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Drying Characteristics and Kinetics of Bitter leave (Vernonia amygdalina) and Scent leave (Ocimum gratissimum)

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Abstract
The effect of temperature on drying of bitter leave and scent leave was studied, using laboratory moisture content analyzer, at temperatures of 50°C, 60°C, 70°C and 80°C. The falling rate phenomenon was observed for both bitter leave and scent leave. The thin layer drying models were fitted to the experimental moisture ratio data. Among the mathematical models investigated, the Page model described better the drying behavior of bitter leaves and scent leaves with highest R^2 and lower x^2 values. The determined effective moisture diffusivity (D_{eff}) values showed the temperature dependency both materials. Effective moisture diffusivity ranged from 8.437 x 10^{-15} to 2.96 x 10^{-13} m^2/s for bitter leave and 8.65 x 10^{-14} to 4.51 x 10^{-13} m^2/s for scent leave with increase in temperature. Hence, the Arrhenius equation was employed to ascertain activation energy for the different samples dried. Activation energies of 53.55kJ/mol and 110kJ/mol for bitter leave and scent leave were obtained respectively.
Keywords: drying, kinetics, bitter leave, scent leave, effective moisture diffusivity

1. Introduction

Drying process involves heat and mass transfer; the removal of water by evaporation from a solid, semi-solid or liquid (Adeboye and Oputa, 1996; Bamire and Oke, 2003). The drying technique is probably the oldest and the most important method of food preservation practiced by humans (Doymaz, 2005a). The removal of moisture prevents the growth and production of microorganisms which causes decay; minimizes the moisture-mediated deteriorative reactions. It also results to substantial reduction in weight and volume, minimizing packaging, storage and transportation costs and enables storability of the product under ambient temperature (Owolarefe *et al*., 2007). During drying a lot of changes occu; both structural and physico-chemical modifications that affect the final product quality (Doymaz, 2005; Okros *et. al*, 1992).

Bitter leave (*Vernonia amygdalina*) is known as *oriwo*, *ewuro*, *shikawa*, and *kiriolugbo*, a tropical shrub, 1-3m height with petiole leave of about 6 mm in diameter, and elliptic in shape (Igile *et al.,* 2005). The leaves are dark green in colour with a characteristics odour and bitter taste. The species are indigenous to tropical Africa and is found wild or cultivated all over sub-Sahara Africa.. It can grow under a range of ecological zones in Africa and produces large mass of forage and is drought tolerant (Akah and Okafor, 1992). It is edible, after washing thoroughly to remove the bitter taste (Mayhew and Penny, 1988). All parts of the plant are pharmacologically useful in phyto-medicine; to treat fever, hiccups, kidney disease and stomach discomfort, among others (Gill 1992). It has anti-emetic and anti-malarial (Hamowia and Saffaf, 1994); as well as anti-tumourigenic properties (Abosi and Raseroka, 2003). It also finds application in the area of skin infection, loss of memory, prostate cancer, stroke, pneumonia, insomia, arthritis and general weakness. Studies have also demonstrated the hypoglycaemic and hypolipidaemic effect of the leave extract on animals (Izevbigie *et al*., 2004).

Scent leave (*Ocimum gratissimum*) is widely distributed in the tropics of Africa and Asia. It belongs to the family *labiatae*, the most abundant of the genus *Ocimum* (Nwanjo, 2005). It is a perennial plant that is woody at the base with an average height of 1-3m. The leaves are broad and narrowly ovate, usually 5-13cm long and 3-9cm wide; a scented shrub with lime-green fuzzy leaves containing alkaloid, tannis, phytates, flavonoids, oligosaccharides and tolerable cyanogenic content. The nutritional value such as aromatic flavor can be used for beverages to baked food without the use of artificial substance; *cinnamon geranium* - sugar alternate (http:www.nchi.nim.nih.gov/pmc/articles/PMC3178946/accessed on 15may 2013). It finds application in areas of anti-convulsant, anti-septics, anti-bacterial and anti-fungal activities mostly in Africa. In Nigeria, it is used in treatment of epilepsy, high fever and diarrhea while the decoctions of the leave are used to treat mental illness. All scented geraniums have fragrant leaves and the essential oils have been used in numerous commercial products over the years. Scented geraniums are easy to grow and thrive in warm temperatures which has enhanced their popularity over the last 200 years (Akah and Okafor, 1992).

The traditional method of preserving agricultural products in developing countries (e.g Nigeria) is mostly sun drying; a technique extremely weather dependent; associated with the problem of contaminants with foreign matter. Therefore, efforts have been made to overcome these problems with solar, microwave, infrared radiation and hot air dryers (Adom *et al*., 1997; Doymaz and Pala 2002; Muskan, 2000; Sharma and Prasad 2004; Sharma *et al*., 2005; Charkraboty *et al*., 2010). Several studies have been carried out on drying of food materials,

where the mass transfer and the dependency of effective diffusivity on temperature were described using the Ficks diffusion model and Arrhenius equation (Doymaz, 2004b; 2006). The drying characteristics of various vegetables such green bean and okra under solar energy, with falling rate period of 89.5% and 88.7 % (w.b) to 15± 0.5% (w.b) for a period of 60 minutes and effective diffusivity of $1.12x10^{-10}$ m^2/s and $1.5x10^{-11}$ m^2/s for okra has been reported (Doymaz,, 2005b; Wanklade *et al.,* 2012; Rosellio *et al*., 1997), carrot (Doymaz, 2004a), red pepper and red chilli (Doymaz and Pala 2002) eggplant (Ertekin and Yalde, 2004).
Although these leaves are drought tolerance, it is not available in every community and scare, mostly in the dry season. These can deteriorate very easily therefore drying becomes an option for both storage and transportation. Drying of bitter leave and scent is scare in literature. The objective of this research was to obtain the effect of drying temperature on drying characteristics and kinetics of bitter leave and scent leave, to evaluate a suitable drying model to describe the drying processes and estimate the effective diffusivity and activation energy for design purposes.

Materials and method

2.1 The laboratory dryer

Drying experiments on bitter leave and scent leave were performed in laboratory scale moisture content analyzer (Denver instrument IR-30). The IR-30 moisture content analyzer utilizes infrared heating and precision weighing for quick and accurate moisture determination. It measures moisture or solid content in a range of samples from powder to liquid with a compact size (8.5''W x 11''L x 6.5''H), a readability of 0.01% precision balance with 0.001g resolution. The combination of internal balance and an infrared dryer provides reproducible result, typically, 5 to 15 minutes. The fresh leave materials are shown in Figure 1

(a) (b)

Figure 1 (a) Fresh bitter leave and (b) Scent leave

Fresh bitter leave (*Vernonia amygdalina*) and scent leave (*Ocimum gratissimum*) of peak flavour and quality were obtained from farmers in Amassoma, Bayelsa State. Nigeria. The leaves were washed with di-ionzed water and the thickness of 0.2 mm and 0.1 mm was measured using micrometer screw gauge for bitter leave and scent leave respectively. The average moisture content was recorded of bitter leave and scent leave of 85.63% (w.b) and 76.66% (w.b), at 50^{o}C for 98 and 78 minutes respectively. Drying experiment was conducted at 50^o C, 60^{o}C, 70^{o}C and 80^{o}C and values of weight loss was taken at interval of 2 minutes until constant value was attained. The product was cooled in the period of 10 minutes and kept in air glass jar. Drying tests were replicated three times at each inlet air temperature, and average value was calculated.

2.2 Mathematical modeling of drying curve

The moisture content of bitter leave and scent leave can be expressed in dimensionless form as moisture ratio MR with the following equation.

$$MR=\frac{M-M_e}{M_o-M_e} \quad (1)$$

M is the mean moisture content; M_o is the initial value; and M_e is the equilibrium moisture content. The M_e values can be neglected; very small compared to M_o and M and the moisture ratio is being simplified (Pala *et al*., 1996; Doymaz 2004a; Saclik and Elicin, 2006).

$$MR=\frac{M}{M_e} \quad (2)$$

Three thin layer drying models were considered for the data analysis to select the best model in describing the drying curve equation of bitter leave and scent leave. The coefficient of determination R^2, one of the primary and main criteria for selecting the best equation to account for variation in the drying curves of dried samples (Erentuk *et al*., 2004; Yaldiz *et al*., 2001). The goodness of fit can also be evaluated by various statistical parameters such as reduced chi-square (x^2), mean bias error (MBE), and root mean square error (RMSE). The best fit is determined by the highest value of R^2 and minimum value of x^2, MBE and RMSE (Ozdemir & Devres, 1999; Ertekin & Yaldiz, 2004). The following mathematical relationship in (equations 3, 4 and 5) were used to calculate the mentioned statistical parameters.

$$X^2 = \frac{\sum_{i=1}^{N}(MR_{expi} - MR_{prei})}{N-Z} \quad (3)$$

$$MBE = \frac{1}{N}\sum_{i=1}^{N}(MR_{expi} - MR_{prei}) \quad (4)$$

$$RMSE = \sqrt{\left[\frac{1}{N}\sum_{i=1}^{N}(MR_{expi} - MR_{prei})\right]} \quad (5)$$

Where N is the number of observations, Z is the number of constants, $MR_{exp,}$ is the experimental moisture ratio and MR_{pre} is the predicted moisture ratio. The experimental data (moisture content) obtained at the drying air temperature was converted to moisture ratio and fitted into the following models in (equations 6,7 and 8).

$$MR = \frac{M-M_e}{M_o-M_e} = Exp(-kt) \quad \text{(Newton's model)} \quad (6)$$

$$MR = \frac{M-M_e}{M_o-M_e} = Exp(-kt^n) \quad \text{(Page model)} \quad (7)$$

$$MR = \frac{M-M_e}{M_o-M_e} = Exp(-kt)^n \quad \text{(Modified Page model)} \quad (8)$$

Where M is the moisture content (kg water/kg dry matter), M_e is the equilibrium moisture content (kg water/kg dry matter), M_o is the initial moisture content (kg Water/kg dry matter), k and n are constants

3.0 Results and Discussion

3.1 Effect of air temperature

Figures 1 and 2 illustrate the relationship between moisture ratio and drying time, with moisture ratio decreasing with increase in time. The effect of four temperatures on the drying curve shows no constant rate drying period in the drying of bitter leave and scent leave, with moisture ratio decreasing rapidly with increased temperature. The result shows that all drying takes place in falling rate period which indicates that internal mass transfer occurred by diffusion. Similar results were obtained for the drying of organic apple slices (Saclik & Elicin 2006), okra (Doymaz, 2004), and (Ertekin and Yaldiz 2004) for eggplant. The time taken to reduce the moisture content from the initial 85.63% (w.b) and 78.66% (w.b), to a final value; 0.9% and 1.2% at air temperature of 50°C, for a period of 68 and 90 minutes for bitter leave and scent leave respectively. The time required to reduce the moisture ratio to a minimum level was depended on the drying condition and material, with highest at 50°C and lowest at 80°C for all samples, a good agreement in literature on drying of okra and (Doymaz, 2005) and Kadam *et al*, 2011) for basil leave. The bitter leave has thickness of 0.2 mm,' higher than that of scent leave with 0.1 mm but the time required to get to the minimum level was faster compared to scent leave. Though there was no further investigation to this effect, it may be attributed to the components involved in the samples dried especially at lower temperatures where mass transfer is low.

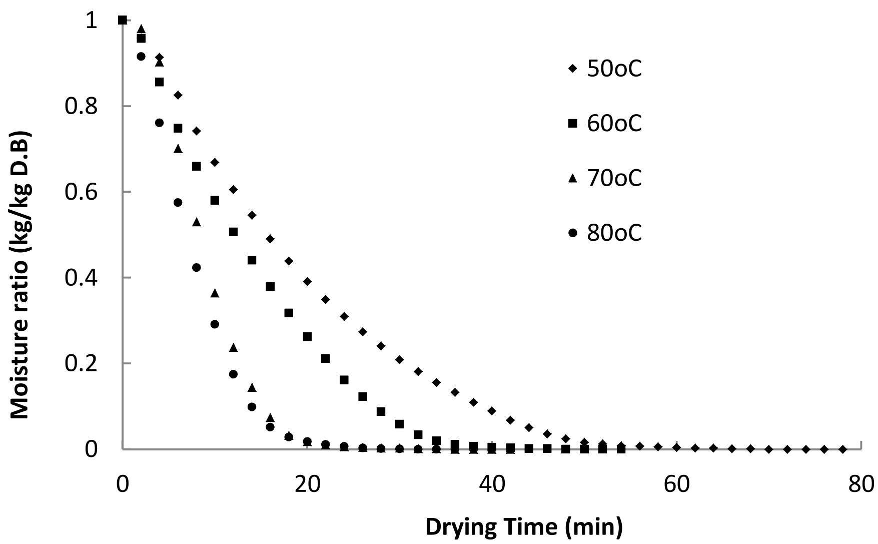

Figure 2 Effect of air drying Temperature on the Moisture ratio with time on Bitter leave.

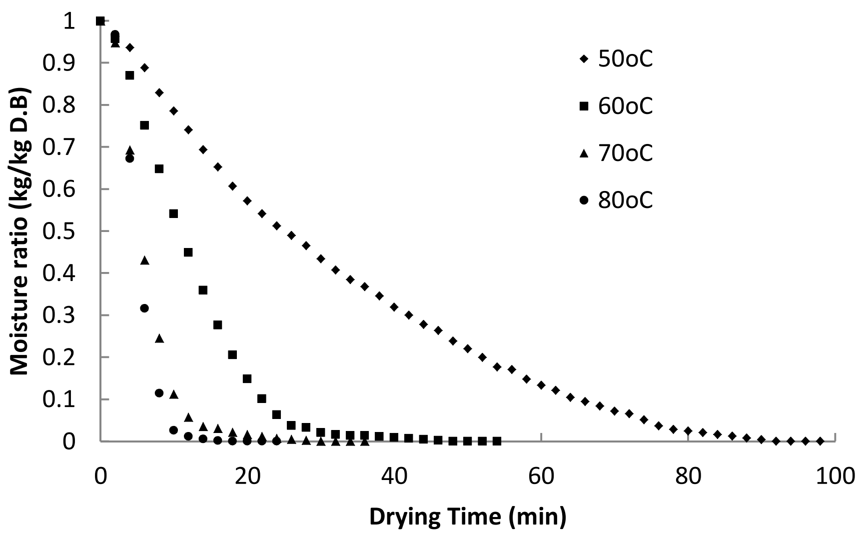

Figure 3 Effect of air drying Temperature on the Moisture ratio with time on Scent leave

3.2 Evaluation of the models.

The linearity of the relationship between Ln(MR) and drying time (t) by using method of slopes is presented in Figures 4 and 5, for all temperatures. The effective moisture diffusivity values (D_{eff}), the corresponding R^2 values (correlation coefficient), statistical values, and constants are listed in Tables 1. Other statistical values MBE, RMSE and χ^2 were determined using equations 3, 4 and 5 which are also listed in Table 2. The lower reduction chi square values of χ^2, (0.0001 - 0.0029) for scent leave were observed compared to (0.0374 - 0.0075) bitter leave; when fitted with the predicted values of Page model. Similar trend was observed for both the Modified model (0.0011 - 0.0112) scent leave, and (0.0084 - 0.1341) bitter; and Newton model (0.0144 - 0.0651) bitter leave and (0.0001- 0.0777) scent leave. The experimental data obtained were fitted into the three moisture ratio models, namely; Newton's model, Page model and the Modified Page model. The Non-linear Page model and Modified Page model fitted well with the experimental data of Scent leave; among all the models tested which are given in Figures 6 and 7. Thus, the Page model may be assumed to represent the thin layer drying behaviour of bitter leave and scent leave, with the coefficient of correlation ranging from 0.976 to 0.996 and 0.942 to 0.994 for bitter leave and scent leave as the temperature was varied from 50°C to 80°C. The R^2 values obtained for Newton and modified models were 0.819 to 0.897 and 0.819 to 0.981 for bitter leave and scent leave respectively. Similar results were reported by (Doymaz , 2005) for okra.

3.3 Effective moisture diffusivity and Activation Energy

The values of effective moisture diffusivity, D_{eff} and coefficient of correlation, R^2 were determined using the most widely studied theoretical model in thin layer drying of foods given by the solution of Fick's second law (Crank, 1975). The values ranged from 8.437×10^{-15} m^2/s to 2.96×10^{-13} m^2/s and 8.65×10^{-14} m^2/s to 4.51×10^{-13} m^2/s for bitter leave and scent leave respectively with increasing temperature. The high effective moisture diffusivity of scent leave may be due to the smaller thickness (0.1 mm) compared to that of bitter leave (0.2 mm).

Table 2 Coefficient and Statistical Analysis of Linear Model of Bitter leave and Scent leave

Sample	**Drying air Temperature °C**	**linear equation**	**K_o**	**D_{eff} (m^2/s**	**R^2**
Bitter leave	50	y= - 0.10x+0.879	-0.1	8.44E-15	0.944
	60	y= - 0.15x+1.004	-0.15	4.22E-14	0.925
	70	y= - 0.226x+.0766	-0.226	1.31E-13	0.975
	80	y= - 0.254x+ 0.856	-0.254	2.96E-13	0.973
Scent leave	50	y= - 0.049x+ 0.537	-0.49	8.65E-14	0.905
	60	y= - 0.135x+0.537	-0.135	1.87E-13	0.981
	70	y= - 0.220x+ 0.199	-0.22	3.63E-13	0.984
	80	y= - 0.421x+ 0.803	-0.421	4.51E-13	0.965

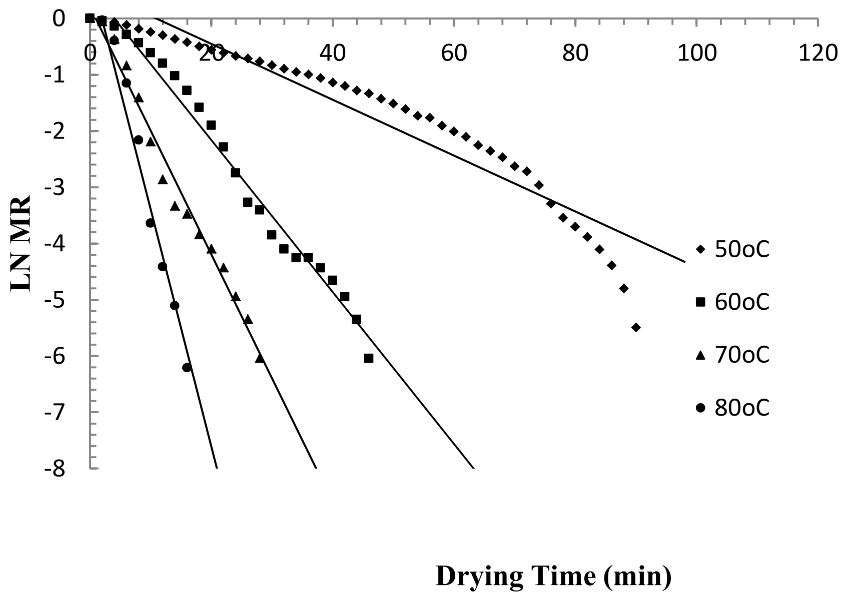

Figure 6 : LN(MR) versus drying Time for scent leave

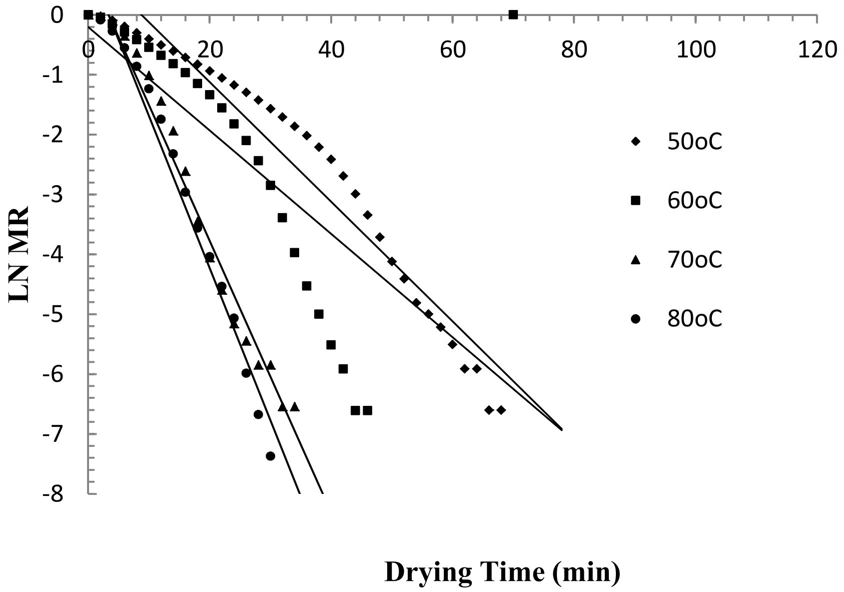

Figure 7 LN (MR) versus Drying Time for bitter leaves

Table 2 Coefficients and Statistical Results obtained Selected from Models of Bitter leave and Scent leave

Name of Model	Sample	Temperature °C	R^2	X^2	MBE	RMSE	K	N
Newton MR=Exp(-kt)	Bitter leave	50	0.897	0.0144	0.014	0.1183	0.08	
		60	0.819	0.0603	0.05809	0.2410	0.206	
		70	0.887	0.0651	0.06198	0.2490	0.325	
		80	0.866	0.0437	0.04599	0.2145	0.348	
	Scent leave	50	0.866	0.0001	5.3E-05	0.0240	0.04	
		60	0.819	0.0139	0.0139	0.1179	0.118	
		70	0.981	0.0010	0.00981	0.0990	0.209	
		80	0.849	0.0777	0.07121	0.2669	0.583	
Page model MR-Exp(-kt^n)	Bitter leave	50	0.983	0.0037	0.00355	0.0596	0.032	1.222
		60	0.976	0.0067	0.00622	0.0789	0.042	1.279
		70	0.988	0.0044	0.00399	0.0632	0.03	1.64
		80	0.996	0.0075	0.00679	0.0824	0.092	1.303
		50	0.975	0.0004	3.2E-05	0.0036	0.025	1.094
	Scent leave	60	0.994	0.0001	0.00012	0.0106	0.017	1.564
		70	0.942	0.0027	0.00258	0.0508	0.034	1.635
		80	0.963	0.0028	0.00242	0.0492	0.01	2.477
Modified page model MR=Exp(-kt)^n	Bitter leave	50	0.983	0.1342	0.12708	0.3565	0.06	1.222
		60	0.976	0.0067	0.00622	0.0789	0.085	1.279
		70	0.988	0.0044	0.00399	0.0632	0.119	1.64
		80	0.996	0.0084	0.00751	0.0856	0.161	1.303
	Scent leave	50	0.975	0.0001	1E-05	0.0032	0.035	1.094
		60	0.976	0.0045	0.0042	0.0646	0.092	1.288
		70	0.988	0.0042	0.0042	0.0650	0.18	1.295
		80	0.951	0.1120	0.0093	0.0966	0.226	1.868

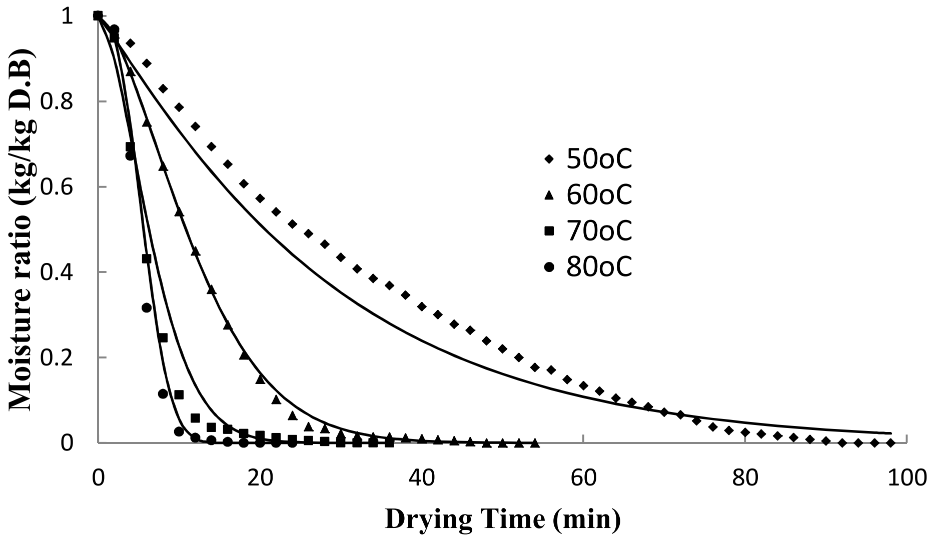

Figure 6 Experimental and Computed Moisture ratio obtained using the Page Model for Scent leave

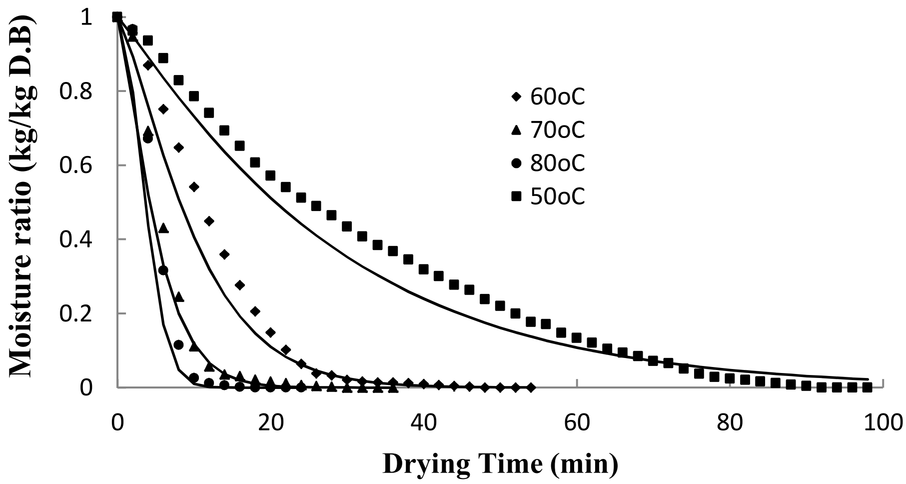

Figure 7 Experimental and Computed Moisture ratio obtained using the Modified Page Model for Scent leave

The mass transfer coefficient K_c was also higher for scent (86×10^{-14} $m^2/s.m$) as compared to that of bitter (42.15×10^{-15} $m^2/s.m$), which may be attributed to the thickness of scent leave. Mass transfer coefficient is inversely proportional to the thickness of the medium through which diffusivity occurs. Similar findings were reported in literature on moisture diffusivity increase with an increase in air temperature (Kadam *et al.*, 2011) of mint leaves. The maximum R^2 value was 0.985 for scent leave drying at 70°C and minimum of 0.905 at 50°C compared to bitter leave at the same temperatures with values of 0.973 and 0.944 respectively.
The dependency of diffusivity coefficient on temperature are presented in Figures 8 and 9; where values of Ln (D_{eff}) versus 1/T were plotted in the range of temperatures studied to give straight curve, indicating Arrhenius dependence.

$$D_{eff} = D_O \, exp\left(-\frac{Ea}{R(T.)}\right) \quad (8)$$

where D_O is the pre-exponential factor of Arrhenius equation (m^2/s), Ea is the activation energy (kJ/mol), T is the temperature of air (°C) and R is the universal gas constant (kJ/mol K). From the slope of the straight lines described by the Arrhenius equation, the activation energy was found to be 53.55kJ/mol and 110kJ/mol, for bitter leave and scent leave respectively. The Activation Energy E_a values compared with other food products available in the literature are presented in Table 4. The activation energy obtained from the present study on Scent leave is higher than the energies of Red chilli drying (41.95 kJ/mol) (Gupta *et al.*, 2002) Onion (58.7 kJ/mol) (Sharma *et al.*, 2005), and (82 kJ/mol) for black tea (Park *et al.*, 2002

Table 3 Activation of Bitter leave , Scent leave and other Products

Material	Activation Energy Ea (kJ/mol)	References
Bitter leave	53.55	Present work
Scent Leave	110	Present work
Red Chilli	41.95	Gupta *et al*., (2002)
Onions	58.7	Sharma *et al*., (2005)
Mint	82.93	Park *et al* ., (2002

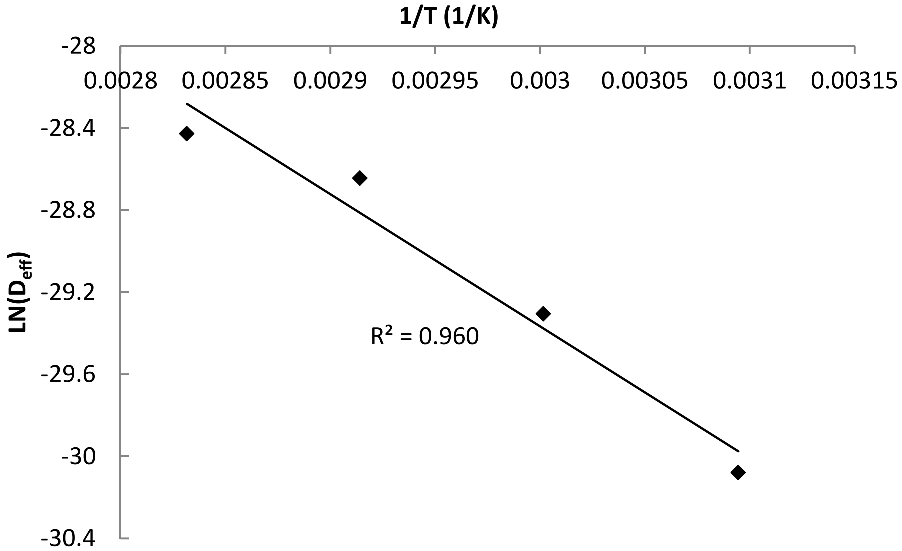

Figure 8 Influence of Temperature on the Effective Diffusivity of bitter leave

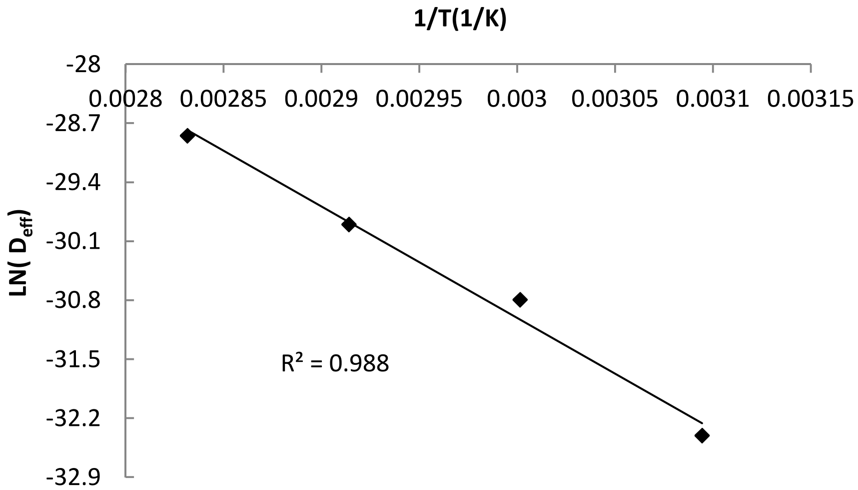

Figure 9 Influence of Temperature on the Effective Diffusivity of Scent leave

4.0 Conclusion

Drying kinetics of bitter leaves and scent leaves was investigated in laboratory scale moisture content analyzer, at temperature ranging from 50°C to 80°C. The drying process took place only in the falling rate period for the two products. Both the Modified Page model and Page models can be used to describe the drying behaviour especially for scent leave but the Page model showed a better fit than modified page model. The values of calculated effective diffusivity of scent leave were higher, ranging from 8.65 x 10^{-14} to 4.51 x 10^{-13} m^2/s as compared to 8.437 x 10^{-15} to 2.96 x 10^{-13} m^2/s for bitter leave. The effective moisture diffusivity increases with increasing temperature. Temperature dependence of the diffusivity coefficients was described by an Arrheniustype relationship. The activation energy for moisture diffusion was found to be 53.55 kJ/mol and 110kJ/mol for bitter leaves and scent leaves respectively.

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Nomenclature

R^2 Correlation coefficient
E_a Activation Energy kJ/mol
D_{eff} Diffusivity Coefficient m^2/s
R Universal gas constant kJ/mol. K
D_o Pre-exponential factor m^2/s
X^2 reduced chi square
t time
n constant
M_o initial moisture content kg water/kg dry matter
M_e Equilibrium moisture content kg water/kg dry matter
M moisture content at time kg water/kg dry matter
MBE mean bias error
RMSE root mean square error
MR_{exp} Moisture ratio experimental value
MR_{pred} Moisture ratio predicted value
N Number of data points observed
Z Number of constants

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