

UDK: 631 (059)

Originalni naučni rad
Original scientific paper

MATHEMATICAL MODELING FOR DRYING OF WHOLE LEAF ALOE VERA (*ALOE BARBADENSIS* MILLER)

**Gritty Pattali^{*1}, Govind Yenge², Ramachandra Cheluvadi³,
Udaykumar Nidoni³, Sharangouda Hiregoudar³**

¹ *Agricultural Research Station, KAU, Thrissur, Kerala, India*

² *Department of Agricultural Process Engineering, MPKV, Rahuri, Maharashtra, India*

³ *University of Agricultural Sciences, Department of Processing and Food Engineering,
Raichur, Karnataka, India*

Abstract: The present work aimed to study the effects of different drying methods in terms of drying behavior, drying rate and mathematical modelling of drying process for whole leaf Aloe vera. Open yard sun drying, hot air drying and dehumidified air drying were taken as different drying methods. The whole leaf Aloe vera slices took 20 h to dry under open yard sun drying, 16 h in case of hot air drying, 11 h in dehumidified air drying having initial moisture content ranging from 3115.43% (d.b.) to a final moisture content of 8.6% (d.b.). The different thin layer drying models were applied on the experimental moisture loss data with respect to time to predict the drying pattern properly. On the basis of coefficient of determination (0.9764) and standard error (0.0552), the Page model showed better fit.

Key words: *Aloe vera, dehumidified air drying, hot air drying, open yard drying, drying time*

INTRODUCTION

The Aloe plant (*Aloe barbadensis* Miller) belongs to a member of the family Liliaceae. Total production of aloe in India is estimated to be about 1.00.000 tons [1]. And the annual consumption of aloe extract by Indian pharmaceutical industries is 200 tonnes [2]. There are many industries now concentrated only on processing of Aloe vera

^{*} Corresponding author. E-mail: grittypat@gmail.com

Acknowledgements: Indian Council of Agricultural Research for funding project under scheme of National Agricultural Innovation Project.

and earning profit to a remarkable level. Potential use of aloe products often involves some type of processing, e.g. heating, dehydration and grinding [3]. In recent times, whole leaf Aloe vera powder has attracted much attention and is presented by manufactures as providing extra benefits [4]. With increasing demand for herbal cure and cosmetics, there is good prospect for its large-scale production, processing and marketing. Since negligible research work has been reported on Aloe vera, it was decided to study the method to increase the quality of whole leaf Aloe vera powder.

Dehydration is an important unit operation in chemical and food processing industries. Several phenomena related to heat and mass transfers are involved in the dehydration process [5]. The main purpose of drying is to decrease the water activity, inhibiting the development of microorganisms, decreasing spoilage reaction, longer periods of storage, minimize packaging requirements and reduce shipping weights [6]. Today, the whole leaf approach is adding new dimensions to the properties of this remarkable plant. [7]. Owing to the increased preference to herbal cosmetics and cosmeceuticals, the demand for Aloe vera is on the rise every year. It is definitely a crop highly suitable for growing in many parts of India. Controlled drying might also lead to an overall improvement in the quality of the final product. Therefore, the use of different dryers such as freeze dryer, hot air dryer, dehumidified air dryer etc. at optimized condition, is considered to improve the shelf-life compared to liquid products and to eliminate the cost of shipping water.

The different drying processes may cause irreversible modifications to active substances, affecting their original structure, which may promote important changes in the proposed physiological and pharmacological properties of these components [8]. So under factual state of affairs the use of non-standardized processing techniques to obtain aloe powder may fetch poor quantitative and qualitative availability of bioactive compounds in the marketable aloe product. The loss of biological activity at different stages of processing and storage should be studied to ensure the maximum retention of active compounds. Unfortunately, because of improper processing procedures, many of these so-called aloe products contain very little or virtually no active ingredients, namely mucopolysaccharides [9]. In view of the importance of biological activities possessed by the leaves of the Aloe vera, it is necessary that the leaf should be processed with the aim of retaining essential bioactive components. In this respect, a proper processing techniques need to be developed to ensure the biological integrity in the final product. At present, very little is known about the effect of drying method on the quality of aloe leaf in its dried form [10]. So it is important to have a systematic study on the Aloe vera for devising suitable processing method giving longer storage stability and satisfying regional palate.

MATERIAL AND METHODS

Aloe vera leaves of 3-year old were purchased from the “North Karnataka Medicinal and Aromatic Plant Growers’ Association” situated in Gadag of North Karnataka, India. The leaves were washed and scrubbed to remove mud, adhering material, sand and bitter exudates on the rind surface. After washing, the leaves were weighed and trimmed using a knife. Trimming was done by cutting the base of the leaves with approximate 25 mm, tip with 30 mm and the sides with 10 mm. The trimmed leaves were cut into slices with

approximate 15 to 50 mm thickness and dried in different drying methods. Three different dryers were used for drying, i.e. hot air drying at 50°C, dehumidified air drying at 55°C and 18% RH and open yard sun drying.

Mathematical modeling. The moisture contents of Aloe vera slices during the experiments were expressed in dimensionless form as moisture ratios (*MR*) with the help of the following equation [11,12]. The mathematical models viz., Newton, Page and Henderson-Pabis models were selected for fitting the experimental data and these selected models were best models to describe the drying curve equation of whole leaf Aloe vera slices during drying. These are explained here under.

$$\text{Newton model: } MR = \exp(-K\theta) \tag{1}$$

$$\text{Page model: } MR = \exp(-K\theta^n) \tag{2}$$

$$\text{Henderson- Pabis model: } MR = a \cdot \exp(-K\theta) \tag{3}$$

where:

MR [-] moisture ratio.

$$MR = \frac{M - M_e}{M_o - M_e} \tag{4}$$

where:

- M_e* [%] - equilibrium moisture content (d.b.),
- M* [%] - moisture content at any time θ (d.b.),
- M_o* [%] - initial moisture content (d.b.),
- K, n, a* [-] - constants,
- θ [min] - drying time.

The constants of the selected models were estimated by non-linear regression [13] and the parameters of all the models were estimated by using MATLAB version 7.0 software package. The fit quality of the proposed models on the experimental data was evaluated using linear regression analysis using curve fitting tool in MATLAB 7.0.

Statistical analysis. The goodness of fit of different models under different drying methods was evaluated based on values of coefficient of determination (R^2) and the model was characterized by root mean square error (*RMSE*), coefficient of determination (R^2) and sum of square error (*SSE*). These parameters can be calculated as follows.

$$RMSE = \sqrt{\frac{\sum_{i=0}^N (MR_o - MR_p)}{df}} \tag{5}$$

$$SSE = \frac{1}{N} \sum_{i=1}^N (MR_o - MR_p)^2 \tag{6}$$

where:

- MR_o* [-] - observed moisture ratio,
- MR_p* [-] - predicted moisture ratio,
- Df* [-] - degrees of freedom,
- N* [-] - No. of data points,
- Z* [-] - No. of constants.

RESULTS AND DISCUSSION

Drying characteristics. The reduction in moisture content of whole leaf Aloe vera dried under open yard sun drying, hot air drying and dehumidified air drying were recorded (Fig. 1 and 2). The whole leaf Aloe vera sample took 20 h to dry the sample under open yard sun drying having initial moisture content from 3115.43% (d.b.) to a final moisture content of 8.66% (d.b.), respectively. In this drying, temperature depends on the climatic conditions of the day. Open yard sun drying is widely practiced in tropical countries, but the method is extremely time-consuming, weather dependent and has the problem of contamination, infestation and microbial attack [14].

In case of hot air drying, the moisture content of whole leaf Aloe vera slices was decreased from 3115.43% (d.b.) to 8.61% (d.b.) in 16 hours at 50°C. As the temperature increased, the drying time decreased. The present results are similar to the findings reported by [5] who reported the variation of moisture content as a function of time. At a temperature of 50 °C in convective dryer, the time required for drying at 50°C was 800 min. [5] reported about the drying of Aloe vera slab at 60°C with initial moisture content of 69.23 ± 1.13 g water·g d.m⁻¹ and concluded that the drying curve showed a clear tendency of equilibrium moisture content of 0.071 ± 0.002 g water·g d.m⁻¹. The results of hot air dried whole leaf Aloe vera were also similar to the results of [15] who reported that a drying temperature of 60-70°C resulted in production of high quality gel.

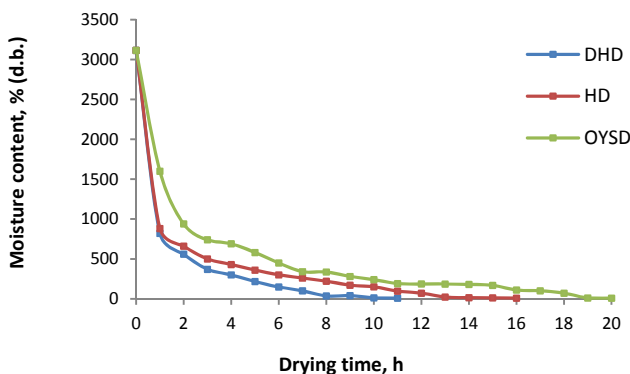


Figure 1. Moisture content variation of whole leaf Aloe vera slices in different drying methods

In dehumidified air drying method, the moisture content of whole leaf Aloe vera slices was decreased from 3115.43% (d.b.) to 8.57% (d.b.) in 11 hours at $55 \pm 1^\circ\text{C}$ and $18 \pm 1\%$ RH. The results are in agreement with the findings of [11] using dehumidified air drying of Aloe vera inner gel at optimum temperature of 64°C and 18% RH and at air velocity of $0.8 \text{ m}\cdot\text{s}^{-1}$. Similar results were found by [16]; [5]; [17]; and [8], working with kale, red bell pepper, various vegetables and kiwis, respectively.

The drying rate was calculated as quantity of moisture removed per unit time per unit dry matter. It can be seen that drying process mainly consisted of three drying periods i.e., heating up, constant rate and falling rate period. While in hot air drying at temperature of 50°C showed only the falling rate period which was due to moderate

temperature of drying. In hot air drying, the drying rate period started from 47.04 to 0.04% (d.b.) min⁻¹ at 50°C. [5] also reported that in hot air drying process of products of vegetal origin, the constant rate period was not observed and there was a marked falling rate period due to quick moisture removal from samples.

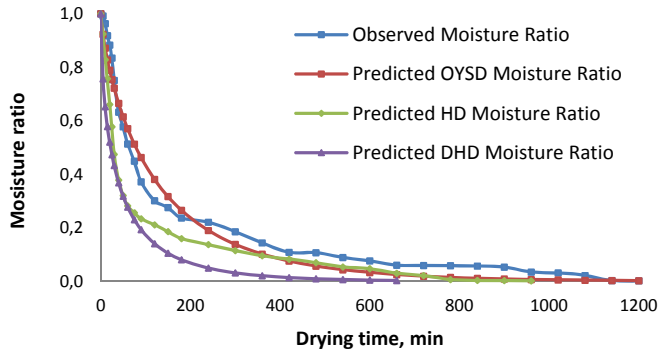


Figure 2. Experimental and Page model predicted moisture ratio for different drying methods of whole leaf Aloe vera

In dehumidified air drying process at temperature of 55±1°C and 18±1% RH only falling rate period was detected and the drying rate was observed from 65.09 to 0.06 per cent (d.b.) min⁻¹, due to higher temperature and lower RH of drying. Similar results were reported by [17; 18] that only falling rate period was observed in microwave drying of banana and kiwi fruit and [19] in Aloe vera gel powder. The drying rate of whole leaf Aloe vera dried under open yard sun drying at different temperatures was varied from 5.14 per cent (d.b.)min⁻¹ in the initial stage of drying to 0.14 per cent (d.b.)min⁻¹. In this drying, the drying rate is mainly depends on varying drying temperature. Here temperature varies according to the climatic condition.

Mathematical modeling of drying of whole leaf Aloe vera in different drying methods. The moisture ratio versus time data were fitted to the selected thin layer drying models namely Newton, Page and Henderson-Pabis model. The model coefficients for all the three models were estimated by nonlinear regression technique using MATLAB 7.0 version software. The estimated values of statistical parameters obtained under different drying methods and varieties for these models are shown in Tab. 1 and 2. The Page model gave the best fit to the experimental data with higher R² value of 0.9675 and lowest root mean square error (RMSE) and sum of square error (SSE) values of 0.051 and 0.055, respectively. Experimental and Page model predicted moisture ratio for different drying methods of whole leaf Aloe vera were shown in Fig.2. The Newton model described a poor fit to the experimental data with lowest R² value of 0.9239 higher root mean square error (RMSE) and sum of square error (SSE) values of 0.1381 and 0.079, respectively. These results are in good agreement with the results obtained by [5] for Aloe vera gel. These results showed positive dependence on temperature. Similar results were obtained by [10] working with grapes, kale and okra. The good fit of the experimental data using the Page model may be due to the incorporation of exponential

parameter 'n' which provides a better mathematical approximation of drying curves [5]. [21] also reported that the page model gives the best fit with high values for the coefficient of determination R^2 (0.9811-0.9859) and lower *SSE* (0.0557-0.0779) for the drying of Aloe vera gel.

Table 1. Constants of drying models

Sl. No.	Method	Newton	Page		Henderson-Pabis	
		K	K	n	K	a
1	Open yard sun drying	0.0089	0.0227	0.783	0.024	0.921
2	Hot air drying	0.0195	0.0638	0.674	5.83	0.003
3	Dehumidified air drying	0.0277	0.1040	0.613	3.60	0.025

Table 2. Estimated values of statistical parameters of Newton, Page and Henderson-Pabis models used for different drying methods

Sl. No.	Parameter	Method	Newton	Page	Henderson Pabis
1	R^2	OYSD	0.9682	0.9695	0.9682
		HD	0.9481	0.9675	0.9492
		DD	0.9239	0.9764	0.9295
2	<i>SSE</i>	OYSD	0.1181	0.0875	0.1181
		HD	0.1285	0.0804	0.1258
		DD	0.1381	0.0552	0.1285
3	<i>RMSE</i>	OYSD	0.0617	0.0540	0.0627
		HD	0.0689	0.0556	0.0695
		DD	0.0792	0.0512	0.0782

CONCLUSION

The reduction of moisture content of whole leaf Aloe vera slices took less drying time of 11 h in dehumidified air drying to dry the sample from an initial moisture content ranging from 3115.43% (d.b.) to final moisture content of 8.57% (d.b), respectively as compared to open yard sun drying and hot air drying methods. The drying rate was higher in the beginning of the drying processes and gradually reduced through the end of the drying process. Page model gave better fit to the experimental data with higher R^2 value of 0.9675 and lowest root mean square error (*RMSE*) and sum of square error (*SSE*) values of 0.051 and 0.055, respectively over the other two models.

BIBLIOGRAPHY

- [1] Anonymous. 2006. *Database on important medicinal and aromatic plants*. Ministry of Commerce Director General of Foreign Trade, Government of India, New Delhi.
- [2] Pandhair, V. 2008. Aloe vera-the wonder herb. *Indian Farm.*, 2: 9-11.
- [3] Ramachandra, C.T., Srinivasa, R.P. 2008. Processing of Aloe vera leaf gel: A review. *American Journal of Agricultural and Biological Sciences*, 3(2):502-510.

- [4] Chang, X.L., Wang, Ch., Feng, Y., Liu, Z. 2006. Effects of heat treatments on the stabilities of polysaccharides substance and barbaloin in the gel juice from Aloe vera Miller. *Journal of Food Engineering*, 75(2):245-251.
- [5] Vega, A., Uribe, E., Lemus, R., Miranda M. 2007. Hot-air drying characteristics of Aloe vera (Aloe barbadensis Miller) and influence of temperature on kinetic parameters. *J. Lebensum Wiss Techn.*, 40(10):1698-1707.
- [6] Okos, M. R., Narasimhan, G., Singh, R.K. 1992. *Food dehydration*. In Heldman, D.R. and Lund, D.B. (Eds.), *Handbook of Food Engineering*. New York: Marcel Dekker.
- [7] Crewe, J.E. 1937. Whole Leaf Aloe Vera the External Use of Aloes. *Minnesota Journal of Medicine*, 20:670-673. Devi, J. (2009), Aloe vera: A gift of nature. Science Tech Entrepreneur. 2009.
- [8] Simal, S., Femenia, A., Llull, P., Rosello, C. 2000. Dehydration of Aloe vera: simulation of drying curves and evaluation of functional properties. *Journal of Food Engineering*, 43(2):109-114.
- [9] Douglas, G., Reynolds, T. 1986. The Aloe vera phenomenon: a review of the properties and modern uses of the leaf parenchyma gel. *Journal of Ethnopharmacology*, 16 (2-3):117-151.
- [10] Gulia, A., Sharma, H.K., Sarkar, B.C., Upadhyay, A., Shitandi, A. 2009. Changes in physico-chemical and functional properties during convective drying of Aloe vera (Aloe barbadensis) leaves. *Food and Bioproducts Processing*, 88(2-3):161-164.
- [11] Kadam, D.A., Gupta, M.K., Kadam, V.M. 2013. Thin layer drying kinetics of Henna leaves. *Agricultural Engineering*, 3: 85-100.
- [12] Soysal, Y., Oztekin, S., Eren, O. 2005. Microwave drying kinetics of thyme. *Agricultural Engineering*, 2:69-78.
- [13] Ramachandra, C.T., Rao, P.S. 2009. *Modelling and optimization of drying variables of Aloe vera (Aloe barbadensis Miller) gel*. Paper presented at ASABE Annual Meet held at Reno, Nevada, USA during June 21-24, paper No. 096498.
- [14] Ratti, C., Mujumdar, A.S. 1997. Solar drying of foods; modelling and numerical simulation. *Solar Energy*, 60:151-157.
- [15] Margarita, M., Maureira, H., Katia, R., Antonio, V.G. 2009. Influence of temperature on the drying kinetics, physicochemical properties and antioxidant capacity of Aloe vera (Aloe barbadensis Miller) gel. *Journal of Food Engineering*, 91(1):297-304.
- [16] Mwithiga, G., Olwal, J.O. 2004. The drying kinetics of Kale in a convective hot air dryer. *Journal of Food Engineering*, 71(4):373-378.
- [17] Maskan, M. 2000. Microwave/air and microwave finish drying of banana. *Journal of Food Engineering*, 44(3-4):71-78.
- [18] Maskan, M. 2001. Drying, shrinkage and rehydration characteristics of kiwifruits during hot air and microwave drying. *Journal of Food Engineering*, 48(3-4):177-182.
- [19] Usha Kiran N. 2012. *Dehydration of Aloe vera gel*. Unpublished M.Tech. Thesis, University of Agricultural Sciences, Raichur, Karnataka.
- [20] Azzouz, S., Guizani, A., Jomaa, W., Belghith, A. 2002. Moisture diffusivity and drying kinetic equation of convective drying of grapes. *Journal of Food Engineering*, 55(4):323-330.
- [21] Pisalkar, P.S., Jain, N.K., Jain, S.K. 2011. Osmo-air drying of aloe vera gel cubes. *Journal of Food Science and Technology*, 48(2):183-189.

MATEMATIČKO MODELIRANJE SUŠENJA CELOG LISTA ALOE VERA (*ALOE BARBADENSIS* MILLER)

Gritty Pattali¹, Govind Yenge², Ramachandra Cheluvadi³,
Udaykumar Nidoni³, Sharangouda Hiregoudar³

¹ Poljoprivredna istraživačka stanica, KAU, Thrissur, Kerala, India

² Institut za inženjering poljoprivrednih procesa, MPKV, Rahuri, Maharashtra, India

³ Univerzitet poljoprivrednih nauka, Institut za prehranbenu tehnologiju,
Raichur, Karnataka, India

Sažetak: U ovom radu su predstavljeni uticaji različitih metoda sušenja na postupak sušenja, intenzitet sušenja i matematičko modeliranje procesa sušenja celog lista Aloe vera. Sušenje na suncu, sušenje vrelim vazduhom i sušenje suvim vazduhom su ispitivani kao različiti postupci sušenja. Ceo list Aloe vera se sušio 20 h pod suncem na otvorenom, 16 h vrelim vazduhom i 11 h suvim vazduhom, sa početne vlažnosti od 3115.43% na konačni sadržaj vlage od 8.6%. Primenjeni su različiti modeli sušenja tankog sloja na eksperimentalne rezultate gubitka vlage i vremena sušenja, da bi se pravilno predvideo postupak sušenja. Na osnovu koeficijenta determinacije (0.9764) i standardne greške (0.0552), najbolje slaganje pokazao je Page model.

Ključne reči: aloe vera, sušenje suvim vazduhom, sušenje vrelim vazduhom, sušenje na otvorenom, vreme sušenja

Prijavljen: 25.12.2014.
Submitted:
Ispravljen: 26.04.2015.
Revised:
Prihvaćen: 12.05.2015.
Accepted: