave oven and releasing the vacuum, which took about 30 to 40 s for each observation. The samples were dried until the moisture content was reduced to around 6% (d.b.).

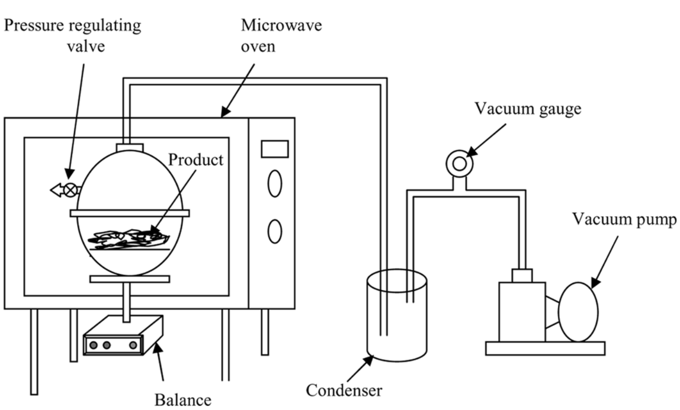

FIG. 1. Experimental microwave-vacuum drying system.

Experimental Design

The variables chosen for microwave-vacuum drying experiments were microwave power level (Q), system pressure (P), and slice thickness (T). The variable levels were selected on the basis of preliminary drying experiments. Twenty experiments were performed according to a second-order central composite rotatable design (CCRD) with five levels of each variable. Table 1 gives the levels of variables in coded and actual units, and Table 2 indicates the combination of variable levels used in the CCRD. Experiments were randomized in order to minimize the effects of unexplained variability in the observed responses due to extraneous factors. The center point in the design was repeated six times to calculate the reproducibility of the method. Response surface methodology was used to determine the relative contributions of Q, P, and T to various responses under study such as drying efficiency (η_d), color (L-value), total color difference (ΔE), hardness (H), rehydration ratio (RR), and sensory score (SS) of dehydrated mushrooms. The second-order polynomial response surface model (Eq. (1)) was fitted to each of the response variables (Y_k).

$$Y_k = b_{k0} + \sum_{i=1}^{3} b_{ki} X_i + \sum_{i=1}^{3} b_{kii} X_i^2 + \sum_{i \neq j=1}^{3} b_{kij} X_i X_j \qquad (1)$$

where b_{k0}, b_{ki}, b_{kii}, and b_{kij} are the constant, linear, quadratic, and cross-product regression coefficients, respectively, and X_is are the coded independent variables of Q, P, and T.

Analysis of Data

Response-surface analysis of the experimental data was carried out using a commercial statistical package Design

TABLE 1
Levels of variables

Variable	Name (units)	Level −1.68	−1	0	1	1.68
Q	Microwave power (W)	115	150	200	250	285
P	System pressure (kPa)	6.5	10	15	20	23.5
T	Thickness (mm)	5.8	7.5	10	12.5	14.2

TABLE 2
The experimental design and data for the response surface analysis

	Variable levels			Responses (Y)					
Expt. No.	Q	P	T	L-value	ΔE	Hardness (N)	RR	η_d (%)	SS
1	1	1	1	46.65	34.29	145	2.28	23.60	6
2	1	1	−1	47.54	33.20	121	2.76	20.63	5
3	1	−1	1	52.80	28.73	122.3	2.45	27.90	7
4	1	−1	−1	52.80	27.38	196.3	3.42	22.33	6
5	−1	1	1	44.36	37.27	132	2.24	29.10	5
6	−1	1	−1	45.65	35.58	115	2.68	24.21	5
7	−1	−1	1	46.40	34.70	116.3	2.51	38.76	6
8	−1	−1	−1	50.00	31.08	84.6	2.87	25.40	6
9	1.68	0	0	49.50	32.75	124	2.65	26.90	6
10	−1.68	0	0	47.87	33.24	113	2.30	28.05	5
11	0	1.68	0	44.12	37.29	125	2.38	23.22	5
12	0	−1.68	0	54.24	26.77	107	3.33	25.41	8
13	0	0	1.68	48.00	33.27	130	2.80	21.60	6
14	0	0	−1.68	48.60	32.54	92	2.75	22.44	6
15	0	0	0	48.00	33.11	125	2.54	25.90	6
16	0	0	0	49.60	31.58	128	2.67	25.13	6
17	0	0	0	47.80	33.18	116	2.52	25.40	5
18	0	0	0	50.20	30.78	120	2.48	24.90	6
19	0	0	0	48.00	33.24	122	2.41	24.50	6
20	0	0	0	49.30	31.99	113	2.49	24.67	6

Expert, version 6.01 (Stat Ease Inc., Minneapolis, MN). Regression analysis and analysis of variance (ANOVA) were conducted for fitting the model represented by Eq. (1) to the experimental data and to examine the statistical significance of the model terms. The adequacies of the models were determined using model analysis, lack-of-fit test, and R^2 (coefficient of determination) analysis as outlined by Lee et al.[18] and Weng et al.[19] The lack-of-fit is a measure of the failure of a model to represent data in the experimental domain at which points were not included in the regression and variations in the models cannot be accounted for by random error.[20] If there is a significant lack of fit as indicated by a low probability value, the response predictor is discarded. The R^2 (coefficient of determination) is defined as the ratio of the explained variation to the total variation and is a measure of the degree of fit.[21] Coefficient of variation (CV) indicates the relative dispersion of the experimental points from the model prediction. Response surfaces were generated and numerical optimization was also performed by Design Expert software.

Optimization Technique

Numerical optimization technique of Design Expert was used for simultaneous optimization of the multiple responses. The desired goals for each factor and response were chosen. The possible goals were maximize, minimize, target, within range, none (for responses only). All the independents factors were kept within the experimental range while the responses were either maximized or minimized. In order to search a solution for multiple responses, the goals were combined into an overall composite function, $D(x)$, called the desirability function,[22] which is defined as:

$$D(x) = (d_1 \times d_2 \times \cdots\cdots \times d_n)^{1/n} \qquad (2)$$

where $d_1, d_2, \ldots, d_n$ are responses and n is the total number of responses in the measure.

The function $D(x)$ reflects the desirable ranges for each response (d_i). Desirability is an objective function that ranges from zero (least desirable) outside of the limits to one (most desirable) at the goal. The numerical optimization finds a point that maximizes the desirability function. The goal-seeking begins at a random starting point and proceeds up the steepest slope to a maximum. There may be two or more maximums because of curvature in the response surfaces and their combination into the desirability function. By starting from several points in the design space, chances improve for finding the best local maximum.[23]

Measurement of Quality Attributes

Color

Color of fresh and dehydrated mushroom slices was measured with a Hunter Lab color meter (D25, DP-9000), consisting of D-25 optical sensors (L-type) and a processor (DP-9000) that processes and displays the results of measurements. The instrument was calibrated using standard white tile before the measurements. Hunter L, a, and b color scale was selected for all measurements. Samples were kept on the specimen port (95 mm diameter) to cover the full exposed area of the port to the light. All measurements were replicated thrice and the mean readings were taken. Hunter L-value and color difference (ΔE) parameters as described by Eq. (3) were used to describe the color of dehydrated mushrooms.

$$\Delta E = [(\mathrm{L} - \mathrm{L}^*)^2 + (\mathrm{a} - \mathrm{a}^*)^2 + (\mathrm{b} - \mathrm{b}^*)^2]^{0.5} \qquad (3)$$

Color difference (ΔE) indicates the degree of overall color change of a sample in comparison to color values of an ideal sample having color values of L^*, a^*, and b^*. Fresh mushroom slices were taken as ideal sample in this case having L^*, a^*, and b^* values of 80.6, 4.3, and 17.2, respectively. A good quality dehydrated mushrooms, therefore, should have a minimum ΔE value.

Rehydration Ratio

Rehydration ratio, a measure of rehydration characteristics of dried food products, was determined by immersing 5 g dried mushroom samples in distilled water at 30°C and 100°C temperatures. The water was drained and the samples weighed at every 30 min interval for those immersed at 30°C and at 2-min intervals for those immersed at 100°C water temperature. Triplicate samples were used. Rehydration ratio was defined as the ratio of weight of rehydrated samples to the dry weight of the sample. Data reported here are those of mushrooms rehydrated at 100°C.

Texture (Hardness)

A texture analyzer (Model TA.XT-2i, Texture Technologies Corp., Stable Microsystems Ltd, Godalming, Surrey, UK) fitted with a 25-kg load cell was used for textural analysis of dehydrated mushroom slices. The analyzer was linked to a computer that recorded and analyzed the data via a software program XT.RA Dimension (Texture Technologies Corp., Scarsdale, NY). A compression test was carried out to generate a plot of force (N) vs. time (s), from which texture values were obtained. A 75-mm-diameter compression platen (P/75) was used to compress the dehydrated mushroom slices to 30% of their original thickness. The pre-speed as well as post-speed of the probe was fixed at 1 mm/s and the test speed was 2 mm/s during compression. A typical plot of force vs. time is shown in Fig. 2. Only hardness value proved to be relevant to the dehydrated slices. The hardness value (H) was expressed as the peak force (N) in the first compression and the mean hardness value of 5 replicates was taken.

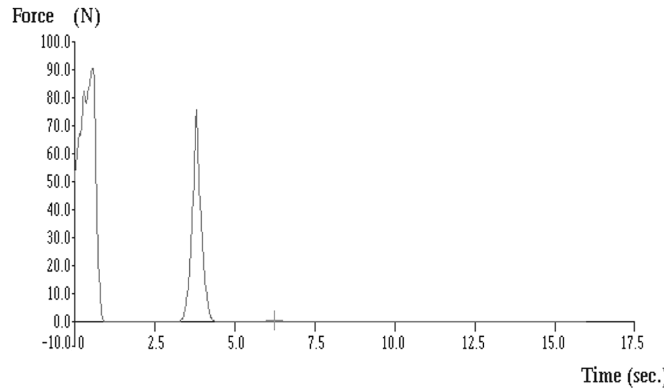

FIG. 2. A typical texture profile analysis curve for dehydrated mushroom.

Sensory Score

The sensory evaluation of dried mushroom samples was carried out by a panel of 10 untrained judges using the hedonic rating test. The hedonic rating test is usually used to measure the consumer acceptability of food products.[24] The panelists were given a specimen evaluation card for sensory evaluation and asked to rate the acceptability of the products based on the quality attributes of color, appearance, texture, and flavor. The acceptability rating of the products was done on a scale of 9 points, ranging from "like extremely" to "dislike extremely." Individual scores of each panel member for overall acceptability of different products were averaged to the nearest whole number and represented as the sensory score of the products.

Drying Efficiency

Drying efficiency was calculated as the ratio of the heat utilized for evaporating water from the sample to the heat supplied by the microwave oven.[25] The known latent heat of vaporization of water at the evaporating temperature and the measured mass of water evaporated were used to calculate the drying efficiency as per the following equation:

$$\eta_d = \frac{m_w \lambda_w}{Q \Delta t} \times 100 \qquad (4)$$

where η_d is the drying efficiency (%), m_w is the mass of water evaporated (g) during the time Δt(s), λ_w is the latent heat of vaporization of water (J/g) at the corresponding pressure, and Q is the applied microwave power (W).

RESULTS AND DISCUSSION

The experimental data of various responses during MVD of button mushrooms are presented in Table 2. The estimated regression coefficients of the quadratic polynomial models (Eq. (1)) for various responses and the corresponding R^2 and CV values are given in Table 3.

TABLE 3
Regression coefficients of the second-order polynomial model for the response variables (in coded units)

	Estimated coefficients					
Variables/factors	L-value	ΔE	Hardness	RR	SS	η_d
Constant	48.83	32.31	120.61	2.52	5.84	25.02
X_1	1.24	−1.16	4.04	0.09	0.27	−1.83
X_2	−2.61	2.65	9.06	−0.21	−0.66	−1.5
X_3	−0.56	0.66	11.91	−1.16	0.15	1.86
X_1^2	−0.12	0.26	−0.4	−0.03	−0.17	1.25
X_2^2	0.05	−0.08	−1.28	0.11	0.18	0.13
X_3^2	−0.25	0.23	−3.05	0.08	0.004	−0.68
X_1X_2	−0.73	0.54	0.16	−0.08	0.25	−0.61
X_1X_3	0.4	−0.36	0.16	−0.08	0.25	−1.21
X_2X_3	0.28	−0.28	−2.09	0.05	0	−1.38
R^2	0.89	0.86	0.92	0.76	0.83	0.68
CV	2.49	4.30	4.87	7.91	7.20	11.67

Analysis of variance (Table 4) indicated that the models are highly significant at $p \leq 0.05$ for all the responses expect drying efficiency. The lack of fit did not result in a significant F-value in case of color (L-value), color difference, hardness, and sensory score, indicating that the models are sufficiently accurate for predicting these responses. However, for rehydration ratio and drying efficiency, the lack of fit was significant and R^2 values were low, indicating that a high proportion of the variability was not explained by the data. Therefore, the models for drying efficiency and rehydration ratio were not adequate. As a general rule, the coefficient of variation should not be greater than 10%. In this case, the coefficients of variation for all the responses except drying efficiency were less than 8% (Table 3).

Color

The L-value of fresh mushroom slices was 80.6 and those of dehydrated mushrooms varied between 44.1 and 54.3. The regression equation describing the effect of the process variables on L-value and color difference (ΔE) of dried button mushroom slices in terms of actual levels of the variables are given as:

TABLE 4
ANOVA for different models

		F-values					
Variables/factors	df	L-value	ΔE	H	RR	SS	η_d
Model	9	9.52***	7.09***	11.76***	3.62**	5.50***	2.33
X_1	1	14.32***	9.34**	6.81**	2.44*	5.60**	5.14**
X_2	1	63.46***	48.57***	34.26***	14.13***	33.79***	3.49*
X_3	1	2.88	3.00	59.13***	7.95**	1.65	5.32**
X_1^2	1	0.14	0.51	0.071	0.27	2.43	2.54
X_2^2	1	0.03	0.043	0.73	3.75*	2.66	0.03
X_3^2	1	0.64	0.39	4.10*	2.02	0.0014	0.75
X_1X_2	1	2.89	1.17	0.0065	0.40	0.00	0.33
X_1X_3	1	0.87	0.53	0.0065	1.22	2.82	1.33
X_2X_3	1	0.42	0.31	1.06	0.49	0.00	1.73
Residual	10						
Lack of fit	5	1.85	2.74	1.11	10.52**	1.13	66.40***
Pure error	5						
Total	19						

***Significant at $p < 0.01$; **$p < 0.05$; *$p < 0.1$.

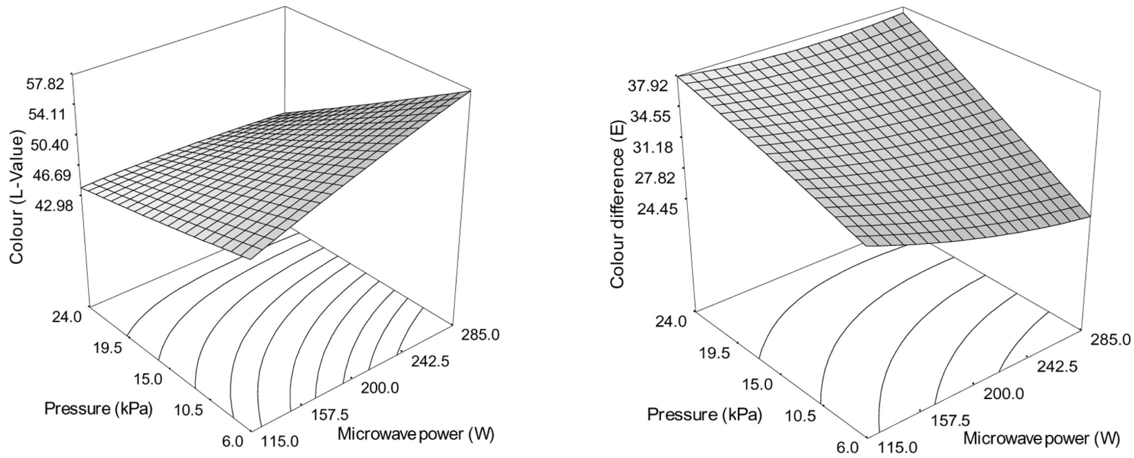

FIG. 3. Effect of microwave power level and pressure on color parameters of dried mushroom slices (T = 10 mm).

$$\begin{aligned}\text{L-value} = {} & 49.46 + 0.055Q - 0.23P - 0.38T \\ & - 4.74\times10^{-5}Q^2 + 2.26\times10^{-3}P^2 - 0.04T^2 \\ & - 2.91\times10^{-3}QP + 3.2\times10^{-3}QT + 0.022PT\end{aligned} \tag{5}$$

$$\begin{aligned}\Delta\text{E} = {} & 30.99 - 0.069Q + 0.41P + 0.43T + 1.05\times10^{-4}Q^2 \\ & - 0.003P^2 + 0.037T^2 + 0.0021QP - 0.0029QT - 0.022PT\end{aligned} \tag{6}$$

It can be observed from ANOVA (Table 4) that microwave power and system pressure are both significant variables affecting the L-value and color difference at $p \leq 0.05$, while there was no significant contribution of slice thickness to the color values. System pressure was the main factor affecting color, as revealed by corresponding regression coefficient and F value. It exerted a negative linear effect on L-value and positive effect on the color difference as depicted in Figs. 3 and 4. The negative effect of P and positive linear effect of Q suggested that higher L-value and lower color differences are observed when high microwave power level is combined with low value of pressure during MVD. The finding is consistent with results in the literature.[3,26]

Rehydration Ratio

The amount of moisture absorbed by dried mushroom slices increased with rehydration time and the rate of absorption decreased with time until a saturation level was achieved. The rehydration process stabilized in about 10 min at 100°C and in 3 h at 30°C water temperature. The rehydration ratio for button mushroom slices was found to be in the range of 2.3 to 3.4 under various drying conditions. Rehydration properties were improved by drying at lower system pressure and higher microwave

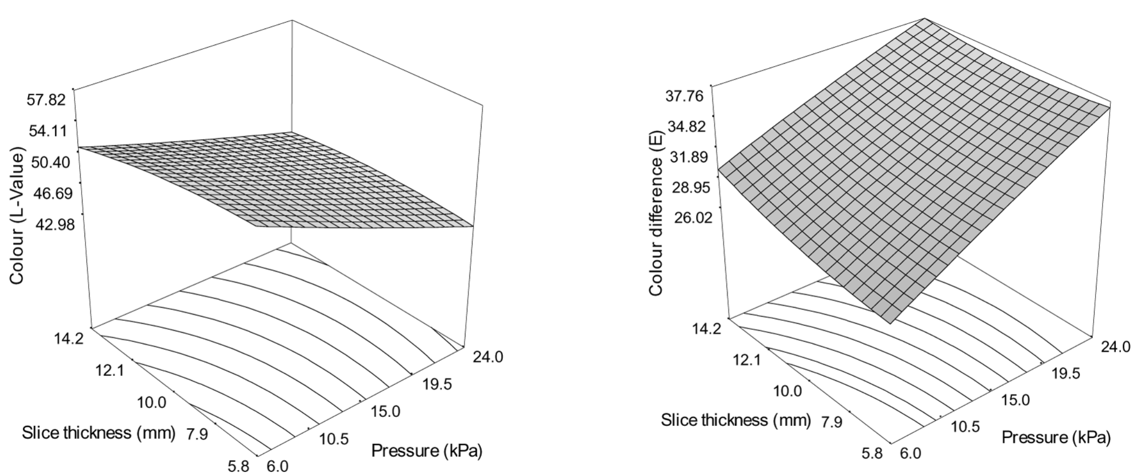

FIG. 4. Effect of pressure and slice thickness on colour parameters of dried mushroom slices (Q = 200 W).

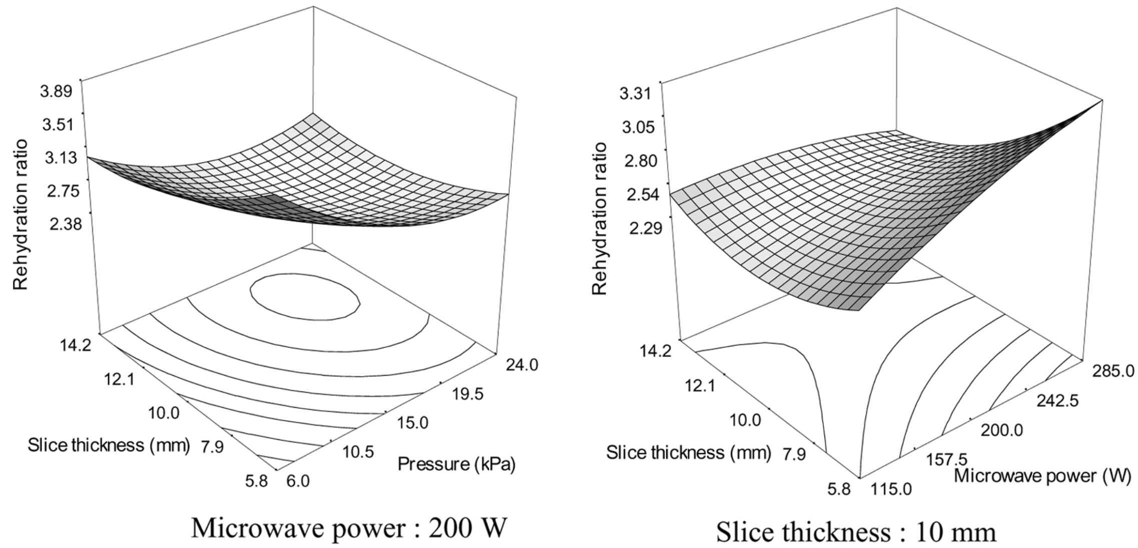

FIG. 5. Effect of different process variables on rehydration ratio of dried mushroom slices.

power level as indicated by higher values of rehydration ratio (Fig. 5). Similar results were reported in the literature by some researchers.[2,5,27] The regression model for RR relating the process variables is given as:

$$RR = 3.94 + 0.0156Q - 0.173P - 0.244T - 1.132 \times 10^{-5}Q^2 + 0.0042P^2 + 0.0125T^2 - 1.85 \times 10^{-10}QP - 6.5 \times 10^{-4}QT + 0.004PT \quad (7)$$

From ANOVA (Table 4) it may be concluded that the rehydration ratio depends mainly on pressure level, as its linear as well as quadratic effects are significant. At lower pressure level, the rehydration ratio increased, owing to the increased drying rate and creation of pores that are induced by vacuum conditions.[28] Sample thickness and microwave power had a less significant effect on rehydration ratio as compared to that of system pressure. While the rehydration ratio was positively correlated with microwave power, slice thickness had a negative effect indicating thin slices rehydrated to a greater extent compared to thick slices. The higher RR at higher microwave power can be attributed to the development of greater internal stresses during drying at higher power levels. The quick microwave energy absorption causes rapid evaporation of water, creating a flux of rapidly escaping vapor that helps in preventing the shrinkage and case hardening, thus improving the rehydration characteristics.[17,29,30]

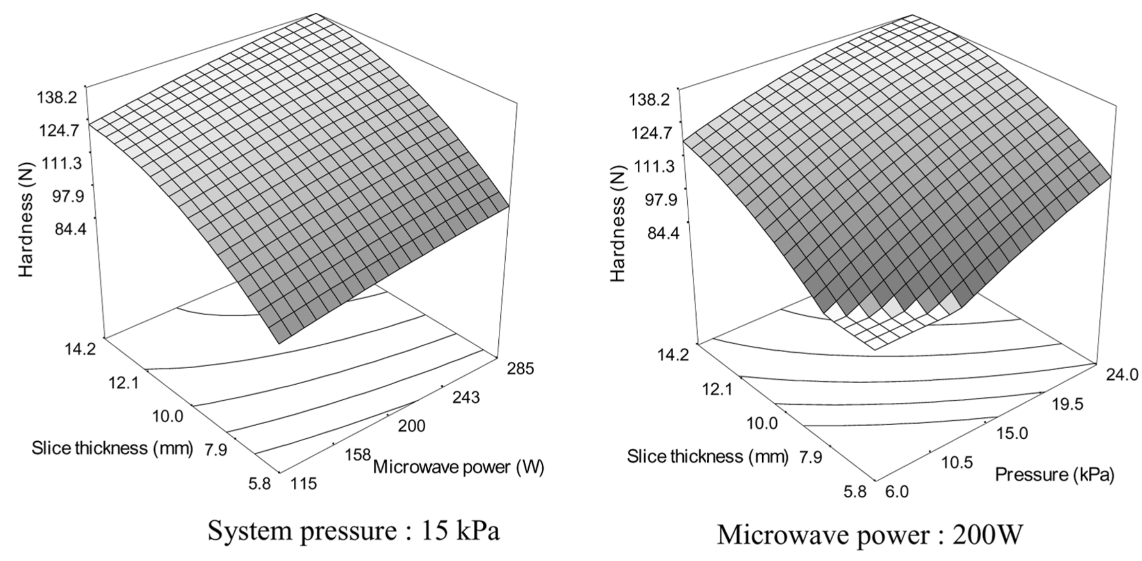

FIG. 6. Effect of different process variables on hardness of dried mushroom slices.

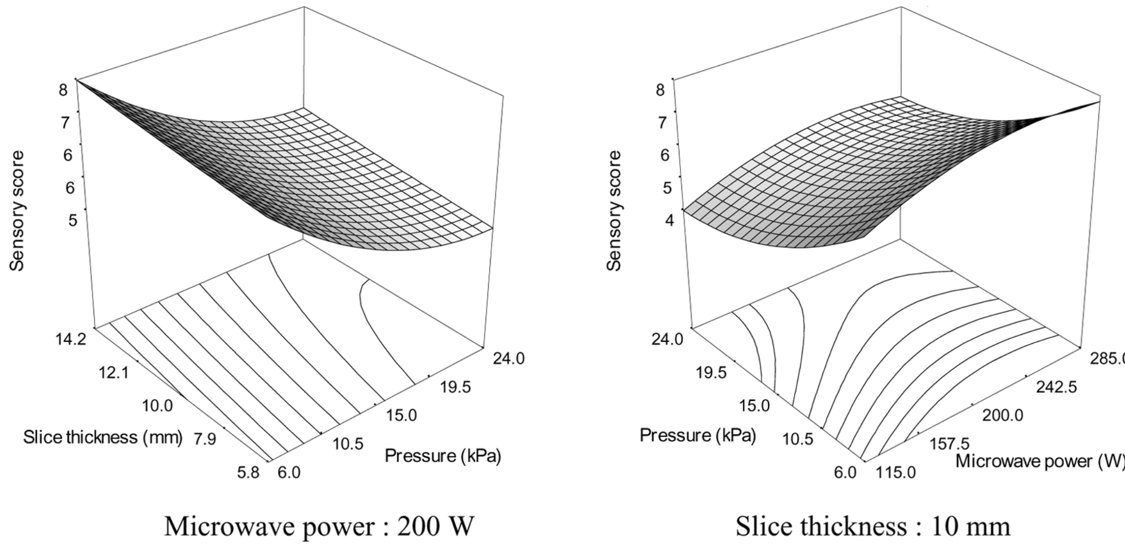

FIG. 7. Effect of different process variables on sensory score of dried mushroom slices.

Texture (Hardness)

The hardness values of dehydrated mushroom slices ranged between 85 and 145 N. It was significantly affected by the linear terms of all the factors as well as a quadratic effect of slice thickness. The following relationship was developed for hardness value with the actual levels of process variables:

$$H = -57.7 + 0.123Q + 4.89P + 16.78T - 1.6 \times 10^{-4}Q^2 - 0.052P^2 - 0.49T^2 + 6.59 \times 10^{-4}QP + 0.0014\ QT - 0.167PT \quad (8)$$

Slices thickness was found to have the strongest effect on hardness as indicated by corresponding F-value (Table 4). All the three factors (Q, P, and T) positively affected hardness value, indicating that thicker samples dried at higher microwave power level and higher pressure were harder in texture (Fig. 6), confirming the findings of some other investigators.[3] Higher microwave power and pressure causes a high product temperature, which may have resulted in a tougher texture.

Sensory Score

The sensory evaluation of dried samples was carried out by a panel of untrained judges. A 9-point hedonic rating

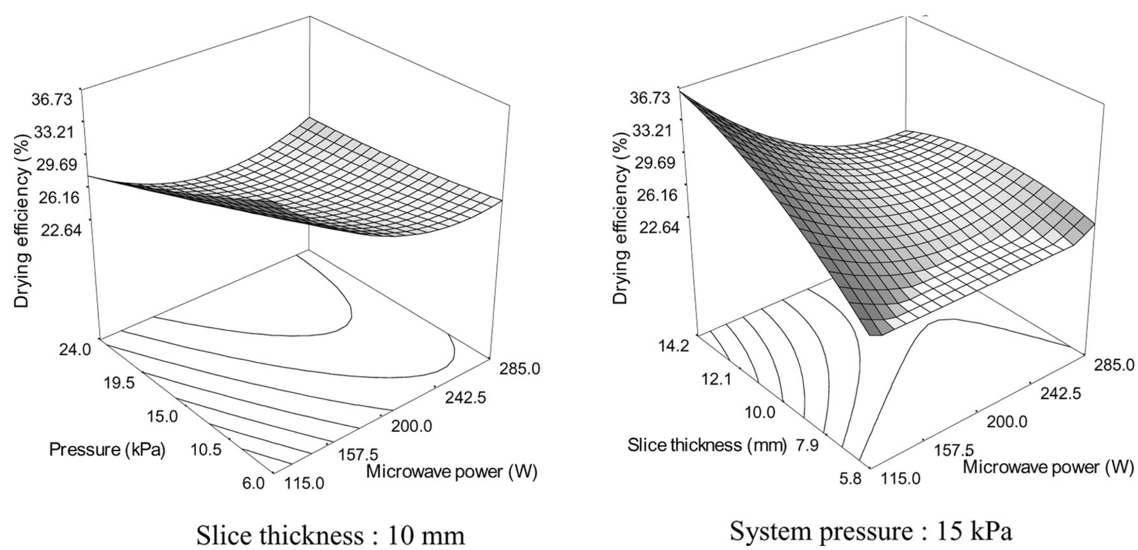

FIG. 8. Effect of different process variables on drying efficiency in MVD of button mushrooms.

TABLE 5
Optimization criteria for different factors and responses

Factors/ responses	Goal	Lower limit	Upper limit	Importance
Q	In the range	115	285	3
P	In the range	6.5	23.5	3
T	In the range	5.8	14.2	3
L-value	Maximize	44.12	54.24	5
E	Minimize	26.78	37.29	4
H	Minimize	84.6	145	4
RR	Maximize	2.24	3.42	5
SS	Maximize	5	8	5

was employed for all the attributes evaluated, where 9 denoted "liked extremely" and 1 indicated "disliked extremely." The sensory scores for overall acceptability of dehydrated mushrooms, as given by the panel members, are presented in Table 2. The regression equation relating the sensory score to the actual levels of the process variables is

$$SS = 9.1 + 0.013Q - 0.35P - 0.354T - 6.91 \times 10^{-5}Q^2 + 7.23 \times 10^{-3}p^2 + 6.46 \times 10^{-4}T^2 + 0.002QT \quad (9)$$

The system pressure had greater effect on sensory score than the microwave power level, as indicated by ANOVA (Table 4). Samples dried at lower pressure and higher power level were lighter in color and there was less shrinkage in these products, resulting in better appearance. Therefore, these products received higher scores (Fig. 7) and were highly accepted by the panel. Slice thickness had little effect on sensory score, but thicker samples were preffered by some of the panel members

Drying Efficiency

From ANOVA (Table 4) it can be observed that microwave power level and thickness had a significant effect ($p \leq 0.05$) on drying efficiency, whereas pressure had a lesser effect (significant at $p \leq 0.1$). Microwave power had a negative effect on drying efficiency, indicating that lower efficiency of the drying system was obtained when microwave power level was higher. A possible reason may be that increasing power level within the experimental range did not result in considerable reduction in drying time, thereby decreasing the efficiency. At a particular pressure level, the effect of slice thickness was more pronounced at lower power levels, as can be seen from Fig. 8. ANOVA also indiacted that the model for drying efficiency is not significant and, thus, a high proportion of variability cannot be explained by the data. The complex behavior of microwave power level and slice thickness toward drying efficiency (Fig. 8) may be the reason for non-significance of the model.

Optimization of MVD for Mushrooms and Experimental Validation

The desired goals for each factor and response were chosen and different weights were assigned to each goal to adjust the shape of its particular desirability function (Table 5). The program was run for the optimum conditions and the solutions obtained are presented in Table 6. The table indicates the optimum conditions of independent variables and also the predicted values of the responses. Solution no. 1, having maximum desirability value, was selected as the optimum conditions for microwave-vacuum drying of button mushrooms.

Drying experiments were performed using the derived optimum drying conditions and the quality attributes of the resulting products were determined. The experimental values (mean of 5 measurements) as well as the predicted values of various attributes are presented in Table 7. One sample T-test was conducted using the statistical software SPSS to compare the mean actual values of the responses with the predicted values. The null hypothesis was that there is no significant difference between the actual and the predicted values (test value). No significant differences between the actual and predicted values were found except

TABLE 6
Solution for optimum conditions

Solution number	Q (W)	P (kPa)	T (mm)	RR	H (N)	L-value	ΔE	SS	Desirability
1	202.11	6.50	7.67	3.55	84.6	54.65	26.68	7	0.949
2	211.28	6.50	7.60	3.54	84.6	54.64	26.35	7	0.948
3	211.23	6.50	7.67	3.50	85.2	54.63	26.37	7	0.947
4	203.40	6.62	7.62	3.49	84.6	54.24	26.69	7	0.946
5	226.76	6.50	7.48	3.54	84.6	54.28	26.86	7	0.944
6	222.77	7.34	7.21	3.46	84.6	54.58	26.50	7	0.924
7	230.30	6.50	12.91	3.04	117.6	53.62	27.81	8	0.772

TABLE 7
Comparison of experimental with predicted values

Response	Predicted value	Actual value ± SD	Standard error	Mean difference	Sig. (2 tailed)
L-value	54.65	54.44 ± 1.82	0.812	− 0.21	0.809
ΔE	26.68	26.87 ± 1.33	0.597	0.19	0.766
H (N)	84.6	96.33 ± 5.09	2.275	11.74	0.007
RR	3.55	3.64 ± 0.085	0.038	0.09	0.08
SS	7	7.6 ± 0.55	0.245	0.60	0.07

for the hardness value, in which case there was a significant difference at $p \leq 0.05$.

CONCLUSIONS

The system pressure in microwave-vacuum drying had a most pronounced effect on the quality attributes of dehydrated mushroom slices. Microwave power and slice thickness were found to affect the responses to a lesser extent. The second-order polynomial model was well fitted to predict the experimental data for most responses with high values of R^2 (>0.8). The optimum condition was found to be 202 W, 6.5 kPa, and 7.7 mm of microwave power, system pressure, and slice thickness, respectively. The experimental response values were found in close proximity to the predicted values from fitted models. The effect of different microwave-vacuum drying parameters on product quality can be effectively analyzed and optimization of the process can be done using RSM, with a minimum number of experiments. With the optimum conditions given for the variables, the process may be scaled up.

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