Modeling of drying *Lavandula officinalis* L. leaves

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Abstract: Storage of agricultural crops after harvesting is important to keep quality and quantity of the dried materials in a good level, particularly for medicinal plants and herbs because of reduction of essential oils and changes of qualitative properties such as color, which both of them influence on the economical value of the products. Drying process of *Lavandula officinalis* L. leaves was studied and modeled in this investigation. Independent variables were temperature at three levels (40, 50 and 60˚C), air velocity at two levels (0.5 and 1 m/s) and product depth at three levels (1, 2, and 3cm). The experiments were performed as factorial with complete random design in three replications. Seven drying models, namely Yagcioglu, modified Page, Page, Henderson and Pabis, Lewis, two-term and Verma, were examined to fit the data. The Page model was found as the best model with highest R^2 and lowest χ^2, RMSE and P-values.

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Introduction

The main aims of drying of agricultural products are to increase the shelf life, to prevent from biological activities including microbial and enzymes, and to reduce the weight and volume of the materials in order to facilitate packaging, transporting and storing [Simal *et al.,* 2005]. During drying process it is important to preserve the texture, color, flavor, and nutritional value of the product. It means to reach moisture at safety level to minimize the quantity and quality losses during storage [Hall, 1980]. The amount and the type of moisture, have direct effects on drying time. The problems of research on medicinal herbs are indentifying and preserving the essential oils especially in different kinds of herbs. Lavander is an important medicinal plant of the Labiatae family. Linalool and linalyl acetate are the main component of lavender oils. The present study was conducted to determine the best model for drying of *Lavandula officinalis* L. leaves to preserve quality properties and effective chemical compounds. Panchariya examined the drying conditions of black tea at temperature ranging from 80 to 120˚C and air velocity from 0.25 to 0.65 m/s. Experimental data was evaluated using Lewis, Page, modified Page, Two-term, and Handerson & pabis drying models with non-linear regression, and the Lewis model was selected as the best model [Panchariya *et al.,* 2002]. Arabhosseini examined drying of *Artemisia dracunculus* L. leaves at temperature range of 40 to 90˚C, different relative humidities and air velocity of 0.6 m/s. Although the Diffusion approach equation showed the best fit, but Page model was chosen since it had almost a similar performance but the equation is simpler as it has only two parameters instead of three in Diffusion approach model [Arabhosseini *et al.,* 2009]. Doymaz assessed the drying behavior of mint leaves at temperatures of 35, 45, 55, and 65˚C and air velocity of 1m/s. He reported that drying time reduced significantly at higher temperature. Four drying models were selected to fit the experimental data and the logarithmic model described satisfactorily the drying behavior of mint leaves [Doymaz, 2007]. Sharma examined thin layers drying of onions in a dryer using x-ray. The experiments were conducted at temperatures of 35, 40, and 45˚C and air velocities of 1, 1.25, and 1.5 m/s. The resulted data was fitted to eight drying models. Following the analysis, the Page model was proposed as the best model because of highest R^2 and least χ^2 [Sharma *et al.*, 2007].

Materials and methods

Drying equipment

Three experimental dryers of Kiln type were used for drying experiments. The experiments were performed at research complex of Asr-e- Enghelab, Tehran, Iran. This kind of dryer consists of two floors and usually use for drying of seeds, food stuffs, fruits and vegetables. In the first floor there is a heat generator and in the second floor, there is a container, with dimensions of 40 by 40 cm and 165cm height, to put the products for drying. At the bottom of this floor there are some holes to pass hot air generated in the first floor (Fig. 1). About 40 cm above the samples, there is a port to escape the moist air. Each dryer has two electric elements to generate required heat which one of them was controlled by a digital thermostat and the other one was controlled manually. The current flow of the hot air was produced by a blower which is located under the elements. The aeration rate of the blowers is adjustable by a dimmer in the range of 180 to 220 m^3/h. Two sensors are in the upper and lower parts of the container to measure the temperature of the drying air just before and after the samples location.

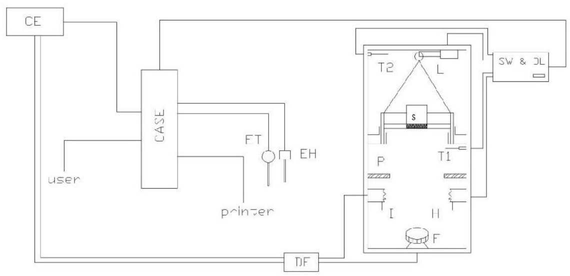

Fig 1. Experimental dryer
(F) fan, (H) heat generator, (S) sample – hold mesh, (T_1) thermometer before(s), (T_2) thermometer after(s), (Sw) switches, (DL) data logger, (CE) control electronic system, (DE) electronic driver, (EH) environment humidity sensor, (ET) environment temperature sensor.

Before starting of each experiment, the temperature was adjusted by the thermostat and the dryers were activated to reach the required heat. Having turned off the element by the switcher, means that the dryer's temperature was balanced then the samples were placed in the container. Data collection for thin layer drying experiments was performed through samples weighting at 5min time intervals using a digital balance (Sartorius, model PT210, Germany) with an accuracy of ±0.001g and then the results were recorded. Weighting of the samples continued until three consecutive readings showed the same value. Sample moisture was measured before and after drying experiment. The mean value of the samples dry weight was used for computations. The final moisture content of the samples was determined by drying in a vacuum dryer (model Galen Kamp) at 70˚C, 150 mbar, for 8hours [Tsami *et al.*, 1990]. The air velocity of drying air was adjusted to the desired level by adjusting the blower motor and measured by an anemometer (AM-4201, Lutron) with an accuracy of ±0.1m/s. During the experiments the ambient air temperature and RH variations in the lab were measured to be between 25 to 29˚C and 31- 33%, respectively. Given the small size of the samples, 35 by 35 cm metal micro-pore meshes were used as tray to keep the samples in the dryers. Aluminum frames of 35 by 35 cm cross section with 1, 2 and 3cm height were placed on the porous plates to obtain the desired bed depths. The samples were placed in the frame while a metal mesh was used on the frame to avoid any sample skip by air current flowing.

Drying process

The used herb in the study was prepared by medicinal herb research collection of Jahad-e-Daneshgahi in May and June, 2009. The plants were harvested just before flowering and then the leaves were immediately removed from the stems. The separated leaves were cut and then the samples were stored separately in plastic bags and refrigerated at temperature of 4± 1˚C to prevent from microbial spoilage. Moisture content of the leaves was found to be 61% db. In this study the independent variables were temperature at 40, 50, and 60˚C, air velocity at 0.5 and 1 m/s and bed depth of 1, 2, and 3cm. The total number of treatments was 18 and all experiment was conducted at three replications. Dependent variable was drying time in order to determine the proper model for thin layer drying of *Lavandula officinalis* L. leaves.

Mathematical modeling of drying

For modeling of thin layer drying of *Lavandula officinalis* L. leaves, the moisture ratio was calculated using equation 1 initial moisture content of the sample (M_0), equilibrium moisture content (M_e), and sample moisture during the drying process using [Doymaz, 2007].

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (1)$$

In which:
MR is moisture ratio (dimensionless), M_t is moisture content at time t (d.b%), M_0 is initial moisture content (d.b%), M_e is equilibrium moisture content(d.b%). For determining the final moisture content, the samples were placed in a vacuum oven at 70˚C and 150 mbar for 8 hours. The samples were weighted before and after drying and their moisture was determined using equation 2 on the dry basis.

$$M_C = \frac{W_w - W_d}{W_d} \quad (2)$$

In which:
M_C is moisture content (d.b%) W_w is weigh of sample (kg) and W_d is dry matter weight (kg).
After drying, the drying models in Table 1 were used to examine moisture variation during the drying process and to determine the best model.

Table1. Mathematical equations used for modeling of drying process

Model name	Model equation	Reference
Lewis	MR=exp(-kt)	(Lewis, 1921)
Henderson and Pabis	MR=a exp(-kt)	(Westerman *et al.*,1937)
Page	$MR=exp(-kt^n)$	(Page, 1949)
Modified Page	$MR=exp(-(kt)^n)$	(White *et al.*, 1981)
Yagcioglu	MR=a exp(-kt)+c	(Yagcioglu *et al.*, 1999)
Verma	MR=a exp(-kt)+(1-a) exp(-gt)	(Verma *et al.*, 1985)
Two-term	$MR=a\ exp(-k_0t)+b\ exp(-k_1t)$	(Gunhan *et al.*, 2004)

In the above equations, k, n, a, b, c, g, k_0 and k_1 are the model coefficients. Non-linear regression method was utilized to fit the data to the selected drying models. For evaluating the goodness of fit, three statistical indicators were used in addition to R^2 (Table 2). The model having the highest R^2 and the lowest Root Mean Squares Error (RMSE), χ^2, and P-value was thus determined as the best model.

Table2. Equations of indicators for evaluation of the drying models [San Martin *et al.,* 2001]

Indicator	Equation
P- value	$P = \frac{100}{N}\sum\frac{\lvert M_i - M_{pre}\rvert}{M_i}$
χ^2	$\chi^2 = \frac{\sum_{i=1}^{n}(MR_{exp} - MR_{pre})^2}{N-n}$
$RMSE$	$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(MR_{pre} - MR_{exp})^2}{N}}$

In Table2 M_i is moisture content of matter, M_{pre} is predicted moister by the model, N is number of observations, n is number of model constants, MR_{exp} is moisture ratio of experimental data, MR_{pre} is predicted moisture ratio.

Results and Discussion

Tables 3 to 5 show the obtained statistical results of R^2, RMSE, p-value and χ^2 for fitting the experimental data to selected drying models in order to determine the best model. The Verma , Yagcioglu, and Two-term models were eliminated for having R^2 values lower than 0.9 while the Henderson and Pabis and Modified Page models were omitted because of undesirable χ^2 values. The Lewis model was eliminated due to very high RMSE. Overall, the Page model showed the best fit having highest R^2 and lowest χ^2, RMSE, and P-value.

Table3. Evaluation of the models at 40°C and air velocities of 0.5 and 1 m/s

Model	RMSE $\times10^{-1}$	χ^2 $\times10^{-2}$	R^2	P- value (%)
v=0.5 m/s				
Lewis	29	13	0.98	11.12
Henderson and Pabis	33	46	0.98	26.13
Page	9	9	0.99	7.11
Modified Page	32	54	0.88	25.31
Yagcioglu	41	27	0.89	23
Verma	39	39	0.80	14
Two - term	51	20	0.88	16.41
v=1.0 m/s				
Lewis	24	10	0.95	9.30
Henderson and Pabis	53	47	0.98	18.01
Page	11	10	0.98	7.22
Modified Page	56	43	0.98	13.14
Yagcioglu	47	17	0.85	15.11
Verma	52	16	0.89	20.13
Two - term	37	17	0.88	15.14

'Table4. Evaluation of the models at 50°C and air velocities of 0.5 and 1 m/s

Model	RMSE ×10^{-1}	χ^2 ×10^{-2}	R^2	P- value (%)
v=0.5 m/s				
Lewis	16	20	0.99	9.13
Henderson and Pabis	22	50	0.88	13.45
Page	9	10	0.99	4.17
Modified Page	33	43	0.98	10.25
Yagcioglu	41	18	0.87	13.14
Verma	45	13	0.88	16.13
Two - term	43	31	0.90	18.31
v=1.0 m/s				
Lewis	12	12	0.99	9.40
Henderson and Pabis	44	31	0.95	18.64
Page	8	7	0.99	3.75
Modified Page	52	21	0.98	12.69
Yagcioglu	41	11	0.88	17.86
Verma	37	34	0.88	20.93
Two - term	29	47	0.89	15.14

Table5. Evaluation of the models at 60°C and air velocities of 0.5 and 1 m/s

Model	RMSE ×10^{-1}	χ^2 ×10^{-2}	R^2	P- value (%)
v=0.5 m/s				
Lewis	14	11	0.97	6.21
Henderson and Pabis	40	21	0.98	18.35
Page	9	8	0.99	2.12
Modified Page	31	30	0.87	25.13
Yagcioglu	44	17	0.88	18.16
Verma	51	20	0.85	20.13
Two - term	35	21	0.85	13.16
v=1.0 m/s				
Lewis	17	13	0.88	11.31
Henderson and Pabis	46	24	0.98	17.25
Page	7	6	0.99	3.45
Modified Page	31	29	0.88	11.31
Yagcioglu	29	14	0.87	27.54
Verma	67	14	0.87	17.10
Two - term	64	21	0.89	24.35

Table 6 shows the fitness of obtained data from experimental treatments using the Page model. The R^2 values are above 0.99 and p-values are below 10% for all temperature and air velocities which statistically shows the good fit.

Table 6 Coefficient of the Page equation fitted to drying data

Temperature, °C	Velocity, m/s	k	n	RMSE ×10^{-1}	P- value (%)	χ^2 ×10^{-2}	R^2
40	0.5	0.012	0.351	9	6.42	19.31	0.998
	1	0.018	0.842	11	5.37	15.19	0.999
50	0.5	0.007	0.341	9	4.21	18.11	0.998
	1	0.025	0.472	8.34	3.42	15.11	0.999
60	0.5	0.030	0.642	11.12	3.41	17	0.999
	1	0.081	0.523	9.31	3.21	16.25	0.998

In a research Park found the Page model as the best model for drying mint leaves because it showed the best fit [Park *et al.,* 2002]. The study on drying *Artemisia dracunculus* L. leaves at air temperatures and relative humidities in the range of 40 to 70 °C and 11 to 84% respectively, and constant air velocity of 0.6 m/s showed that the Diffusion approach model was the best while Page model came second. However, since the Page model has one less parameter, it was selected as the better model [Arabhosseini *et al.*, 2009]. Also, in a research about thin- layer drying of onions using x-ray, the Page model was proposed as the best one for having the highest R^2 and the least χ^2 [Sharma, 2007].

Conclusion

Among the drying models, the Page equation showed the best fit for drying of *Lavandula officinalis* L. leaves. Thus this model is suitable as a relevant equation for drying of *Lavandula officinalis* L. leaves. The "n" and "k" parameters were estimated as function of temperature for *Lavandula officinalis* L. leaves. This model is suitable to estimate the moisture content during drying in order to determine drying time and energy consumption. It is also applicable for designing of relevant dryer for this kind of crops.

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