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MATHEMATICAL MODELING OF DRYING KINETICS OF SOME MEDICINAL PLANTS

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In this research experimental data on drying kinetics for nettle and mint leaves were obtained. In order to predict the drying process, Henderson and Pabis thin layer drying model was correlated with experimental data. The nonlinear regression analysis was carried out using CurveExpert Professional 2.4.0 software tool. It was determined that Henderson and Pabis model quite accurately describes the drying kinetics of nettle and mint leaves and can be used to evaluate the herbs drying time.

Key words*: nettle leaves, mint leaves, medicinal plants, drying kinetics, mathematical model, nonlinear regression analysis*

Introduction. Today, in the pharmaceutical industry, plant raw materials are increasingly used for the production of medicines. One of the means of storage of medicinal plant raw materials is drying. Drying helps to reduce transportation and storage costs. At the same time it is necessary to keep in mind that during drying it is necessary to preserve the healing properties of medicinal plants.

It is known that drying is one of the most energy-efficient methods of processing raw materials. Therefore, it is important to optimize the drying time not only in view of the quality of the finished product but also in the amount of energy consumed for drying.

To predict the duration of drying in convective dryers under certain ambient conditions (temperature, air velocity, relative humidity of air), modeling of drying processes is widely used.

Several studies have been devoted to the mathematical modeling and experimental study of the drying of vegetable raw materials, including medicinal products, in a thin layer [1–5].

Aghbashlo et al. [1] experimentally investigated potato drying in thin layers. In order to quantify the drying kinetics, three drying models were correlated with the experimental data. As a result, the Page model most accurately describes the drying process according to the correlation coefficient R^2, reduced chi-value χ^2 and root mean square error RMSE.

Waewsak et al. [2] investigated mathematical modeling of drying in a stream of heated air of agricultural products. The authors compared thirteen mathematical models. The comparison results showed that the Midilli model best describes the process of red pepper and leech lime leeves drying, but the Wangh and Singh model was best for lemon grass drying.

Kaleta et al. [3] introduced three new types of apples drying models. Drying kinetics were investigated in a fluidized bed dryer. The three models developed were compared to the accuracy of sixteen models known from the literature. The accuracy of the models was estimated based on the values of R^2, RMSE, and χ^2. The result of the comparison showed that the Page model and one of the models proposed by the authors most adequately describe the drying process, with the RMSE ranging from 0.0094 to 0.0167, the value of χ^2 lying between 0.0001 and 0.0002, and $R^2 > 0.9977$.

Kumar at el. [4] evaluated characteristics of thin layer carrot pomace drying in a laboratory scale hot air forced convective dryer. The drying experiments were carried out at 60, 65, 70 & 75 °C and at an air velocity of 0.7 m/s. Mathematical models were tested to fit drying data of carrot pomace.

Rashimi et al. [5] investigated the drying kinetics of chamomile flowers under different operating conditions in a fluidized bed vibration dryer. Three mathematical models were correlated with the experimental data. There was found that Henderson and Pabis model most adequately described chamomile flowers drying kinetics.

It should be noted that a limited amount of information is provided in the literature regarding the modeling of the drying process of medicinal plants.

Therefore, this study was conducted to choose a matematical model that can be used to predict the drying kinetics of some medicinal herbs such as nettle and mint.

Nettle has hemostatic, diuretic, choleretic and tonic action, normalizes lipid metabolism, promotes the regeneration of the mucous membranes of the gastrointestinal tract, increases the number of erythrocytes, normalizes the blood content, reduces blood sugar. As for mint than the pharmacological action is as following: it increases the secretion of the digestive glands, stimulates the appetite, suppresses the processes of decay and fermentation in the digestive canal, reduces the tone of the smooth muscles of the intestine, biliary and urinary tract, increases the excretion of bile, provides sedative effects.

The main objectives of the study consist in analyzing experimental data on the drying kinetics of nettle and mint leaves and selection an appropriate mathematical model describing the medicinal plants drying kinetics.

Materials and methods. Drying of mint and nettles leaves was carried out in a convective dryer. The leaves were placed on shelves in a thin layer. The air flow was used as the drying agent. The temperature, relative humidity and air flow rate could be varied. The experiments were carried out at fixed values of these parameters, namely: at temperature of T = 36 ^{o}C, at relative humidity of RH=42%, at air velocity of u=0.2 m/s.

To determine the drying kinetics, the weight of the dried leaves was measured at regular intervals.

The moisture content of leaves was first expressed as a percentage per wet basis, and then converted to dry basis.

To build drying kinetics plots the moisture ratio (MR) versus time relationship was used.

The moisture ratio can be calculated as:

$$MR = \frac{M-M_e}{M_o-M_e} \tag{1}$$

where M, M_o, M_e are moisture content at any time, initial and equilibrium, respectively.

Moisture ratio *MR* can be calculated by simplified expression (2) due to the small value of M_e compared to M and M_o [6]:

$$MR = \frac{M}{M_o} \quad (2)$$

To predict drying kinetics (drying curves), it is necessary to select an adequate drying model.

Mathematical models widely used to describe thin layer drying kinetics are listed in Table 1 (*a*, *k*, *n*, *c* – model parameters; *t* - time) [7].

Table 1

Thin layer drying models

Model No.	Model name	Model
1	Newton	$MR = e^{-kt}$
2	Page	$MR = e^{-kt^n}$
3	Henderson and Pabis	$MR = a \cdot e^{-kt}$
4	Logarithmic	$MR = a \cdot e^{-kt} + c$

In this study, the experimental data on the drying of medicinal herbs were correlated with Henderson and Pabis model:

$$MR = a \cdot e^{-kt} \quad (3)$$

Values of the model parameters have been estimated by fitting the model to the experimental data.

The nonlinear regression analysis was performed using CurveExpert Professional 2.4.0 software tool.

The goodness of the fit was assessed by using statistical test methods. The coefficient of determination (R^2) was used as a primary criterion for the suitability of the model.

Results and discussion. The changes in the moisture content ratio *MR* of raw materials over time t, obtained as a result of the experiment, are shown in Fig. 1 and Fig. 2.

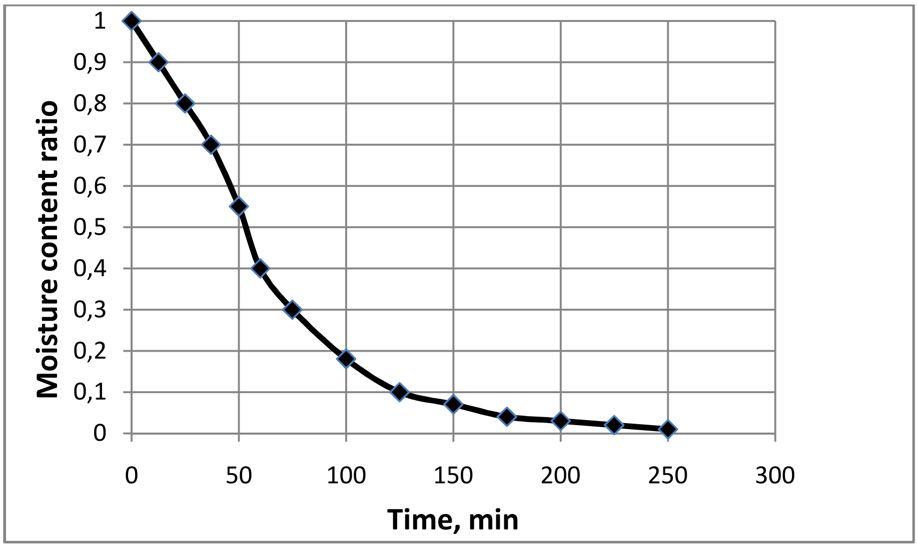

Fig. 1. The drying kinetics for nettle leaves at *T*=36 °C, *RH*=40 % and *u*=0,22 m/s

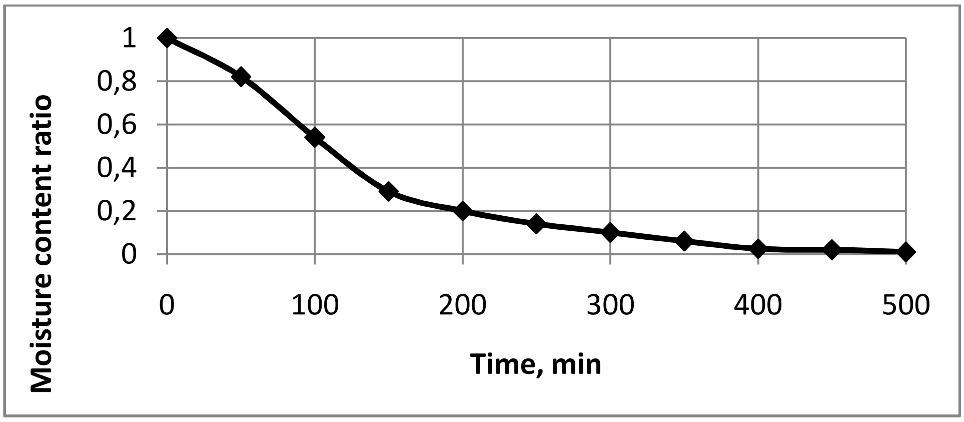

Fig. 2. The drying kinetics for mint leaves at *T*=36 °C, *RH*=40 % and *u*=0,22 m/s

The results of nonlinear regression analysis are shown in Table 2.

Table 2

Nonlinear regression analysis results

Materials	Henderson and Pabis model parameters	Coefficient of determination R^2	Temperature *T*, relative humidity *RH* and velocity *u* of air
Nettle leaves	*a*=1,085; *k*=0,0157	0,981	*T*=36 °C; *RH*=42 %; *u*=0,2 m/c
Mint leaves	*a*=1,060; *k*=0,0077	0,983	*T*=36 °C; *RH*=42 %; *u*=0,2 m/c

Considering that the determination coefficients obtained from the analysis are quite high, it can be concluded that the model chosen adequately describes the kinetics of drying the nettle and mint leaves at the corresponding values of temperature, relative humidity and air velocity. Therefore, the following dependencies (4) and (5) can be used to predict the drying time of nettle leaves and mint ones under given conditions, respectively:

$$MR = 1{,}085 \cdot e^{-0{,}0157t} \quad (4)$$

$$MR = 1{,}060 \cdot e^{-0{,}0077t} \quad (5)$$

At the same time, it is obvious that it is necessary to carry out the further research to determine the optimal ambient conditions for drying nettle and mint leaves in a thin layer, while determining the Henderson and Pabis model parameters that correspond to the optimal regime of drying.

CONCLUSIONS

In this study, the experimental data obtained during the drying of such herbs as nettle and mint leaves were analyzed. In order to predict the drying process behavior, Henderson and Pabis mathematical model describing the drying kinetics was correlated with experimental data. The nonlinear regression analysis was carried out using CurveExpert Professional 2.4.0 software tool. As a result of the analysis it was determined that Henderson and Pabis mathematical thin layer drying model quite adequately describes the drying kinetics of nettle and mint leaves and can be used to predict the drying time under given conditions.

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МАТЕМАТИЧНЕ МОДЕЛЮВАННЯ КІНЕТИКИ СУШІННЯ ДЕЯКИХ ЛІКАРСЬКИХ РОСЛИН

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У цьому дослідженні отримано експериментальні дані з кінетики сушіння листя кропиви та м'яти. З метою прогнозування процесу модель Хендерсона та Пабіса для сушіння у тонкому шарі була корельована з експериментальними даними. Нелінійний регресійний аналіз був проведений за допомогою програмного засобу CurveExpert Professional 2.4.0. Було встановлено, що *модель Хендерсона та Пабіса досить точно описує кінетику сушіння листя кропиви та м'яти і може бути використана для оцінювання часу сушіння цих рослин.*

Ключові слова: *листя кропиви, листя м’яти, лікарські рослини, кінетика сушіння, математична модель, нелінійний регресійний аналіз.*

МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ КИНЕТИКИ СУШКИ НЕКОТОРЫХ ЛЕКАРСТВЕННЫХ РАСТЕНИЙ

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В этом исследовании получены экспериментальные данные по кинетике сушки листьев крапивы и мяты. С целью прогнозирования процесса модель Хендерсона и Пабиса для сушки в тонком слое была коррелирована с экспериментальными данными. Нелинейный регрессионный анализ был выполнен с помощью программного средства CurveExpert Professional 2.4.0. Было установлено, что модель Хендерсона и Пабиса достаточно точно описывает кинетику сушки листьев крапивы и мяты и может быть использована для оценки времени сушки этих растений.

Ключевые слова: *листья крапивы, листья мяты, лекарственные растения, кинетика сушки, математическая модель, нелинейный регрессионный анализ.*