ORIGINAL ARTICLE

Kinetics and Mathematical Modeling of Drying Characteristics of Curry (*Murraya koenigii., Rutaceae*) Leaves

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ABSTRACT Hybrid Drying is one of the best methods to preserve the heat sensitive components of fruits, vegetables, and herbs and also fastens the drying process. Curry (*Murraya koenigii., Rutaceae*) leaves were dried by two drying methods viz., 1. Conventional drying (CD) at 40, 50 and 60 °C with air velocity 5.2 m/s. 2. Vacuum assisted conventional drying (CVD) with 250, 400 and 600 mmHg are used to dehydrate the curry leaves. The dried leaves were analyzed for their retention of colour. Four drying models, including Lewis thin layer, Page, Midilli, and modified Henderson & Pebis model were fitted to drying data. Modified Henderson model adequately express the drying behaviour of curry leaves. The activation energy required for conventional vacuum drying of curry leaves was found to be 19.75 kJ/mol. The L*, a*, b*, ΔE, a*/b* colour characteristics of the dried leaves range from 39.4 to 44, 3.5 to -7.6, 36.2 to 42.7, 8.78 to 13.68, and -0.081 to -0.219 respectively. Conventional vacuum drying conditions of 60°C with 600mmHg resulted to dried leaves with desirable colour characteristics.

Keywords: Hybrid drying, Vacuum, Activation energy, Diffusivity, Curry leaves

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INTRODUCTION

Curry leaf (*Murraya koenigii., Rutaceae*), is a popular Indian leafy-spice used in all over India as a fresh form for its characterizing authentic flavor and distinct aroma. The curry leaf is even used by some other countries like Sri Lanka, Pakistan and other Asian Americans originating from South Asia. Curry leaves are nutritionally rich interns of Vitamins, minerals and other medicinal values as well. The demand for fresh and dehydrated curry leaves in food industries, pharmaceutical industries and Ayurvedic, has considerably increased over the last two decades due to the functional and antioxidant activities.

Drying is a preservation method of fruits and vegetables for long time with good quality. It is a process of moisture removal due to simultaneous heat and mass transfer. Agricultural products, especially fruits and vegetables require hot air in the temperature range of 45-60 ^{O}C for safe drying. When any agricultural product is drying under controlled condition at specific humidity as well as temperature it gives rapid superior quality of dry product[8]. Drying involves the application of heat to vaporize moisture and some means of removing water vapor after its separation from the food products. It is thus a combined and simultaneous heat and mass transfer operation for which energy must be supplied.

The conventional drying is more often used method in fruits and vegetable dehydration industries to reduce the time of drying. The high temperature process has the limitation on heat sensible parameters as color, flavor, texture, and nutritional value of dry curry leaves. A lower operating temperature, as well as a higher quality of products, can be achieved carrying out the process at reduced pressure. Hence hybrid drying (vacuum assisted conventional drying) can be applied to retention of heat sensible parameters like colour.

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MATERIALS AND METHODS

Preparation of Material

Curry Leaves were collected from the local Dharani Agro Farm from Moinabad, Hyderabad were used in this study. The leaves were rinsed with water to remove soil particles. These leaves were then washed with 0.1% hypochloride solution. Leaves were then spread on filter paper and kept under fan for 10 mins to remove the surface moisture. Later leaves were loaded into trays and dried in different drying conditions with different set of parameters.

The curry leaves were dehydrated by conventional drying without vacuum pressure at three different temperatures viz., 40, 50 and 60 ºC with constant air velocity 5.2 m/s and with three different vacuum pressures 250,400 and 600 mmHg, at three different temperatures viz., 40, 50 and 60 ºC.

Drying Experiment

Prior to drying experiments, the initial moisture content of curry leaves was determined AOAC [3] method using hot air oven drying method. 5 gm of the leaves sample was weighed into a pre-dried moisture pan covered and placed in hot air oven drier at 105±5 °C for 24 h. The initial and final weights of the sample were noted and the moisture content was calculated using Eq. (1)[3].

$$\text{MC}\ \% = \frac{\text{Intial weight} - \text{Final weight}}{\text{Intial weight}} * 100 \qquad \text{...(1)}$$

Where MC, Wo and Wd is the moisture content (%), weight (g) of sample and dried sample respectively.

The initial moisture content of the leaves was 66-74% while the final moisture content of the dried samples was in the range of 8.6-10.6% (w/w). In conventional drying, temperatures used to determine the drying characteristics of curry leaves were 40, 50 and 60°C. Fresh leaves of 35 g were used for each experimental run. The velocity of air in the dryer was maintained at 5.2 m/s. Leaves with bulk density of 0.10 gm/ml [25] were spread evenly in trays and placed in the oven after it had setted the experimental conditions. The reduction in moisture content of the leaves was constantly monitored at fixed intervals of 20 minute during the drying process. Drying was carried out until a constant moisture drop in samples was noticed. The dried sample were cooled were and preserved in a sealable polyethylene bags. The packaged samples were stored at room temperatures prior to further analysis. All the drying experiments were carried out twice.

Modeling of Drying Curves

The drying data were computed as moisture ratio (MR) using Eq. (2)[4].

$$MR = \frac{M}{M_o} \qquad \text{...(2)}$$

where *M* is the moisture content at different time and Mo is the initial moisture content.

In order to efficiently ascertain the drying kinetics of curry leaves, there is need to fit the drying behaviour with different mathematical models. The curve fitting of the hot air drying data was achieved with aid of a MATLAB software version 6.

Table 1: Drying Treatments

Treatment Code	Treatment Details
CDA2	Conventional drying 40 °C
CDB2	Conventional drying 50 °C
CDC2	Conventional drying 60 °C
CVDA1	Conventional vacuum drying 40 °C with pressure 250 mmHg
CVDB1	Conventional vacuum drying 50 °C with pressure 250 mmHg
CVDC1	Conventional vacuum drying 60 °C with pressure 250 mmHg
CVDA2	Conventional vacuum drying 40 °C with pressure 400 mmHg
CVDB2	Conventional vacuum drying 50 °C with pressure 400 mmHg
CVDC2	Conventional vacuum drying 60 °C with pressure 400 mmHg
CVDA3	Conventional vacuum drying 40 °C with pressure 600 mmHg
CVDB3	Conventional vacuum drying 50 °C with pressure 600 mmHg
CVDC3	Conventional vacuum drying 60 °C with pressure 600 mmHg

The different mathematical models need to be studied to establish the best suitable drying model for curry leaves drying kinetics behaviour in conventional vacuum drying. Four mathematical equations listed in Table 2 were used for this purpose[5]. The curve fitting of the conventional and conventional vacuum drying data was achieved with the support of MATLAB software version 6.

Statistical Analysis

The sum of square error (SSE), root mean square error (RMSE) and coefficient of determination (R2) were used to verify the reliability of the fits. The criteria used for picking the most excellent and reliable model was based on the highest value of R^2 and the lowest values RMSE and SSE [16, 17]. The statistical parameters were computed using Eqs. (3) and (5) respectively. N is the number of observations, MR_{cal},i is the predicted moisture ratio, MR_{exp},i is the experimental moisture ratio, and n is the number of constant.

$$R^2 = \frac{\sum_{i=1}^{N}(MR_i - MR_{cal,i}).\sum_{i=1}^{N}(MR_i - MR_{exp,i})}{\sqrt{[\sum_{i=1}^{N}(MR_i - MR_{cal,i})^2].\ [\sum_{i=1}^{N}(MR_i - MR_{exp,i})^2]}} \quad ...(3)$$

$$RMSE = \left(\frac{1}{N}\sum_{i=1}^{N}(MR_{cal,i} - MR_{exp,i})^2\right)^{\frac{1}{2}} \quad ...(4)$$

$$SSE = \sum_{i=1}^{N}(MR_{cal,i} - MR_{exp,i}) \quad ...(5)$$

Determination of Effective Moisture Diffusivity

Effective moisture diffusivity was determined using Eqs. (6) to (8) respectively as described by Doymaz [12]

$$MR = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\exp\left(-\frac{\pi^2(2n+1)^2}{4L^2}D_{eff}t\right) \quad ...(6)$$

where Eq. (6) relies on the postulation that the moisture distribution in the samples is uniform and has a stable diffusivity with negligible shrinkage: The slope (u) obtained from plotting ln (MR) against time issued in Eq. (8) to compute the moisture diffusivity of the samples.

$$\ln(MR) = \ln\left(\frac{8}{\pi^2}\right) - \left(\frac{\pi^2 D_{eff}}{4L^2}t\right) \quad ...(7)$$

where MR is moisture ratio, D_{eff} is the effective moisture diffusivity (m^2/s) and L is the half-thickness (m) of the samples.

$$\varphi = \frac{\pi^2 D_{eff}}{4L^2} \quad ...(8)$$

Determination of Activation Energy

The activation energy of the drying process was obtained using Eqs. (9)-(11)[4].

$$D_{eff} = D_0\exp\left(-\frac{E_a}{R(T + 273.15)}\right) \quad ...(9)$$

Eq. (9) could be expressed or re-written as Eq. (10) by taking the logarithm of both sides

$$\ln(D_{eff}) = \ln(D_0) - \frac{E_a}{RT_{abs}} \quad ...(10)$$

Where Do is the Arrhenius factor (m2 /s), Ea is the activation energy (kJ/mol), R is the universal gas constant (8.314 X 10^3 kJ/mol K), k is slope and T is the oven temperature (°C).

$$k = -\frac{E_a}{R} \quad ...(11)$$

ln D_{eff} was plotted against the absolute values of the given temperatures ($1/T_{abs}$). The slope (k) of the plot is equal to (-Ea/R).

RESULTS AND DISCUSSION:

Drying Characteristics of Curry Leaves

The curry leaves drying curves of conventional and vacuum drying at different temperatures, and vacuum pressures are presented in Figure 1. The initial moisture content of the leaves were reduced from 65.07 (w.b) to 9-10% (w.b). The drying data obtained from the experiments at temperatures (40, 50 and 60 °C) and vacuum pressures (250, 400 and 600 mmHg) were analysed with regards to removal of moisture

Table 2: Models Applied to the Conventional and Conventional Vacuum Drying of Curry Leaves

Model	Equation	References
Lewis thin layer	MR = exp(-kt)	[26]
Page model	MR = exp(-ktn)	[22]
Midlli *et al.*	MR = aexp(-kt^n) + bt	[24]
Modified Henderson and Pebis Model	MR = aexp(-kt) + bexp(-gt) + c exp(-ht)	[23]

with drying time. According to Ashtiani et al. [6], moisture content curves are more appropriate in unfolding the drying characteristics of foodstuffs.

The time needed to decrease the moisture present in the samples to a definite point was reliant on drying temperature, being the maximum in conventional drying at 40 °C (580 min) and lowest in conventional vacuum drying in all three pressure levels at 60 °C (160 min).

A short constant rate drying period at 0–20 min (Figures 1 to 4) was observed for all the drying temperatures and vacuum pressures used. This is could be attributed to the short initial settling down period of the samples in the

Figure 1: Moisture Ratio vs Drying Time of Conventional Drying Curves of Curry Leaves at Different Temperatures with Constant Velocity 5.2 m/s

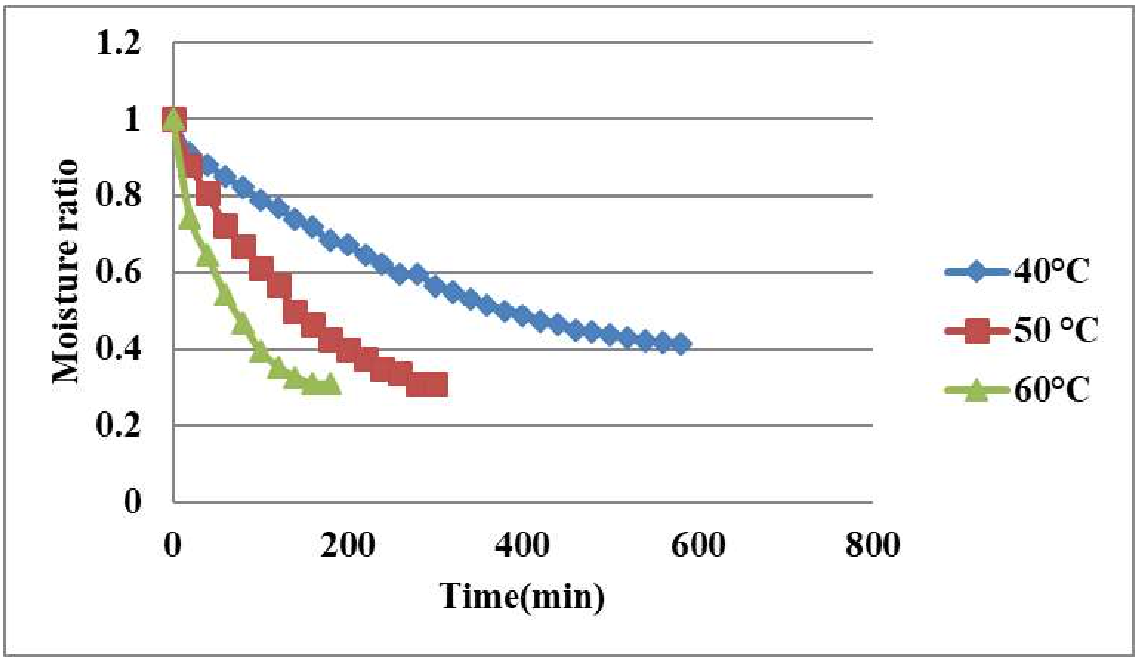
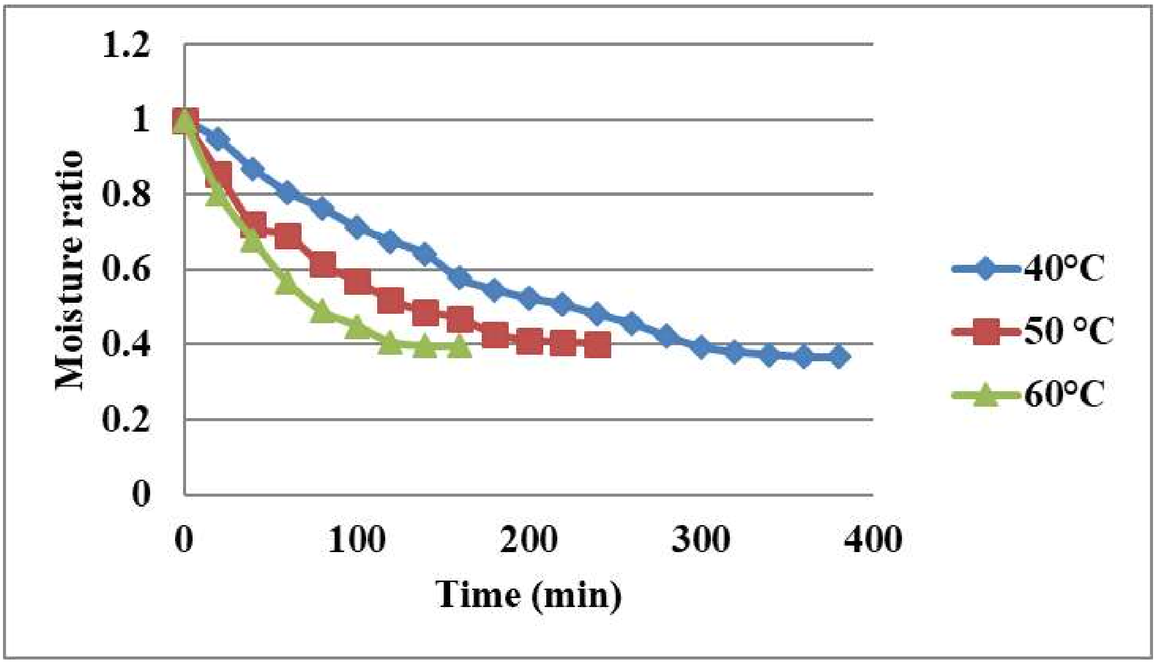


Figure 2: Moisture Ratio vs Drying Time of Conventional Vacuum Drying Curves of Curry Leaves with 250 mmHg at Different Temperatures



oven as the surface of the samples heats up to wet bulb temperature. In additionally the drying curves from the Figures 1 to 4 are shows that the drying of curry leaves happens mostly in the falling rate period. In falling rate period the water moment rate starts from the interior to the surface which falls below the rate which water evaporates to the surrounding air, therefore sample surface dries out. This phenomena shows that the primarily cause of moisture diffusivity in the samples is diffusion mechanism. Similar works have been reported for spinach leaves, peppermint leaves, persimmon slices, avishan leaves, and rosy garlic leaves[6, 7, 8, 9].

Figure 3: Moisture Ratio vs Drying Time of Conventional Vacuum Drying Curves of Curry Leaves with 400 mmHg at Different Temperatures

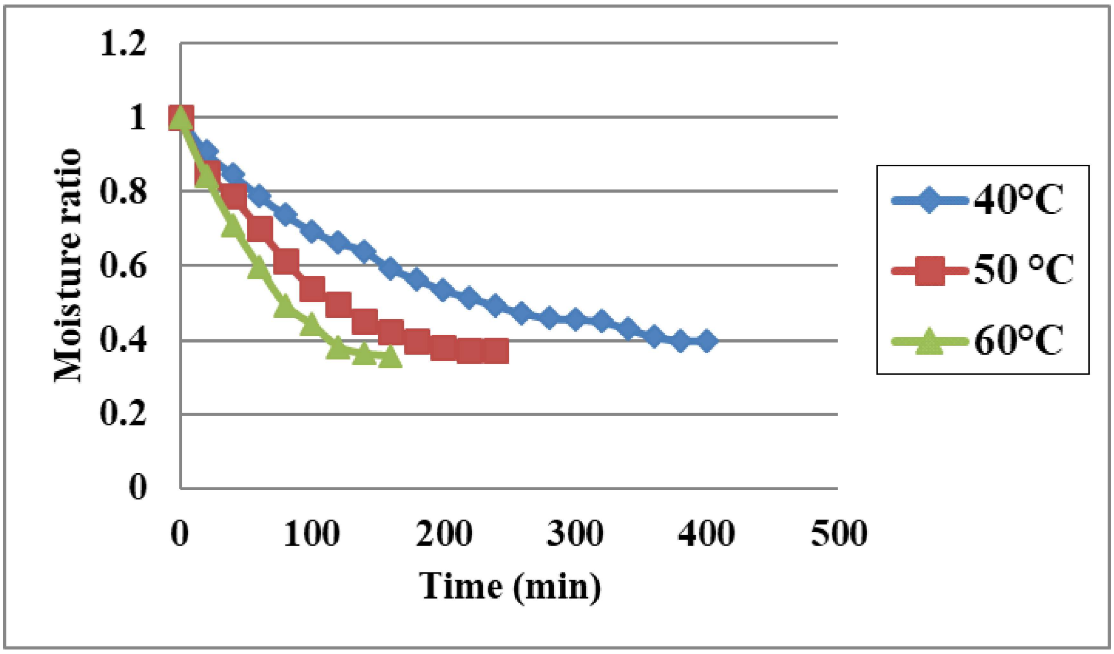


Figure 4: Moisture Ratio vs Drying Time of Conventional Vacuum Drying Curves of Curry Leaves with 600 mmHg at Different Temperatures

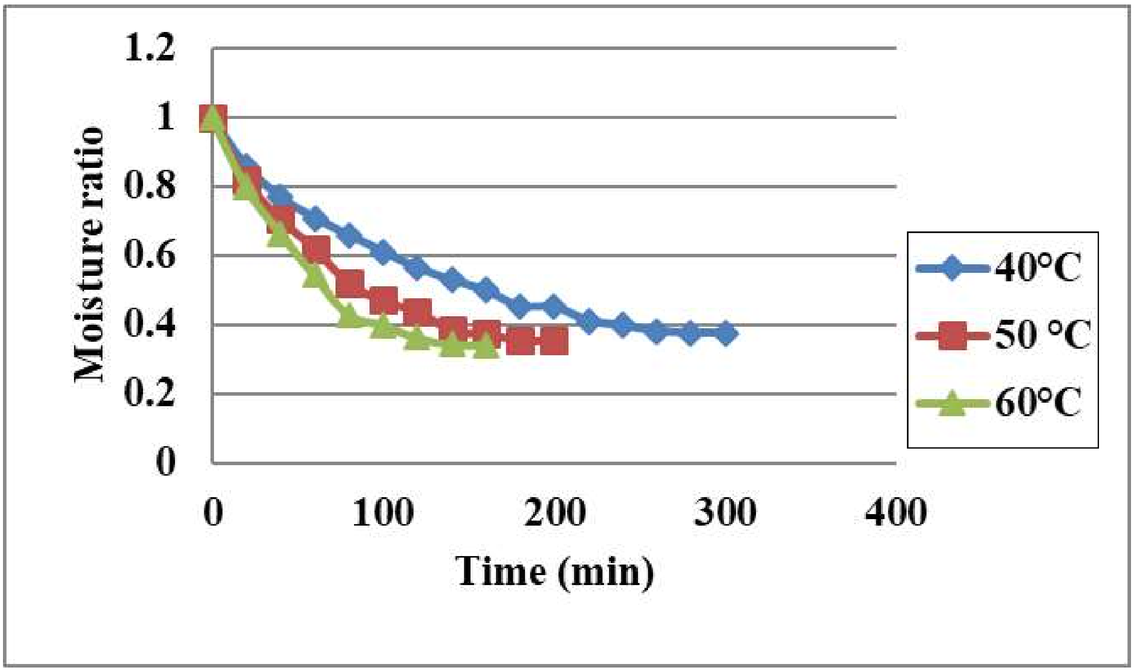


Table 3: Mathematical Data and Statistical Analysis of Curry Leaves

Model	Exp. Code	k	n	a	b	g	c	h	RMSE	RSQR	SSE
Lewis Thin Layer	CDA2	0.10906	-	-					0.03458	0.98923	0.03468
	CDB2	0.27527	-	-					0.02687	0.99055	0.01083
	CDC2	0.49493	-	-					0.04367	0.97986	0.01717
	CVDA1	0.18414							0.02216	0.99155	0.00933
	CVDB1	0.29344							0.05641	0.9576	0.03819
	CVDC1	0.46125							0.05841	0.95322	0.02729
	CVDA2	0.1689	-	-					0.0439	0.97575	0.03855
	CVDB2	0.31467	-	-					0.04284	0.97445	0.02202
	CVDC2	0.46955	-	-					0.03404	0.98301	0.00927
	CVDA3	0.2496							0.05086	0.97221	0.0388
	CVDB3	0.40511							0.05288	0.96633	0.02796
	CVDC3	0.52784							0.0528	0.96493	0.0223
	Average								**0.0433**	**0.9749**	**0.0247**
Page Model	CDA2	0.16696	0.7594		-				0.00858	0.99744	0.00214
	CDB2	0.31973	0.8586		-				0.01506	0.99542	0.0034
	CDC2	0.56251	0.761		-				0.01783	0.99421	0.00286
	CVDA1	0.21571	0.8816						0.0141	0.99525	0.00378
	CVDB1	0.39553	0.659						0.01712	0.99175	0.00352
	CVDC1	0.53793	0.6735						0.02513	0.98598	0.00505
	CVDA2	0.24935	0.7191		-				0.0123	0.9953	0.00303
	CVDB2	0.38408	0.7683		-				0.02267	0.98813	0.00617
	CVDC2	0.50674	0.8393		-				0.0233	0.98984	0.00434
	CVDA3	0.34986	0.6873						0.01124	0.99649	0.0019
	CVDB3	0.49243	0.7053						0.02065	0.99072	0.00426
	CVDC3	0.59166	0.7368						0.02938	0.98415	0.00691
	Average								**0.01811**	**0.99206**	**0.00395**
Medli *et al.*	CDA2	0.15575	0.8849	0.98425	0.00954				0.00683	0.99807	0.00135
	CDB2	0.99808	1.0499	0.99808	0.03123				0.00468	0.99955	0.00033
	CDC2	0.67273	0.967	0.99776	0.05262				0.0081	0.99879	0.00059
	CVDA1	0.23101	1.0342	1.0014	0.02272				0.00929	0.99788	0.00164
	CVDB1	0.46001	0.8396	1.0004	0.04141				0.01178	0.99607	0.00167
	CVDC1	0.76007	1.0109	0.99855	0.09893				0.00594	0.99921	0.00028
	CVDA2	0.26442	0.885	0.99852	0.02335				0.00631	0.99874	0.0008
	CVDB2	0.45533	1.0665	0.99142	0.05775				0.01022	0.99743	0.00125
	CVDC2	0.68379	1.1467	0.99743	0.08649				0.00683	0.99911	0.00037
	CVDA3	0.37493	0.8159	0.99725	0.02308				0.00754	0.9984	0.00085
	CVDB3	0.60667	0.9593	0.99762	0.06118				0.00805	0.99857	0.00065
	CVDC3	0.81654	1.0847	0.99754	0.0927				0.01053	0.99794	0.00089
	Average								**0.00801**	**0.99831**	**0.00089**

Table 3 (cont.)

Modified Henderson and Pebis Model	CDA2	-0.32743		0.00364	0.05634	11.0104	0.94003	0.10951	0.00288	0.99971	0.00024
	CDB2	-0.37839		0.01783	0.61998	0.32591	0.36299	0.32591	0.00457	0.99957	0.00031
	CDC2	3.02041		0.09204	0.90391	0.51151	0.00408	-1.11706	0.00736	0.99928	0.00049
	CVDA1	-2.27037		2.20E-08	0.59475	0.11353	0.41041	0.36839	0.00812	0.99835	0.00125
	CVDB1	-1.3622		0.00032	0.18711	2.20982	0.81457	0.22536	0.01052	0.99685	0.00133
	CVDC1	-0.54111		0.05734	0.02123	68.0391	0.92143	0.67111	0.00497	0.99945	0.0002
	CVDA2	-0.01928		0.26888	0.03198	4.9394	0.6991	0.30357	0.00619	0.99879	0.00077
	CVDB2	-0.55893		0.01838	0.69728	0.39464	0.27698	0.39464	0.00918	0.99794	0.00101
	CVDC2	-1.53136		0.002	0.72102	0.53443	0.27943	0.53443	0.00552	0.99941	0.00024
	CVDA3	-0.84296		0.00131	0.12418	3.10498	0.87467	0.22278	0.00481	0.99935	0.00035
	CVDB3	65.7505		0.03887	0.91852	0.52689	0.0426	-0.45837	0.00683	0.99898	0.00047
	CVDC3	-0.7013		0.0308	0.73853	0.71284	0.23087	0.71284	0.01043	0.99799	0.00087
	Average								**0.00678**	**0.99881**	**0.00063**

Modelling of the Drying Curves

The investigational data of moisture contents were converted to further more functional moisture ratio[6]. The drying curves plotted between the moisture ratios and drying time were fitted with different mathematical models listed in Table 2. To determine the model adequacy, reliability and consistency the statistical outputs in the Table 3 are applied to obtain the best fitting model. Highest R^2 value and the lowest RMSE and SSE values are selected as the most excellent model. The mean values of R^2, SSE and RMSE of the tested mathematical models were in the range of 0.9749-0.9988, 0.0006-0.0247, and 0.00678-0.0433 respectively in both conventional and conventional vacuum dryings.

Apart from the all four tested methods Table 3 shows Modified Henderson and Pebis model satisfied the decisive factor hence is chosen outstanding model due to its R^2 (0.9988) was the highest while its SSE (0.0006) and RMSE (0.00678) values were the lowest.

The Modified Henderson and Pebis model curve fit for curry leaves drying characteristics of conventional at 40, 50 and 60 °C (A), and Conventional vacuum drying at 40, 50 and 60 °C

Figure 5: Modified Henderson and Pebis Curve Fit of Curry Leaves Drying Curves Conventional at 40, 50 and 60 °C (A), and Conventional Vacuum Drying at 40, 50 and 60° with Vacuum Pressures 250, 400 and 600 mmHg (B)

(A)

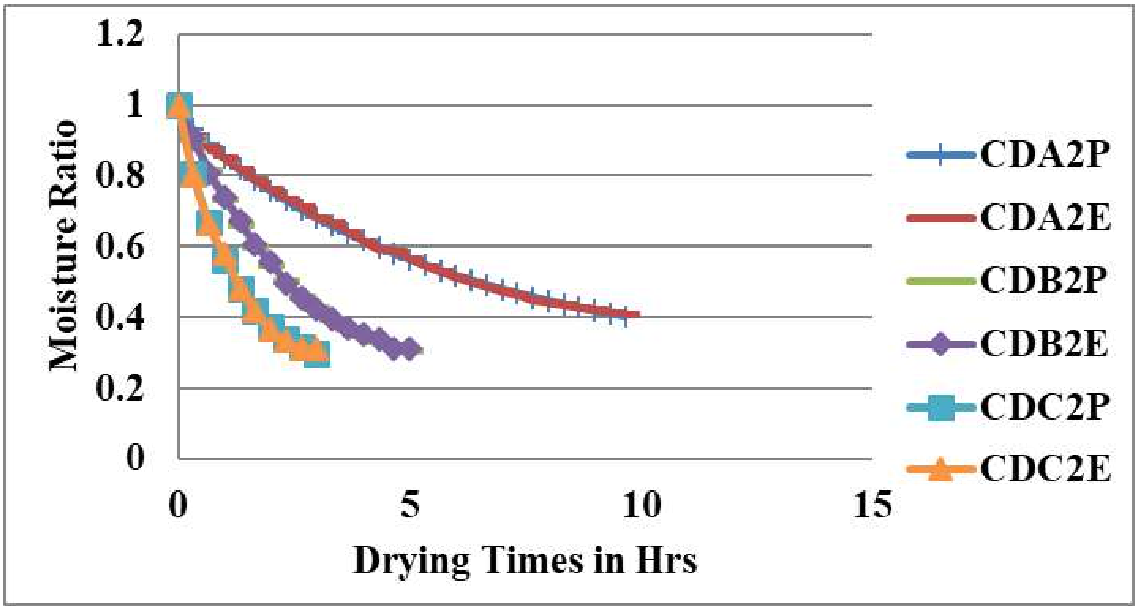
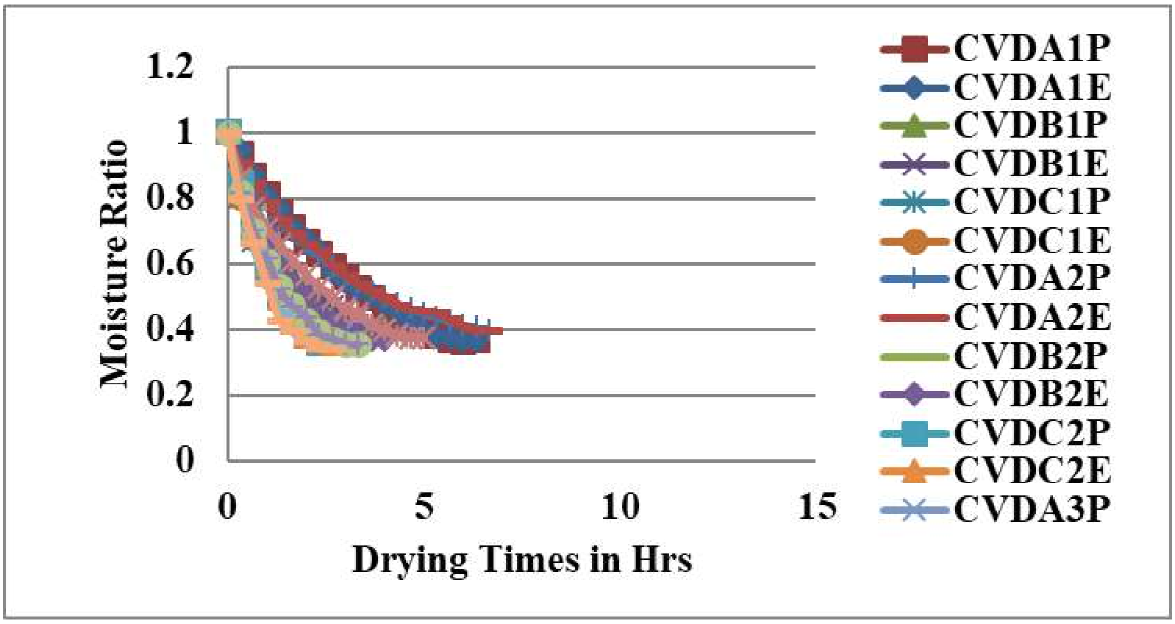


Figure 5 (Cont.)

(B)



with Vacuum pressures 250,400 and 600 mmHg (B) is shown as in Figure 5. The capability, consistency and regularity of Modified Henderson and Pebis model was substantiated by plotting the calculated moisture ratios obtained from the model against the experimental moisture ratio data temperatures at 40, 50, 60 °C and vacuum pressures 250, 400 and 600 shown in Figures 6 and 7(a-c) respectively.

The coefficients of correlation of the conventional and conventional vacuum drying through Modified Henderson and Pebis model straight lines obtained were 0.999, 0.996, 0.997 and 0.999 respectively. This implies good correlation between the predicted moisture ratios obtained from Modified Henderson and Pebis model and experimental moisture ratios. Hence the model is adequate, reliable and suitable for

Figure 6: Validation of Modified Henderson and Pebis Model for Predicting the Conventional Drying Characteristics of Curry Leaves at 40, 50 and 60 °C

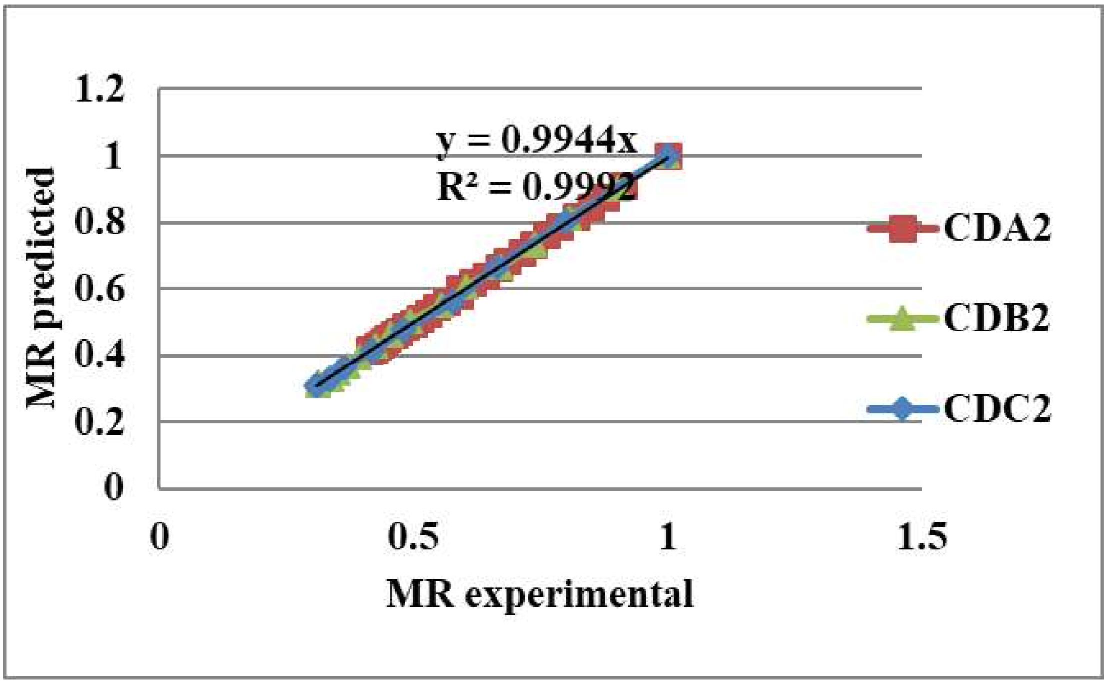
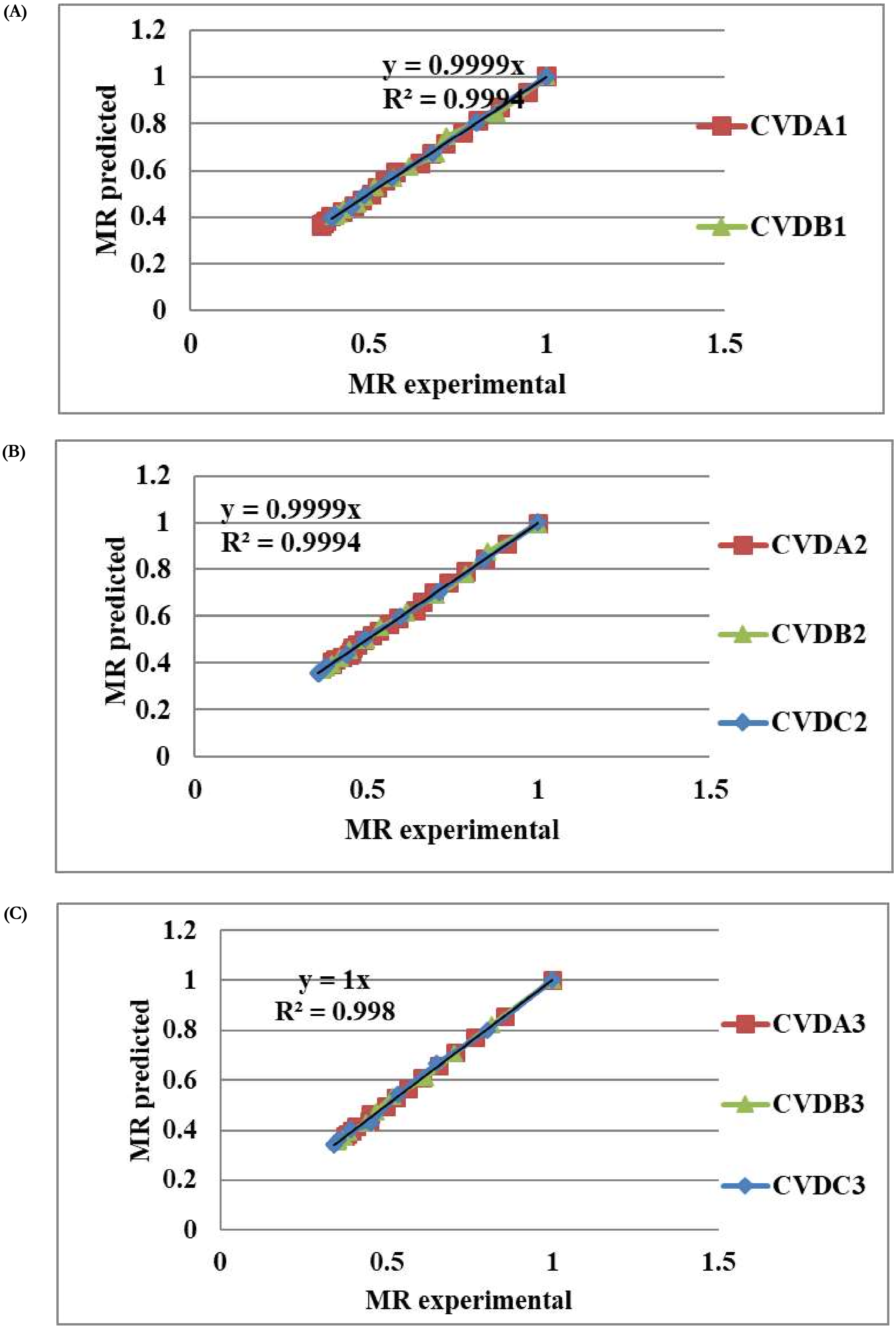


Figure 7: Validation of Modified Henderson and Pebis Model for Predicting the Conventional Vacuum Drying Characteristics of Curry Leaves at 40, 50 and 60 °C with 250 (a), 400 (b) and 600 (c) mmHg Pressures



predicting the drying kinetics of curry leaves using conventional and conventional vacuum drying method.

Effective Moisture Diffusivity

The curry leaves D_{eff} values obtained from Eq. (6) at different temperatures and vacuum pressures is presented in Figure 8. And Figures 9(A-C) respectively. The D_{eff} of curry leaves ranged from 7.73X10^{-8} and 2.75X10^{-8} m^2/s in conventional drying and 2.56X10^{-8} to 7.97X10^{-8} m^2/s in conventional vacuum drying. The similar values have been reported by Adewale *et al.* [12] for Jew's mallowleaves and Zogzas *et al.* [13] for food products of agriculture.

Figure 8: Conventional Drying Effective Moisture Diffusivity of Curry Leaves

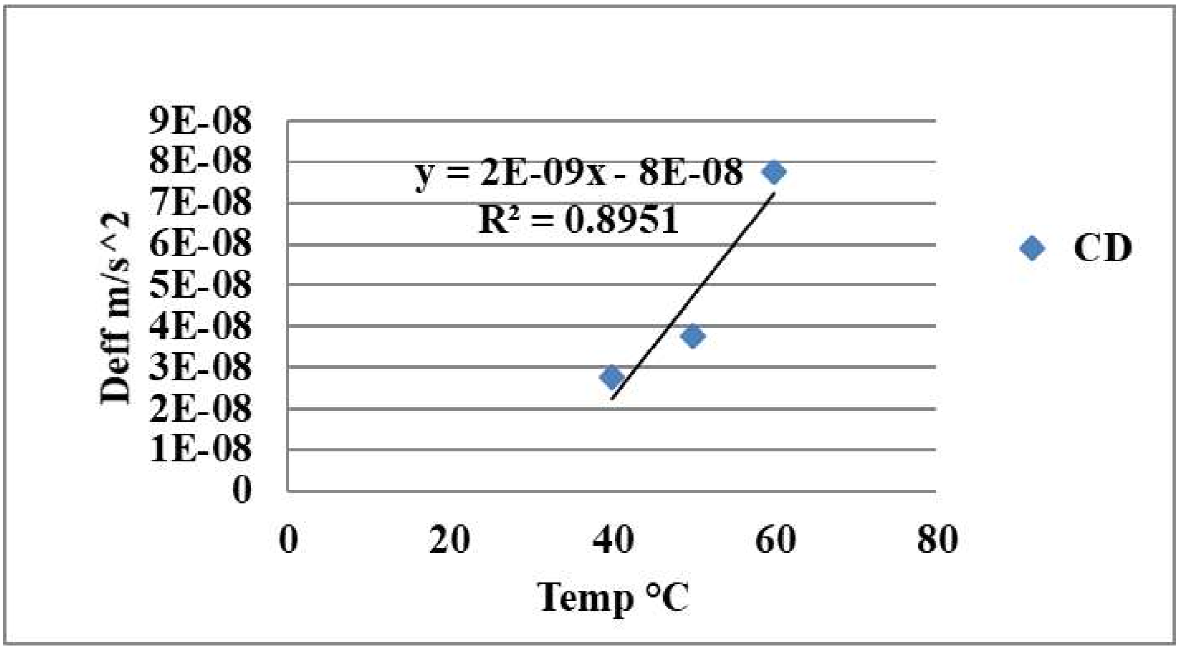


Figure 9: Conventional Vacuum Drying Effect on Moisture Diffusivity of Curry Leaves (A), (B) and (C) with 250, 400 and 600 mmHg Respectively

(A)

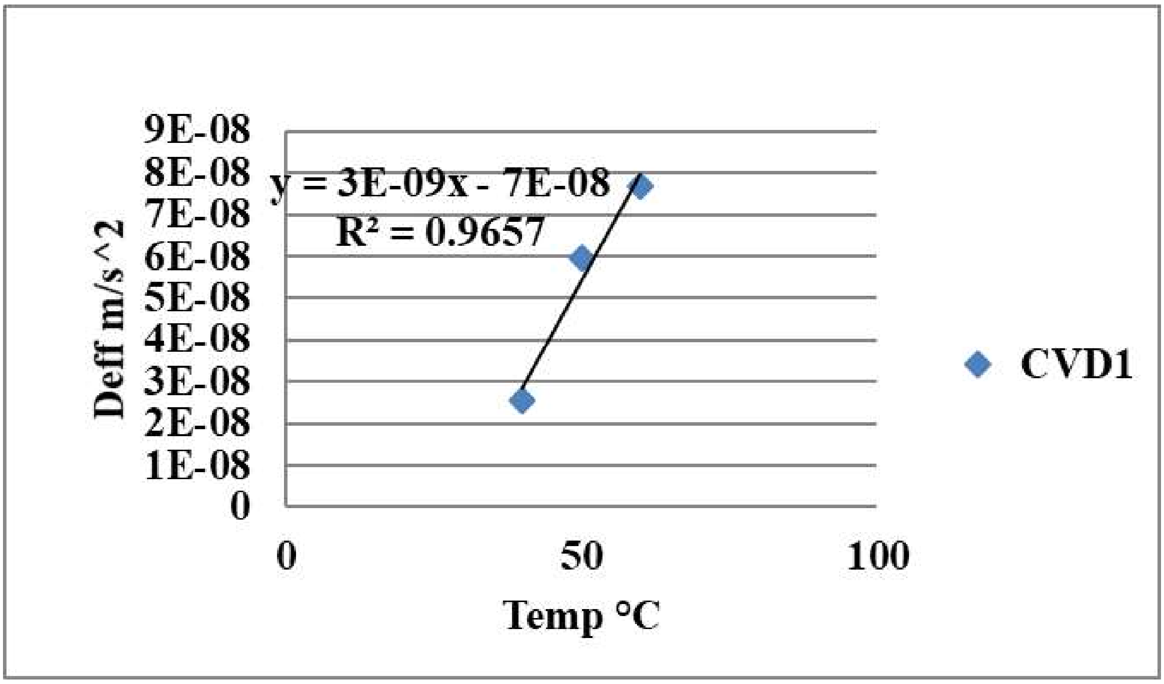
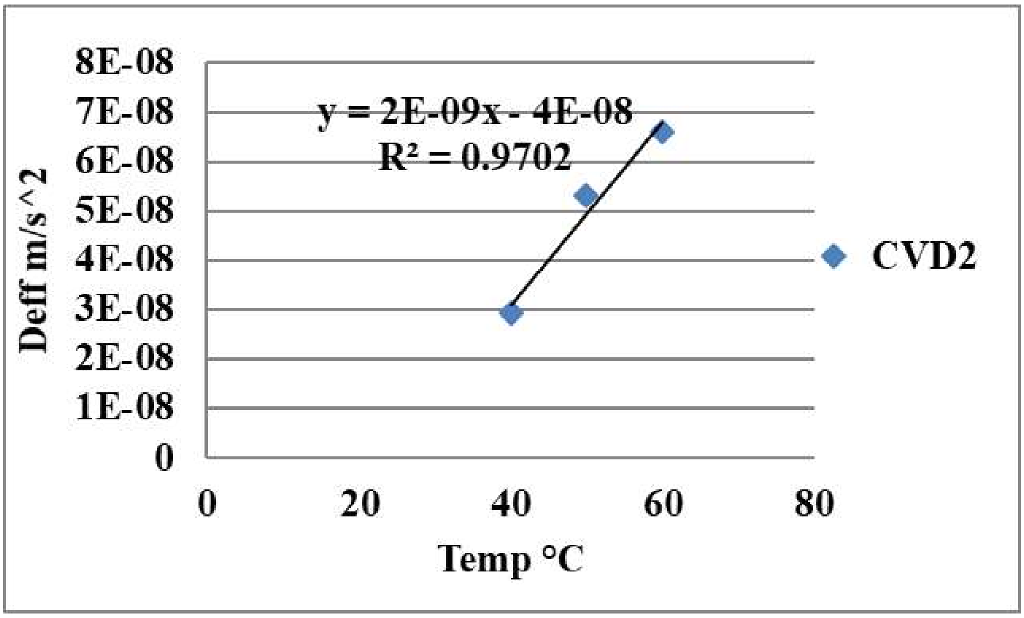
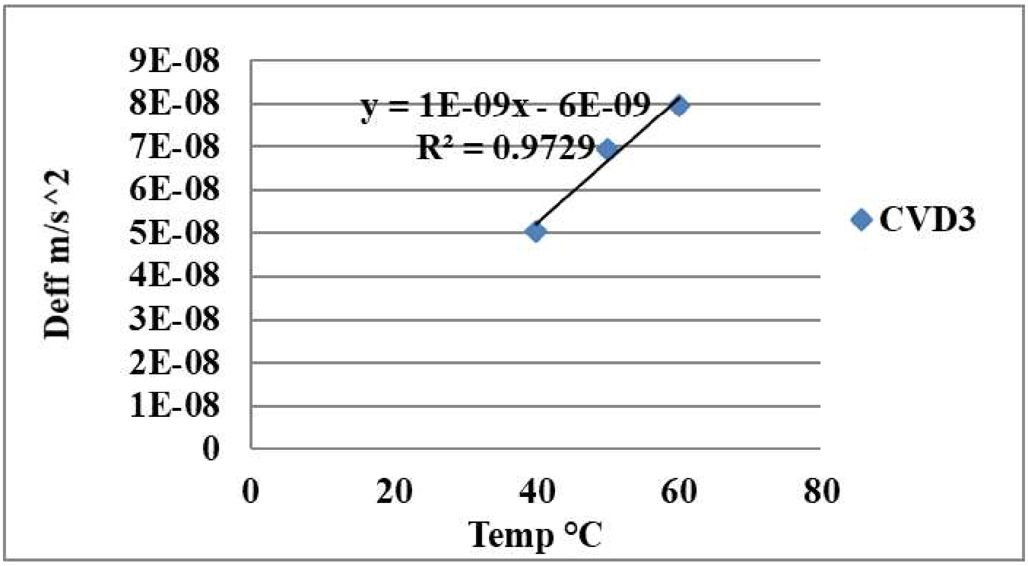


Figure 9: (cont.)

(B)



(C)



Effective Activation Energy

The activation energy for conventional drying and conventional vacuum of curry leaves have been taken from the slope obtained from the plot of In D_{eff} against temperature Figure 10 was found to be 44.57 (kJ/mol) In conventional drying. From Figures 11(A-C) the activation energy for conventional vacuum drying with 250, 400 and 600 mmHg pressures are 47.88, 35.60 and 19.75 (kJ/mol) respectively. Xiao *et al.* [14], reported that the range of activation energy, for a typical drying operation between 12.7 to 110 kJ/mol. The obtained activation energy in conventional vacuum drying with 600 mmHg pressure is lesser than the activation energies reported by Khazael *et al.* [15], avishan leaves (38.6-51.1 kJ/mol), Doymaz [16] banana slices (32.65 kJ/mol), Kaymak-Ertekin [17], Red pepper (42.80 kJ/mol) and Simal *et al.* [18], Green peas (24.70 kJ/mol). It was observed that the activation energy obtained for conventional vacuum drying in present study is greater than the value reported by Premi *et al.* [19] for drum-stick leaves (12.50 kJ/mol).

Colour Effects

Colour is an important quality characteristic of dehydrated fruits and vegetables. The relationship of colour with consumer acceptability of foodstuffs is common and inevitable [21]. Generally dehydration process effects the characteristics of foods and hence alters their reflectivity and colour [20].

The colour of the curry leaves samples was assessed by using a Hunter Lab Colosrflex colorimeter with illuminant D65 and 10° observer angle. Each sample was placed onto a white tile and values of CIE (Commission Internationale de Elcairage) color space co-ordinates L*, a*, b* values were acquired. Where L* the lightness, a* the grade of greenness/redness and b* the grade of blueness/yellowness. The curry leaves colour data is shown in Table 3. The mean colour varied across the applied drying temperatures, vacuum pressures and time range. This variation was expected as dissimilar drying conditions were used in this study. L*, a*, b* ΔE, and a*/b* ranged from 39.4 to 44, 3.5 to -7.6, 36.2 to 42.7, 8.78 to 13.68, and -0.081 to -0.219 respectively. According to Doymaz *et al.* [20], higher L* and lower a*/b* are required in dried foodstuff.

Figure 10: Arrhenius Type Relationship Between Modified Henderson and Pebis of Effective Moisture Diffusivity and Absolute Temperature

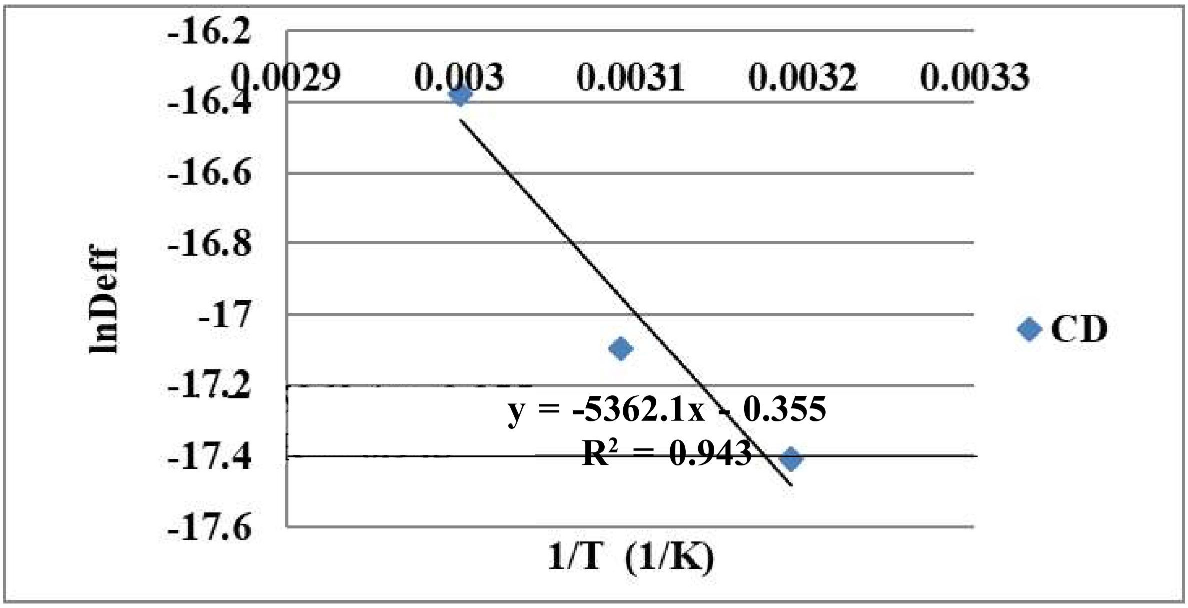


Figure 11: Arrhenius-Type Relationships Between Modified Henderson and Pebis of Effective Moisture Diffusivity and Absolute Temperature with 250 (A), 400 (B) and 600 (C) mmHg Pressures

(A)

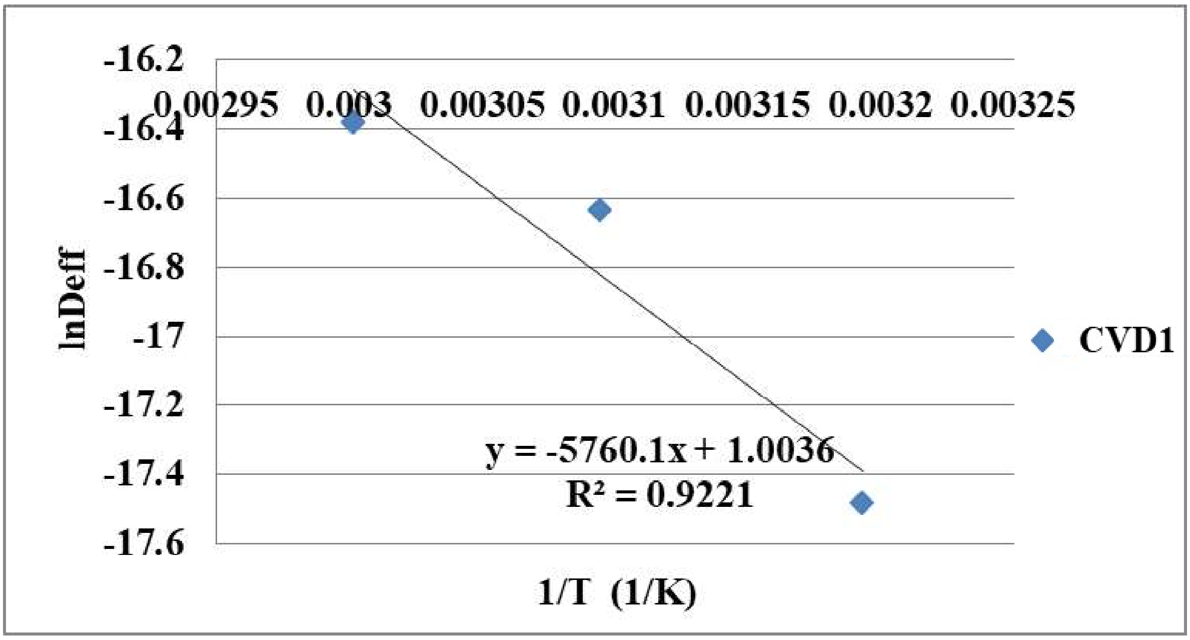
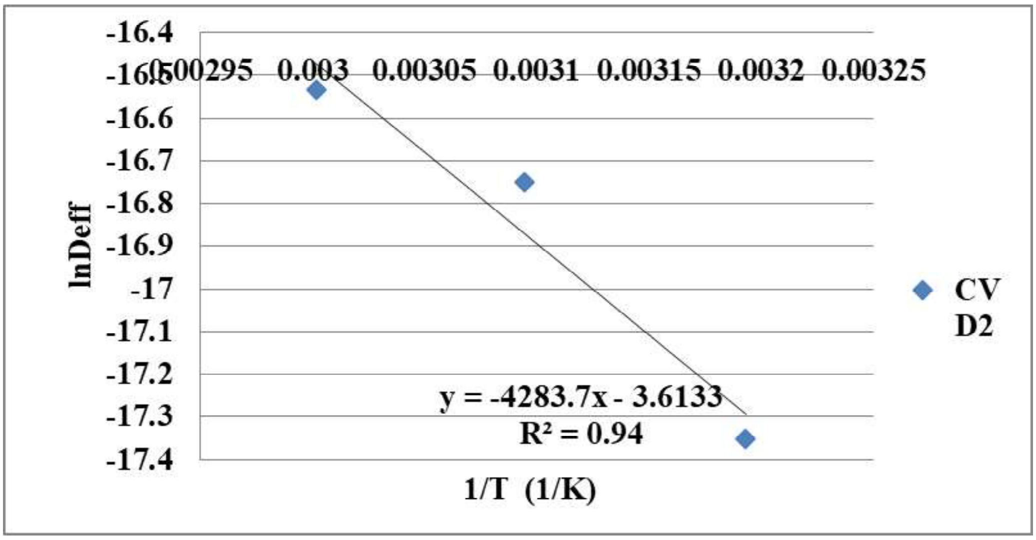


Figure 11: (cont.)

(B)



(C)

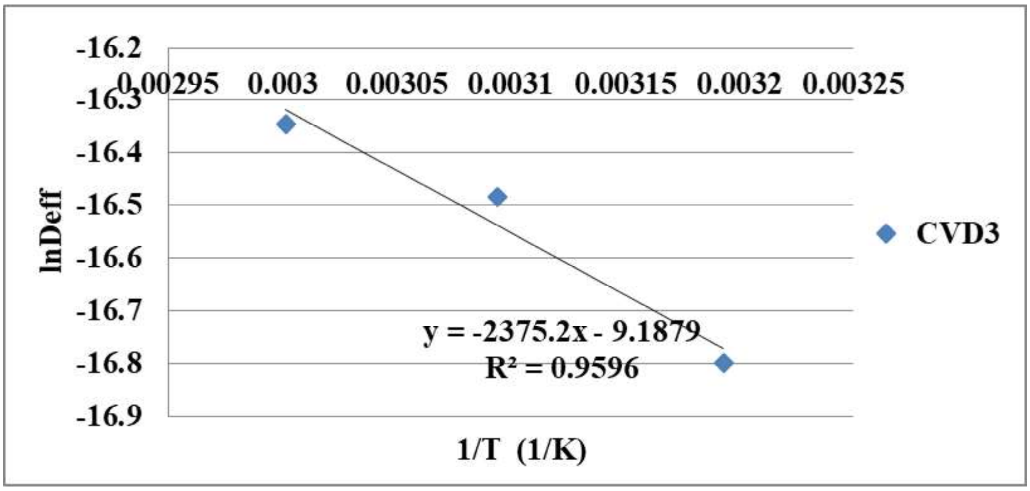


Table 4: Colour Analysis of Dried Curry Leaves

Code	Treatment	L*	a*	b*	ΔE	a*/b*
CDA2	40°C	39.4	-5.4	37.3	8.787633	-0.14477
CDB2	50°C	43.8	-6.1	39.4	9.620941	-0.15482
CDC2	60°C	41	-3.8	39.6	11.17732	-0.09596
CVDA1	40°C and 250 mmHg	40.8	-4.9	37	8.958934	-0.13243
CVDA2	40°C and 400 mmHg	40.6	-5.8	39.9	9.78481	-0.14536
CVDA3	40°C and 600 mmHg	46.5	-9	41	10.21139	-0.21951
CVDB1	50°C and 250 mmHg	37.7	-7.6	36.2	7.022286	-0.20994
CVDB2	50°C and 400 mmHg	38.3	-5	39.1	10.27923	-0.12788
CVDB3	50°C and 600 mmHg	42.1	-6.6	40.6	9.756664	-0.16256
CVDC1	60°C and 250 mmHg	40.6	-6.1	42.1	11.17553	-0.14489
CVDC2	60°C and 400 mmHg	43.6	-5.4	42.2	11.96798	-0.12796
CVDC3	60°C and 600 mmHg	44	-3.5	42.7	13.68768	-0.08197

For this study, samples dried at 60 °C and 600 mmHg had higher L* and lower a*/b* values. This suggests that 60 °C and 600 mmHg can be taken as the optimum parameter for drying curry leaves.

CONCLUSION

The curve fitting revealed that the Modified Henderson and Pebis model adequately predicted the drying behaviour of conventional vacuum drying of curry leaves as its R2 (0.9988) was the highest while its SSE (0.0006) and RMSE (0.00678) values were the lowest. The Deff of curry leaves ranged from 7.73X10-8 and 2.75X10-8 m^2/s in conventional drying and 2.56X10-8 to 7.97X10-8 m^2/s in conventional vacuum drying. Activation energy required to get rid of moisture within the leaves throughout the conventional vacuum oven drying process was found to be 19.75 kJ/mol. Colour analysis carried out on the dried leaves suggest that drying conditions of 60 °C and 600 mmHg can be taken as the optimum parameter for drying curry leaves.

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REFERENCES

1. Wojdylo, A., Lech, K., Nowicka, P., Hernandez, F., Figiel, A. and Carbonell-Barrachina, A. A. (2019). Influence of different drying techniques on phenolic compounds, antioxidant capacity and colour of ziziphus jujube mill. Fruits. *Molecules*, 24(13), p. 2361. https://doi.org/10.3390/molecules24132361.
2. Barreiro Ja, Milano M. and Sandoval A. J. (1997). Kinetics of colour change of double concentrated tomato paste during thermal treatment. *Journal of Food Engineering*, 33, 3-4, pp. 359-371.
3. AOAC. (2000). Official methods of analysis of the association of official's analytical chemists. Virginia.
4. Miranda M., Maureira H., Rodriguez K. and Vega-Galvez A. (2009). Influence of temperature on the drying kinetics, physicochemical properties, and antioxidant capacity of Aleo vera gel. *Journal of Food Engineering*, 91(2), pp. 297-304. https://doi.org/10.1016/j.jfoodeng.2008.09.007.
5. Adewale Olusegun Omolola A., Patrick Francis Kapila A. and Henry Mbitha Silungwe. (2019). Mathematical modeling of drying characteristics of Jew's mallow (Corchorus olitorius) leaves. *Information Processing In Agriculture*, pp. 109-115. https://doi.org/10.1016/j.inpa.2018.08.003.
6. Ashtiani S. M., Salarikia A. and Golzarian M. R. (2017). Analyzing drying characteristics and modeling of thin layers of peppermint leaves under hot-air and infrared treatments. *Information Processing in Agriculture*, 4(2), pp. 128-39. https://doi.org/10.1016/j.inpa.2017.03.001.
7. Doymaz I. (2009). Thin layer drying of spinach leaves in a convective dryer. *Journal of Food Process Engineering*, 32(1), pp. 112-25.
8. Doymaz I. (2012). Evaluation of some thin-layer drying models of persimmon slices (Diospyros kaki L.). *Energy Convers Manage,* 56, pp. 199-205. https://doi.org/10.1016/j.enconman.2011.11.027.
9. Ben Haj Said L., Najjaa H., Farhat A., Neffati M. and Bellagha S. (2015). Thin layer convective air drying of wild edible plant (Allium roseum) leaves: experimental kinetics, modeling and quality. *Journal of Food Science Technology*, 52(6), pp. 3739-49.
10. Nachaisin M., Jamradloedluk J. and Niamnuy C. (2016). Application of combined far-infrared radiation and air convection for drying of instant germinated brown rice. *Journal of Food Process Engineering,* 39(3), pp. 306-18. https://doi.org/10.1111/jfpe.12226.
11. Zogzas N. P., Maroulis Z. B. and Marinos-Kouris D. (1996). Moisture diffusivity data compilation in foodstuffs. *Dry Technology*, 14(10), pp. 2225-53. https://doi.org/10.1080/07373939608917205.
12. Adewale Olusegun Omolola, Patrick Francis Kapila and Henry Mbitha Silungwe. (2019). Mathematical modeling of drying characteristics of Jew's mallow (Corchorus olitorius) leaves. *Information Processing In Agricultur,* pp. 109-115. https://doi.org/10.1016/j.inpa.2018.08.003.
13. Miranda M., Maureira H., Rodriguez K. and Vega-Galvez A. (2009). Influence of temperature on the drying kinetics, physicochemical properties, and antioxidant capacity of Aleo vera gel. *Journal of Food Engineering,* 91(2), pp. 297-304. https://doi.org/10.1016/j.jfoodeng.2008.09.007.
14. Xiao H. W., Yao X. D., Lin H., Yang W. X., Meng J. S. and Gao Z. J. (2012). Effect of SSB (superheated steam blanching) time and drying temperature on hot air impingement drying kinetics and quality attributes of yam slices. *Journal of Food Process Engineering*, 35(3), pp. 370-90. https://doi.org/10.1111/j.1745-4530.2010.00594.x.

15. Khazaei J., Arabhosseini A. and Khosrobeygi Z. (2008). Application of superposition technique for modeling drying behavior of avishan (Zataria multiflora) leaves. *American Society of Agricultural and Biological Engineers*, 51(4), pp. 1383-93.

16. Doymaz I. (2010). Evaluation of mathematical models for prediction of thin-layer drying of banana slices. *International Journal of Food Properties,* 13(3), pp. 486-97. https://doi.org/10.1080/10942910802650424.

17. Kaymak E. F. (2002). Drying and rehydration kinetics of green and red pepper. *Journal of Food Science*, 67, pp. 168-175. http://dx.doi.org/10.1111/j.1365-2621.2002.tb11378.x.

18. Simal S., Mulet A., Tarrazo J. and Rosello C. (1996). Drying models for green peas. *Food Chemistry*, 55, pp. 121-128. https://doi.org/10.1016/0308-8146(95)00074-7.

19. Premi M., Sharma H. K., Sarkar B. C. and Singh C. (2010). Kinetics of drumstick (Moringa oleifera) during convective drying. African Journal of Plant Science, 4(10), pp. 391-400.

20. Fellows P. (2009). *Food Processing Technology* (pp. 311-6). Wood head Publishing, England.

21. Doymaz I., Tugrul N. and Pala M. (2006). Drying characteristics of dill and parsley leaves. *Journal of Food Engineering,* 77(3), pp. 559-65. https://doi.org/10.1016/j.jfoodeng.2005.06.070.

22. Page, G. E. (1949). Factors Influencing the Maximum Rates of Air Drying Shelled Corn in Thin Layers. Master's Thesis, Department of Mechanical Engineering, Prude University, Prude, West Lafayette, IN, USA.

23. Karathanos, V. T. (1999). Determination of water content of dried fruits by drying kinetics. *Journal of Food Engineering,* 39*,* pp. 337-344. https://doi.org/10.1016/S0260-8774(98)00132-0.

24. Midilli A., Kucuk H. and Yapar Z. (2002). A new model for single layer drying. *Drying Technology*, 20(7), pp. 1503-1513. https://doi.org/10.1081/DRT-120005864.

25. Ranganna, S. (1995). *Handbook of Analysis and Quality Control for Fruits and Vegetable Products*, New Delhi: Tata McGraw Hill Publishing Co. Ltd.

26. Ayensu, A. (1997). Dehydration of food crops using a solar dryer with convective heat flow. *Solar Energy,* 59(4-6)*,* pp. 121-126. https://doi.org/10.1016/S0038-092X(96)00130-2.

APPENDIX

NOMENCLATURE

CD	Conventional drying
CVD	Conventional vacuum drying
D_{eff}	Effective moisture diffusivity, m^2/s
MR	Moisture ratio
R^2	Coefficient of determination
RMSE	Root mean square error
SSE	Sum of square error
t	Time
°C	Degree Celsius
MR_{exp}	Experimental moisture ratio
MR_{pre}	Predicted moisture ratio
Mo	Initial moisture content (kg water/kg dry matter)
MC	Moisture content
D0	Arrhenius factor (m^2/s)
Ea	activation energy
L	half the thickness
K, n, a, b, c, g and h	Model constants;
T	Temperature (°C)
R	Universal gas constant (8.314×10^{-3} kJ/mol K),
w.b	Wet basis
ΔE	Change in color