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Drying and colour characteristics of *Cleome gynandra* L. (spider plant) leaves

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Abstract

Drying characteristics of *Cleome* leaves in an oven dryer was studied. The impact of oven drying temperature (50, 60 and 70 °C) on moisture composition of the plant at a uniform air speed was considered. Eight drying models, namely, simple exponential, Page, Verma, modified Henderson and Pabis, Lewis, two term exponential, Newton, logarithmic, and Wang and Singh were fitted to drying data. Modified Henderson and Pabis model satisfactorily depicts the drying behaviour of *Cleome* leaves. Effective moisture diffusivity of *Cleome* ranged from 1.03×10^{-6} to 1.77×10^{-5} m^2/s. Reliance of the calculated effective diffusivity on oven temperature was unavoidable. The required activation energy for oven drying of *Cleome* leaves was found to be 24.46 kJ/mol. The colour characteristics of *Cleome* leaves in terms of L*, a* and b* were determined. Based on the colour characteristics results, drying condition of 70 °C 90 min was found to be optimum for oven drying of *Cleome* leaves.

Keywords: *Cleome gynandra* L.; colour; oven drying; effective diffusivity; mathematical modeling; activation energy.

Practical Application: Drying of *Cleome* leaves can help improve its shelf stability and diversify its use. Furthermore, the results obtained from modeling the drying characteristics of *Cleome* can be used in the design and optimization of drying equipment for *Cleome* leaves.

1 Introduction

Cleome gynandra L. is an erect herbaceous plant belonging to the *Capparaceae* family. It's height range from 0.5 m to 1.5 m. The leaves are palmate in nature including 3-7 leaflets. Pigmentation on the stems ranges from green to pink and purple. It has a varying coloured flower from white to pink and lilac. The terminal inflorescences have exceptionally unmistakable little white blossoms, while its fruit comprises of little siliques (Van Wyk, 2000). *Cleome* is known for its nutritional and medicinal value. It contains 6 mg, 4.8 g, 5.2 g, 13 mg, 288 mg, and 111 µg of iron, protein, carbohydrate, ascorbic acid, calcium and phosphorus respectively. It is used to help mothers recuperate after giving birth and during breast-feeding; also for stomach ailments (Jansen van Rensburg et al., 2004).

Drying is a preservation method which is extensively applied in food processing. It plays the role of preservation by lessening the moisture content present in foodstuffs. Advancement in science, technology and engineering has made the design and fabrication of diverse drying equipment's possible (Bennamoun & Li, 2018). The most used drying technique is hot air drying. In this technique, a wet foodstuff is subject to hot air. The flow of the hot air over the surface of the wet foodstuff is usually dependent on the configuration of the drier. Generally heat transfer during hot air dying is by conduction while diffusion is main mechanism responsible for the removal of moisture from inside the food (Ahmed et al., 2011).

The drying behavior or characteristics of most agricultural foodstuffs can be determined theoretically through mathematical modeling and simulation. According to Bennamoun & Li (2018), mathematical modeling is an important part of drying studies. This is on the account that no important research can be accomplished without created models that foresee the conduct of any tested sample, utilizing graphical illustrations known by the drying curves.

2 Materials and methods

2.1 Preparation of material

Fresh and cleaned *Cleome* leaves used in this study was purchased at a local market in Thohoyandou, Limpopo province, South Africa. Soil particles were removed from the leaves by rinsing with water. A convective air dryer (Labotec instrument-model 278) installed in University of Venda, Thohoyandou, South Africa was used to dry the leaves according to the selected temperatures.

2.2 Drying experiment

Preceding the drying experiments, original moisture content of *Cleome* leaves was ascertained using AOAC method 925.45 (Association of Official Analytical Chemists, 2000). Three oven drying temperatures (50, 60 and 70 °C) were used to evaluate the drying behaviour of *Cleome* leaves. 30 g of fresh and cleaned leaves was used for each experimental run. The velocity of air in the dryer was maintained at 1.1 m/s. The leaves were distributed evenly in a drying pan and placed in the oven after it had reached the balanced-state conditions for the set temperature. The decrease in moisture composition of the leaves was checked

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at 10 min interludes all through the drying operation. Drying was insistent up until a constant moisture content of samples was observed. Subsequent to each drying experiment, the dried samples were conserved in a sealable polyethylene bags. The packaged samples were kept at -20 °C prior to further analysis.

2.3 Mathematical modeling of drying kinetics

Semi-hypothetical and observational models are regularly used to depict the drying characteristics of foodstuffs. On account of the present study, the models utilized are shown in Table 1. The air drying curves information gotten from the drying experiments were fitted with eight experimental models recorded in Table 1. Curve fitting of the hot air drying information was accomplished utilizing MATLAB programming (form 7.11.0.584 (R2010a)).

The moisture ratio (MR) of dried *Cleome* at dissimilar oven temperatures was ascertained utilizing Equation 1 (Miranda et al., 2009),

$$MR = \frac{M}{M_o} \tag{1}$$

where: M and M_o denote the moisture substance of *Cleome* at each moment and original moisture substance of *Cleome* before initiation of the drying task respectively.

Statistical analysis of drying models

The parameters used to decide the integrity of model fits incorporates coefficient of determination (R^2), root mean square error (RMSE), and sum of square error (SSE). The model having the most noteworthy estimation of R^2 and the least values of RMSE and SSE (Equations 2-4) was viewed as the best fit (Ganesapillai et al., 2011).

$$R^2 = \frac{\sum_{i=1}^{N}\left(MR_i - MR_{cal,i}\right) \cdot \sum_{i=1}^{N}\left(MR_i - MR_{exp,i}\right)}{\sqrt{\left[\sum_{i=1}^{N}\left(MR_i - MR_{cal,i}\right)^2\right] \cdot \left[\sum_{i=1}^{N}\left(MR_i = MR_{exp,i}\right)^2\right]}} \tag{2}$$

$$RMSE = \left(\frac{1}{N}\sum_{i=1}^{N}\left(MR_{cal,i} - MR_{exp,i}\right)^2\right)^{\frac{1}{2}} \tag{3}$$

$$SSE = \sum_{i=1}^{N}\left(MR_{cal,i} - MR_{exp,i}\right) \tag{4}$$

where: MR_{exp},i = laboratory moisture ratio; MR_{pre},i = calculated moisture ratio; N = sum of observations.

2.4 Determination of moisture diffusivity and activation energy

It has been acknowledged that drying kinetics of foodstuffs in the falling rate time frame can be portrayed by utilizing Fick's equations. The explanation for this equations as described by Crank (1975) can be utilized for different shaped foodstuffs, for example, rectangular, tubular and circular items. Equations 5 to 7 survey the arrangement of Fick's law of diffusion.

$$MR = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\exp\left(-\frac{\pi^2(2n+1)^2}{4L^2}D_{eff}t\right) \tag{5}$$

where: D_{eff} = effective moisture diffusivity (m^2/s); n = sum of constants; L = half-thickness (m) of the samples.

Unvarying initial moisture appropriation, consistent diffusivity and negligible shrinkage of samples is required for the functionality and dependability of Equation 5:

$$\ln(MR) = \ln\left(\frac{8}{\pi^2}\right) - \left(\frac{\pi^2 D_{eff}}{4L^2}t\right) \tag{6}$$

The plot of experimental drying information as far as ln (MR) versus time gives a straight line with a negative slope (φ).

$$\varphi = \frac{\pi^2 D_{eff}}{4L^2} \tag{7}$$

The activation energy was calculated using Equations 8-10 (Doymaz, 2005).

$$D_{eff} = D_o \exp\left(-\frac{E_a}{R(T+273.15)}\right) \tag{8}$$

$$\ln\left(D_{eff}\right) = \ln\left(D_o\right) - \frac{E_a}{RT_{abs}} \tag{9}$$

$$k = \frac{-E_a}{R} \tag{10}$$

where: D_0 is the Arrhenius factor (m^2/s); E_a = activation energy (kJ/mol); R = the universal gas constant (8.314×10^{-3} kJ/mol K); T = air temperature (°C).

Table 1. Mathematical models applied to the oven drying curves of *Cleome* leaves.

S/N	Model	Equation	References
1	Wang & Singh	$MR = 1 + at + bt^2$	Miranda et al. (2009)
2	Simple exponential	$MR = a \exp(-kt)$	Doymaz (2005)
3	Two-term exponential	$MR = a \exp(-kt) + b \exp(gt)$	Doymaz (2009)
4	Page	$MR = \exp(-kt^N)$	Omolola et al. (2014)
5	Logarithmic	$MR = a \exp(-kt) + c$	Ganesapillai et al. (2011)
6	Lewis	$MR=\exp(-kt)$	Evin (2012)
7	Verma et al	$MR = a \exp(-kt)+(1-a)\exp(-gt)$	Verma et al. (1985)
8	Modified Henderson and Pabis	$MR = a \exp(-kt)+b \exp(-gt)+c \exp(-ht)$	Karathanos (1999)

In an attempt to calculate the activation energy, values of lnDeff were plotted against the absolute values of temperature (1/Tabs). The slope of the straight line obtained from the plot is equal to (-Ea/R).

2.5 Colour measurement

Colour characteristics of dried *Cleome* leaves were determined using Lovibond spectrocolorimeter (Model LC 100). Upon calibration of the spectrocolorimeter, the dried leaves were placed in cuvettes and inserted in the device for colour measurement. The measurements were carried out in triplicates and data obtained were subjected to a one way ANOVA by Duncan's multiple comparison test using SPSS version 24.0.

3 Result and discussion

3.1 Drying characteristics of Cleome gynandra leaves

The oven drying curves of *Cleome* leaves is shown in Figure 1. The initial moisture substance of the leaves was observed to be 81.33% (w.b) though the final moisture substance of the dried examples was in the scope of 17.33-19.60% (d.b). The experimental drying information of *Cleome* leaves at oven temperatures 50, 60, and 70 °C were analysed with regards to drop in moisture ratio against drying time. Ashtiani et al. (2017) reported that moisture ratio curves are more suitable for explaining the drying characteristics of foodstuffs than moisture content curves. Figure 1 show that drying of *Cleome* leaves was drastically affected by the applied drying temperatures. The drying duration dropped from 160 to 90 min by increasing the oven temperature 50 to 70 °C. Consequently the moisture substance of *Cleome* leaves dropped from 81.33% (w.b) to a concluding moisture content of 17.33%, 17.66%, and 19.60% (d.b) at a drying time of 160, 110 and 90 min, respectively. Abdul Rahman et al. (2015) also observed that the drying of *Nephelium Lappaceum* (Rambutan) amplified with a surge in oven temperature. According to Jamali et al. (2006) the drying rate of foodstuffs tends to be faster at elevated drying temperatures due to the excitation of molecules. This implies that water molecules embedded in foodstuffs travel at a faster speed, which in turn broaden the separation amongst molecules and indirectly lessens the power of attraction amongst them. Hence, an upsurge in the drying temperature rises the amount of moisture expelled from foodstuffs during drying. Drying rate of *Cleome* as reflected in Figure 2 was observed to initially increase and then decreased continuously all through the rest of the drying period. It is detectable from Figures 1 and 2 that the drying of *Cleome* leaves happened in the falling rate time frame. This indicates that as the drying time expanded, the superficial film of water gradually withdrew beneath the surface, and hot air occupied the spaces left by moisture expelled from the leaves. Hence, moisture was interminably evacuated by diffusion till there was insufficient moisture left to keep up a steady film over the pores (Geankoplis, 2003; Perre et al., 2007; Ankita & Prasad, 2013). Doymaz (2009, 2012), Ashtiani et al. (2017), Khazaei et al. (2008) and Ben Haj Said et al. (2015) equally reported a falling rate drying period for the drying of spinach leaves, peppermint leaves, persimmon slices, avishan leaves and rosy garlic leaves respectively.

3.2 Mathematical modeling of oven drying curves of Cleome leaves

According to Perea-Flores et al. (2012) and Shahhoseini et al. (2013), mathematical models have proven to be critical in the evaluation of drying kinetics, heat and mass transfer analysis, design and optimization of drying equipment's. The coefficients, R^2, RMSE and SSE of the applied drying models are revealed in Table 2. As reflected in the Table, the mean values of R^2, SSE, and RMSE of the models were in the range of 0.9386 to 0.9866, 0.0109 to 0.0594 and 0.0382 to 0.0716, respectively. Average values of R^2 of the tested models were higher than 0.95, signifying a good fitness. Although, the modified Henderson and Pabis model had the lowest mean of SSE (0.0109) and RMSE (0.0382) and highest average of R^2 (0.9866) which makes it a better and stronger model in contrast to other tested models for fitting the drying curves of *Cleome* leaves. Furthermore, the drying constants g, h and k for modified Henderson and Pabis model ranged from -0.01556 to 0.0614, 0.01466 to 0.02606, and 0.05958 to 0.3797, respectively. It is observed that drying constants g, h and k increased with increase in temperature (Table 2). This is in agreement with Dinani et al. (2014) and Ah-Hen et al. (2011). Authentication of the chosen model was established by comparing the calculated moisture ratios from the model against the laboratory moisture ratios (Figures 3A-C). The figures show a good relationship between the calculated moisture ratios and laboratory moisture ratios as they all have relatively high coefficient of correlation.

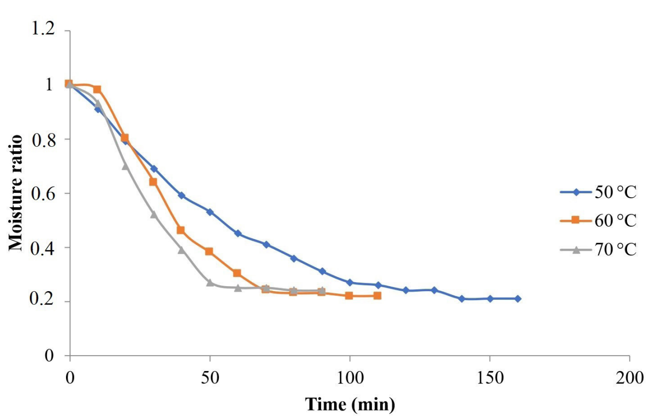

Figure 1. Oven drying curves of *Cleome* leaves at different temperatures.

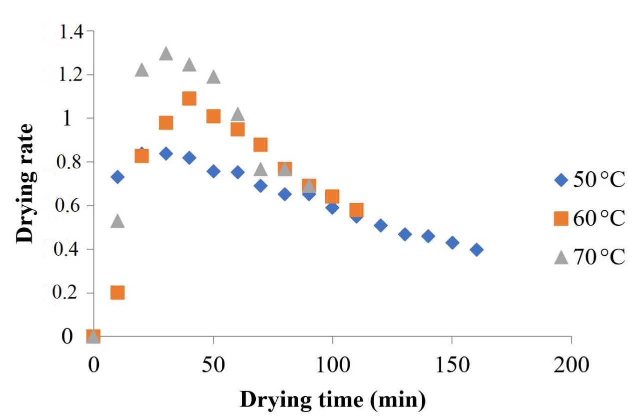

Figure 2. Drying rate curve of *Cleome* leaves at different temperatures.

Table 2. Statistical computations and values of model constants obtained from models applied to oven drying curves of *Cleome* leaves.

Model	Temperature (°C)	Constants							R^2	SSE	RMSE
	50	a = -0.0113	b = 4.06E-05						0.9975	0.0027	0.0134
Wang & Singh	60	a = -0.0157	b =7.75E-05						0.9692	0.0311	0.0558
	70	a = -0.0197	b = 0.0001						0.9753	0.0197	0.0496
								Average	**0.9806**	**0.0178**	**0.0396**
	50	a = 0.9924	k = 0.0120						0.9877	0.0132	0.0296
Simple exponential	60	a = 1.0710	k = 0.0184						0.9627	0.0376	0.0613
	70	a = 1.0420	k = 0.0216						0.9579	0.0335	0.0647
								Average	**0.9692**	**0.0281**	**0.0518**
	50	a =1.0180	k = 0.0135	b = 0.0019		g = 0.0244			0.9983	0.0018	0.0118
Two-term exponential	60	a = 1.0900	k = 0.0198	b = 4.21E-05		g = 0.0711			0.9735	0.0268	0.0579
	70	a = 1.0660	k = 0.0238	b = 0.0002		g = 0.0734			0.9756	0.0194	0.0569
								Average	**0.9824**	**0.0160**	**0.0422**
	50	k = 0.0170	n = 0.9227						0.9902	0.0105	0.0265
Page	60	k = 0.0095	n = 1.1450						0.9597	0.0406	0.0637
	70	k = 0.0169	n = 1.0510					Average	0.9553	0.0356	0.0667
									0.9684	**0.0289**	**0.0523**
	50	a = 0.9058	b = 0.0166	c = 0.1234					0.9964	0.0035	0.0166
Logarithmic	60	a = 0.5163	b = 0.9661	c = 0.9019					0.8542	0.1471	0.1356
	70	a = 0.9518	b = 0.0283	c = 0.1158					0.9653	0.0276	0.0628
								Average	**0.9386**	**0.0594**	**0.0716**
	50	k = -0.0121							0.9876	0.0133	0.0288
Lewis	60	k = -0.0170							0.9536	0.0468	0.0652
	70	k = -0.0205							0.9545	0.0363	0.0635
								Average	**0.9652**	**0.0321**	**0.0525**
	50	a = 0.0007	b = 0.0129	c = -0.0305					0.9977	0.0025	0.0134
Verma et al	60	a = -0.1723	b = 0.0204	c =1.396					0.9747	0.0255	0.0532
	70	a = 1	b = -0.0904	c = 0.0218					0.9676	0.0258	0.0607
								Average	**0.9800**	**0.0179**	**0.0424**
	50	a = -0.0523	b = 0.0092	c = 1.0430	g = -0.0156	h = 0.0147	k = 0.0596		0.9993	0.0008	0.0085
Modified Henderson & Pabis	60	a = -0.3104	b = 0.0063	c = 1.3040	g = -0.0289	h = 0.0261	k = 0.2421		0.9975	0.0025	0.0204
	70	a = 22.42	b = -21.39	c = 0.1314	g = 0.0614	h = -0.0047	k = 0.3797		0.9630	0.0295	0.0858
								Average	**0.9866**	**0.0109**	**0.0382**

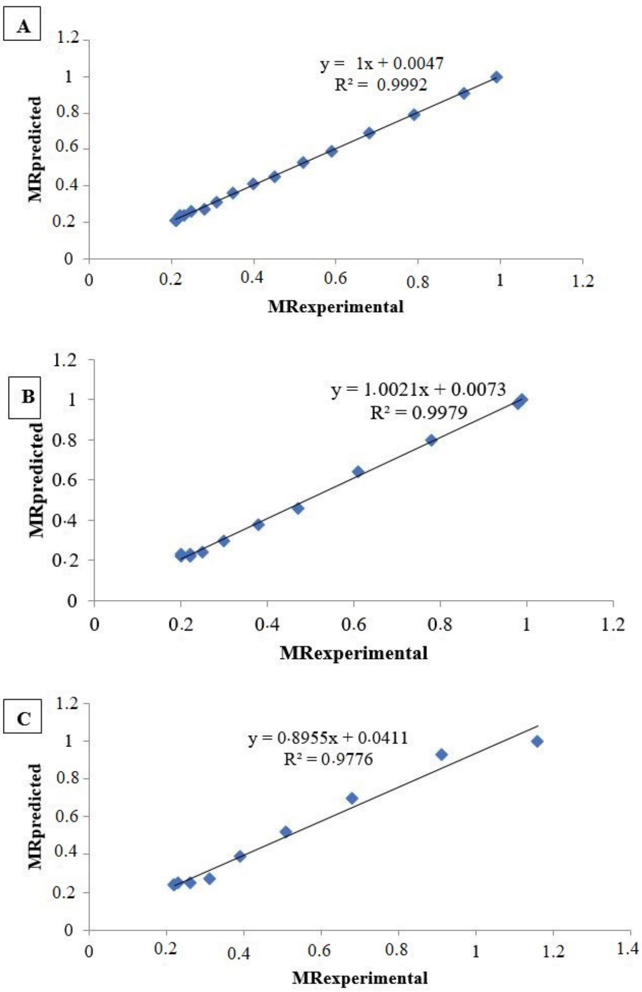

Figure 3. Validation of modified Henderson and Pabis model for predicting the oven drying characteristics of *Cleome* leaves at 50 (A), 60 (B) and 70 °C (C).

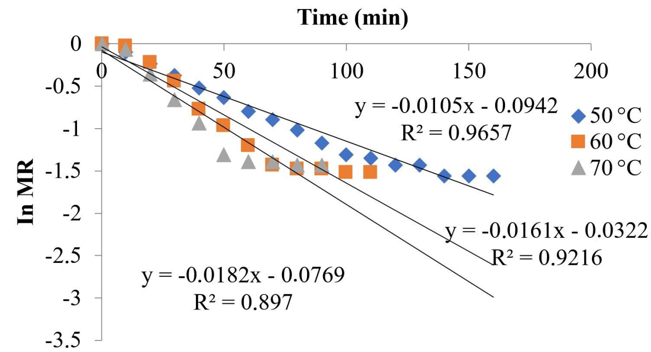

Figure 4. Variation of InMR with drying time at different oven temperature.

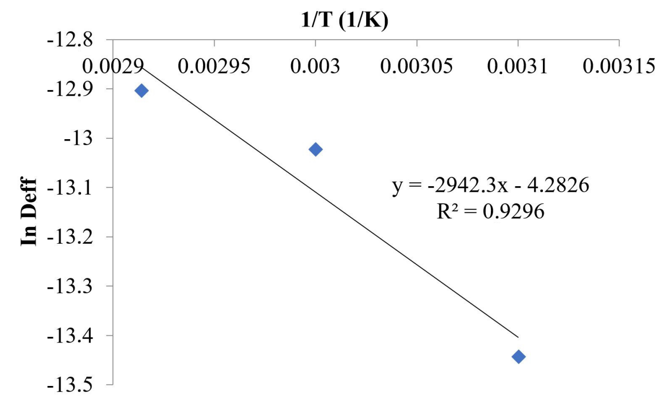

Figure 5. Plot of ln D_{eff} vs. 1/T of oven drying of *Cleome* leaves.

3.3 Effective moisture diffusivity and activation energy

The effective moisture diffusivities of *Cleome* determined using Equation 6 together with the slope obtained from the plot of ln (MR) versus time are shown in Figure 4. The effective moisture diffusivities of *Cleome* under oven drying at 50-70 °C ranged from 1.45×10^{-6} to 2.49×10^{-6} m²/s. As expected an increase in D_{eff} with increase in oven temperature was noticed. There was no literature data of D_{eff} of *Cleome* found. Nevertheless, it was noticed that the moisture diffusivity of *Cleome* is on the high side when compared with moisture diffusivity estimations of different foodstuffs found in the literature under comparable drying situations. Doymaz et al. (2006) reported $6.693 \cdot 10^{-10}$ - 1.434×10^{-9} m²/s and 9.0×10^{-10} - 2.337×10^{-9} m²/s at a temperature range of 50-70 °C for dill and parsley leaves respectively. The D_{eff} value of spinach leaves undergoing oven drying at 50, 60, 70, and 80 °C as reported by Doymaz (2009) and Ankita & Prasad (2013) were in the range of 6.590×10^{-10} to 1.927×10^{-9} m²/s and 2.150×10^{-12} to 9.710×10^{-12} m²/s, respectively. The activation energy for oven drying of *Cleome* leaves calculated from the slope obtained from the plot of InD_{eff} versus absolute temperature (Figure 5) was found to be 24.46 kJ/mol. Xiao et al. (2012) reported that the activation energy of most drying operations range from 12.7-110 kJ/mol. The activation energy obtained in this study is lesser than the activation energies reported by Simal et al. (1998) and Ankita & Prasad (2013) for broccoli drying (26.2 kJ/mol), and spinach leaves drying (50.85 kJ/mol) respectively. Nevertheless, the activation energy for *Cleome* leaves drying in the present study was observed to be higher than the activation energy reported by Premi et al. (2010) for drum-stick leaves (12.50 kJ/mol).

3.4 Colour of dried Cleome leaves

According to Fellows (2009), most drying operation impacts changes to the surface physical appearance of foodstuffs and hence changes their reflectivity and colour. Table 3 shows the colour characteristics of *Cleome* leaves. Colour characteristics of *Cleome* in terms of L*, a*, b*, ΔE, and a*/b* were in the range of 23.87 to 35.05, -2.23 to -3.37, 6.23 to 15.01, 66.98 to 77.27, and -0.16 to -0.36 respectively. The variation observed in the colour characteristics of *Cleome* as reflected in Table 3 could be attributed to the use of different drying conditions during the drying experiments. Doymaz et al. (2006) reported that a higher L* and lower a*/b* is required for dried foodstuffs. In this study as reflected in Table 3, samples dried at 70 °C/90 min had the highest L* ($p < 0.05$) and lowest a*/b* ($p < 0.05$) when compared to the other drying conditions used. Consequently it is obvious from Table 3 that there was no significant difference between

Table 3. Colour quality of dried *Cleome* leaves.

Temperature (°C)	Time (min)	L*	a*	b*	ΔE	a*/b*
0 (Fresh leaves)	0 (Fresh leaves)	$35.05^{a} \pm 0.05$	$-2.42^{a} \pm 0.02$	$15.01^{a} \pm 0.01$	$66.98^{a} \pm 0.03$	$-0.16^{a} \pm 0.05$
50	160	$23.87^{b} \pm 1.41$	$-2.23^{b} \pm 0.31$	$6.23^{b} \pm 1.31$	$77.27^{b} \pm 0.40$	$-0.36^{b} \pm 0.03$
60	110	$30.50^{c} \pm 1.49$	$-3.37^{c} \pm 0.64$	$10.87^{c} \pm 1.12$	$70.73^{c} \pm 1.42$	$-0.31^{b} \pm 0.03$
70	90	$34.40^{a} \pm 1.85$	$-2.67^{ac} \pm 0.21$	$14.20^{a} \pm 1.15$	$67.13^{a} \pm 1.80$	$-0.19^{a} \pm 0.03$

Means values with different letters are statistically significant at $p < 0.05$

the colour characteristics of the fresh leaves and samples dried at 70 °C/90 min. Considering the above observations, drying condition of 70 °C/90 min can be taken as the optimum drying condition for drying *Cleome* leaves.

4 Conclusion

Drying characteristics of *Cleome gynandra* leaves was explored using a convective air oven dryer at three dissimilar drying temperatures (50, 60, and 70 °C). The moisture substance of the leaves dropped from 81.33% (w.b) to a final moisture contents of 17.33%, 17.66%, and 19.60% (d.b) at a drying time of 160, 110 and 90 min, respectively. Increase in the oven temperature increased the drying rate and thus lessened the drying time. Drying of *Cleome gynandra* happened majorly in the falling rate time frame. Out of the eight (8) thin-layer drying models applied to the drying curves of *Cleome gynandra*, modified Henderson and Pabis model was the most reliable and acceptable model for describing the oven drying characteristics of *Cleome gynandra*. D_{eff} of *Cleome* under oven drying at 50-70 °C ranged from 1.45×10^{-6} to 2.49×10^{-6} m^2 /s while the energy required for removal moisture was found to be 24.46 kJ/mol. *Deff* of *Cleome gynandra* was found to be higher than that of different plants under comparable drying conditions. With regards to the colour analysis carried out on *Cleome gynandra* leaves, drying condition of 70 °C/90 min was found to be the optimum condition for oven drying of *Cleome* leaves.

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