Optimization of Convective Hot Air Drying of *Ganodermalucidum* Slices Using Response Surface Methodology

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***Abstract*-** In this study, response surface methodology was applied to optimize the drying conditions of *Ganodermalucidum* slices during convective hot air drying, by referring to the retention of its active ingredients. The independent variables are drying temperature (40 to 80^{o}C), velocity of air circulation (0.19 to 1.66 ms^{-1}) and slice thickness (0.1 to 0.5 cm) whereas the response variables are ganoderic acid content (GA), water-soluble polysaccharides content (Poly), total drying time (DT) and equilibrium moisture content (EMC). Analysis of variance showed that all independent variables had significant effect on DT and the degradation of GA in the slices. Effect of drying temperature and air velocity were more significant on the retention of Poly than the effect of slice thickness whereas EMC of the slices was only affected by drying temperature. The optimum drying condition to maximize both GA and Poly in the slices at minimum drying time was found at temperature of 62.80^{o}C, air circulation of 1.66 ms^{-1} and 0.1 cm of slice thickness. At this optimum condition, the predicted responses for GA, Poly, DT and EMC were 37.043 µg / g DM, 0.414 mg / g DM, 80.11 min., and 3.41% d. b., respectively.

***Index Terms*-** Ganoderic acids, *Ganodermalucidum*, hot air drying, optimization,response surface methodology, water-soluble polysaccharides.

I. Introduction

Hot air drying is a conventional drying method for the drying of *G. lucidum* upon harvesting to reduce moisture content of the fruiting bodies to a level low enough for safe storage or to be sold in dehydrated form. It has been applied in *Ganoderma* processing industry as this method is simple and economical feasible. However, the bio-active ingredients of *G. lucidum* such as ganoderic acids and water soluble polysaccharides are heat sensitive and therefore tend to degrade in considerable ratio if improper drying condition, such as high drying temperature is applied (Chin et al., 2009). Similar findings were obtained for hot air drying of onion slices, betel leaves, and fingerroot when higher drying temperature (or lower drying temperature with longer drying time) was applied, which resulted in serious degradation of the active ingredients as well as physical quality (Praveen kumar et al., 2005; Rayaguru et al., 2011; Therdthai and Northongkom, 2011).

Optimization is therefore required to ensure rapid processing while maintaining optimum product quality especially in term of the retention of bioactive ingredients. Besides bioactive ingredients, the quality aspects for drying of food materials may include color parameters, texture, rehydration ratio and final moisture content, whereas the process parameters to be optimized include drying temperature, flow-rate of drying air, pressure, power intensity, thickness of slices and drying time, which are dependent on the method of drying (Giri and Prasad, 2007; Sobukola et al., 2010; Singh et al., 2008; Manivannan and Rajasimman, 2011).

Response surface methodology (RSM) is a useful technique for optimization studies. According to Montgomery (2001), RSM is a collection of mathematical and statistical techniques that is useful for modelling and analysis in applications where a response is influenced by several factors. This technique has been extensively applied to different drying process in fruits and vegetables (Madamba, 1997; Madamba and Liboon, 2001; Eren and Kaymak-Ertekin, 2007; Lidhoo and Agrawal, 2008; Perez-Francisco et al., 2008; Singh et al., 2006).

Thus far, study on the optimization of drying of medicinal mushrooms by referring to the retention of bioactive ingredients is not available in the literature. Several papers have so far dealt with the optimization of drying process to maximize the retention of bioactive ingredients (or conversely, minimize the undesirable active components) in other food products for instances total phenolic content, flavonoid content and total volatile base nitrogen (TVBN) compounds using RSM (Shi et al., 2008; Erbay and Icier, 2009; Silva et al., 2010). Erbay and Icier (2009) optimized the operating conditions and the process time of a pilot scale heat pump dryer for the drying of olive leaves, by referring to the total phenolic content, total antioxidant loss, final moisture content of olive leaves and exergic efficiency of the drying chamber. High exergic efficiency with minimum total phenolic content and antioxidant activity loss was found at the optimal drying temperature of 53.43^{o}C with air velocity of 0.64 ms^{-1} for drying time of 288.32 minutes. Using the same drying method, the optimum operating conditions of heat pump dryer that yielded maximum specific moisture evaporation rate (SMER) and drying rate (DR) with minimum total volatile base nitrogen (TVBN) and color change (ΔE) of horse mackerel, was successfully determined at drying temperature of 30^{o}C, velocity of air circulation at 1.5 ms^{-1} and osmostic pre-drying treatment in 9.9% sodium chloride (NaCl) solution (Shi et al., 2008).

Furthermore, Erbay and Icier (2009) also found that hot air drying at temperature of 51.16°C, air velocity of 1.01 ms^{-1} and process time of 298.68 minutes corresponded to the minimum loss of both total phenolic content and antioxidant activity with maximum exergetic efficiency when optimization study was performed for hot air tray drying of olive leaves. Similar to this, Silva et al., (2010) optimized the convective hot air drying process of flavonoid-rich Inga edulis leaves and found that Inga edulis leaves dried at 70°C with air flow velocity of 1.4 ms^{-1} showed minimum loss of flavanols content with insignificant degradation of flavonols (as compared to freeze dried product) at total drying time less than 40 minutes.

It is evident that optimization is an essential tool to formulate an efficient drying process which in turn produces high quality of dried product. It is crucial to the *Ganoderma* processing industry to carry out the process in an operating condition that can maximize the retention of both ganoderic acids and water-soluble polysaccharides as they are the most important quality attribute which translate to the commercial value of this medicinal mushroom in the commercial market. Thus, the objective of this research was to optimize the operating conditions of convective hot air drying (which is the technique applied in the industry now) of *G. lucidum* slices by maximizing the retention of crude ganoderic acids and water soluble polysaccharides content, while minimising processing time, using response surface methodology.

II. MATERIAL

Fruiting bodies of G. lucidum was supplied by GanofarmSdn. Bhd., TanjungSepat, Selangor DarulEhsan, Malaysia. Slices of desired thickness were obtained by cutting the fruiting bodies with vegetable slicer to obtain torispherical shape (height = 2.3 ± 0.1cm, length = 5.3± 0.1cm).It's the foremost preliminary step for proceeding with any research work writing.

III. METHODS

A. Hot air drying

Slices of *G. lucidum* (0.1 to 0.5 cm thickness) were dried in a laboratory scale hot air circulation oven (Memmert, Germany, range 20-250°C with accuracy of 0.5°C) at temperature range of 40 to 80°C and velocity of air circulation of 0.19 to 1.66 ms-1.The drying process was terminated when equilibrium moisture content (EMC) of the samples was achieved.EMC refers to the final moisture content of the dried samples when no change in sample weight (W) is observed at a certain drying condition. EMC can be obtained from equation (1):

$$Equilibrium\ Moisture\ Content\ (d.b): \frac{W_{eq} - W_d}{W_d} \times 100\% \quad (1)$$

Where subscripts d and eq denote bone dry and equilibrium, respectively.

B. Analysis of crude ganoderic acids

Dried samples at EMC were ground into powder using a mechanical grinder (Retsch, SM100, Haan, Germany) which is attached with a sieve (conidur holes, 5 mm) to obtain a homogeneous powder size. The powder (17 ± 0.1 g) was subjected to extraction process for 5 days at room temperature using 180 ml of 95% (v/v) ethanol. During extraction, the powder in ethanol solution was shaken for 24 hours using a mechanical shaker (Model 903, PROTECH, Malaysia). After the removal of the solid powder by vacuum filtration, the supernatants were dried at 45°C under vacuum condition (150 mbar) in rotary evaporator (Heidolph, 4000 series, Schwabach, Germany) until all ethanol was vaporized. The residue was then suspended in distilled water (10 ml) and later extracted with 10 ml chloroform (Fisher, Pittsburgh, PA) for 24 hours. After removal of water by centrifugation (6000 rpm, 15 min.), the ganoderic acids in the chloroform extract was further extracted with 5% (w/v) aqueous sodium hydrogen carbonate (NaHCO3) in order to convert the ganoderic acids into ganoderic acids salts which is insoluble in chloroform but miscible in water. After removal of chloroform phase, the basic aqueous solution containing ganoderic acids salts was neutralized with hydrochloric acid (HCl) (2N) until the pH of the solution was lower than 3.0 to yield pure crude ganoderic acids which are soluble in organic solvent. Finally, the crude ganoderic acids was dissolved in absolute ethanol (99.4% v/v, Fisher, Pittsburgh, PA) and absorbance was measured at 245 nm in a spectrophotometer (Biochrom, Libra S12, UK) (Fang et al., 2002).

The standard curve for quantitative analysis of crude ganoderic acids content in the dried samples was obtained using thymol (Sigma, Milwaukee, WI) as standard solution (Tang and Zhong, 2003) whereas absolute ethanol was used as blank solution. The standard curve is shown in Figure 1.

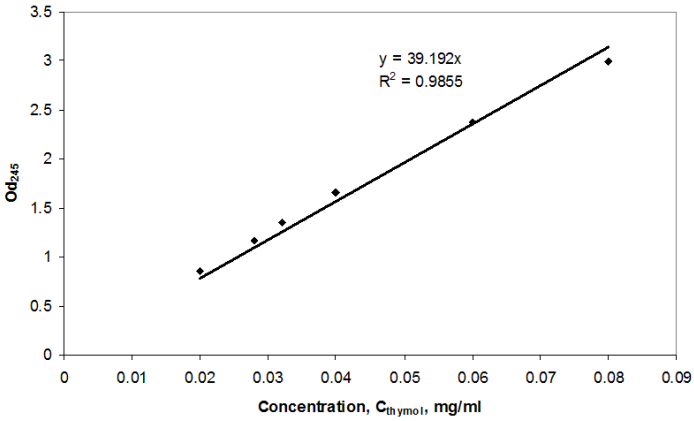


Figure 1: Profile of the standard curve of thymol concentration (C_{thymol}) which varies linearly with optical density (Od) at 245 nm.

C. Analysis of water-soluble polysaccharides

The total water-soluble polysaccharides content were determined based on colored reaction of polysaccharides and their derivatives with phenol and concentrated sulphuric acid(Cui et al., 2006).

Dried samples at EMC were ground into powder using a mechanical grinder (Retsch, SM 100, Haan, Germany). The powder (1 ± 0.1 g) was subjected to hot water extraction (50 ml) at 60 - 65°C to accelerate the extraction rate without affecting the stability of water-soluble polysaccharides (Chang et al., 2006). During extraction, the powder in the hot water was shaken for more than 15 hours using a mechanical shaker (Model 903, PROTECH, Malaysia). After the removal of the solid powder by vacuum filtration, the supernatants were dried at 50°C under vacuum (100 mbar) in a rotary evaporator (Heidolph, 4000 series, Schwabach, Germany) until all water was vaporized. The polysaccharides were then washed with 85% ethanol which was vaporized again in the rotary evaporator at 45°C and 150 mbar. The residue was then dissolved with distilled water to form a solution. The solution was then transferred to a 250 ml flask, which was then diluted to 250 ml with distilled water. 2 ml of the solution was pipet into a 10 ml centrifuge tube and 1 ml of 5% phenol was added. The mixture was shaken for 2 minutes. 5 ml of concentrated sulphuric acid (H_2SO_4) (98% v/v) was then added to the solution and shaken for another 5 minutes. The concentration of water-soluble polysaccharides in the solution was determined quantitatively by measuring the absorbance at 490 nm using a spectrophotometer (DR 2800, Hach, USA).

The standard curve for quantitative analysis of total water-soluble polysaccharides content in the dried samples was plotted using β-1,3-glucan (Sigma, Milwaukee, WI) as standard solution(Cui et al., 2006) whereas distilled water was used as blank solution. The standard curve is shown in Figure 2.

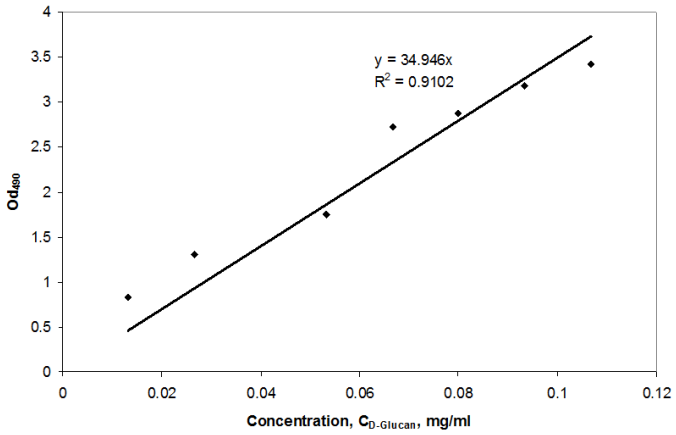


Figure 2: Profile of the standard curve of β-1,3-Glucan concentration (C_{D}-glucan) which varies linearly with optical density (Od) at 490 nm.

D. Experimental design

The effect of three independent variables, A (drying temperature), B (velocity of air circulation) and C (slice thickness), on four response variables namely crude ganoderic acids content (GA), water-soluble polysaccharides (Poly), total drying time (DT) and equilibrium moisture content (EMC) of the slices was evaluated by using response surface methodology (RSM). The variable levels were selected on the basis of preliminary drying experiments and the restriction of equipment setting such as the velocity of air circulation. 15 experiments were performed according to Box and Behnken design with three levels of each independent variable and 3 central points (Box and Behnken, 1960). Table 1 shows the levels of variable applied whereas the combination of variables and the corresponding responses for response surface analysis are shown in Table 2. The behaviour of the response surface was investigated for each of the response variables (Y_i). Experiment data were fitted to a second order polynomial model and the regression coefficients were obtained. The generalized second order polynomial model proposed for predicting the response variables is given as:

$$Y_i = \beta_o + \beta_A A + \beta_B B + \beta_C C + \beta_{AA} A^2 + \beta_{BB} B^2 + \beta_{CC} C^2 + \beta_{AB} AB + \beta_{AC} AC + \beta_{BC} BC \quad (2)$$

Where β_o, $\beta_{A,B\ and\ C}$, $\beta_{AA,BB\ and\ CC}$, and $\beta_{AB,\ AC\ and\ BC}$are the constant, linear, quadratic and cross-product regression coefficients, respectively and A, B, C are the coded independent variables of drying temperature, velocity of air circulation and slices thickness.

Table 1: Independent variables used in optimization study.

Variables (Unit)	Symbol Code	Variable levels		
Temperature,T (°C)	A	40	60	80
Air circulation, V (ms^{-1})	B	0.19	0.93	1.66
Slice thickness, t (cm)	C	0.10	0.30	0.50

E. Analysis of data

Response surface analysis of the experimental data in Table 2 was carried out using a commercial statistical package Design Expert, version 8.0.2 (Stat-Ease Inc, Minneapolis, MN). Regression analysis and analysis of variance (ANOVA) were conducted by fitting equation (2) to the experimental data to determine the regression coefficients and statistical significance of model terms. The significance of the model terms was assessed by F-ratio at a probability (p) of 0.05. Model adequacies were determined using model analysis, lack of fit test, coefficient of determination (R^2), predicted error sum of squares (PRESS) and coefficient of variation (CV).

F. Optimization procedure

Numerical optimization was performed using Design Expert software. Multiple responses were optimized simultaneously through the use of a desirability function that combines all the responses into one measurement (Eren and Kaymak-Ertekin). The desirability function D(x) is defined as:

$$D(x) = (d_1 \times d_2 \times .... \times d_n)^{1/n} \quad (3)$$

Where d_1, d_2,…,d_n are responses and n is the total number of responses in the measure. Numerical optimization method finds operating conditions (combination of independent variables) that maximizes the desirability function, ranging from zero (least desirable) outside of the limits to one (most desirable) at the goal

Table 2: The experimental design data for the response surface analysis.

Exp. No.	Run No.	Variables			Responses (Y_i)			
		T (^oC)	V (ms^{-1})	t (cm)	GA (µg / g DM)	Poly (mg / g DM)	DT (min.)	EMC (% d.b.)
1	15	40	0.19	0.30	35.401	0.343	400	10.01
2	9	80	0.19	0.30	31.644	0.389	90	2.06
3	12	40	1.66	0.30	38.009	0.361	255	10.3
4	10	80	1.66	0.30	34.974	0.384	75	1.61
5	11	40	0.92	0.10	34.528	0.326	120	9.16
6	6	80	0.92	0.10	29.708	0.363	80	2.06
7	7	40	0.92	0.50	33.238	0.327	315	10.12
8	3	80	0.92	0.50	27.141	0.332	120	2.13
9	2	60	0.19	0.10	31.183	0.380	120	3.80
10	5	60	1.66	0.10	38.993	0.416	90	3.96
11	14	60	0.19	0.50	27.112	0.380	255	4.41
12	4	60	1.66	0.50	28.955	0.408	150	4.25
13	13	60	0.92	0.30	30.783	0.361	120	4.21
14	8	60	0.92	0.30	30.909	0.365	115	4.6
15	1	60	0.92	0.30	31.230	0.357	105	4.75

Table 3: Desired goals for independent variables and responses

Independent variables / Responses	Goal	Weight (1: least important; 5: most important)
Drying Temperature, T (^oC)	In the range	-
Air Circulation, V (ms^{-1})	In the range	-
Slice thickness, t (cm)	In the range	-
GA (µg / g DM)	Maximize	5
Poly (mg / g DM)	Maximize	5
DT (min.)	Minimize	5
EMC (% d. b)	In the range	-

(most favorable response values). The desired goal for each independent variable and response was chosen. The independent variables were kept within the range while the responses were set to maximum for both GA and Poly, and minimum for DT. Different weights were also assigned to each goal to adjust the shape of desirability function for optimization of the multiple responses (Table 3).

G. Verification of models

The adequacy of response surface model (equation 2) for predicting the optimum response values was verified by conducting experiments under the recommended optimum conditions. The responses of the experimental and predicted values were compared in order to check the validity of the models. The standard error between the experimental value and predicted value is defined as:

$$\sigma = \sqrt{\frac{\Sigma(Z_i - Z_i')^2}{N}} \quad (4)$$

Where σ is the standard error, Z_i is a predicted value, Z_i' is an experimental value and N is the number of replication.

IV. RESULTS AND DISCUSSION

Table 4 shows the ANOVA results for different runs of drying experiment. Analysis of variance shows the models are statistically significant for all responses at 95% confidence level.

Apparently, the lack of fit and pure error for total drying time are the highest with sum of squares error 8410 and 116.67 respectively, which results in relatively high value of residual variance, PRESS and CV. This indicates that the model is not adequate to represent the experiment data, although both R^2 and adj-R^2 are higher than 0.80. According to Bas and Boyaci (2007), large value of R^2 does not necessarily imply that the regression model is good one (Bas and Boyaci, 2007).However, the adeq. precision value (signal to noise ratio) of the model which is greater than 4.0 indicates an adequate signal, such that the model can be used to navigate the design space(Montgomery, 2001).

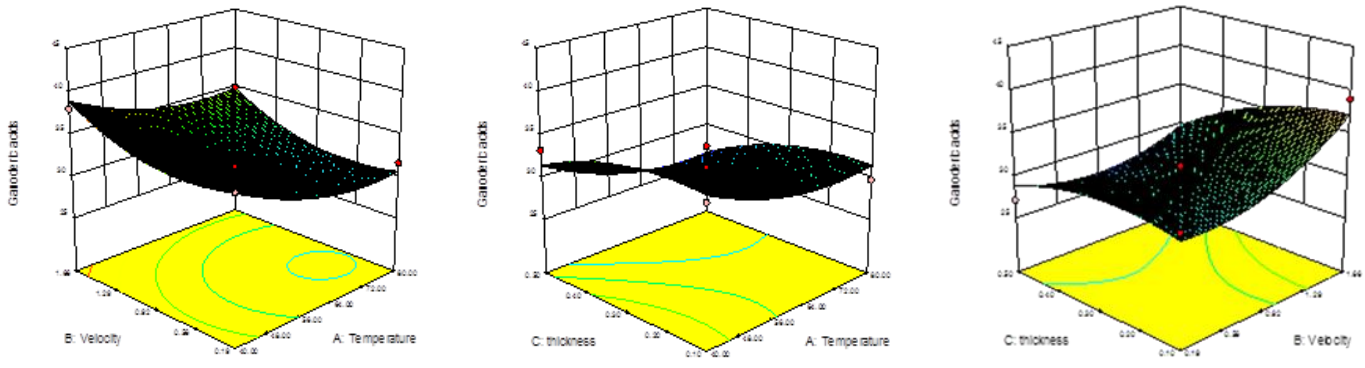
Despite the lack of fit is significant in the case of ganoderic acids content, acceptable PRESS, CV (less than 10%), $R^2$and

adeq. precision values indicating that the model is sufficient to predict the response (Giri and Prasad, 2007). Analysis of variance also confirms that the models predicted the water-soluble polysaccharides content and EMC accurately with insignificant lack of fit, low PRESS and CV values, and high R^2, adj-R^2 and adeq. precision values. As shown in Table 4, drying temperature is a significant factor for all the responses. The

Table 4: ANOVA table showing the independent variables as linear, quadratic and interaction terms on each response variable and coefficients (β_i) in terms of actual levels of the independent variables

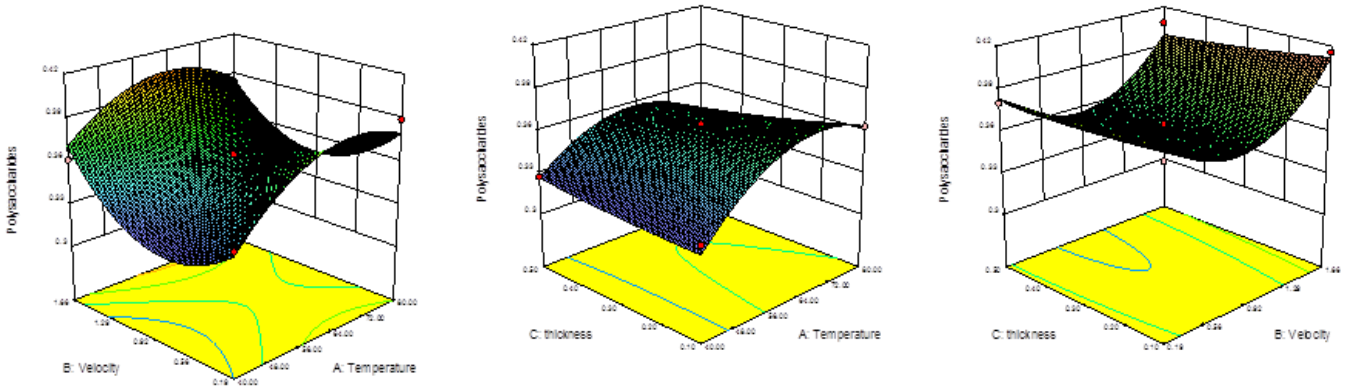
Source	df	**Ganoderic acids (GA)**			**Polysaccharides (Poly)**			**Drying time (DT)**			**EMC**		
		β_i	Sum of squares	*p*-value	β_i	Sum of squares	*p*-value	β_i	Sum of squares	*p*-value	β_i	Sum of squares	*p*-value
Model	9	51.119	161.38	0.041*	0.083	9.90E-3	0.009*	760.994	1.26E5	0.016*	27.965	137.11	<0.001*
A	1	-0.642	39.23	0.020*	9.21E-3	1.55E-3	0.011*	-18.170	6.57E4	0.002*	0.656	125.80	<0.001*
B	1	-2.646	30.41	0.031*	-0.075	7.30E-4	0.044*	-292.953	1.09E4	0.053	1.386	3.20E-3	0.860
C	1	27.428	40.35	0.019*	0.087	1.79E-4	0.242	-1.01E3	2.31E4	0.014*	9.111	0.46	0.075
A^2	1	4.53E-3	12.12	0.118	-6.30E-5	2.34E-3	0.005*	0.121	8.63E3	0.074	4.05E-3	9.68	<0.001*
B^2	1	4.107	18.18	0.069	0.062	4.17E-3	0.001*	80.213	6.93E3	0.100	-0.268	0.08	0.404
C^2	1	-40.807	9.84	0.151	0.034	6.94E-6	0.804	72.917	31.41	0.897	-6.763	0.27	0.148
AB	1	0.012	0.13	0.851	-3.96E-4	1.36E-4	0.299	2.211	4.23E3	0.176	-0.013	0.14	0.278
AC	1	-0.080	0.41	0.744	-1.99E-3	2.54E-4	0.174	9.688	6.01E3	0.119	-0.056	0.20	0.203
BC	1	-10.148	8.90	0.167	-0.013	1.41E-5	0.725	127.55	1.41E3	0.405	-0.544	0.03	0.622
Residual	5	-	17.08	-	-	5.06E-4	-	-	8.52E3	-	-	0.46	-
Lack of fit	3	-	16.97	0.009*	-	4.71E-4	8.90	-	8.41E3	0.021*	-	0.31	0.458
Pure error	2	-	0.11	-	-	3.53E-5	-	-	116.67	-	-	0.16	-
Total	14	-	178.46	-	-	0.010	-	-	1.35E5	-	-	137.57	-
R^2	-	0.904	-	-	0.951	-	-	0.934	-	-	0.997	-	-
Adj-R^2	-	0.732	-	-	0.864	-	-	0.823	-	-	0.991	-	-
PRESS	-	271.81	-	-	7.62E-3	-	-	1.35E5	-	-	5.28	-	-
CV (%)	-	5.73	-	-	2.75	-	-	25.70	-	-	5.90	-	-

*Significant at $p< 0.05$ (95% level).



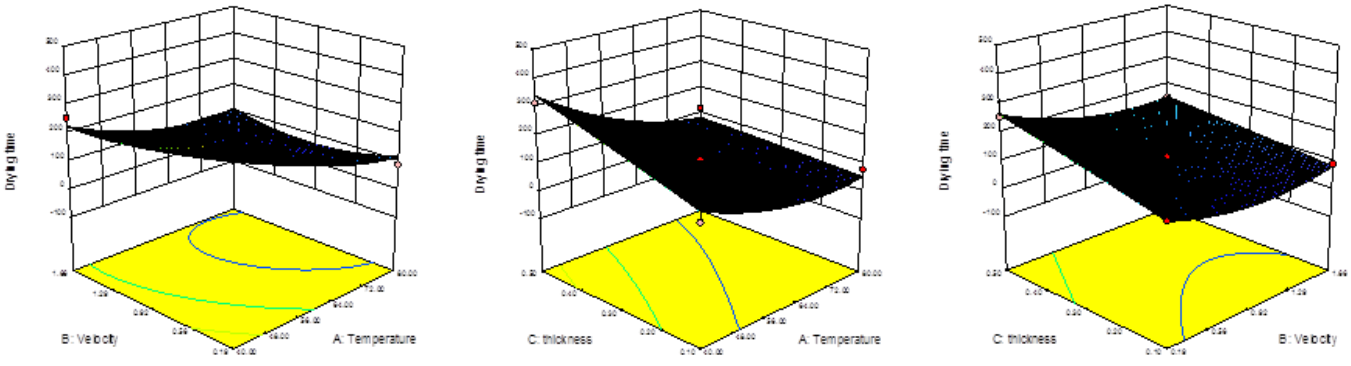
(a) (b) (c)

Figure 3: Profile of response surface and contour plots for ganoderic acids content (GA) (µg / g DM) as a function of (a) velocity of air circulation (ms^{-1}) and temperature (^oC) , (b) thickness (cm) and temperature (^oC) and (c) thickness (cm) and velocity of air circulation (ms^{-1}).



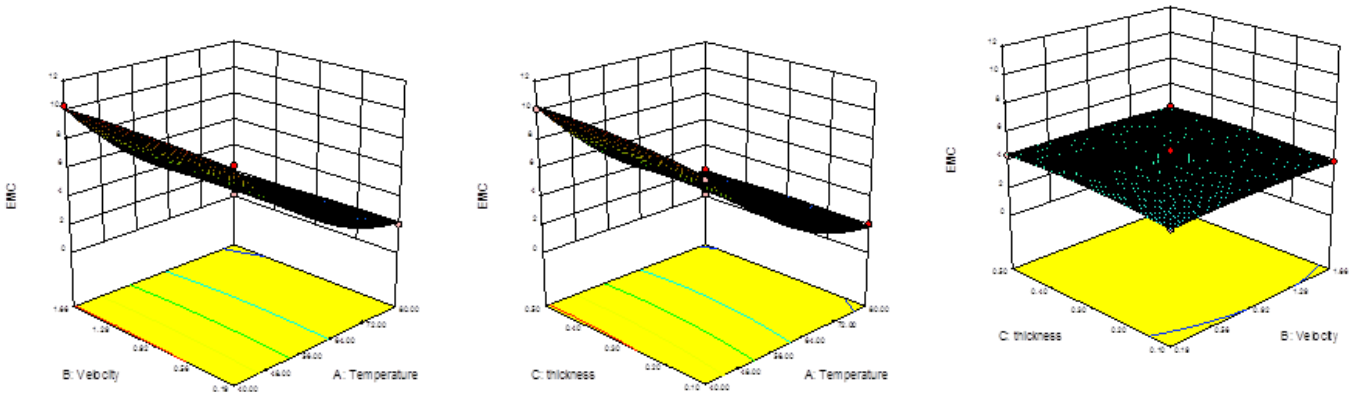
(a) (b) (c)

Figure 4: Profile of response surface and contour plots for water-soluble polysaccharides content (Poly) (mg / g DM) as a function of (a) velocity of air circulation (ms^{-1}) and temperature (^oC), (b) thickness (cm) and temperature (^oC) and (c) thickness (cm) and velocity of air circulation (ms^{-1}).



(a) (b) (c)

Figure 5: Profile of response surface and contour plots for total drying time (DT) (min.) as a function of (a) velocity of air circulation (ms^{-1}) and temperature (^oC), (b) thickness (cm) and temperature (^oC) and (c) thickness (cm) and velocity of air circulation (ms^{-1}).



(a) (b) (c)

Figure 6: Profile of response surface and contour plots for equilibrium moisture content (EMC) (% d.b) as a function of (a) velocity of air circulation (ms^{-1}) and temperature (^oC), (b) thickness (cm) and temperature (^oC) and (c) thickness (cm) and velocity of air circulation (ms^{-1}).

velocity of air circulation affected the ganoderic acids and water-soluble polysaccharides content prominently during the drying process. Nevertheless, there is no significant contribution of slice thickness to the water-soluble polysaccharides content and EMC of the slices. To visualize the combined effect of the two factors on the response, the response surface and contour plots were generated for each of the models in the function of two independent variables, while keeping the remaining independent variable at the central value (Figure 3 to 6).

A. Ganoderic acids (GA)

The second order polynomial regression equation (response surface model) describing the effect of process variables on crude ganoderic acids content of *Ganoderma* slices is given in equation (5).

$$GA = 51.119 - 0.642T - 2.464V + 27.428T + 4.53 \times 10^{-3}T^2 + 4.107V^2 - 40.807T^2 + 0.012TV - 0.08TT - 10.148VT \quad (5)$$

Table 4 clearly shows that the ganoderic acids content is significantly affected by all independent variables namely drying temperature (T), velocity of hot air circulation (V) and slice thickness (t) at $p < 0.05$. Drying temperature and slice thickness are the main factors affecting the degradation of ganoderic acids in the slices during drying. Both drying temperature and slice thickness exhibit a negative linear effect on ganoderic acids content whereas the velocity of hot air circulation exerts a positive linear effect to this response variable, which are shown in Figure 3(a to c). However, it was found that the quadratic and interaction effects of all the independent variables did not influence the ganoderic acid content significantly ($p > 0.05$) as compared to linear term (Table 4). Therefore, *Ganderma* slices dried with the combination of lower drying temperature, smaller slice thickness and higher air velocity could retain higher amount of crude ganoderic acids. Drying at high temperature stimulates the volatilization of ganoderic acids (Chin et al., 2009). On the other hand, high velocity of air circulation enhances the drying rate and reduces heat treatment time for the drying process, which in turn mitigates the decomposition of ganoderic acids by enzymes (Chin et al., 2009; Cui et al., 2006).

B. Water-soluble polysaccharides (Poly)

ANOVA results in Table 4 show that water-soluble polysaccharides content of the slices is significantly ($p<0.05$) influenced by drying temperature and velocity of air circulation. There is no significant ($p>0.05$) contribution of slice thickness to the degradation of water-soluble polysaccharides during the drying process. The response surface model for water-soluble polysaccharides relating the process variables is given in equation (6).

$$Poly = 0.083 + 9.21 \times 10^{-3}T - 0.075V + 0.087t - 6.30 \times 10^{-5}T^2 + 0.062V^2 - 0.034t^2 - 3.96 \times 10^{-4}TV - 1.99 \times 10^{-3}Tt - 0.013Vt \quad (6)$$

Figure 4 (a and b) shows that the quadratic term of drying temperature had a significant ($p< 0.05$) negative effect on water-soluble polysaccharides while the linear term has a positive effect. Both linear and quadratic terms of the velocity of air circulation show significant ($p< 0.05$) positive effect on water-soluble polysaccharides content (Figure 4 (a and c)). Similar to ganoderic acids content, the interaction terms of the independent variables demonstrated insignificant ($p> 0.05$) effect on the retention of water-soluble polysaccharides during the drying process. Water-soluble polysaccharides exhibit reverse behaviour in terms of drying temperature as compared to ganoderic acids content. Higher amount of water-soluble polysaccharides were observed when higher drying temperature and velocity of air circulation were applied during the drying process, as compared to low temperature drying such as drying at 40^oC. Polysaccharides tend to be hydrolyzed when water is bound to the molecule, with the aids of hydrolytic enzymes in weak acidic condition (Kallander and Landel, 2007; Zhao et al., 1999; Cui et al., 2006). Hence, water content in the slices has to be removed instantly at relatively high drying temperature and velocity of air circulation during the drying process. Generally, hydrolytic enzyme is denatured at temperature higher than 50^oC. Thus,

drying at high temperature could reduce the hydrolysis degree of water-soluble polysaccharides as the enzyme activity is slow. In addition, high velocity of air circulation increases the rate of moisture removal and halts the hydrolysis process of water-soluble polysaccharides in the slices. Nevertheless, water-soluble polysaccharides content was found to decrease gradually at drying temperature higher than 60^{o}C, as shown in Figure 4 (a and b). This may be due to the thermal degradation of polysaccharides at high drying temperature which is resulted from the breakdown of cell wall polysaccharide network(Cohen and Yang, 1995; Simal et al., 2000; Chang et al., 2006).

C. Drying time (DT)

The total drying time for a drying process is affected by drying condition and slice thickness. Referring to Table 4, drying temperature can be seen to have the strongest effect on the total drying time, followed by slice thickness and velocity of hot air circulation. It is significantly affected by the linear terms of all the independent variables (Table 4). Both drying temperature and velocity of air circulation show negative linear effect on total drying time while the slice thickness shows positive linear effect, as depicted by Figure 5 (a – c). Drying at higher temperature and high velocity of air circulation intensifies the drying rate of the slices and leads to a shorter drying time (Chin et al., 2008). For smaller slice thickness, the moisture evaporation rate of the drying process is enhanced due to a shorter distance for the moisture to travel from the interior of the slices to the surface, which in turn shortens the total drying time (Chin et al., 2009). The response surface model relating the total drying time to the process variables is given in equation (7).

$$DT = 760.994 - 18.170T - 292.953V - 1.01 \times 10^{-3}t + 0.121T^2 + 80.213V^2 + 72.917t^2 + 2.211TV + 9.688Tt + 127.55Vt \quad (7)$$

D. Equilibrium moisture content (EMC)

Drying temperature is the main process variable that affects the EMC of *Ganoderma* slices significantly at $p < 0.05$ (Table 4). As shown in Figure 6 (a and b), the EMC is negatively affected by the linear term of drying temperature, whereas its quadratic terms show an opposite effect. The velocity of air circulation and slice thickness do not affect the EMC significantly ($p > 0.05$), neither in terms of linear, quadratic nor interaction terms of both variables (Figure 6 (c)). Chen et al., (2001) reported that the equilibrium moisture content is a function of equilibrium relative humidity and drying temperature. Higher drying temperature with lower relative humidity stimulates the moisture transfer from the inner part of the slices and contributes to the attainment of lower moisture content (Chin et al., 2008). The response surface model relating the total drying time to the process variables is given in equation (8).

$$EMC = 137.11 + 125.80T + 3.2 \times 10^{-3}V + 0.46t + 9.68T^2 + 0.08V^2 + 0.27t^2 + 0.14TV + 0.20Tt + 0.03Vt \quad (8)$$

E. Optimization and experimental validation

Numerical optimization procedures were carried out to predict the optimum drying condition and slice thickness within selected ranges which generated the desired response goal. Table 5 indicates that 19 solutions were obtained at different desirability for the various combinations of independent variables and the results of the responses. The highest desirability value (nearest to the response goal), which is 0.931 (solution 1), was selected as the optimum conditions for hot air circulation oven drying of *Ganoderma* slices. The optimum condition is found at 62.80^{o}C of drying temperature, 1.66 ms^{-1} of air circulation and 0.1 cm of slice thickness. At this point, the predicted responses for GA, Poly, DT and EMC are 37.043 µg / g DM, 0.414 mg / g DM, 80.11 min., and 3.41% d.b, respectively. Drying experiments were performed using the derived optimum condition and the resulted responses were determined. Table 6 shows the comparison between predicted and experimental values for each of the response. The experimental response values are in agreement with the predicted values.

V. CONCLUSION

Respond surface analysis was effectively used to determine the effect of drying conditions and slice thickness on the retention of active ingredients, equilibrium moisture content as well as the total drying time of *Ganoderma* slices during hot air drying. Based on the profiles of response surface, drying at lower hot air temperature, smaller slice thickness and higher velocity of air circulation retained higher amount of ganoderic acids in the dried slices whereas higher retention of water-soluble polysaccharides was found in the slices dried at higher drying temperature and higher velocity of air circulation, without significantly affected by the slice thickness. In terms of total drying time and equilibrium moisture content of the slices, drying temperature shows the strongest effect to these responses as compared to the other variables such as velocity of air circulation and slice thickness. Results of numerical optimization show that maximum retention of ganoderic acids and water-soluble polysaccharides at minimum total drying time of the slices could be achieved at drying temperature of 62.8^{o}C, air circulation of 1.66 ms^{-1}and slice thickness of 0.1 cm.

NOMENCLATURE

T	Drying temperature	oC
V	Velocity of air circulation	ms^{-1}
t	Slice thickness	cm
DM	Dry material	-
GA	Ganoderic acids	µg/g DM
Poly	Water-soluble polysaccharides	mg/g DM
DT	Drying time	min
EMC	Equilibrium moisture content	% d.b
d.b	Drying basis	-
SD	Standard deviation	-
N	Number of responses	-
ANOVA	Anaysis of variance	-
PRESS	Predicted error sum of squares	-

Table 5: Solutions for optimum conditions

Solution number	T (^oC)	V (ms^{-1})	t (cm)	GA (µg / g DM)	Poly (mg / g DM)	DT (min.)	EMC (% d.b.)	Desirability
1	62.80	1.66	0.10	37.043	0.414	80.11	3.41	0.931
2	62.35	1.66	0.10	37.071	0.414	80.27	3.48	0.931
3	61.65	1.66	0.10	37.119	0.413	80.60	3.61	0.931
4	62.06	1.66	0.10	37.081	0.413	81.03	3.55	0.930
5	65.50	1.66	0.10	36.890	0.414	79.96	2.97	0.928
19 (Last solution)	67.28	0.19	0.18	30.529	0.393	118.10	2.98	0.571

Table 6: Predicted and experimental values of the responses at optimum drying conditions

Responses	Predicted values	Experimental values ± SD	Standard error
GA (µg / g DM)	37.043	36.397 ± 0.716	0.909
Poly (mg / gDM)	0.414	0.409 ± 0.05	0.086
DT (min.)	80.11	80 ± 0.577	0.577
EMC (% d.b.)	3.41	3.47 ± 0.028	0.096

*SD: Standard deviation

CV	Coefficient of variation	-
d	Responses	-
p	Probability	-

Greek letters:

β	Regression coefficient	-
σ	Standard error	-

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