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EFFECT OF SURFACE AREA AND TEMPERATURE ON DRYING CHARACTERISTICS OF BETEL LEAF (*PIPER BETLE* L.)

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Abstract
Betel leaf is the green gold of India for its food and medicinal values. In India, betel leaf is cultivated around 55,000 hectors of land encompassing about 20 lakhs Boroj and employing same number of agricultural families. But due to its perishability and short shelf life, 35-70% wastage takes place every year due to storage and transport, logistics. So, drying can be an effective tool to preserve the betel leaf for a long time period. Therefore, the aim of the study was to optimize the drying time as a function of leaf surface area and drying temperature as well as determine the changes in drying characteristics for changes in drying temperature and leaf surface areas. Piper betel leaf cultivated in Midnapore district, West Bengal, India, was considered as raw material for the study. The experiments were conducted at three range of temperature and leaf surface area. Temperature and leaf surface area both have a significant effect on drying rate and in decrement of total drying time ($p<0.05$). With increase in surface area of exposure and drying temperature the moisture diffusivity initially increases but later on decreases. Three drying mathematical models were applied and one response surface model was developed in this study. Wang & Singh model and response surface model both were found to be best ($p<0.05$) for describing the drying kinetics.

Key words: betel leaf, surface area, drying characteristics, mathematical modeling, response surface modeling

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1.INTRODUCTION

The deep green heart shaped leaves of betel vine are popularly known as *Paan* in India. It is also known as Nagaballi, Nagurvel, Saptaseera, Sompatra, Tamalapaku, Tambul, Tambuli, Vaksha Patra, Vettilai, Voojangalata etc in different parts of the country (CSIR, 1969; Guha and Jain, 1997). The scientific name of betel vine is *Piper betle* L. It belongs to the family Piperaceae, i.e. the Black Pepper family (Gunther, 1952). There are about 100 varieties of betel vine in the world, of which about 40 are found in India and 30 in West Bengal (Guha, 1997; Maity, 1989; Samanta, 1994). The key varieties produced in West Bengal are Bangla, Satchi, Mitha (Guha, 2006).
The betel leaf has a vast impact on Indian economy and it can be established by several facts discuss following. In India betel leaf is cultivated around 55,000 hectors of land encompassing about 20 lakhs Boroj and employing same number of agricultural families. In west Bengal 20,000 hectors where the leaf is cultivated, encompassing about 4-5 Lakhs boroj and same number of families are associated. The annual yield of a good crop is about 60-70 leaves/ plant and 6-7 million leaves/ ha (Guha and Jain, 1997; ICAR, 1997; Jana, 1996; Maity, 1996, Guha, 2006). So, from the gross production of leaves around Rs. 9000 million is contributed to the Indian economy every year including an income of Rs 800-1000 million to the state of West Bengal (Guha, 2006).
Betel leaf has a very short shelf life and very perishable commodity. 35-70% wastage takes place every year due to storage and transport, logistics. Moreover, the surplus leaf, if not disposed properly, it may cause environmental pollution and health hazards. The surplus leaves also fed to cattle (Guha, 2006). So, drying can be an effective tool to preserve the betel leaf to increase shelf life and leads a way

to further use in development of food and pharmaceutical products. Different drying techniques have been performed for drying of betel leaves like sun drying, solar drying, shade drying, mechanical drying, and microwave drying, vacuum drying etc (Rayaguru et al., 2007; Ramalakshmi et al., 2002).
Therefore, the objectives of this present study were (1) to determine the drying characteristics as a function of leaf surface area and drying temperature, (2) Optimize drying time with respect to independent variables of drying, and (3) development of suitable mathematical models of drying based on experimental data. The developed mathematical models of drying characteristics may help to predict directly the time or moisture ratio for drying at different temperature.

2. MATERIAL AND METHODS

2.1 Collection and preparation of raw material

The leaves used in this study were of Piper variety cultivated in Midnapore district, West Bengal, India. Leaves were procured from local market. The petiole was separated first. Then the leaves were washed with running tap water and distilled water to make free from dust followed by removal of excess surface water by tissue paper. Then the leaves were divided into three categories first category where the leaves were chopped by knife into small pieces (approximate surface area- 0.000366±0.00014 square meter), Second category where the leaves were divided from middle (approximate surface area- 0.005405±0.00318 square meter) and in third category where the leaves were kept intact (approximate surface area- 0.010808±0.000692 square meter).

2.2 Drying Equipments

The hot air drying experiments were carried out in a batch type tray drier (Suan Scientific Instruments & Equipments). The drier was equipped with an electrical heater, blower (230rpm), temperature indicators, and a temperature controller (45-100ºC).

2.3 Design of drying experiment and drying prcedure

A full factorial design with three level treatment of temperature (50°C, 55°C, 60°C) and three type shape and size of leaf (chopped, divided from middle and intact leaf) was chosen for drying. The design leads to nine sets of experiments. The tray drier was run intermittently in order to stabilize the desired temperatures (i.e. 50ºC, 55ºC, 60ºC respectively) inside the chamber. Three different types of leaves was kept on a butter paper and placed inside tray drier. The weight of the samples (i.e. chopped leaf and leaf divided from middle) were measured at 5 minutes interval for first 30minutes, then 10 minutes interval for 30-60minutes, followed by 15 minutes interval for 60-120minutes, and then 30 minutes interval till constant weight achieved, respectively. The weight of intact leaf was measured 30minutes interval till constant weight achieved. The initial moisture content of the fresh betel leaves was determined (AOAC 1990). The initial moisture content was found as 84.72±0.85 (wet basis).

2.4 Determination of drying rate

Drying rate can be defined as

$$DR= [M_{t+\Delta t}-M_t]/ \Delta t \qquad (1)$$

Where, M_t is moisture content at t, $M_{t+\Delta t}$ is moisture content at t+Δt, t is time in minutes, DR is drying rate.

2.5 Determination of moisture ratio (MR)

Moisture ratio of samples during drying was determined using following equation

$$MR= (M_t-M_e)/ (M_o-M_e) \qquad (2)$$

Here, M_t is moisture content at any specific time, M_e is the equilibrium moisture content and M_o is the initial moisture content.

2.6 Determination of moisture Diffusivity

The moisture migration process during drying is complex and often involves one or more transport mechanisms such as liquid diffusion, vapour diffusion, surface diffusion and hydrostatic pressure differences (Mujumdar et al, 2008). The term effective diffusivity (D_{eff}) is defined to describe the rate of moisture movement, no matter which mechanism is involved. Fick's diffusion equation for particles with slab geometry was used for calculation of effective moisture diffusivity. The equation is expressed as

$$MR = [(8/\pi^2)*\exp\{(-\pi^2 D_{eff}t)/(4L^2)\}] \quad (3)$$

The equation can be rewritten as $D_{eff} = [\{\ln MR - \ln(8/\pi^2)\}/\{(\pi^2 t)/(4L^2)\}]$ (4)

Now, $k_o = [(\pi^2 D_{eff})/(4L^2)]$
The slope (k_o) is calculated by plotting ln (MR) vs. time to determine the effective diffusivity at a particular temperature.

2.7 Statistical analysis

A main effects analysis of variance (ANOVA) was used to establish the significance of differences among the values of drying rate at the 0.05 significance level. Statistical analyses were performed using Statistica (version 7, Stat Soft, Inc., USA).

2.8 RSM Modelling

Relationships between the independent variables (temperature, time) and dependent variables (moisture ratio) for foam mat drying were studied. The regression equation was determined (using Statistica, version 7, Stat Soft, Inc., USA) using multiple regression technique by fitting second order regression equation (Khuri and Cornell, 1987) of the following type

$$Y=\beta_o + \sum_{i=1}^{n} \beta_i X_i + \sum_{i=1}^{n} \beta_{ii} X_i^2 + \sum_{i=1}^{n} \sum_{j=i+1}^{n-1} \beta_{ij} X_i X_j + e \quad (5)$$

where β_0, β_i, β_{ii}, β_{ij} are regression coefficients of variables for intercept, linear, quadratic and interaction terms, respectively, X_i, X_j are the independent variables, Y is the dependent variables n is number of independent variables. The relationships between the responses were judged by correlation multiple R, multiple R^2 which indicates the value of correlation coefficient and co-efficient of determination between the experimental and predicted data. The significance or P-value was decided at a probability level of 0.05.

2.9 Mathematical modeling of drying curves

For mathematical modeling, the thin layer drying equations presented in Table 1 were tested to select the best model for describing the drying curves of betel leaves. Selection of the best equation to explain the drying curve was done according to their coefficients of determination (R^2), root mean square error (RMSE) and chi square (χ^2) to determine the best fit. These parameters were calculated as follows

$$\chi^2 = \sum_{i=1}^{n} (MR_{exp,i} - MR_{pre,i})^2/(N-n) \quad (6)$$

$$RMSE = \sqrt{\sum_{i=1}^{n} (MR_{pre,i} - MR_{exp,i})^2/N} \quad (7)$$

Table 1: Selected drying models for describing drying behaviour of betel leaves

Model Name	Model equation	Reference
Modified page	$MR=\exp[-(kt)^n]$	Overhults et al. 1973; Balasubramanian et al. 2011
Henderson and Pabis	$MR = a \exp(-kt)$	Henderson & Pabis, 1961
Wang and Singh	$MR= at^2+ bt + 1$	Wang & Singh, 1978

3. RESULTS AND DISCUTION

3.1 Effect of leaf surface area and temperature on drying characteristics

The changes in drying rate have shown in Fig 1. The drying rate increased with increment in temperature. All the drying process took place in falling rate period. The constant decrease in drying rate is absent throughout the drying process. Similar observation was found earlier by for vacuum drying of betel leaf Wahida et al., (2012). It has also seen that the maximum drying rate achieved for leaves divided from middle and intact one at 55°C where as at 60°C the drying rate becomes almost constant (Table 1). One probable explanation is the internal diffusion rate with in the betel leaf that controls the drying process as well as drying rate. The same findings were suggested by Pin et al., (2009). ANOVA analysis showed that while increasing in temperature from 50°C to 55°C, temperature and leaf surface area has a significant effect on drying rate (drying temperature F value- 63.92, p value- 0.015, and leaf surface area F value-29.10, p value- 0.033) at $p<0.05$ level. Where as, when the elevation of drying temperature was from 55°C to 60°C took place, leaf size did not show any significant effect on drying rate. This is because of negligible changes in drying rate. However, throughout the drying process the elevation in drying temperature has a significant effect on overall drying rate (F value- 6.778, p value- 0.029) at $p<0.05$ level (Table 2). Similar observation was also found in earlier studies reported by Balasubramanian et al., (2010) for cabinet and tunnel drying of betel leaf.

Fig 2 shows the change in dimensionless moisture ratio with respect to time. It is evident from the curve that leaf divided from middle and intact leaf dried much faster than chopped leaf at 50 and 55°C. The drying time for chopped leaf was 210, 120, and 90 minutes at 50ºC, 55 ºC and 60 ºC respectively to drop down the moisture content to an average 3-4% level.

Where as, leaf divided from middle and intact leaf required 150, 105 and 105 minutes at 50ºC, 55 ºC and 60 ºC respectively to drop down the moisture content to an average 2-3% level. Hence, it can be concluded that, surface area in other terms size of the sample and temperature are the key factors and played a significant role in decreasing the drying time.

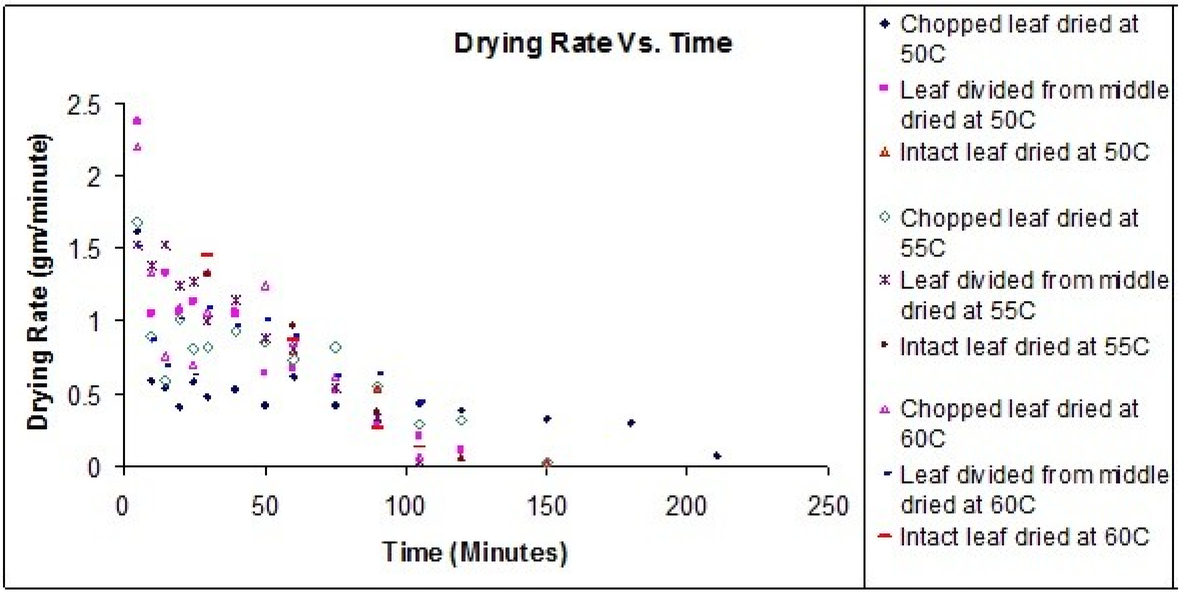

Fig 1: Change in drying rate w.r.t time

Table 2: Overall drying rates

Temperature	Chopped leaf	Leaf divided from middle	Intact leaf
50°C	0.385[a,b]	0.552[a,b]	0.550[a,b]
55°C	0.536[a,b]	0.780[a,b]	0.775[a,b]
60°C	0.780[a,]	0.789[a,]	0.777[a]

a- significantly different for elevation of temperature at $p<0.05$ level
b- significantly different for both of elevation in temperature and leaf size at $p<0.05$ level

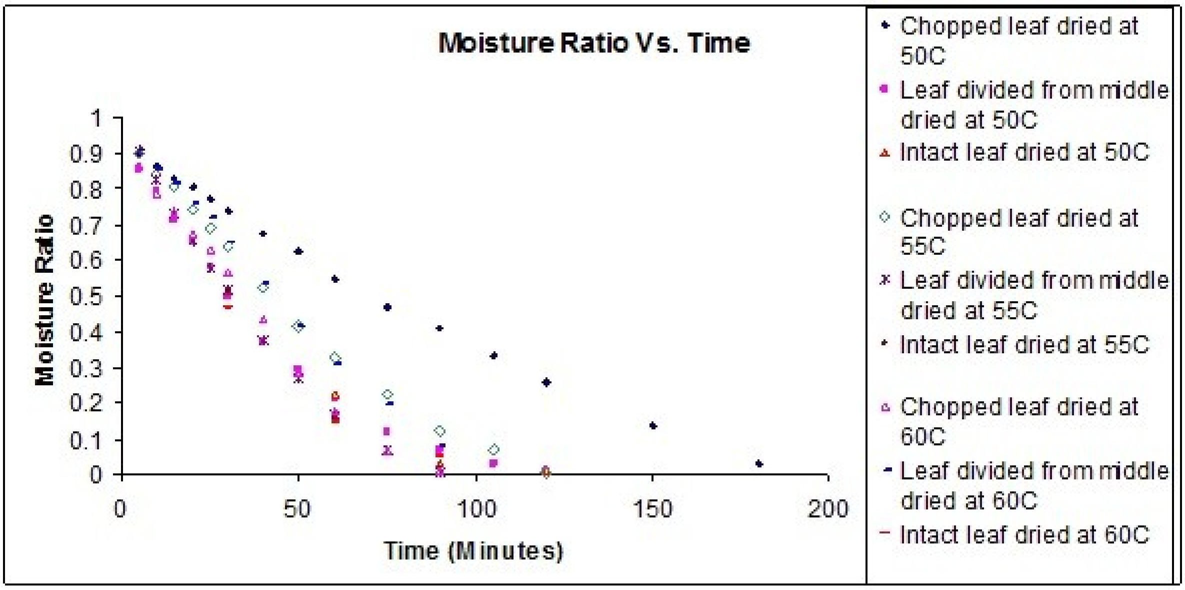

Fig 2: Changes moisture ratio w.r.t. time

The elevation of drying temperature increased the moisture removal and resulted substantial decrease in drying time. Similar findings of positive effect of drying temperature were also reported earlier by Balasubramanian et al., (2010); Doymaz and Pala (2002).

3.2 Effect of leaf surface area and temperature on effective moisture diffusivity

Table 3 shows the effective moisture diffusivity (D_{eff}). It has been seen that with the elevation in drying temperature the moisture diffusivity for chopped leaf increases. Where as, in case of leaf divided from middle and intact leaf the moisture diffusivity first increased with elevation in temperature from 50°C to 55°C but the moisture diffusivity decreases when drying temperature was elevated from 55°C to 60°C. One probable explanation is the drying rate reached to maximum at 55°C (Table 2) for leaf divided from middle and intact leaf. Due to this when the temperature was further elevated to 60°C the surface of the leaf became crust and it affect the internal diffusion. Because, the extra energy that released at high temperature may directly affect on the surface of the leaf. However, the internal diffusion rate controls the release of moisture and a fluctuation in release of moisture has already been observed in Fig 2. Hence, the effective moisture diffusivity at 60°C became lower than 55°C though the total drying time remains constant.

3.3 Response surface modelling

Firstly, the RSM model was fitted to response data of moisture ratio of chopped leave, leaf divided from middle, intact leaf respectively and individually (Table: 4). It was found that time and square term of time and interaction of time and temperature have significant effect on moisture ratio of chopped leaf at $p<0.05$.
The model equation is

$$MR= 2.541885- 0.053813*T+0.000443*T^2+0.01393*t+0.000016*t^2-0.000436*T*t \quad (8)$$

The value of multiple R and multiple R^2 is 0.995 and 0.990 respectively.

Where as, time and temperature, square term of time and square term of temperature have significant effect on moisture ratio of leaf divided from middle at $p<0.05$.

The model equation is

$$MR= 7.027666-0.233215*T+0.002231*T^2-0.130578*t+0.000072*t^2-0.000069*T*t \quad (9)$$

The value of multiple R and multiple R^2 is 0.996 and 0.993 respectively.

Table 3: Effective moisture diffusivity and its linear equation

Temperature (^oC)	Leaf Condition	Equations	K_o value	Effective moisture diffusivity (D_{eff})
50	Chopped leaf	y = -0.0162x + 0.2254	-0.0162	6.560E-09
50	Leaf divided from middle	y = -0.0358x + 0.3173	-0.0358	1.449E-08
50	Intact leaf	y = -0.0483x + 1.0085	-0.0483	1.995E-08
55	Chopped leaf	y = -0.0341x + 0.4921	-0.0341	1.380E-08
55	Leaf divided from middle	y = -0.0500x + 0.6260	-0.0500	2.024E-08
55	Intact leaf	y = -0.0578x + 1.2480	-0.0578	2.340E-08
60	Chopped leaf	y = -0.0453x + 0.5381	-0.0453	1.834E-08
60	Leaf divided from middle	y = -0.0265x + 0.2525	-0.0265	1.073E-08
60	Intact leaf	y = -0.0375x + 0.3530	-0.0375	1.518E-08

Table 4: Moisture ratio for different drying condition

Temperature (^oC)	Time (Minutes)	MR (Chopped Leaf)	MR (leaf divided from middle)	MR (Intact leaf)
50	5	0.9	0.856	-
50	10	0.863	0.793	-
50	15	0.83	0.712	-
50	20	0.804	0.648	-
50	25	0.769	0.579	-
50	30	0.739	0.5	0.516
50	40	0.674	0.372	-
50	50	0.622	0.295	-
50	60	0.546	0.213	0.226
50	75	0.468	0.118	-
50	90	0.41	0.068	0.031
50	105	0.33	0.03	-
50	120	0.259	0.011	0.008
50	150	0.138	-	-
50	180	0.027	-	-
55	5	0.896	0.907	-
55	10	0.84	0.823	-
55	15	0.803	0.73	-
55	20	0.74	0.654	-
55	25	0.69	0.576	-
55	30	0.639	0.515	0.513
55	40	0.524	0.375	-
55	50	0.417	0.267	-
55	60	0.326	0.168	0.156
55	75	0.223	0.069	-
55	90	0.12	0.006	0.016
55	105	0.066	-	-
55	120	0.007	-	-
60	5	0.865	0.909	-
60	10	0.784	0.856	-
60	15	0.738	0.815	-
60	20	0.671	0.754	-
60	25	0.629	0.716	-
60	30	0.564	0.65	0.466
60	40	0.435	0.534	-
60	50	0.282	0.414	-
60	60	0.178	0.307	0.147
60	75	0.065	0.195	-
60	90	0.012	0.08	0.049

The drying time and square term of time has significant effect on moisture ratio of intact leaf at $p<0.05$.

$$MR= 2.794714-0.055157*T+0.000398*T^2-0.025702*t+0.000089*t^2+0.000131*T*t \quad (10)$$

The value of multiple R and multiple R^2 is 0.996 and 0.993 respectively.

In the above equations 8, 9, and 10, T denotes temperature (^oC) and t denotes time (minute(s)). The value multiple R and multiple R^2 were found to be very good. All the R^2 values are the proportion of variation in the response attributed to the model was > 0.80, which implies that, the predicted values were fitted well with the experimental data and indicates that the models can be efficient for prediction of moisture ratio at different temperature and time.

3.4 Determination of best mathematical model

The moisture content data of different time and at different drying temperatures was converted to more useful moisture ratio and the curve fitting computations with the drying time were done by using the 3 drying models as given in Table 1. The results of analysis are given in Table 5. The best model describing the drying kinetics was chosen as with highest R^2, and lowest χ^2 and RMSE. Based on this criterion it was found that Wang and Singh model was best fit for the drying of betel leaves. A similar finding was also reported earlier by Das & Mazumder (2014) for drying of carrot.

Table 5: Values of drying constants and coefficients of different models for betel leaves

Drying Model	Temperature (^oC)	Type of Leaves	Constants	χ^2	RMSE	R^2
Henderson Pabis Model	50	chopped	a=1.2521, k=0.016	0.0149	0.1135	0.9409
		Divided from middle	a=1.3727, k=0.036	0.0124	0.1026	0.9607
		Intact	a=2.7426, k=0.048	0.0115	0.0758	0.9533
	55	chopped	a=1.6355, k=0.034	0.0391	0.1819	0.9056
		Divided from middle	a=1.8709, k=0.05	0.0521	0.2066	0.9033
		Intact	a=3.4816, k=0.058	0.0120	0.0632	0.9811
	60	chopped	a=1.7128, k=0.045	0.0465	0.1951	0.8658
		Divided from middle	a=1.2869, k=0.026	0.0099	0.0902	0.9401
		Intact	a=1.4239, k=0.038	0.0001	0.0059	0.9999
Wang and Singh Model	50	chopped	a=2E-05, b= -0.0085	0.0018	0.04	0.9862
		Divided from middle	a=9E-05, b= -0.0188	0.0007	0.0244	0.9971
		intact	a=8E-05, b= -0.0181	0.0008	0.0065	0.9982
	55	chopped	a=5E-05, b= -0.014	0.0004	0.0182	0.9976
		Divided from middle	a=9E-05, b= -0.0191	0.00003	0.0047	0.9998
		intact	a=1E-04, b= -0.0195	0.0026	0.0294	0.9996
	60	chopped	a=7E-05, b= -0.0178	0.00086	0.0266	0.993
		Divided from middle	a=3E-05, b= -0.013	0.00025	0.0144	0.9972
		intact	a=1E-04, b= -0.0215	0.0004	0.0115	0.9865
Modified Page Model	50	chopped	k=0.01134, n=0.9361	0.0027	0.0487	0.9707
		Divided from middle	k=0.02654, n=1.0883	0.0022	0.0438	0.9913
		Intact	k=0.02422, n=1.4742	0.00035	0.0132	0.9833
	55	chopped	k=0.02033, n=1.1594	0.0023	0.0439	0.9826
		Divided from middle	k=0.02762, n=1.2922	0.002	0.0394	0.99
		Intact	k=0.02556, n=1.6403	0.0006	0.0141	0.9965
	60	chopped	k=0.02646, n=1.1517	0.0042	0.059	0.9628
		Divided from middle	k=0.01741, n=1.0749	0.0025	0.0498	0.9805
		Intact	k=0.02717, n=1.2587	0.0003	0.0096	0.9987

4. CONCLUSIONS

Drying of betel leaves indicate that all the drying took place in falling rate period. The constant rate of drying is absent throughout the process. The total drying time reduced substantially with increase in drying temperature. At a constant temperature level the rate of drying increases with increasing surface area. The comparison of all the models Wang and Singh model showed the best fit. Where as, the response surface model was also showed very good fit.

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