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Optimization of Drying Technique of Lentinus Edodes (Berk.) Sing with Microwave Vacuum Equipment via Response Surface Analysis

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Abstract: In this study, microwave vacuum equipment was employed to dry lentinus edodes (Berk.) Sing. Response Surface Methodology was used to determine the optimal drying conditions. The significant levels were obtained by the equations. The optimal conditions for drying lentinus edodes (Berk.) Sing with microwave vacuum equipment were obtained as following: microwave power 2650W, lentinus edodes load 171 g. Under these optimum conditions, lentinus edodes sensory evaluation, lentinan content and drying time were 80, 4.33% and 11 min, respectively.

Keywords: Lentinus edodes, microwave vacuum drying, response surface method

INTRODUCTION

Lentinus edodes (Berk.) Sing are edible fungus of high protein and low fat, have some function of anti-aging, anti-cancer, lowering blood pressure, lowering blood fat, lowering cholesterol and are considered a delicacy in China (Eva *et al*., 2010). Lentinus edodes are often eaten as dried products. Currently, hot air convection drying is employed to dry lentinus edodes, which lead to extend drying time, control temperature and humidity difficultly. Also, lentinus edodes nutrients lose seriously and lentinus edodes color darken easily in this way (Ali *et al*., 2011). Microwave vacuum drying technology combines microwave drying with vacuum drying to overcome the drawbacks of slow regular rate of heat conduction in the vacuum state because vacuum reduces the drying temperature and the microwave provides heat for drying. Microwave vacuum drying can greatly reduce the drying time and improve production efficiency (Sadoth *et al*., 2011). Currently, microwave vacuum drying technology is used for dehydration of grapes, bananas, carrots, apples, bananas, garlic, scallops and other products (Angel *et al*., 2011; Joanna *et al*., 2007), has not been reported for lentinus edodes.

In this study, microwave vacuum drying of lentinus edodes was studied. Drying rates and lentinan content of lentinus edodes were studied by varying microwave power and amount of lentinus edodes loaded. The test data was analyzed and the regression equation of microwave vacuum drying of lentinus edodes was establish, in order to provide the basis for industrial applications of microwave vacuum drying of lentinus edodes.

MATERIALS AND METHODS

Preparation of materials: Lentinus edodes were harvested in Gutian County, Fujian Province, China. After precooling, lentinus edodes were arrived to Fuzhou on the same day and then stored at low temperature. They were sorted for similar size and selected with on sign of demage by pest and diseases and stored at 4°C.

Determine methods of moisture content and drying rate: A certain quality of lentinus edodes was spread on the tray of microwave vacuum drying oven. This drying system which was manufactured by Guangzhou Kailing Industrial Microwave Equipment Ltd., (Guangzhou, Guangdong, China), each tray was dried using a different power and different load. Moisture content was calculated by moisture content of dry lentinus edodes. Measurements of quality and moisture content were recorded every 1min (AB204-N electronic analytical balance, Mettler-Toledo Co., Shanghai) until the moisture content of the samples below 13%. The moisture content is calculated as follows:

$w = (m_0 - m) / m * 100\%$ (calculated by moisture content of dried lentinus edodes)

$\eta = \Delta m / \Delta t$

where,
w : The moisture content (%)
m_0 : The weight of initial material (g)
m : The weight of material dried (g)
η : The drying rate of lentinus edodes
Δm : The amount of water loss between two measurements adjacently

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Table 1: Appearance quality of lentinus edodes

Score index	Grade				Weight value
Color of lid	Sandy beige 10	Brown 7.5	Dark brown 5	Black 2.5	3
Color of plait	Pale yellow 10	Yellow 7.5	Deep yellow 5	Brown 2.5	3
Fragrance	Strong 10	General 7.5	Diluted 5	None 2.5	2.5
Shape	Flat semi-spheroidal displacement, slightly flatten, regular 10	Flat semi-spheroidal displacement, slightly flatten, irregular 7.5	Flat semi-spheroidal displacement, irregular 5	Flat collapse, Irregular 2.5	1.5

Table 2: Factor and level of orthogonal regression design

Factors	X_1 (microwave power, W)	X_2 (load, g)
Upper axis (+γ)	4000	200
Upper level (+1)	4000	200
Zero level (0)	3000	150
Lower level (-1)	2000	100
Lower axis (-γ)	2000	100
Varying gap value (Δ_j)	1000	175

Table 3: The orthogonal regression design and experiment result

Code	X_1	X_2	Polysacch-aride content (%)	Drying time (min)
1	1	1	3.568	8.00
2	1	-1	2.823	4.50
3	-1	1	4.325	13.5
4	-1	-1	3.412	9.00
5	-1	0	4.177	11.2
6	1	0	3.527	6.50
7	0	-1	3.251	6.30
8	0	1	4.285	11.5
9	0	0	4.051	9.00

Δt : The time interval between two consecutive measurement

Determination method of lentinan (Zhao *et al*., 2010):

Drawing of a glucose standard curve: Standard glucose solution was prepared. The solution was allowed to stand for 10 min, shaken, the optical density determined at 490 nm. Solution was set aside 20 min at room temperature. A standard curve was drawn in which the abscissa was the polysaccharide content and ordinate was the optical density values:

$$Y = 0.077X + 0.1726R = 0.9968$$

where,
Y : The optical density values
X : The polysaccharide content (ug)

Determination of lentinan content: Dried lentinus edodes were ground with a mill (FW-80, Taisite Co., Tianjin, China) and sieved using a 60-mesh sieve. Ten grams of dried lentinus edodes powder were extracted for 6 h with 200 mL of distilled water at 100°C in a beaker. After filtration, the filtrate was precipitated with threefold of dehydrated alcohol overnight. The precipitate was collected by centrifugation at 4,000 rpm for 15 min (TDL-5-A low speed desktop centrifuge, Anting Scientific Instruments Factory, Shanghai, China) and dissolved with distilled water. One milliliter of the polysaccharide solution was placed into a 50 mL flask and brought to a constant volume with distilled water. One mL of diluted polysaccharide solution was placed into a 25 mL volumetric flask and then brought to a constant volume with distilled water. One milliliter of diluted polysaccharide solution was combined distilled water and brought to constant volume with distilled water. Removing 1 mL diluted polysaccharide solution, then water was added to 2 mL volume finally, then 1.0 mL 6% phenol solution and 5.0 mL concentrated sulfuric acid solution was added. The solution was allowed to stand for 10 min, shaken and after it was aside 20 min at room temperature, the optical density was determined at 490 nm. The percentage polysaccharides yield (%) was calculated using the polysaccharide standard curve.

Standard for sensory evaluation: Comprehensive Weight Grade Method was used to evaluate the sensory quality of dried lentinus edodes. The best score is 100, as a lentinus edodes sample with good quality should be given high scores. According to Chinese Fresh Lentinus Edodes Classification Standards and reference, the weighted regulations were showed in Table 1. An appraisal group with ten members judged the sensory characteristics of the dried lentinus edodes.

Optimization of microwave vacuum drying: When the vacuum degree was below -90 kPa, serious browning discoloration would appear on the surface of lentinus edodes. Comparing the quality and energy consumption comprehensively, -90 kPa was selected as one of the parameters during microwave vacuum drying. A Second Order Regressive Orthogonal Composite Design was applied to optimize the microwave power (X_1) and load (X_2). The sensory score (Y_1), polysaccharide content (Y_2) and dying time (Y_3) were chosen as the response values. According to reference, the zero level l = (upper level + lower level) /2. The axis γ value could be found based on the number of factors P and testing times m_0, For example, when $p = 2$ and $m_0 = 1$, $\gamma = 1$ could be found in the table. The factors and levels are shown in Table 2 and the results are shown in Table 3.

Table 4: Regression equation and statistical verification of different indexes

Regression model	Statistic of Durbin-Watson	Related coefficient R^2	Variance F	Significant level p
Y_1	2.9605	0.998	133.04	0.001
Y_2	3.2088	0.997	87.940	0.002
Y_3	3.1814	0.996	76.910	0.002

RESULTS AND ANALYSIS

Optimization of microwave vacuum drying for lentinus edodes: Based on the results in Table 3, the regression model (formulas 1, 2, 3) for dried lentinus edodes with safety moisture content was analyzed using DPS software. Each formula indicates the relationship between each response and factor:

$$Y_1 = 81.778 + 1.667 X_1 - 1.417X_2 - 4.166X_1^2 - 3.416 X_2^2 - 2.750X_1X_2 \quad (1)$$

$$Y_2 = 4.067 - 0.333X_1 + 0.449X_2 - 0.224X_1^2 - 0.308X_2^2 - 0.042X_1X_2 \quad (2)$$

$$Y_3 = 9.000 - 2.450X_1 + 2.200X_2 - 0.150X_1^2 - 0.100X_2^2 - 0.250X_1X_2 \quad (3)$$

where,

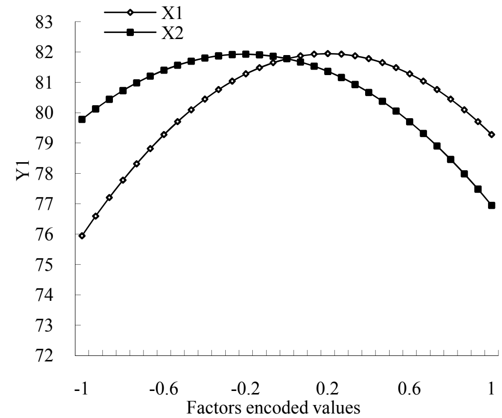
Y_1, Y_2 & Y_3 : The sensory score, polysaccharide content (%) and drying time (min), respectively

X_1 & X_2 : The microwave power (W) and load (g), respectively

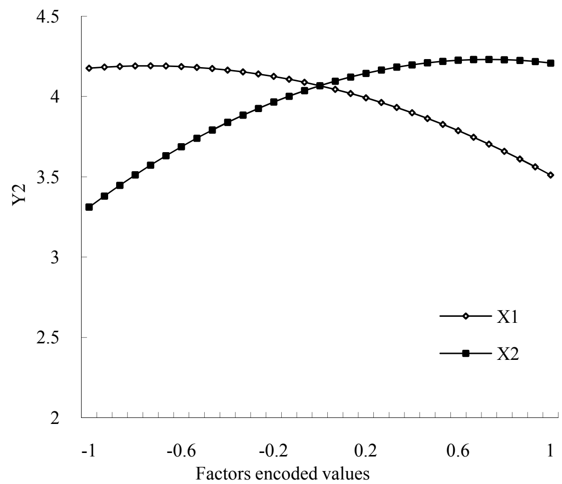
Table 4 shows the results of the significance test of the model which was checked through an Analysis of Variance (ANOVA). Based on the results, the Durbin-Watson statistics (Error statistics between measured value and calculated value) were all around 2.0, indicating that the model was suitable and there was a close relationship between factors and response values. According to the analysis, $F_1 = 133.04 > F_{0.01}$ (5, 3) = 28.24, $0.01 > p_1 = 0.001$ indicating the regression equation Y_1 was significant at $\alpha = 0.01$ level and the regression model was fit for the experiment. $F_2 = 87.94 > F_{0.01}$ (5, 3) = 28.24, $0.01 > p_2 = 0.002$ indicating the regression equation Y_2 was significant at $\alpha = 0.01$ level and the regression model is fit for the experiment. $F_3 = 76.91 > F_{0.01}(5, 3) = 28.24$, $0.01 > p_3 = 0.007$ indicating the regression equation Y_3 was significant at $\alpha = 0.01$ level and the regression model was fit for the experiment.

Based on the analysis of regression coefficients for each response value obtained, the order of the factors which influence the sensory score was:

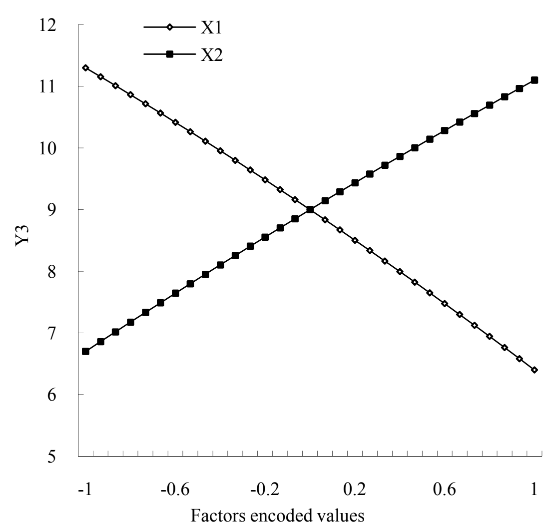
- Microwave power (X_1), load (X_2)
- The order of the factors which influence the polysaccharide content was: load (X_2), microwave power (X_1)
- The order of the factors which influence the drying time was: microwave power (X_1), load (X_2)



(a)



(b)



(c)

Fig. 1: Effect of single factor on, (a) sensory score, (b) the content of polysaccharides, (c) drying time

Analysis on the influence of each single factor: After solving the regression equation for each response value, Fig. 1 shows the effects of each factor on every response.

As shown in Fig. 1a, the sensory score at first increased and then decreased with an increase of both microwave power and load. The influence curve of microwave power on the sensory score reached a maximum when the level was 0.3 and the influence curve of load on the sensory score reached a maximum when the level was -0.3. Drying temperature and water evaporation rate could be improved by increasing the microwave power which could restrain the enzymatic browning, reduce the browning rate on the surface of lentinus edodes, provide a good appearance for the lentinus edodes, resulting in a higher sensory score. But when the power became too high, the plait parts of lentinus edodes would appear partially cooked. It affected the comprehensive sensory score. Through reducing the load, it could reduce the microwave energy absorbed by the lentinus edodes and avoided over-coking in the plait parts of lentinus edodes and resulted in higher sensory scores. But when there was a greater amount of load, the drying time was extended. The growing vapor in the cavity could cause enzyme browning and the Maillard reaction, so it can increase the rate of browning on the surface and then make lower sensory score.

According to Fig. 1b, the polysaccharide content decreased with increasing microwave power and the higher the microwave power, the declining amplitude of the curve of polysaccharide content would be larger. The polysaccharide content increased with the rise of load. When the load level was around 0.2, the increasing amplitude of polysaccharide content decreased. Increasing of microwave power could lead a higher drying temperature and the loss of polysaccharide would increase. When there was a heavy load, the microwave energy absorbed by the lentinus edodes reduced the quality. It can reduce the drying temperature to improve the rate of polysaccharide loss. But in that case, it will also extend the drying time, which would increase the rate at which polysaccharides are lost. When the load was in higher level, the increasing amplitude of polysaccharide content decreased.

According to Fig. 1c, the influence of each factor on the drying time reveals a linear relation. Drying time decreased as microwave power increased and drying time increased as load increased. The increase in microwave power accelerated the thermal motion of internal water in the lentinus edodes. The water quickly reached the boiling point at a high speed which shortened the drying time. In a tight cabinet with a larger load, more water in the lentinus edodes should evaporate. However, the larger load also reduces the microwave energy absorbed by unit quality of lentinus edodes and extends the drying time.

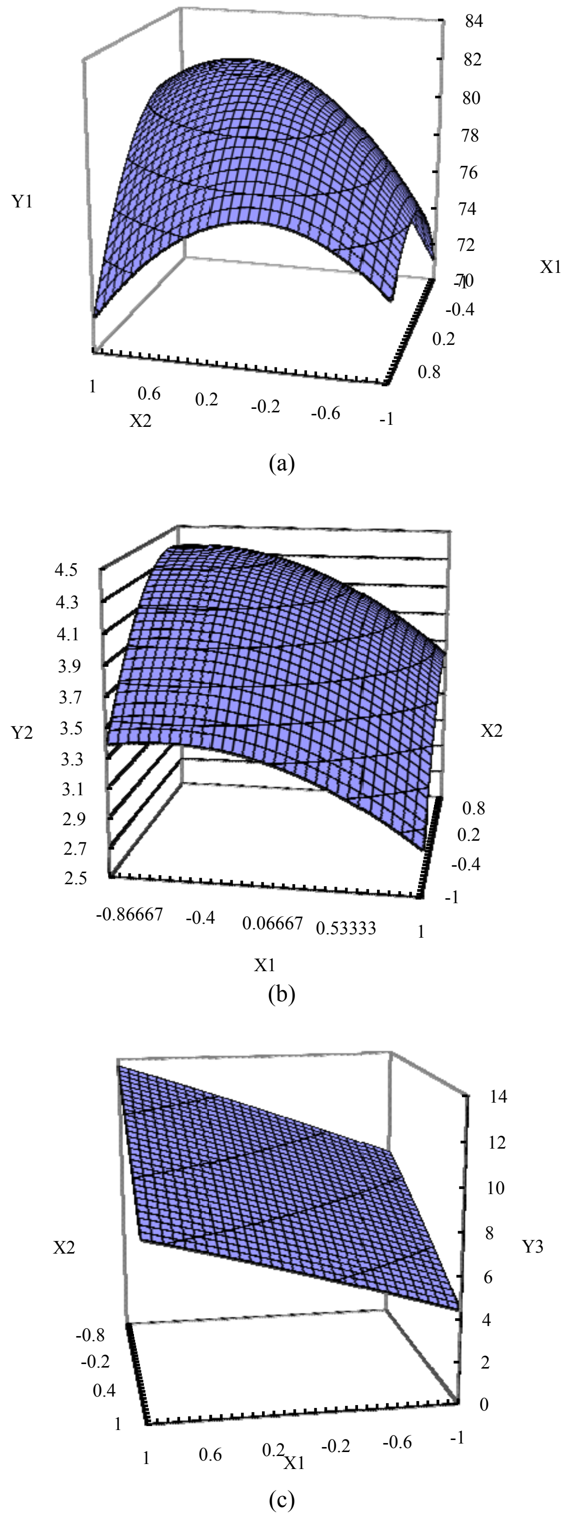


Fig. 2: Interaction of microwave power and load on, (a) sensory score, (b) the content of polysaccharides, (c) drying time

Analysis of two independent variables: Figure 2 shows the interaction effect of two factors based on the regression models.

As Fig. 2a shows, under the same microwave power level, as the volume of lentinus edodes loaded into the machine increased the sensory score first increased and then decreased. Under the same load level, the sensory score was increased at first and then decreased with an increase of microwave power. While the microwave power level was at 0.3 and load level was at -0.3, the sensory score was the highest.

As Fig. 2b shows, at the same load level, the polysaccharide content decreased with the increasing of microwave power. At the same microwave power level, the polysaccharide content increased with the rise of load. The optimization point was around level -0.8 of microwave power and level 0.8 of load.

As Fig. 2c shows, at the same load level, the drying time decreased with the increasing of microwave power. At the same microwave power level, the drying time increased with the rise of microwave power. The optimization point was around level 1 for microwave power and level -1 of load.

Optimization of microwave vacuum drying parameters: Sensory score, polysaccharide content and drying time should be calculated to optimize microwave vacuum drying parameters. $X = (X_1, X_2)$ indicates the parameters of the solution set and $Y = (Y_1, Y_2, Y_3)$ indicates the index set, these can then be used for seeking out the optimized conditions in the test range. According to the extreme value point in the equation, optimum conditions could be obtained.

- Y_{1max} = 82.3, X = (0.31, -0.33) were the process conditions which achieved the highest sensory score, that is to say X = (3929, 133) was the actual numerical value. It shows the sensory score for microwave vacuum dried lentinus edodes was high under high microwave power and low load.
- Y_{2max} = 4.379, X = (-0.82, 0.78) were the process conditions which achieved the most polysaccharide content, that is to say X = (2148, 189) was the actual numerical value. It shows there was more polysaccharide content in microwave vacuum drying lentinus edodes under appropriate microwave power and load.
- Y_{3max} = 4.35, X = (1, -1) were the process conditions which cost the shortest drying time, that is to say X = (4000, 100) was the actual numerical value. It shows there would be a shorter microwave vacuum drying time under strong microwave power and lower load.

Optimization of microwave vacuum drying comprehensive response value: During the microwave vacuum drying, microwave power and load parameters influenced each response value of dried lentinus edodes. To obtain a shorter drying time, higher sensory score and high polysaccharide content, it is necessary to consider the influence of each factor on the lentinus edodes. Thus integrated optimization was used to find the best parameters which satisfied all three objective functions.

This was a multi-objective nonlinear optimization problem and it would be turned into a single objective for nonlinear optimization by the evaluation function method. A larger optimization value of objective function Y_1 and Y_2 tended to be chosen, while a smaller optimization value of objective function Y_3 was better. Also, when dealing with the relationship among three objectives, each function should be standardized because of the different dimensions among them. Taking the test response as factors, then factors set D = {sensory score, polysaccharide content, drying time} = $\{d_1, d_2, d_3\}$. Parameters in formulation 4, 5, 6 would be substituted by results calculated from formulation 1, 2, 3 and got membership functions of each factor:

$$d_{1i} = (Y_1 - Y_{1min}) / (Y_{1max} - Y_{1min}) \quad (4)$$

$$d_{2i} = (Y_2 - Y_{2min}) / (Y_{2max} - Y_{2min}) \quad (5)$$

$$d_{3i} = (Y_{3max} - Y_3) / (Y_{3max} - Y_{3min}) \quad (6)$$

There was a linear relationship between d_{1i}, d_{2i}, d_{3i} and Y_1, Y_2, Y_3, so it translated finding the extreme value from objective function into finding the maximum from efficacy coefficient d_{1i}, d_{2i}, d_{3i}.

Let be:

$$F = \lambda_1 d_{1i} + \lambda_2 d_{2i} + \lambda_3 d_{3i} \quad (7)$$

F indicates comprehensive performance response evaluation sets, λ_1, λ_2, λ_3 was a group of weighted coefficient depending on the importance of sensory evaluation, polysaccharide content and drying time. Satisfaction conditions: $\lambda_1>0$, $\lambda_2>0$, $\lambda_3>0$ and $\lambda_1 + \lambda_2 + \lambda_3 = 1$.

The weighted coefficient of each response value was decided on the production practice. The weighted coefficient of sensory evaluation (λ_1), polysaccharide content (λ_1) and drying time (λ_3) was 0.4, 0.25 and 0.35, respectively. Equation (8) was obtained by substitution of λ_1, λ_1, λ_3 in Eq. (7):

$$F = 0.4d_{1i} + 0.25d_{2i} + 0.35d_{3i} \quad (8)$$

The integrated response evaluation sets were considered as the new response value and then a regression analysis of each process parameter was made. The regression equation of integrated response value could be obtained after data processing:

$$Y = 0.921 - 0.086X_1 + 0.104X_2 - 0.188X_1^2 - 0.173X_2^2 - 0.113X_1X_2 \quad (9)$$

Table 5: Analysis of variance procedure of predictive model *Y*

Residual standard deviation *S*	Statistic of Durbin-Watson	Related coefficient R^2	Variance F	Significant level p
0.0148	2.608	0.999	265.61	0.000

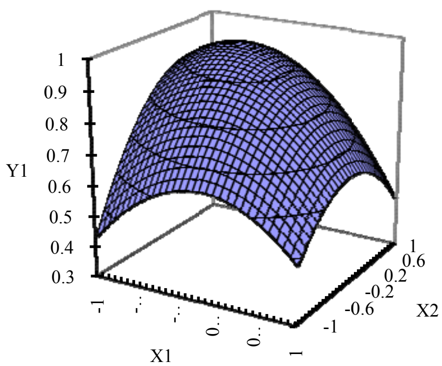


Fig. 3: Interaction of microwave power and load on synthetically performance parameters

Constraint conditions were: $2000 \le X_1 \le 4000$, $100 \le X_2 \le 200$

where,
X_1 : The microwave power
X_2 : The load

As Table 5 shows, $F = 265.61 > F_{0.01}(5, 3) = 28.24$ and $0.01 > p_1 = 0.000$ indicates the regression equation Y_1 was significant at level of $\alpha = 0.01$. The R^2 value for Equation Y_1 was 0.999, which was relatively high, indicating the good correspondence between the experiment and regression model.

Figure 3 shows, in the independent variable range, there was only one optimization point Y (-0.35, 0.41). This could mean $Y_{max} = 0.958$ in Eq. (9). Changing the coding value into an actual value, we found microwave power was 2650 W and load was 171 g. Substituting the coding value into regression model (1) - (3), so the predicted value of sensory evaluation, polysaccharide content and drying time were obtained and was 79.9, 4.29 and 10.8, respectively.

Based on the comprehensive optimization parameters, the process was verified by testing. When *X* was (2650 W, 171 g), the response Y was (80, 4.33, 11). This was close to the predicted value, indicating the optimizing results were correct. Therefore, they are the optimal microwave vacuum conditions.

CONCLUSION

In this study, Microwave vacuum equipment was employed to dry lentinus edodes. Response Surface Methodology was used to determine the optimal drying conditions. Effects of microwave power and amount of lentinus edodes load on lentinus edodes sensory evaluation, lentinus edodes drying rate and lentinan content were studied. The response surface with SAS9.2 analytical procedures RSREG get regression equation. The results showed the equations obtained significant levels and the optimal conditions of drying technique of lentinus edodes with microwave vacuum equipment were obtained as following: microwave power 2650 W, lentinus edodes load 171 g. Under this conditions, lentinus edodes sensory evaluation, lentinan content and drying time were 80, 4.33% and 11 min, respectively.

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