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Selection of a suitable drying model for drying Shatavari Roots (*Asparagus Racemosus*)

Bhagyashree N Patil, Priya G Tipre, Sudama R Kakade and Dr. Suchita V Gupta

Bhagyashree N Patil
Assistant Professor, Department of Agriculture Process Engineering, College of Agricultural Engineering and Technology, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

Priya G Tipre
PhD Scholars, Department of Agriculture Process Engineering, College of Agricultural, Engineering and Technology, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Maharashtra, India

Sudama R Kakade
PhD Scholars, Department of Agriculture Process Engineering Dr. Annasaheb Shinde College of Agricultural Engineering and Technology, Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra, India

Dr. Suchita V Gupta
Associate Professor, Head, Department of Farm Structures College of Agricultural, Engineering and Technology, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

Corresponding Author:
Sudama R Kakade
PhD Scholars, Department of Agriculture Process Engineering Dr. Annasaheb Shinde College of Agricultural Engineering and Technology, Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra, India

Abstract
The effect of drying air temperatures on the drying kinetics of satavari (*Asparagus Racemosus*, family Asparagaceae Liliaceae) was investigated at Akola (Maharashtra) using different drying method. In order to select the appropriate drying model, mathematical drying models were fitted to the experimental data. Result indicated that the drying took place in the falling rate period. The average effective moisture diffusivity $(D_{eff})_{avg}$ values of shatavari roots varied considerably with moisture content and air drying temperature. The moisture diffusivity was found in the range of 1.01×10^{-7} to 9.20×10^{-8} for drying method. Midilli *et al.*, and Page model had the highest $R^2$and the lowest χ^2 and RMSE values. The value of R^2, χ^2, and E_{RMS} was found 0.997, 0.001 and 0.017 in Midilli *et al*. model and in the Page model the value of R^2, χ^2, and E_{RMS} was found 0.997, 0.001 and 0.013.

Keywords: Shatavari roots, mathematical modeling, medicinal plant, sun drying, tray drying, osmotic dehydration.

Introduction
Asparagus racemosus (family Asparagaceae; Liliaceae), is commonly called Satavari, Satawar or Satmuli in Hindi. The plant grows throughout the tropical and subtropical parts of India up to an altitude of 1500 m. The plant is a spinous under-shrub, with tuberous, short rootstock bearing numerous succulent tuberous roots (30–100 cm long and 1–2 cm thick) that are silvery white or ash colored externally and white internally. These roots are the part that finds use in various medicinal preparations. The root Asparagus racemosus (Shatavari) also has proved its effectiveness as a natural sex stimulant and spermatogenic medicine in both male and female sexual and gyanecological disorders. The root is important for increasing the seminal qualities due to its ability to increase sperm count as well as improves its motility enhances libido due to its general tonic effects. It also acts as a nutritive tonic.

Generally shatavari crop does not affect with pest and diseases. Harvesting is done in 1.5-2 years after transplanting, which continues for 10-15 years. The roots are dugout collected and cleared. The roots are peeled off with the help of knife immediately after harvesting. It is observed that in case the roots are not peeled off within a few days, it is bit difficult to remove the skin. In such conditions the roots are kept in boiling water for about ten minutes followed by cold water treatment to facilitate peeling. After this it can be cut into small pieces and dried. This needs experimental drying studies and application of simplified models for predicting drying behavior. The objective of this work was to study the effect of drying air temperature on the drying characteristics, drying time, drying rate, moisture content, moisture ratio for the long pepper drying process. In addition to this, development of a mathematical model for thin-layer drying of long pepper, choosing a suitable model, and investigating the effects of drying air temperature on the model coefficients, which can describe the drying characteristics of long pepper, was investigated.

Materials and Methods
Raw Material Collection: The fresh sample of Shatavari roots was procured from Nagarjun Medicinal plant research Unit, Dr. PDKV, Dist Akola. The cleaning, sorting and peeling was done manually for removing impurities, dirt, dust and infected roots etc.

Methods for drying

Osmotic Dehydration: In the process of osmotic dehydration, water comes out from a sample placed in the hypertonic solution due to concentration difference and the simultaneous transport of solids takes place from solution to sample. The mass transport in terms of water loss, mass reduction and sugar gain.

Tray drying: It is the most commonly used method of drying in which air is circulated by forced convection. The product is spread over the screened trays. The drying medium is air which is heated generally in temperature range from ambient to 50 ^{0}C during roots drying. The air velocity ranges from 0.1 to1.9 m/s.

Sun drying: The sun drying of Shatavari roots was done during the month of December to January at 33-37 ºC temperature and 40% relative humidity.

Drying Characteristics

1) Dry matter

The dry matter (%) in sample were calculated as

DM (%) = 100 –IMC (%w.b.) …. (1)

Where, DM = Dry matter of the sample, g
IMC = Initial moisture content

2) Drying rate: The drying rate of sample was calculated by

$$R = \frac{\text{WML (kg)}}{\text{Time interval (min) x DM (kg)}} \quad .... (2)$$

R = Drying rate at time θ, kg water/ kg, min
WML = Initial weight of sample

3) Moisture Ratio

The moisture ratio (MR) at each moisture content level was determined by the following equation.

$$MR = \frac{M - M_\infty}{M_o - M_\infty} \quad .... (3)$$

Where, MR = Moisture ratio
M = Moisture content at any time (d.b.)
M_o = Initial moisture content (d.b.)
M_∞ = Equilibrium moisture content

Moisture Diffusivity

Fick's diffusion equation for particles with slab geometry was used to calculate the moisture diffusivity. For the determination of moisture diffusivity the Shatavari roots were considered as having slab geometry (Doymaz 2006) [10]. The equation for moisture diffusivity is expressed by (Crank 1975) [7].

$$M_R = \frac{M - M_e}{M_0 - M_e} = \frac{8}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{(2n+1)^2}\exp\left[\frac{-(2n+1)^2\pi^2 D_{eff}\, t}{4H^2}\right] \quad .... (4)$$

For long drying periods, the Equation can be further simplified to only the first term of the series as,

$$\ln\left(\frac{M - M_e}{M_0 - M_e}\right) = \ln\frac{8}{\pi^2} - \left(\frac{\pi^2 D_{eff}\, t}{4H^2}\right) \quad ..... (5)$$

Where, M_R= Moisture ratio, dimensionless
M = Moisture content at any time, g water / g dry matter
M_0 = Initial moisture content, g water/g dry matter
M_e = Equilibrium moisture content, g H_2O/g dry matter
D_{eff}= Effective diffusivity in m^2/s
H = Half thickness of shatavari roots in, m
n = Positive Integer
t = Time (s).
A general form of Equation in semi-logarithmic form, as follows.

$$\ln(M_R) = A - Bt \quad ….. (6)$$

Where, A is constant and B is slope.
A plot of ln (M_R) versus the drying time gives a straight line with a slope of B as,
The slope is calculated by plotting ln (MR) versus time to determine the effective diffusivity for different temperatures.

$$Slope = \frac{\pi^2 D_{eff}}{4H^2}$$

Mathematical Modeling of Shatavari roots during drying

To determine the most suitable drying equations, the experimental drying data were fitted in the various drying models. The coefficient of determination (R^2) was the main criteria for deciding acceptability and subsequently selecting the best equation. In addition to the coefficient of determination, the goodness of fit was determined by various statistical parameters such as reduced mean square of the deviation $\chi^2$and root mean square error E_{RMS}, mean bias error (MBE). For quality fit, R^2 value should be higher or close to one and χ^2*and* E_{RMS} values should be lower (Pangavhane *et al.*, 1999; Demir *et al.*, 2004) [27, 16]. The above parameters were calculated as follows:
a, b, c, k and n = model coefficients, t = drying time, min and MR = moisture ratio

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(M_{R,\exp,i} - M_{R,pre,i}\right)^2}{N - z} \quad ….. (3.14)$$

$$E_{RMS} = \left[\frac{1}{N}\sum_{i=1}^{N}\left(M_{R,pre,i} - M_{R,\exp,i}\right)^2\right]^{1/2} \quad ….. (3.15)$$

$$\frac{1}{N}\sum_{i=1}^{N}\left(MR_{exp,i}\ \ MBE = -MR_{pre,i}\right) \ldots (3.16)$$

Where, $M_{R,exp,i}$ and $M_{R,pre,i}$ are the experimental and predicted Dimension less moisture ratios, respectively,
N is the number of observations,
Z is the number of drying constants.

Table 1: Mathematical model used

Sr. No.	Name of the model	Model /equation	References
1	Lewis/ Newtons' model	MR = Exp(-k*t)	Lewis, 1921, Ayensu (1997)
2	Henderson and Pabis	MR = a*Exp(-k*t)	Henderson and Pabis, 1961 [19]
3	Modified Henderson and Pabis	MR=a exp ("kt) + b exp ("k0t) + c exp ("k1t)	Karathanos (1999)
4	Pages' model	MR = Exp(-K*t)^n	Zhang and Litchfield (1991)
5	Logarithmic	MR = a*Exp(-k*t) +c	Doymaz, 2004a [9]
6	Two- term	MR = a*Exp(-k*t) + b*Exp(-n*t)	Gunhan *et al*. 2004 [16]
7	Two–term exponential	MR = a*Exp(-k*t) + (1-a)*Exp(-k*a*t)	Gunhan *et al*. 2004 [16]
8	Diffusion approach	MR = a*Exp(-k*t) + (1-a)*Exp(-k*b*t)	Togrul and Pehlivan, 2003
9	Simplifed Fick's diffusion	MR = a *exp(-c* (t/L2))	Diamante and Munro (1991)
10	Verma *et al*.	MR=a *exp (k*t) + (1-a) exp (-g*t)	Verma *et al*. (1985)
11	Midilli and Kukuk	MR=a *exp (k*t*n) + b*t	Midilli *et al*. (2002)
12	Magee	MR=a* exp (k*t*n) + b*t	Midilli *et al*. (2002)
13	Wang and sing	MR = 1+ (a*t) + (b*(t**2))	Ertekin and Yaldiz, 2004 [12]

a, b, c, k and n = model coefficients, t = drying time, min

Result and discussion

The typical drying curves showing variation in moisture content of dried Shatavari roots with drying time, drying rate and moisture ratio were calculated and shown in the Fig.1 and Fig. 3 respectively. The similar results reported by Patil and Tipre (2017) [28] on shatavari roots. The moisture ratio was found higher at higher concentration. Similar results reported by Shedame *et al*., 2008 [34] for grapes.

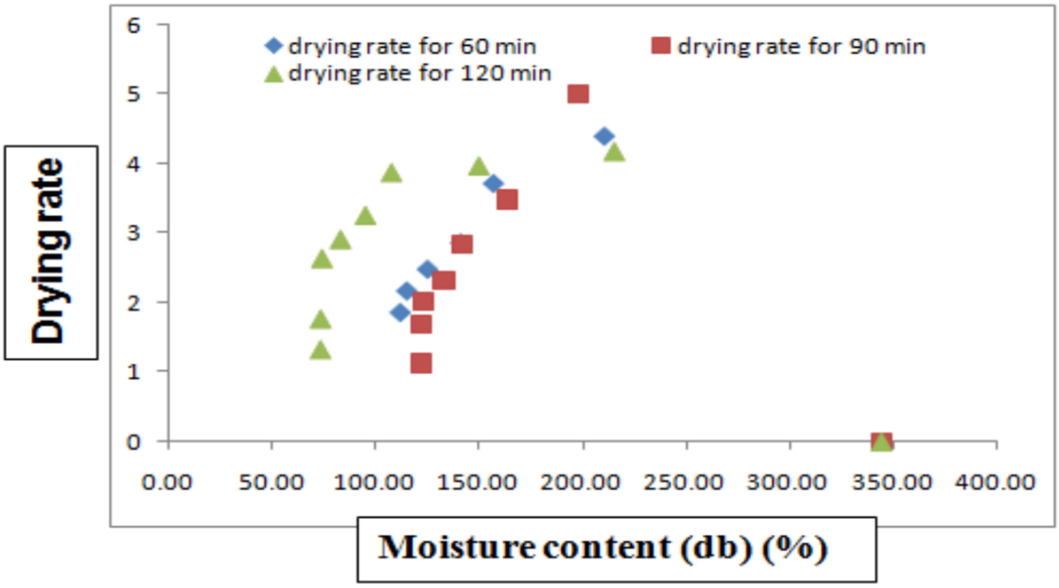

Fig A: Variation in moisture content vs. drying rate for osmotic dehydration

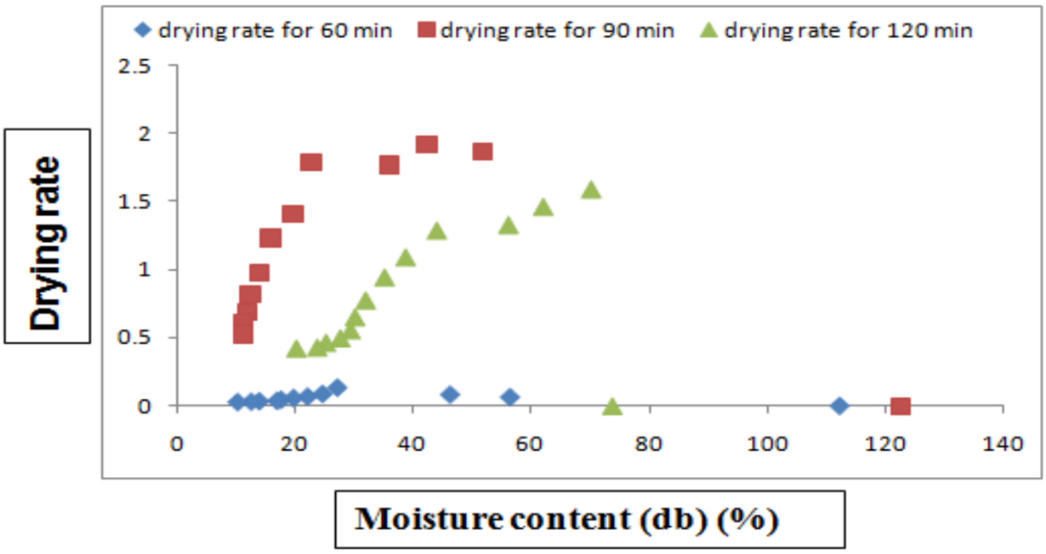

Fig B: Variation in moisture content vs. drying rate for convective tray drying

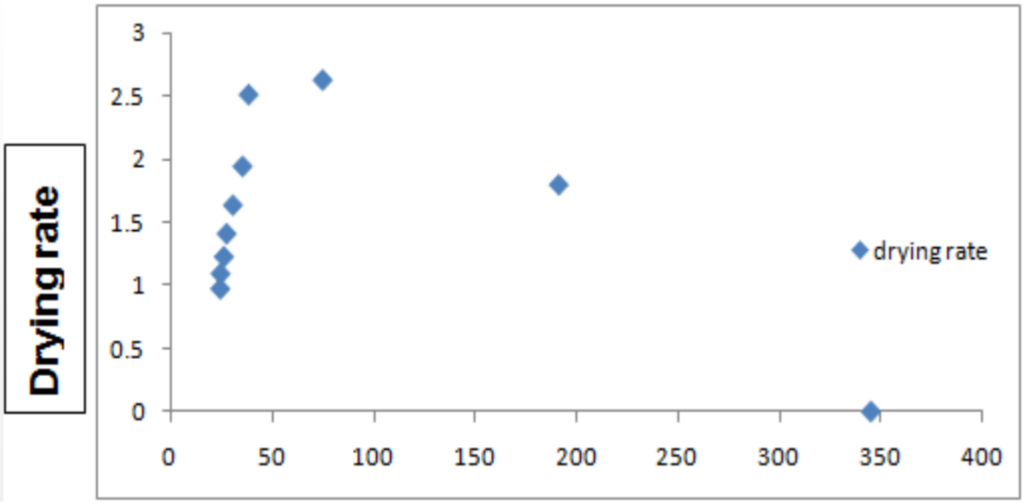

Fig C: Variation in moisture content vs. drying rate for tray drying

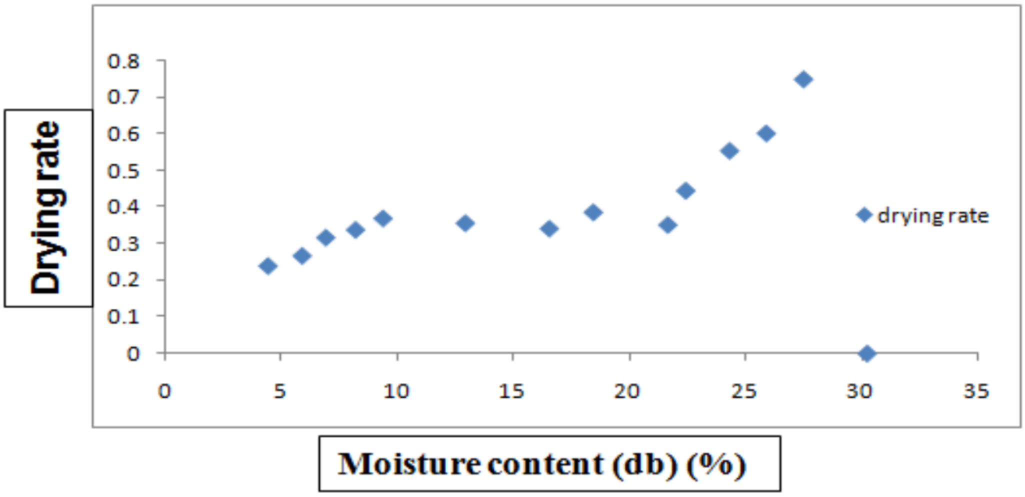

Fig D: Variation in moisture content vs. drying rate for sun drying

Fig 1: Variation in moisture content with respect to drying rate in osmotic dehydration, convective tray drying; tray drying and sun drying at varying power

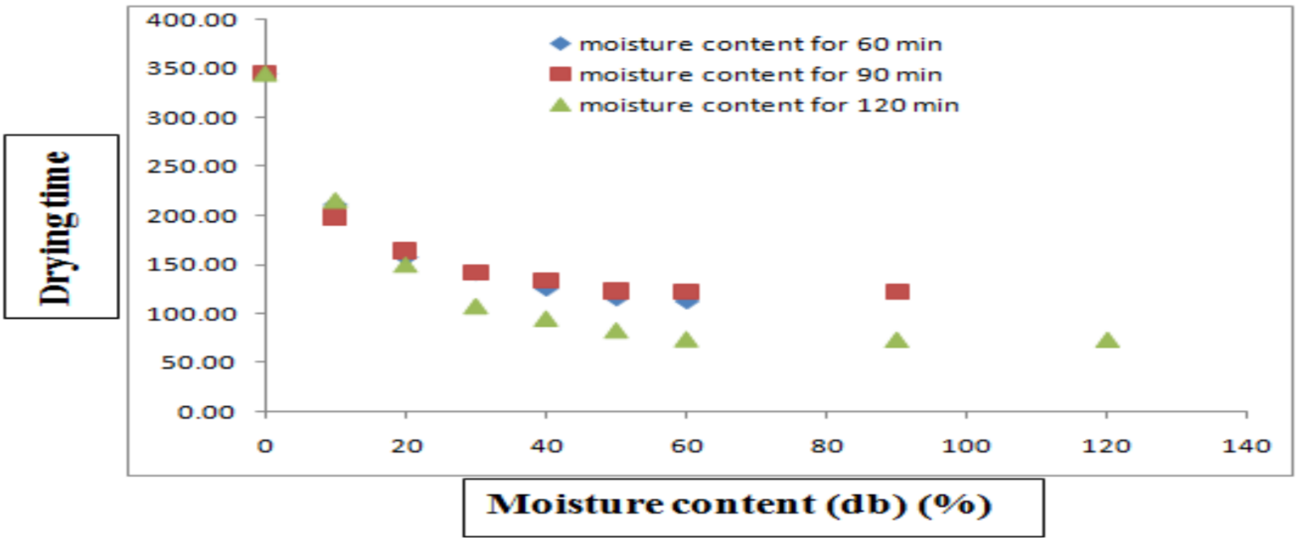

Fig E: Variation in drying time vs. moisture content for osmotic dehydration

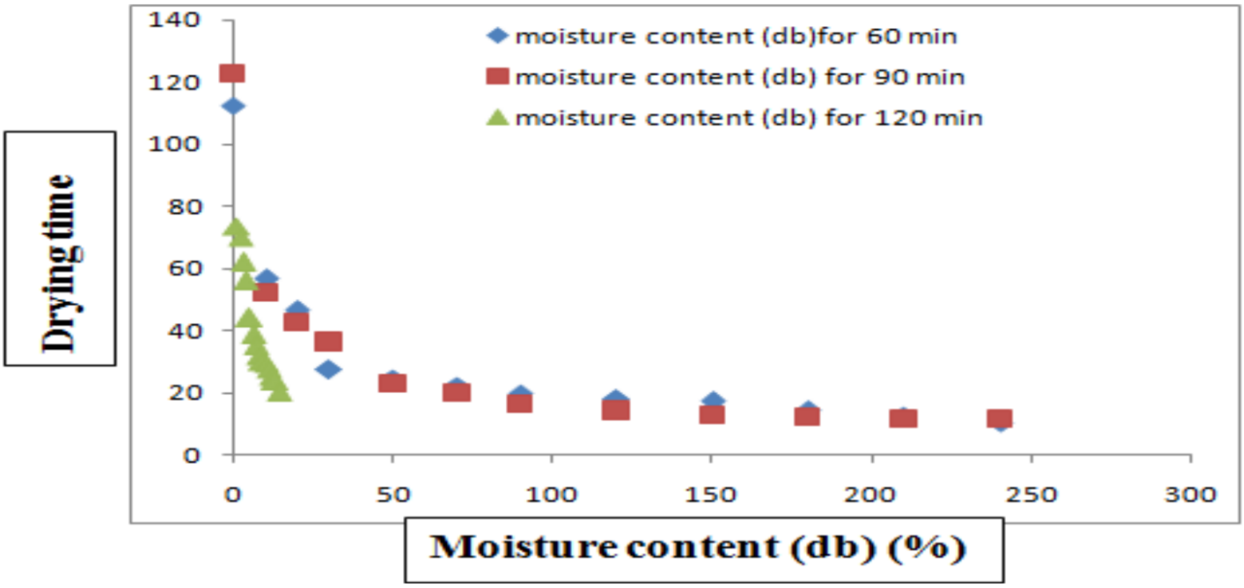

Fig F: Variation in drying time vs. moisture content for convective tray drying

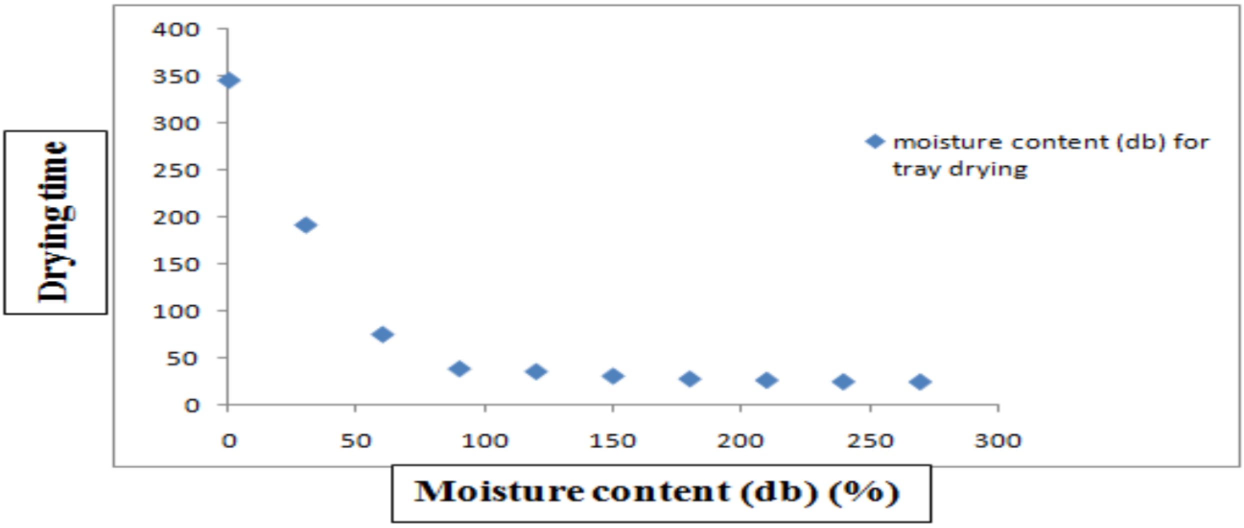

Fig G: Variation in drying time vs. moisture content for tray drying

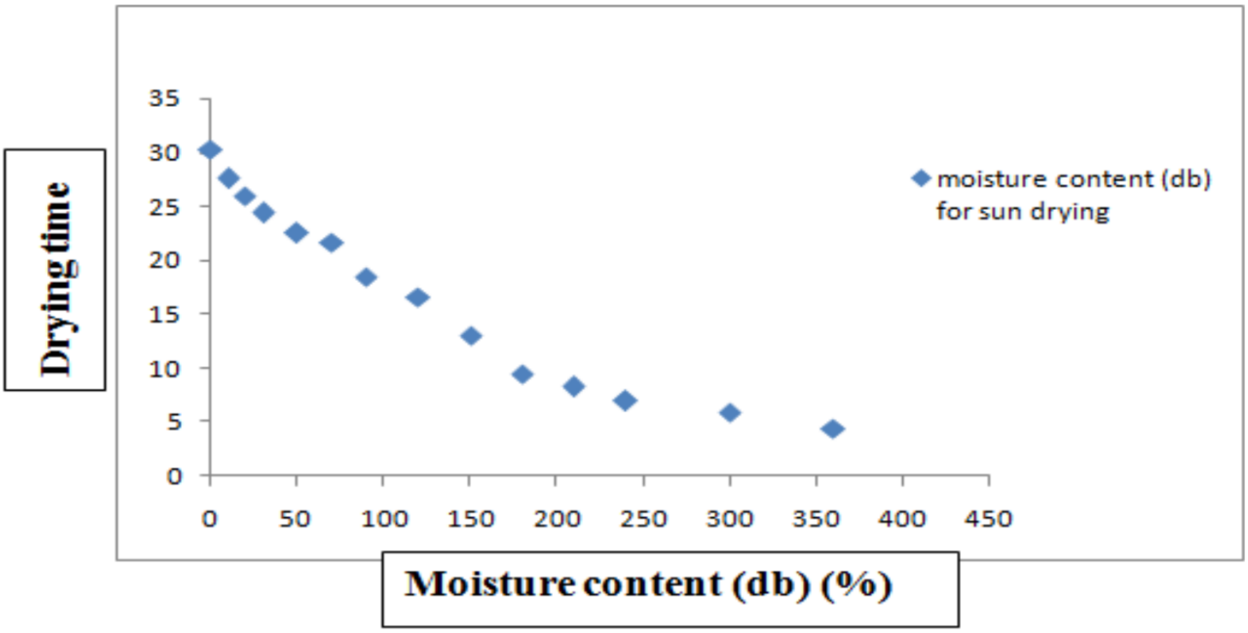

Fig H: Variation in drying time vs. moisture content for sun drying

Fig 2: Variation in moisture content with respect to drying time in osmotic dehydration, convective tray drying; tray drying and sun drying at varying power

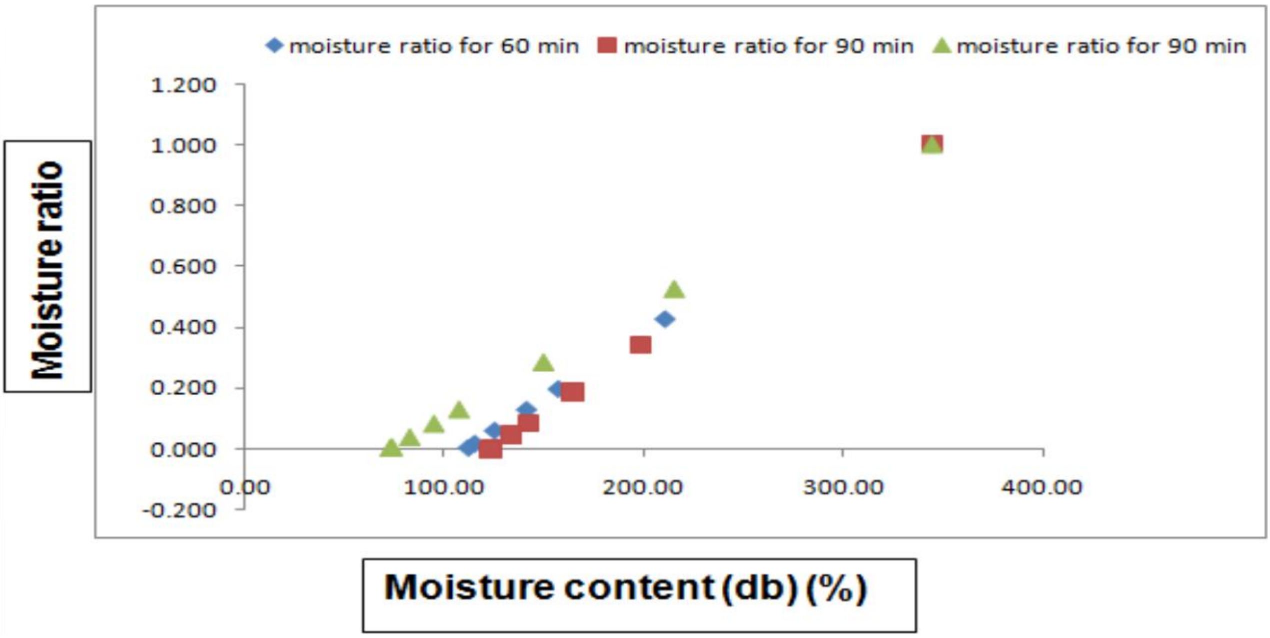

Fig I: Variation in moisture ratio vs. moisture content for osmotic dehydration

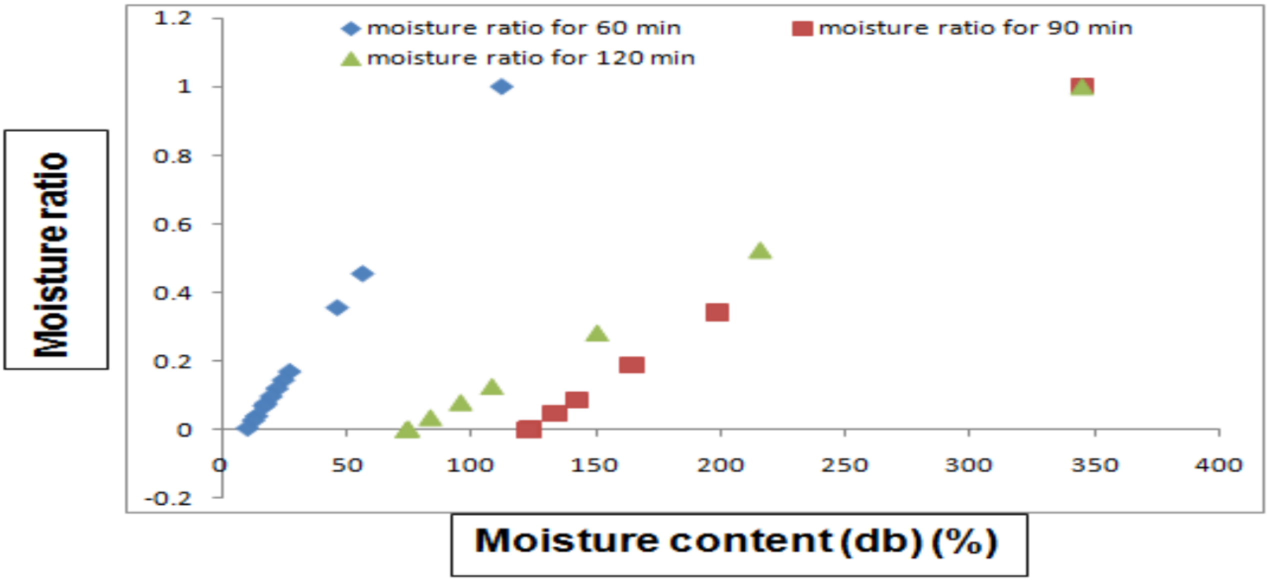

Fig J: Variation in moisture ratio vs. moisture content for convective tray drying

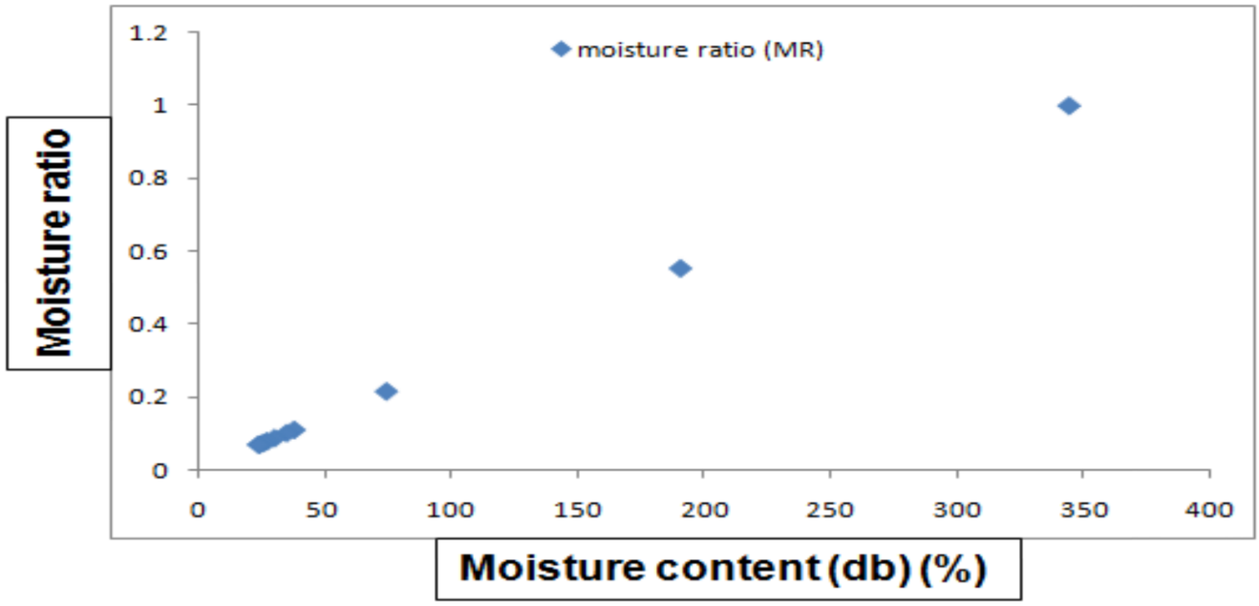

Fig K: Variation in moisture ratio vs. moisture content for tray drying

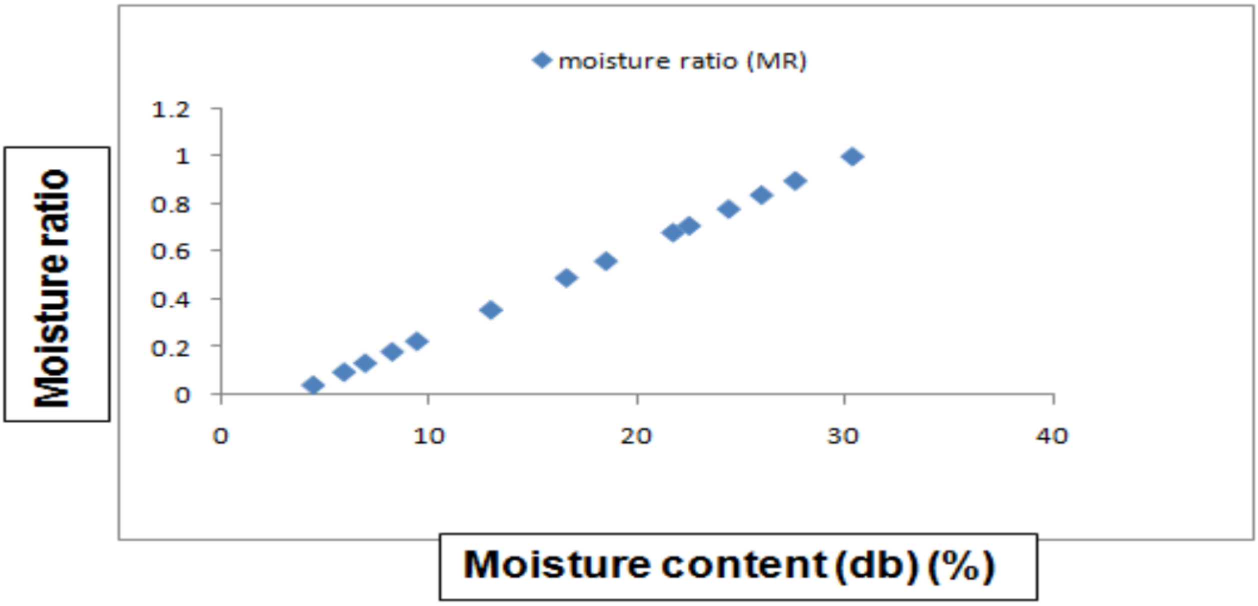

Fig L: Variation in moisture ratio vs. moisture content for sun drying

Fig 3: Variation in moisture content with respect to moisture ratio in osmotic dehydration, convective tray drying; tray drying and sun drying at varying power

Moisture Diffusivity

The moisture diffusivity D_{eff} values during drying of shatavari roots were obtained by the modified method of slopes. The average effective moisture diffusivity $(D_{eff})_{avg}$ values of shatavari roots varied considerably with moisture content and air drying temperature. The moisture diffusivity was found in the range of 1.01×10^{-7} to 9.20×10^{-8} for drying method (Table 2). Similar results were reported for food materials by (Mcminn and Magee, 1999) [23], the diffusivity was found in the range of4.28 x 10^{-10} to 6.8 x 10^{-9} for okra by Gogus and Maskan, 1999, 2.93 x 10^{-9} to 7.99 x 10^{-9} m^2/s and 2.69 x 10^{-8} to 4.59 x 10^{-9} m^2/s for dehydrated and fresh alovera, respectively, etc. In microwave oven drying the moisture diffusivity is in the range of 9.02×10^{-8} to 2.14×10^{-7}. Similar results were reported for drying of safed musli by (Sakkalkar *et al.*, 2013) [32]

The effective moisture diffusivity increased as temperature was increased similar results was found by (Kuitche *et al.*, 2007 [21]. Diffusion of moisture controls the rate of drying in the falling rate period, and increase in effective diffusivity is an indicator of lower resistance to mass transfer in the material being dried. The diffusivity of water or vapor during drying of a product is dependent on its structure (porosity) and the temperature (Naidu *et al*. 2012) [25].

Table 2: Moisture Diffusivity in different drying methods

Drying method	Ko	Equation	R^2	D eff
Osmotic				
60 min	-0.092	y = -0.092x + 0.243	R² = 0.949	-4.24175E-07
90 min	-0.059	y = -0.059x - 0.526	R² = 0.922	-2.71679E-07
120 min	-0.022	y = -0.022x - 0.596	R² = 0.853	-1.01368E-07
Convective tray				
sample 1	-0.032	y = -0.032x - 0.229	R² = 0.964	-1.47351E-07
sample 2	-0.033	y = -0.033x - 0.023	R² = 0.991	-1.51956E-07
sample 3	-0.031	y = -0.031x + 0.087	R² = 0.981	-1.42747E-07
Tray	-0.02	y = -0.020x - 0.522	R² = 0.952	-9.20945E-08
Sun	-0.013	y = -0.013x - 0.230	R² = 0.950	-5.98614E-08

Modeling of drying curves

The moisture content data obtained at different air temperatures were converted to dimensionless moisture ratio (MR) and then fitted to five drying models (Table 1). Thirteen thin layer drying models were evaluated according to the statistical criteriaR^2, χ^2, and E_{RMS} (Table 3). By comparing the values of these criteria, it is obvious that the Midilli *et al*., and Page model had the highest $R^2$and the lowestχ^2 and RMSE values.The value of R^2, χ^2, and E_{RMS} was found 0.997, 0.001 and 0.017 in Midilli *et al*. model and in the Page model the value of R^2, χ^2, and E_{RMS} was found 0.997, 0.001 and 0.013. Generally R^2, χ^2, and RMSE values of the selected model in all experiments. Accordingly, the similar result was found Page *et al*., (2002) and Midilli *et al*., models were selected as the suitable model to represent the thin layer drying behavior of shatavari roots. Similarly the Page *et al*., model is best fitted for sapota (Gupta and Patil, 2014) [17] for long pepper (Gawande *et al*., 2016) [14]. Midilli *et al.* model was found to fit well to describe the drying behavior of long pepper (Bhagyashree *et al*., 2013) [5]. Midilli *et al*. model was the best for predicting of the drying kinetics of eggplant slices.

Table 3: Results of statistical analysis of drying models for different drying methods

Name of Model	Drying constant						Statistical parameters		
	K	N	A	b	C	D	R^2	χ^2	E_{RMS}
Lewis/Newton	0.013						0.965	0.003	0.055
Henderson and Pabis	0.198	0.207	0.409	4.28	4.28	0.45	0.874	0.01	0.383
Page	0.053	0.683	0.997	0	0.02		0.997	0.001	0.017
Logarithmic	0.029		90.86	0.03			0.987	0.001	0.104
Two term	0.017	0.044	0.538	0.5	1	0	0.032	0.017	0.044
Two term exponential	0.04	-	0.223	-	-	-	0.984	0.001	0.032
Diffusion	0.152		0.345	0.2			0.996	0.001	0.024
Simplified Diffusion approach	0.196		0.837	0			0.985	0.001	0.037
Verma	0.088		0.43	-0.01			0.994	0.001	0.019
Midllii *et al.*	0.122	0.504	1.008	0			0.997	2E-04	0.013
Magee	0.036		0.728				0.942	0.004	0.07
Wang and Singh			0.006	0			0.798	0.033	0.127

Conclusion

In this investigation various drying methods such as osmotic dehydration with convective tray drying, tray and sun drying method were studied. The drying experiments were conducted for different drying time at 60, 90,120 min in osmotic dehydration, tray drying for 270 min at 50 °C and sun drying for 420 min at atmospheric temperature and RH (33-37 °C and 40%RH). The drying of shatavari roots was done at constant weight loss until the final moisture content reaches up to 3 to 4%. From the drying data drying characteristics viz, drying time, moisture content, drying rate, moisture ratio and moisture diffusivity were determined.

The average effective moisture diffusivity $(D_{eff})_{avg}$ values of shatavari roots varied considerably with moisture content and air drying temperature. The moisture diffusivity was found in the range of 1.01×10^{-7} to 9.20×10^{-8} for drying method. Midilli *et al*., and Page model had the highest $R^2$and the lowest χ^2 and RMSE values. The value of R^2, χ^2, and E_{RMS} was found 0.997, 0.001 and 0.017 in Midilli *et al*. model and in the Page model the value of R^2, χ^2, and E_{RMS} was found 0.997, 0.001 and 0.013.

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