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MODELING AND QUALITY ASSESSMENT OF *Moringa oleifera* LEAVES UNDER DIFFERENT DRYING CONDITIONS

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ABSTRACT

Moringa oleifera **leaves because of high nutrition content are consumed both in fresh and dried form. In order to find the effect of drying under conventional and controlled conditions on kinetics and quality of dried leaves, freshly harvested, mechanically stripped and washed Moringa leaves were dried by different drying methods *viz*., sun, shade, solar, vacuum and cabinet drying (45, 50, 55 and 60°C). The drying data was applied to five mathematical models to find out the best fit. The effect of drying on colour and biochemical constituents of Moringa leaves was studied. Study revealed that drying rate increased with drying time. Among the different models, Wang & Singh gave the best fit by higher R^2 and lesser χ^2 values. The quality analysis of dried Moringa leaves revealed that cabinet drying at 50°C resulted in better quality in terms of colour and nutrient content.**

Key words: Biochemical constituents, colour, drying kinetics, mathematical modeling, Moringa leaves, quality

INTRODUCTION

Moringa oleifera Lam., commonly known as drumstick tree and miracle tree, is a medicinal plant which belongs to family *Moringaceae*. It is a softwood tree, believed to be the native of India. It is now cultivated in South and South East Asian countries, Africa, Latin America and in the Caribbean Islands. Moringa has long been considered a panacea for combating malnutrition among lactating mothers and infants especially in the African continent. Every part of the tree has its own use due to the nutrients present in them. The pods are eaten as vegetable and the seeds as flocculent and in cosmetic industries. The roots are used in the traditional system of medicine while stalks and branches are used as fodder. Moringa leaves are nutritious so consumed fresh as vegetable or as health supplement in dried form. Moringa leaves contain high quantities of nutrients *viz*., vitamin A 7564 IU, vitamin C 51.7 mg, calcium 185 mg and potassium 337 mg 100 g^{-1} fresh weight (Foidl and Paull, 2008). In India, Moringa is commercially cultivated in the southern states of Andhra Pradesh, Tamil Nadu and Karnataka. The leaves are dried and exported as a health supplement in capsules and tablet form and also as Moringa tea leaves. Drying is the major unit operation to convert the fresh leaves into dry leaves or powder. In Tamil Nadu, they are generally dried under sun in open fields. The freshly harvested Moringa branches are spread in the fields and by shedding off the leaflets from the branches drying is accomplished. Open sun drying takes in more time and greatly affects the colour and nutrient quality of leaves. This problem could be overcome if Moringa leaves are dried under controlled conditions using mechanical dryers and solar polyhouse dryers. The possibility of evaluating the quality of Moringa leaves in terms of colour and nutrient content under different drying methods and conditions has been found to be a viable option. Several studies have reported drying of Moringa leaves on convective driers at temperatures > 60°C (Satwase *et al.*, 2013; Alakali *et al.*, 2015). Since temperature plays an effective role in nutrient retention during drying, therefore higher temperatures are not preferred for drying. The present investigation was aimed to dry Moringa leaves under controlled conditions at temperatures not more than 60°C for better nutrient retention, to know the best drying condition in terms of quality parameters and to evaluate drying data on mathematical models to arrive at best fit.

MATERIALS AND METHODS

Raw material preparation

Moringa leaves of variety 'PKM-1' were obtained from the farmer's fields. The fresh Moringa leaves were stripped in a mechanical stripper [developed at CIAE-Regional Centre, Coimbatore]. The stripped leaflets were washed in 4% sodium hypochlorite 100 ppm for 1 min. (Luo *et al.*, 2004).

Drying experiments

The initial moisture content of fresh Moringa leaves was estimated by calculating the losses after oven drying at 70°C till constant weight. Drying of leaves was carried out by different drying methods *viz.*, shade, sun, solar, vacuum and cabinet drying (45, 50, 55 and 60°C). The leaves were dried till they attained a moisture content of 2-5%. For each drying experiment, 200 g mechanically stripped and washed leaves were used. Under sun drying, the fresh Moringa leaves (after stripping and washing) were spread on stainless steel tray of size 400 × 600 mm and kept open in sun for drying. The ambient air temperature ranged from 31 to 41ºC and relative humidity was 42 to 27%. Similarly another lot of sample was kept under shade for drying. The temperature ranged between 30 and 35ºC and relative humidity was between 44 and 36% during the drying period. In case of solar polyhouse drying, the cleaned leaves were kept on trays inside dryer for drying under controlled conditions. The temperature inside dryer ranged from 35 to 44ºC. Drying under vacuum was carried out in a vacuum dryer. The temperature was set at 60ºC with 15 mm Hg pressure. Cabinet drying involved the drying of samples spread on 600 × 600 mm size trays at different temperatures (45, 50, 55 and 60ºC). The air velocity was maintained at 7 m/s. In the above drying methods, the weight of samples was noted after every 15 min. for each temperature with the help of an electronic balance till constant weight. The experiments were replicated thrice.

Analysis of drying data

In this study, the moisture ratio (MR) and drying rate of samples during drying process were calculated using the following equations:

$$MR = \frac{M_t - M_e}{M_o - M_e} \quad \text{.................................... (1)}$$

$$\text{Drying rate} = \frac{M_t - M_{t+dt}}{dt} \quad \text{.................................... (2)}$$

Where, MR, M_0, Me, Mt and Mt + dt are the moisture ratio, initial moisture content, equilibrium moisture content, moisture content at 't' and moisture content at 't + dt' (kg moisture per kg dry matter), respectively, and t is drying time (min.). To select the best model for describing the drying curve during drying process four drying models *viz.*, Page (Ankita and Prasad, 2013), modified Page (Fabrizio *et al.*, 2014), Newton (Shilpi *et al.*, 2010), logarithmic (Raveendran *et al.*, 2015) and Wang & Singh models (İzli *et al.*, 2014) with respective model equations of moisture ratio equal to

$\exp(-kt^n)$, $\exp[-(kt)^n]$, $\exp(-kt)$, $a\exp(-kt)+c$ and $1+at+bt^2$ were tested. The regression (R^2), the root mean square error (RMSE) and mean square of deviations between experimental and calculated values for the models or χ2 were performed.

$$\mathrm{RMSE} = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre\ i} - MR_{\exp\ i}\right)^2\right]^{\frac{1}{2}} \quad \text{.................................} \ (3)$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{\exp\ i} - MR_{pre\ i}\right)^2}{N-n} \quad \text{..} \ (4)$$

Biochemical analysis of Moringa oleifera leaves

Colour value in terms of L, a and b values of freshly processed and dry processed Moringa leaves were estimated using colour flex meter (Hunter Lab, Model: 45º/0º). Ascorbic acid content in the samples was estimated as per Srivastava *et al.* (1998). Leaf samples (10 g) were blended with 3% metaphosphoric acid, the volume made upto 100 mL and filtered, titrated with a standard dye to a pink end-point and calculated based on standard formula. β-carotene in leaves was estimated as per Srivastava *et al.* (1998). Leaves (5 g) were crushed in 10-15 mL acetone with an addition of few crystals of anhydrous sodium sulphate in a pestle and mortar. The supernatant was discarded into a beaker and the process repeated twice to transfer the combined supernatant to a separatory funnel. Petroleum ether (10-15 mL) was added and mixed thoroughly. On standing two layers were separated. The lower layer was discarded and upper layer collected in a volumetric flask. The volume was made upto 100 mL with petroleum ether. The optical density was recorded at 452 nm using petroleum ether as blank.

The chlorophyll content in Moringa leaves were estimated as per Srivastava *et al.* (1998). Leaf sample (1 g) was cut into small pieces and homogenized in a blender. The homogenate was made upto 10 mL with water and centrifuged. To extract the pigment 4.5 mL 80% acetone was added to 0.5 mL aliquot and the supernatant recorded for optical density (O.D) at 480, 645 and 663 nm, using acetone as blank. Iron in samples was estimated as per standard method (FSSAI, 2012). A known weight of sample was kept for ashing in a muffle furnace at 450ºC for 3 h and then cooled and 50 mL dilute HCl added and kept in a water bath for 30 min. Another 10 ml HCl and water were added and filtered to a 100 ml volumetric flask and volume made up with HCl. To ash solution, 1% ammonium citrate, 1% hydroquinone solution, 1% o-phenanthroline was added and diluted with distilled water. The solution was incubated for 1 h and the absorbance measured at 510 nm.

Statistical analysis

The experiment was designed based on single and three factor in a complete randomized design of three replicates. The effect of drying treatments on Moringa leaves was found by using of statistical analysis using ANOVA at $p \leq 0.05$ and the significant effects further evaluated by the use of F–LSD at $p \leq 0.05$ using AGRES software.

RESULTS AND DISCUSSION

Drying kinetics of Moringa leaves

The initial moisture present in Moringa leaves was 230% (d.b). The moisture content reached at subsequent drying time under various drying condition is presented in Fig. 1. It appeared that the moisture removal was faster with increase in drying time. Sun drying took 5 h from drying from initial moisture of 230% (d.b) to final moisture of 3% (d.b). The temperature recorded during sun drying was 40±2ºC and relative humidity (RH) 27%. Similar results were observed during sun drying of Moringa leaves by Satwase *et al*. (2013). Shade drying took a time of 10 h to reach the final moisture content of 3% (d.b). The reason for long drying time seemed due to low temperature of 30±2ºC and a RH 47% maintained inside the room. This was in agreement with Bhosale and

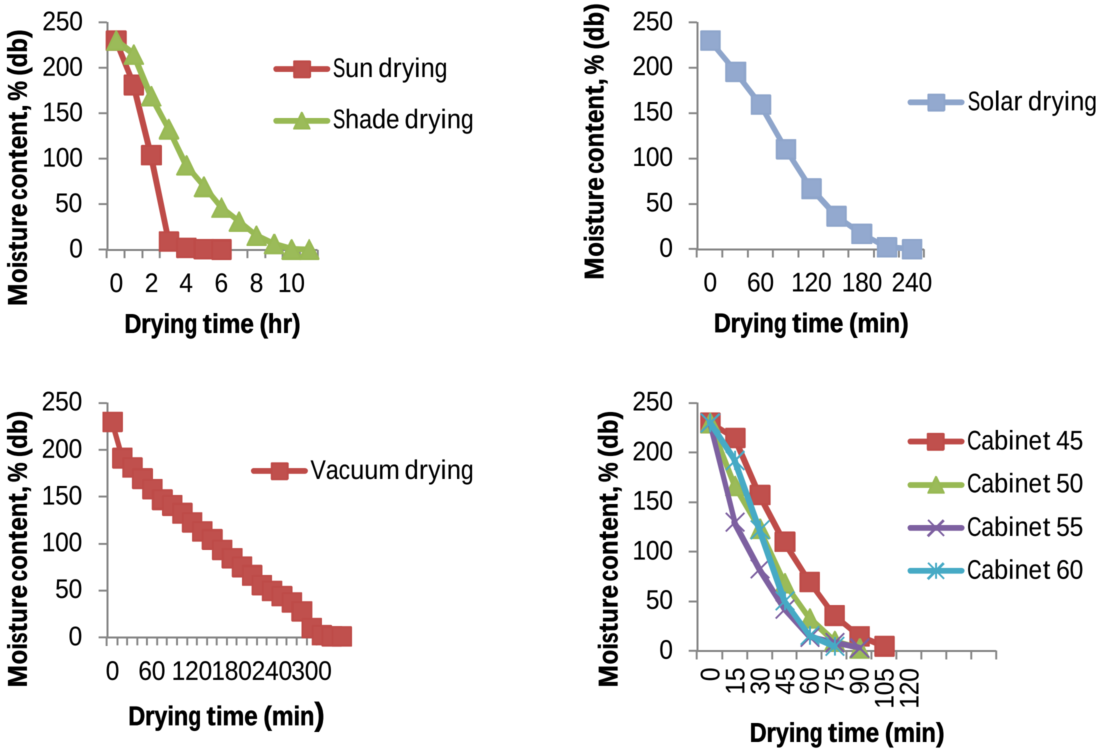

Fig. 1: Drying curves for Moringa leaves upper left) sun and shade drying upper right) solar polyhouse drying; lower left) vacuum drying; lower right) cabinet drying

Arya (2004) for leafy vegetables. In case of solar polyhouse drying, the drying time was 210 min. to reach final moisture of 3% (d.b). Solar drying took a much lesser time compared to sun drying which may be attributed to the increase in temperature created inside the poly galvanized sheet. Vacuum drying took 330 min. to reach final moisture of 3% (d.b). İlknur Alibas (2012) conducted vacuum drying of celeriac slices at different temperatures (55, 65 and 75°C) and pressures (0.1, 3, 7, 10, 13 and 17 kP) and reported increase in temperature during vacuum drying resulted in the reduction of drying time. Since drying temperature selected for Moringa drying under vacuum was only 60°C, the drying time was much longer. Cabinet drying of Moringa leaves were carried at four different temperatures. In case of the samples dried at 45°C, the drying time was 135 min. to reach final moisture of 3%. Cabinet drying at 50ºC took 120 min. drying time. Drying was faster at 60ºC as compared to all other drying conditions. Drying time reduced with increase in temperature during hot air convective drying as reported by earlier researchers (İlknur Alibas, 2012; Olalusi 2014; Singh *et al*., 2015).

Drying models prediction

The experimental data obtained under laboratory drying studies of Moringa leaves were used for modeling purpose. The moisture content data at different drying air temperature were converted to moisture ratio and the values fitted to five drying models (Table 1). The best model was selected based on highest R^2 and lowest RMSE and χ^2 values. All the models varied with temperature. Similar findings have been reported for henna leaves (Kadam *et al*., 2013). Even though all the test models satisfactorily predicted, the drying of Moringa leaves, the Wang & Singh model performed better than the rest with highest R^2 and lowest RMSE and χ^2. Wang & Singh model resulted in best fit for bay leaves (Tuncay *et al*., 2005) and Brazilian lemon-scented verbena leaves (Fabrizio *et al*., 2014). This indicated that when the values of R^2 were higher and the values of χ_2 and RMSE were lower, the goodness of fit was better (Yaldiz *et al*., 2001; Akpinar, 2006).

Table 1: Goodness of fit parameters for drying models for Moringa by different drying methods

Drying method	Model name	Model equation	R^2	RMSE	$\chi 2$
Sun	Page	MR = $\exp(-kt^n)$	0.9730	0.066332	0.00375
	Modified Page	MR = $\exp[-(kt)^n]$	0.9730	0.077753	0.00503
	Newton	MR = exp(-kt)	0.9175	0.01538	0.13585
	Logarithmic	MR = aexp(-kt)+c	0.9662	0.085141	0.00604
	Wang and Singh	MR = $1+at+bt^2$	0.9827	0.06224	0.00322
Shade	Page	MR = $\exp(-kt^n)$	0.9852	0.04126	0.00193
	Modified Page	MR = $\exp[-(kt)^n]$	0.9852	0.04126	0.00193
	Newton	MR = exp(-kt)	0.9574	0.07835	0.00558
	Logarithmic	MR = aexp(-kt)+c	0.9978	0.01668	0.00025
	Wang and Singh	MR = $1+at+bt^2$	0.9992	0.0105	0.0001
Solar	Page	MR = $\exp(-kt^n)$	0.9725	0.06221	0.0032
	Modified Page	MR = $\exp[-(kt)^n]$	0.9725	0.06221	0.0032
	Newton	MR = exp(-kt)	0.9182	0.0124	0.1389
	Logarithmic	MR = aexp(-kt)+c	0.9818	0.0680	0.00411
	Wang and Singh	MR = $1+at+bt^2$	0.9883	0.0608	0.00329
Vacuum	Page	MR = $\exp(-kt^n)$	0.9650	0.0653	0.0040
	Modified Page	MR = $\exp[-(kt)^n]$	0.9650	0.0653	0.0040
	Newton	MR = exp(-kt)	0.9083	0.1057	0.0106
	Logarithmic	MR = aexp (-kt)+c	0.9962	0.0213	0.00043
	Wang and Singh	MR = $1+at+bt^2$	0.9963	0.0213	0.00043
Cabinet,45° C	Page	MR = $\exp(-kt^n)$	0.9858	0.0446	0.0018
	Modified Page	MR = $\exp[-(kt)^n]$	0.9844	0.04364	0.0017
	Newton	MR = exp(-kt)	0.9586	0.0762	0.0058
	Logarithmic	MR = aexp(-kt)+c	0.9948	0.0265	0.00064
	Wang and Singh	MR = $1+at+bt^2$	0.9992	0.0103	0.000098
Cabinet, 50°C	Page	MR = $\exp(-kt^n)$	0.9656	0.07861	0.00541
	Modified Page	MR = $\exp[-(kt)^n]$	0.9656	0.07861	0.00541
	Newton	MR = exp(-kt)	0.9356	0.1075	0.0810
	Logarithmic	MR = aexp(-kt)+c	0.9911	0.0387	0.0013
	Wang and Singh	MR = $1+at+bt^2$	0.9939	0.033	0.0009
Cabinet, 55°C	Page	MR = $\exp(-kt^n)$	0.9794	0.0634	0.0034
	Modified Page	MR = $\exp[-(kt)^n]$	0.9794	0.0634	0.0034
	Newton	MR = exp(-kt)	0.9289	0.1180	0.0119
	Logarithmic	MR = aexp(-kt)+c	0.9883	0.0462	0.0021
	Wang and Singh	MR = $1+at+bt^2$	0.9948	0.0318	0.00087
Cabinet, 60°C	Page	MR = $\exp(-kt^n)$	0.9845	0.0524	0.0033
	Modified Page	MR = $\exp[-(kt)^n]$	0.9845	0.0524	0.0033
	Newton	MR = exp(-kt)	0.9337	0.1187	0.0117
	Logarithmic	MR = aexp(-kt)+c	0.9862	0.0522	0.0022
	Wang and Singh	MR = $1+at+bt^2$	0.9941	0.0352	0.00010

Effect of drying on the quality of Moringa leaves

Colour: For dried Moringa leaves obtained by different drying methods, out of three colour values i.e. *L*, *a* and *b*, *a*-value was of maximum significance as it indicated green colour and changes thereof (Table 2). Among the conventional drying methods, shade drying showed best results with a value of -7.38. Under controlled drying, maximum 'a' value was found for cabinet drying at 55ºC. There was no much significant difference for the sample dried at 50°C. Increase in drying temperature increased 'a' value. This is in agreement with the results for drying green kiwi fruits (Diamante *et al.*, 2010). Overall, all mechanically dried samples had a good retention of colour. This is in agreement with the results on leafy vegetables by Singh *et al.* (2006).

Proximate composition: The changes in nutrient composition of Moringa leaves by different drying methods are presented in Table 3. The nutrient analysis was carried out in fresh Moringa leaves as well as the dried leaves obtained by different drying methods. Vitamin C content of fresh leaves was

Table 2: Colour values of dried Moringa leaves

Type of drying	Colour value		
	L	A	B
Sun drying	45.62	-4.33	27.44
Shade drying	42.09	-6.71	24.90
Solar drying	43.96	-4.70	26.52
Vacuum drying	44.88	-7.38	27.09
Cabinet drying			
45ºC	45.60	-6.89	25.61
50ºC	48.77	-8.28	30.32
55ºC	45.20	-8.40	27.61
60ºC	43.75	-7.59	26.60
SE±	0.142	0.053	0.090
$CD_{0.01}$	0.416	0.155	0.190
$CD_{0.05}$	0.302	0.113	0.262

more than their dried counterparts. During the entire drying process there was loss in ascorbic acid content. Vitamin C is a heat labile vitamin and it is destroyed when exposed to direct sunlight and heat, due to oxidation. There was a continuous decrease in the value of vitamin C as drying time and temperature increased (Peter *et al.*, 2010). Vitamin C retention was more in the dried sample obtained at 50°C cabinet drying, resulting in significant increase compared to other samples ($P<0.05$). In case of β-carotene content, the fresh leaves had a higher concentration and among the dried samples, the highest was recorded for cabinet drying at 45ºC with the value of 4479.84 µg 100 g^{-1} followed by shade drying. Earlier studies on Moringa revealed that 80% carotenoids could be retained by shade drying (Olushola, 2006). According to Pallavi and Dipika (2010) shade drying recorded highest β-carotene content followed by oven drying at 60°C. Statistical analysis showed significant difference among the treatments. The results are in agreement with the works conducted on dehydrated leafy vegetables (Kowsalya and Vidhya, 2004). β-carotene is a precursor of vitamin A so similar results were recorded for vitamin A content of dried Moringa leaves. There was significant difference in chlorophyll content during drying. Chlorophyll content of shade dried Moringa leaves was almost on par with the fresh leaves (Table 3). Chlorophyll content decreased with increase in temperature. Similar results have been reported for coriander during drying (Ahmed *et al.*, 2001). Iron content of fresh Moringa leaves was less as compared to dried samples. This may be due to the fact that concentration of solids increases with moisture removal. This was in agreement with Alakali *et al*. (2015). There was no much significant difference in the iron content during drying by different methods. The iron content varied from 18.33 to 21.6 mg with the highest value recorded at 60ºC cabinet drying. Iron content was not much destroyed while drying. This is in agreement with the reports in case of leafy vegetables (Lakshmi and Vimala, 2000).

Table 3: Nutrient analysis of dried Moringa leaves

Type of sample	Ascorbic acid (mg 100 g^{-1})	β-carotene (µg 100 g^{-1})	Vitamin A (IU)	Chlorophyll (mg 100 g^{-1})	Iron (mg 100 g^{-1})
Fresh leaves	266.15	6528.95	10881.58	97.28	0.171
Sun dried	151.34	2954.82	4924.70	57.21	18.33
Solar dried	199.18	3021.68	5036.13	63.21	19.06
Shade dried	38.28	4462.77	7437.96	97.05	18.40
Vacuum dried	83.39	2937.03	4895.06	81.88	18.60
Cabinet Dried					
45ºC	155.19	4479.84	7466.40	66.47	18.10
50ºC	229.63	2296.80	3828.01	73.48	19.70
55ºC	100.48	2430.53	4050.89	75.45	19.40
60ºC	185.26	1646.29	2743.82	72.15	21.60
SED	0.550	10.256	11.078	0.477	0.11
$CD_{0.01}$	1.606	21.654	34.1916	1.393	0.32
$CD_{0.05}$	1.1653	19.357	24.815	1.0107	0.2344

Conclusions: Drying time reduced with increasing temperature for Moringa leaves at different drying condition. Based on mathematical analysis of the drying data, Wang & Singh model resulted in best fit for drying of *Moringa oleifera* leaves. Drying at 50°C in a cabinet dryer resulted in better quality of the leaves and faster drying.

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