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Modelling the drying characteristics of ashwagandha (*Withania somnifera*) roots

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Abstract
Ashwagandha (*Withania somnifera*) is a medicinal plant, the roots of which have been used in Indian traditional system of medicines, Ayurveda and Unani. Generally, roots in powder form are utilized in pharmaceuticals industries. In the present study, the drying behaviour of Ashwagandha roots was investigated by performing mathematical modelling. The roots were dried in shade and in tray dryer at three different temperatures (45, 50 and 55°C). The experimental results were fitted into six semi-theoretical thin layer drying mathematical models. From statistical parameters (coefficient of determination and root mean square error), the Modified Page Model represented the best fit for establishing the drying kinetics at three drying temperatures. Further, the effective moisture diffusivity ranges between 6.35×10^{-8} and 9.92×10^{-8} m^2/s over the temperature range and drying occurs in the falling rate period. This study will be helpful in designing a drying system for ashwagandha.

Keywords: Ashwagandha, roots, drying, mathematical models, effective moisture diffusivity

Introduction
Ashwagandha (*Withania somnifera*) is a valuable medicinal herb that has been used in the various traditional medicinal system mainly Ayurveda, Unani, Siddha, homoeopathy, Chinese, Tibetan, African etc. (Zahiruddin *et al*., 2020) [26]. Some herbalist referred it as Indian ginseng, poison gooseberry and winter cherry. In India, it is mainly cultivated in Northwestern and central parts like Madhya Pradesh, Gujrat, Haryana, Maharashtra, Punjab, Rajasthan and Uttar Pradesh. In Ayurvedic, Ashwagandha means "odour of the horse" as its root smells like a horse. It is classified as "Rasayana" means tonic because it mainly acts as body rejuvenator, defence against disease, slows ageing and enhances memory (Samadi 2013; Forman and Kerna, 2018) [23, 9]. It is cultivated specifically for its root, which is germicidal, aphrodisiac and diuretic and used to treat ulcers, fever, cough, consumption, dropsy, rheumatism and leukoderma (Agarwal *et al*., 2014) [1]. The root extract has been extensively used due to the chief source of two main classes of compound: steroidal alkaloids and steroidal lactones, together known as withanolides (Matsuda *et al*., 2001) [18]. The research conducted on active phytoconstituents provides a rationale background for drug design with an upgrade and better pharmacological properties. The roots are the main component of drugs, always administered in the form of fine powder for which drying is necessary to improve the shelf life, safe storage and reduction in the volume of dried product. Ashwagandha roots have a high moisture content which causes growth and reproduction of microorganisms; hence, downgrading the quality of the product. In India, ashwagandha roots are dried by small scale industries using sun drying without any aseptic conditions, which is a time-consuming process and also cause the deterioration of the quality of a dried product. So, drying using hot air is considered as a viable option for removal of moisture up to a level required for safe storage along with the preservation of quality of a product. After drying, the roots are to be crushed to get smaller particle size with good aroma, colour and retention of constituents. In the normal grinding process, the temperature rises to a level that causes loss of volatile components. The loss of volatiles can be reduced by adopting a cryogenic grinding technique for which optimization of drying parameters is necessary. To maintain the quality of bioproduct, the study of drying kinetics is desirable to select the appropriate condition of temperature and time required for drying. Further, the development of the mathematical model for drying method is equally important as it would allow the engineers to design the drying process to meet the suitable

operating parameters (Perea-Flores *et al*., 2012; Gunhan *et al*., 2005) [21, 12]. Considering this, the prime objective of the current study was to study the drying kinetics of ashwagandha roots at three drying air temperatures by using empirical models.

Materials and Methods

Materials

Fresh roots of ashwagandha were procured from Anand Agricultural University, Anand, Gujrat. They were cleaned manually to remove any organic debris. Samples of uniform shape and size were selected and checked for any defect on visual inspection. The selected roots were cut into small pieces of length 5 cm and drying experiments were performed. The initial moisture content of the material was determined by hot air oven method.

Drying Experiments

The experiments for drying of ashwagandha were conducted at Food Grains and Oilseeds Processing Division of Central Institute of Post-harvest Engineering and Technology, Ludhiana, Punjab. The samples were dried by two methods: shade drying and tray dryer. In shade drying, the sample was spread uniformly in aluminium trays and kept under the shade. The temperature during shade drying ranged from 12 to 27°C. In tray dryer, the samples were dried at three different temperature (45, 50 and 55°C). The drying experiments were performed in triplicates and the loss in the weight of the samples was recorded at definite time intervals. Drying was continued until equilibrium moisture content (EMC) reached. This point was perceived when two or three consecutive readings of weight loss showed a non-significant change in value. The initial moisture content of the sample was calculated on a dry basis by the oven method in accordance with AOAC (2000) [3] using formula

$$MC_{db} = \frac{W_1 - W_2}{W_2} \times 100 \quad (1)$$

where MC_{db} is the moisture content of the sample in dry basis (%); W_1 is the initial weight of the sample before drying (g); W_2 is the weight of the sample after drying (g).

The moisture content of the sample at any time is determined by using equation (Chijioke *et al*., 2016) [6].

$$MC_{t(db)} = MC_{o(db)} - \left(\frac{100(W_o - W_t)}{(1 - MC_{o(wb)})W_o}\right) \quad (2)$$

where $MC_{t(db)}$ is the moisture content at any time in dry basis (%); $MC_{o(db)}$ is the initial moisture content in dry basis (%); $MC_{o(wb)}$ is the initial moisture content in wet basis (%); W_t is the weight of the sample at any time (g), and W_o is the initial weight of sample (g)

The recorded weight loss data of ashwagandha at regular time intervals were converted to moisture loss data. Further, this moisture loss data was used to calculate moisture ratio (MR) and drying rate (DR). The dimensionless moisture ratio (MR), a function of time was used for fitting the mathematical models. The MR and DR of ashwagandha during drying experiments were calculated using the following expression:

$$MR = \frac{M_t - M_e}{M_o - M_e} \quad (3)$$

$$DR = \frac{M_{t+dt} - M_t}{dt} \quad (4)$$

where M_o is the initial moisture content, M_e is EMC, M_t is the moisture content at time t, and M_{t+dt} is moisture content at a time (t+dt).

Mathematical modelling for drying kinetics

Mathematical modelling is used to determine the optimum drying parameters and the performance of the process. It is necessary to select the drying mathematical model that fits best to the drying curve in different condition (Fudholi *et al.*, 2012) [10]. To predict the drying kinetics of the ashwagandha, it is essential to accurately model its drying behaviour. Therefore, in this study, the drying data from three different temperatures were fitted into six mathematical models listed in Table 1. The parameters of mathematical equations were assessed by non-linear regression technique. The regression analysis was performed with SPSS statistical software.

Table 1: Mathematical models applied in the study

Model	Equation	References
Newton's Model	$MR = exp[-kt]$	Ajala and Abubakar, 2018 [2]
Page Model	$MR = \exp[-kt^n]$	Aremu and Akintola, 2016 [4]
Modified Page Model	$MR = exp[-(kt)^n]$	Kingsly and Singh, 2007 [15]
Henderson & Pabis Model	$MR = a\exp(-kt)$	Keneni *et al*., 2019 [14]
Wang & Singh Model	$MR = 1 + at + bt^2$	Doymaz, 2010 [8]
Thompson Model	$t = aln(MR) + b(lnMR)^2]$	Asiru et al., 2013 [5]

The selection of the best mathematical model was based on the various statistical parameters, such as coefficient of determination (R^2) and root mean square error (RMSE).

The R^2 is the primary criteria for selecting the best model to describe the drying kinetics (Doymaz, 2010) [8]. Further, the evaluation of the goodness of fit of the model was determined by another statistical parameter RMSE. The model with the value of R^2 close to unity and RSME close to zero represents a good agreement between experimental data and predicted values (Pin *et al*., 2009) [22].

The value of R^2 and RMSE was calculated from the following equations (Goyal *et al*., 2007) [11].

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2}{\sum_{i=1}^{N}(MR_{exp,i} - MR_{\exp mean})^2}\right] \quad (5)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2\right]^{1/2} \quad (6)$$

where, $MR_{exp,i}$ is the experimental moisture ratio at observation *i*; $MR_{pre,i}$ is the predicted moisture ratio at this observation and; N is the number of observations.

Determination of Effective Moisture Diffusivity

Moisture diffusivity is used to indicate the flow of moisture within a material and is largely influenced by moisture content and temperature of the material (Pathare and Sharma, 2006) [20]. The ashwagandha roots were assumed to be similar to slab geometry, so, Fick's diffusion equation is used to calculate effective moisture diffusivity for slab geometry food particles (Kohli *et al.*, 2018) [16]. The solution of Fick's law is determined by assuming there is uniform moisture distribution, the surface is at equilibrium with the drying air, constant diffusivity and shrinkage is negligible and is given in following equation (Doymaz, 2016) [7].

$$MR = \frac{8}{\pi^2}\sum_{n=8}^{\infty}\frac{1}{(2n+1)^2} exp\left(-\frac{(2n+1)^2\pi^2 D_{eff}t}{4L^2}\right) \quad (7)$$

where D_{eff} is the effective moisture diffusivity (m^2/s); t is the drying time (min); L is the half-thickness of the sample (m) and n is a positive integer.
For a longer drying period, the first term of series is used (Lopez *et al.*, 2000) [17]. The equation becomes:

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

Logarithmic form of the equation is

$$\ln MR = \ln\left(\frac{8}{\pi^2}\right) - \left(\frac{\pi^2 D_{eff}t}{4L^2}\right) \quad (9)$$

By plotting graph of ln (MR) against drying time, the slope was calculated. Then D_{eff} was calculated by the following equation:

$$D_{eff} = \frac{-slope(4L^2)}{\pi^2} \quad (10)$$

Results and Discussion

Drying curves: The effect of temperature on drying kinetics is shown in drying cure of moisture content versus drying time (Fig. 1 and 2). In shade drying, 163 hours were involved to attain equilibrium moisture content (EMC) (14.10% db) from the initial moisture content of 263.24% (db) (Fig. 1). The variation in drying conditions of ambient temperature and relative humidity is presented in Table 2. It took a longer period of almost 7 days to reach EMC within drying temperature range of 12°C to 27°C.

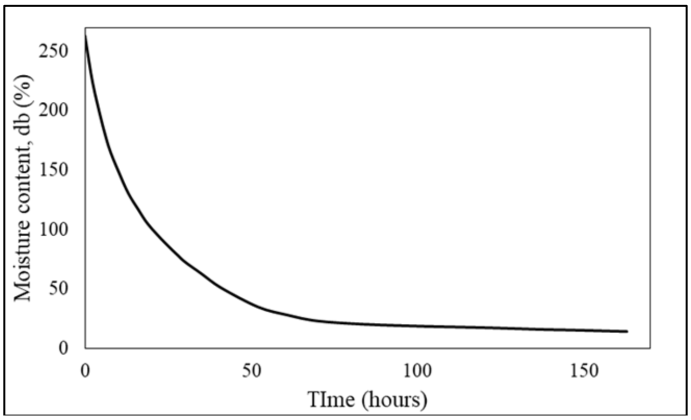

Fig 1: Moisture content versus drying time of Ashwagandha dried in shade

Table 2: Temperature and relative humidity during shade drying

S.No.	Drying time (days)	Temperature (°C)	RH (%)
1.	0	21	78
2.	1	16-22	55-82
3.	2	14-18	71-90
4.	3	12-19	72-91
5.	4	14-24	40-74
6.	5	18-27	26-58
7.	6	15-22	46-60
8.	7	19-24	50-79

The moisture content versus drying data obtained from drying of ashwagandha at different temperatures (45, 50 and 55°C) was used to determine the effect of drying conditions on drying kinetics. Fig. 2 shows that increase in drying temperature from 45 to 55°C causes a significant reduction of drying time to reach EMC. Moreover, EMC value was found to be higher at a lower drying temperature of 45°C and vice versa at a higher temperature. The time taken to reduce the initial moisture content of ashwagandha to EMC at 45°C was double than it was dried at 55°C. The rise in temperature increases the water vapour pressure within ashwagandha roots, causes greater and faster migration of moisture from inside of the product to the surface, leads to decrease in drying time (Senapati *et al.*, 2017) [25]. Moreover, high temperature decreases the relative humidity of the drying air which causes an increase in drying potential (Doymaz, 2010) [8].

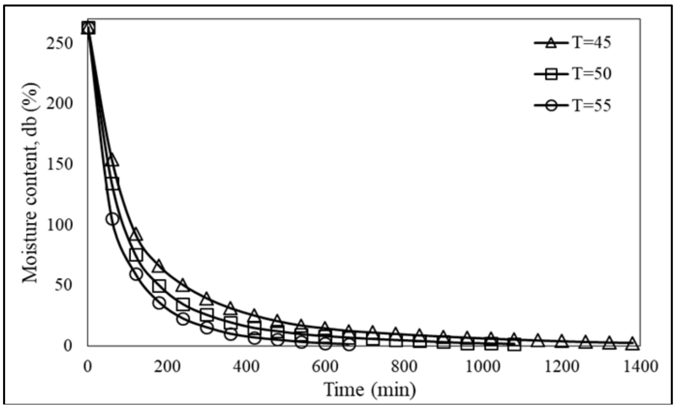

Fig 2: Moisture content versus drying time of Ashwagandha at 45, 50 and 55 °C

The drying rate (g water/ g dry matter/h) of ashwagandha as a function of moisture content is presented in Fig. 3. The drying process occurs at a higher temperature has the fastest drying rate, hence, reached the EMC more quickly than others (Ndukwe, 2009) [19]. The drying rate was high at the beginning of drying due to the high amount of water to be removed and decreases as the EMC approached. As the drying experiment proceeds, the rate of drying decreases from initial moisture content shows an absence of constant rate period or the existence of constant rate for an insignificant time relative to the entire time of drying (Sandeepa *et al*., 2013) [24] indicating the drying of ashwagandha occurs in the falling rate period.

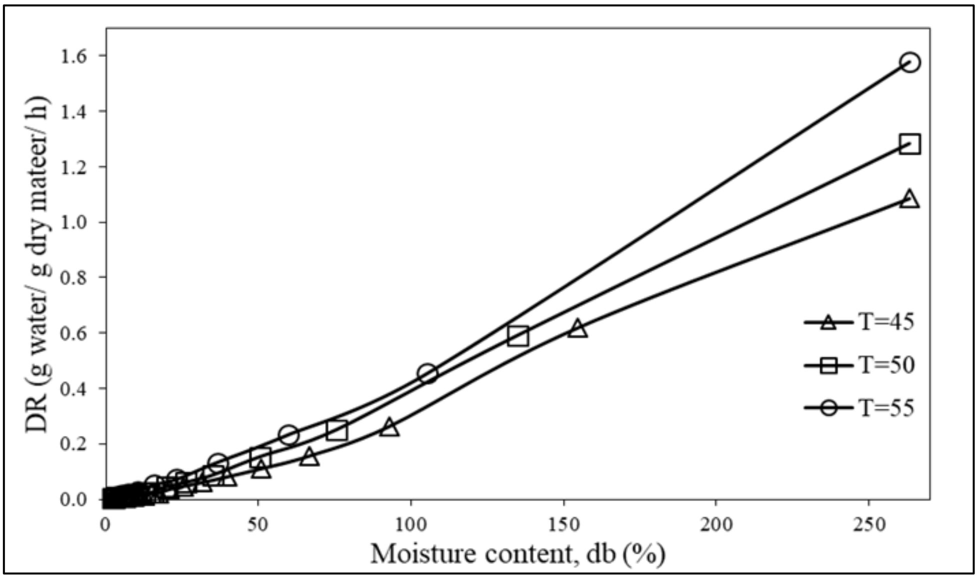

Fig 3: Variation of drying rate versus as a function of moisture content at 45, 50 and 55 °C

Mathematical modelling

The moisture ratio (MR), a function of drying time was fitted into six mathematical models listed in Table 1. The goodness of fit was evaluated by comparing the value of statistical parameters, namely, R^2 and RMSE. The result of the non-linear regression analysis of different models is presented in Table 3. The Modified Page model provided an excellent fit to experimental data at all three drying temperatures with the highest R^2 value (0.9943-0.9993). However, the value of RMSE lies in the range of 0.0069-0.0186. The value of R^2 obtained from the Modified Page Model at 45°C and 55°C were found to be equivalent to that of Page Model at the same temperature.

Table 3: Results obtained from the thin layer drying mathematical models

Model	Temp (°C)	Drying constants & coefficients	R^2	RMSE
Newton's	45	k = 0.569	0.986	0.0285
	50	k = 0.468	0.9742	0.0129
	55	k = 0.457	0.9859	0.0245
Page	45	k = 0.672, n = 0.737	0.9966	0.0128
	50	k = 0.526, n = 0.865	0.9784	0.0069
	55	k = 0.543, n = 0.797	0.9943	0.0186
Modified Page	45	k = 0.583, n = 0.737	0.9966	0.0128
	50	k = 0.476, n = 0.865	0.9993	0.0069
	55	k = 0.464, n = 0.797	0.9943	0.0186
Henderson & Pabis	45	k = 0.489, a = 0.898	0.9837	0.0186
	50	k = 0.444, a = 0.958	0.9964	0.0093
	55	k = 0.410, a = 0.923	0.9861	0.0173
Wang & Singh	45	a = -0.282, b = 0.052	0.9681	0.0232
	50	a = -0.652, b = 0.105	0.9615	0.0283
	55	a = -0.612, b = 0.005	0.9742	0.0285
Thompson	45	a = -14.53, b = -0.895	0.9775	0.0222
	50	a = -17.58, b = -1.238	0.9812	0.0343
	55	a = -15.56, b = -0.993	0.9678	0.0468

The accuracy of the model was evaluated by plotting the predicted moisture ratio with the experimental data in specific drying conditions (Asiru *et al*., 2013) [5]. Fig. 4 represents the comparison between experimental and predicted moisture ratio obtained at three different drying temperatures. The graphical representation showed that the predicted data banded along a straight line, indicate the suitability of Modified Page model in describing the drying kinetics of ashwagandha roots at drying temperature 45, 50 and 55°C with R^2 value varied from 0.9810 to 0.9981. However, the fitting quality of Modified Page model was superior at drying temperature 50°C as evident with maximum R^2 value. Therefore, the Modified Page model was considered the best model in determining the drying behaviour of ashwagandha.

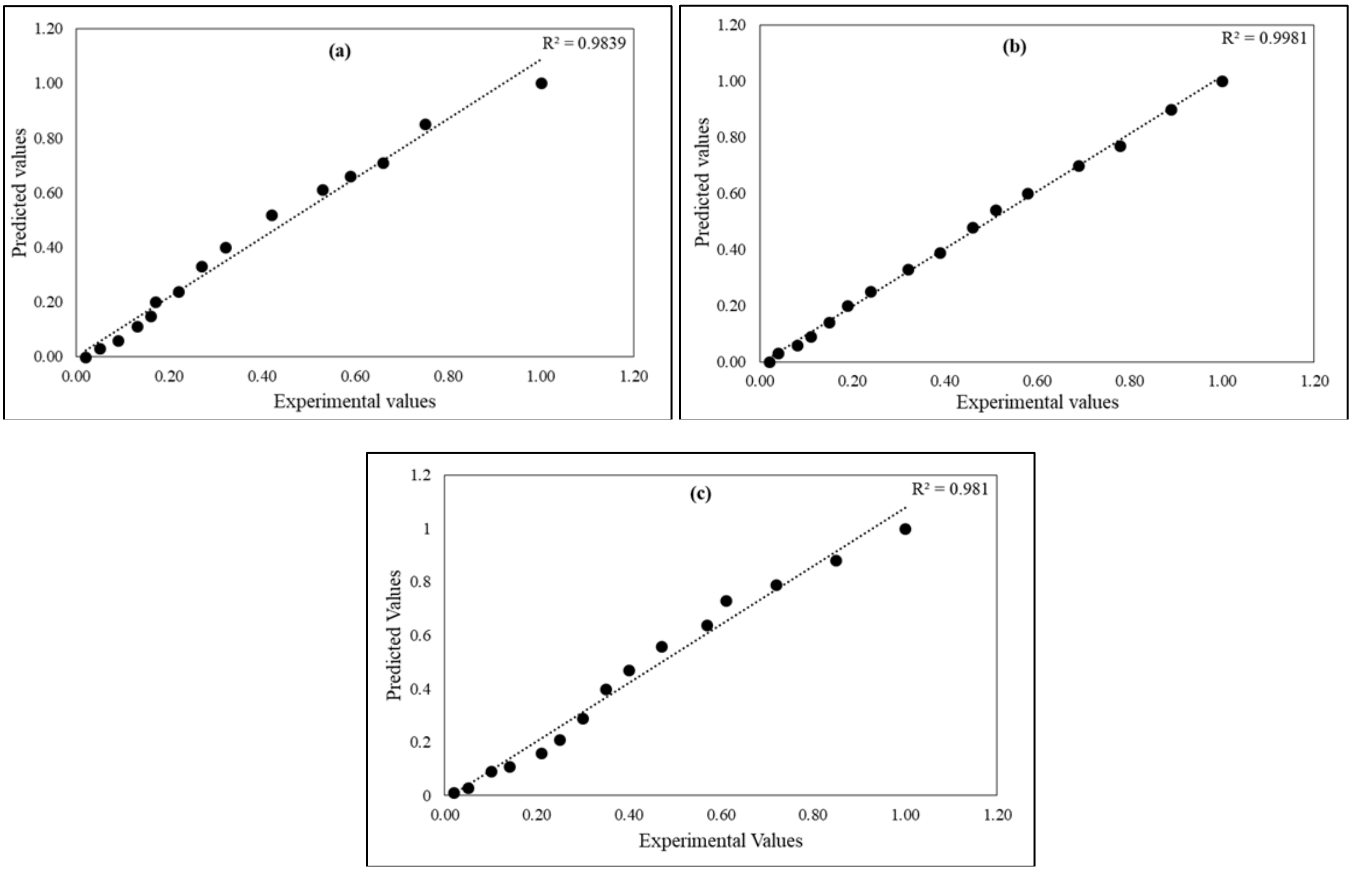

Fig 4: Validation of Modified Page model at drying temperature (a) 45 °C; (b) 50 °C; and (c) 5 5°C

Effective Moisture Diffusivity

The value of D_{eff} at different drying temperature was presented in Table 4, which was calculated by using a value of slope obtained by plotting ln (MR) versus drying time (Fig. 5). It was found that the D_{eff} increased with increasing drying temperature. The effective moisture diffusivity was determined to be 6.35 × 10^{-8} to 9.92 × 10^{-8} m^2/s for ashwagandha in the temperature range of 45 to 55°C. At higher drying temperature, the drying rate is high due to more heat energy that speeds up the movement of water molecules causes the faster decrease of moisture content in the sample and results in a higher value of effective moisture diffusivity (Jun-Ling *et al.*, 2008) [13]. The value of D_{eff} obtained in this study are in general range from 10^{-12} to 10^{-8} m^2/s for biological material (Zogzas *et al*., 1996) [27].

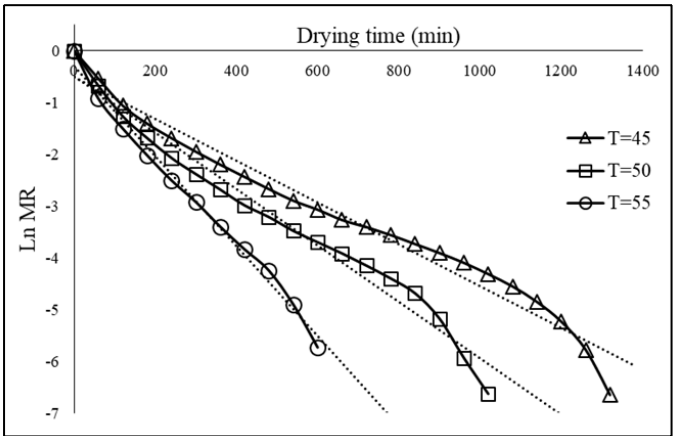

Fig 5: Lograthmic moisture ratio versus drying time

Table 4: Effective moisture diffusivity at different drying temperature

Temp (°C)	D_{eff} (m^2/s)
45	6.35 × 10^{-8}
50	7.45 × 10^{-8}
55	9.92 × 10^{-8}

Conclusion

The information provided in this article could be utilized to simulate the drying kinetics of ashwagandha. Drying of ashwagandha by using hot air with a temperature range of 45 to 55°C was more efficient than shade drying which consumes much time. The rise in temperature accelerates the rate of moisture removal from ashwagandha and drying was carried out in a falling rate period. The mathematical modelling concluded that the Modified Page model gave a better fit to experimental data than other models with a higher value of R^2 at all three drying temperature with a maximum value at 50°C. The effective moisture diffusivity ranges between 6.35 × 10^{-8} and 9.92 × 10^{-8} m^2/s over a temperature range of 45 to 5 5°C.

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