MODELING OF OIL CROP SEED DRYING

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ABSTRACT

The agricultural sector of the economy increases the production of oil crops. Demand for vegetable oils is growing worldwide. Prices of oil crops are comparatively higher than for grain crops. Despite the increase in production costs, the profitability of the cultivation of oil crops determines the growth trend in their production and processing volumes. The processing industry is one of the main and largest users of oilseeds. In Ukraine, the main oil crops are sunflower, soybean and rapeseed, and linseed. In Ukraine, including the region of Western Polissya, more and more attention is paid to the cultivation of linseed. The main value of linseed is in the seed, so it is important to obtain high quality seeds when growing this crop. Weather conditions can cause increased crop moisture. Excessive seed moisture content during storage has a very negative effect on seed quality, leading to deterioration and, as a result, significant losses at the stage of post-harvest processing and storage, which leads to the need for artificial drying. The purpose of the study is to substantiate the most rational drying regimes of linseed by modeling drying process, ensuring high productivity and quality of the seeds, avoiding undesirable excessive energy costs. Experimental studies were carried out using the developed experimental equipment. For the study, linseed of the variety «Southern Night», which was obtained by harvesting in a single-phase method, was used. Then, linseed was cleaned. The initial moisture content of linseed was 14.3%. Linseed drying was carried out at drying agent temperatures of 35, 45, 55 and 65°C. The air flow rate in the drying chamber was 1.9–2.0 m/s and the thickness of the linseed layer was 2 cm. A drying process models of bulk materials are summarized in the article. The coefficients of the drying process models were obtained as a result of a non-linear regression analysis carried out using SPSS 17.0 software. The accuracy of drying process models and their comparison was assessed. The obtained mathematical model of the linseed drying process takes into account the following parameters: type of drying, interaction of the seed with the drying agent, moisture content of the seed layer.

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МОДЕЛЮВАННЯ СУШІННЯ НАСІННЯ ОЛІЙНИХ КУЛЬТУР

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АНОТАЦІЯ

Аграрний сектор економіки збільшує виробництво олійних культур. Попит на рослинні олії зростає у всьому світі. Ціни на олійні культури вищі, ніж на зернові. Попри зростання собівартості агропродукції, рентабельність вирощування олійних культур визначає тенденцію зростання обсягів їх виробництва та перероблення. Переробна промисловість є одним із основних і найбільших споживачів олійних культур. В Україні основними олійними культурами є соняшник, соя, ріпак, льон. В Україні, зокрема у Західному Поліссі, все більше уваги приділяється вирощуванню льону олійного. Основна цінність льону олійного полягає в насінні, тому під час вирощування цієї культури важливо отримати насіння високої якості. Погодні умови можуть спричинити підвищену вологість насіння. Надмірна вологість насіння під час зберігання дуже негативно впливає на якість насіння, спричиняє його псування і, як наслідок, значні втрати на етапі післязбирального оброблення та зберігання, що спричиняє необхідності штучного сушіння насіння. Мета дослідження – шляхом моделювання процесу сушіння обґрунтувати найбільш раціональні режими сушіння насіння льону, що забезпечують високу продуктивність та якість насіння, уникаючи небажаних надлишкових витрат енергії. Експериментальні дослідження проводили на розробленій установці. Для дослідження використовували льон олійний сорту «Південна ніч», що отриманий шляхом збирання прямим комбайнуванням. Початкова вологість насіння льону становила 14,3%. Сушіння насіння льону проводили за температури сушильного агента 35, 45, 55 та 65°С. Швидкість потоку повітря в сушильній камері становила 1,9–2,0 м/с, товщина шару льону – 2 см. У статті узагальнено моделі процесу сушіння сипких матеріалів. Коефіцієнти моделей процесу сушіння були отримані за результатами нелінійного регресійного аналізу, що проведено за допомогою програмного забезпечення SPSS 17.0. Оцінено точність моделей процесу сушіння.

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INTRODUCTION AND PROBLEM STATEMENT

In Ukraine, the agricultural sector of the economy increases the production of oil crops. Demand for vegetable oils is growing worldwide. Prices of oil crops are comparatively higher than for grain crops. Despite the increase in production costs, the profitability of the cultivation of oil crops determines the growth trend in their production and processing volumes.

The processing industry is one of the main and largest users of oil crop seeds. Their products – vegetable oils, meal, and cakes – provide a fairly significant share of foreign exchange earnings from agricultural exports. Between 2010 and 2018, the production of vegetable oil processing companies almost doubled. About 6.2 million tons of vegetable oil were produced, and vegetable oil export was 6 million tons. Therefore, determining the effectiveness of Ukraine's export of oil crop seeds and their processed products in the conditions of modern integration processes is an urgent problem.

In Ukraine, the main oil crops are sunflower, soybean and rapeseed, and linseed. In Ukraine, including the region of Western Polissya, more and more attention is paid to the cultivation of linseed. Linseed is an agricultural crop of great economic importance. In different branches of economy, it is possible to use stems, straw, seeds, linseed cake. However, the main purpose of cultivation of linseed is to obtain oil, which, depending on the linseed variety, can contain about 50% in flax seeds (*Didukh, 2002*). The main value of linseed is in the seed, so it is important to obtain high quality seeds.

Weather conditions can cause increased crop moisture. Excessive seed moisture content during storage has a very negative effect on seed quality, leading to deterioration and, as a result, significant losses at the stage of post-harvest processing and storage, which leads to the need for artificial drying. The study of the drying process of various plant materials, especially a dense layer of bulk seed material, has been carried out by a number of scientists (*Mujumdar, 2006; Yaschuk & Kirchuk, 2011; Didukh et al., 2013; Yaschuk et al., 2013*).

Research on harvesting and post-harvest processing of flax is mainly related to the study of the properties of flax components, seed cleaning problems, as well as drying of flax and flax straw, and is mainly devoted to fibre flax (*Didukh et al., 2008; Dudarev & Kirchuk, 2011*). Insufficient attention has been paid to the study of harvesting and post-harvest processing of linseed.

The Goal of the Study is to substantiate the most rational drying regimes of linseed by modeling seed drying process, ensuring high productivity and quality of the seeds, avoiding undesirable excessive energy costs.

MATERIALS AND METHODS

Experimental studies were carried out using the developed experimental equipment (**Fig. 1**). For the study, linseed of the variety «Southern Night», which was obtained by harvesting in a single-phase method, was used. Then, linseed was cleaned. The initial moisture content of linseed was 14.3%. The experimental equipment worked as follows: air was pumped by a fan and heated by a heater; the heated air was supplied to the drying chamber by a flexible pipe. The sample of linseed was placed in the drying chamber of experimental equipment. The heater was equipped with a regulator for the temperature of the heated air.

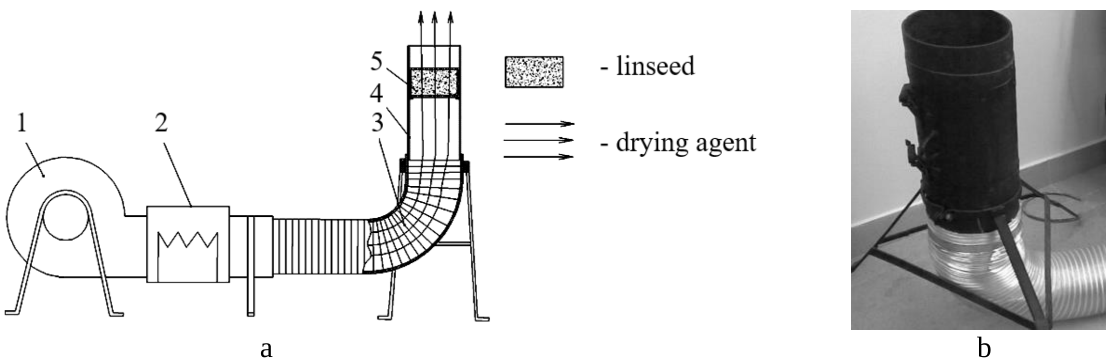


Fig. 1 – Experimental equipment for linseed drying:
a – scheme of the equipment (1 – fan; 2 – heater; 3 – flexible branch pipe; 4 – drying chamber; 5 – section with linseed); b – drying chamber

RESULTS AND DISCUSSION

Linseed drying was carried out at drying agent temperatures of 35, 45, 55 and 65°C. The air flow rate in the drying chamber was 1.9–2.0 m/s and the thickness of the linseed layer was 2 cm. The results of the experimental studies are summarized in the graph shown in **Fig. 2**.

As a result of the reference analysis (*Doymaz & Pala, 2003; Cihan et al. ,2007; Yadollahinia et al., 2008; Rafiee Sh et al., 2009*), mathematical models of drying process of bulk materials are summarized in **Table 1**.

In **Table1**, the parameters are as follows: *MR* – coefficient of initial moisture content of the bulk material; *a*, *b*, *c*, *k*, *n* – coefficients determined by the properties of a bulk material, and the initial parameters of a bulk material, and drying modes; *t* – drying time, min.

Coefficient of initial moisture content of bulk material was calculated by Equation:

$$MR = \frac{W_{in.m.}}{W_{m.}}, \qquad (1)$$

where $W_{in.m.}$ – initial moisture content of bulk material, %; $W_{m.}$ – moisture content of bulk material at drying time *t*, %.

The coefficients of the drying process models presented in **Table 1** were obtained as a result of a non-linear regression analysis carried out using SPSS 17.0 software (**Fig. 3**). The experimental data of linseed drying was accurately reproduced by these drying process models (**Fig. 4**).

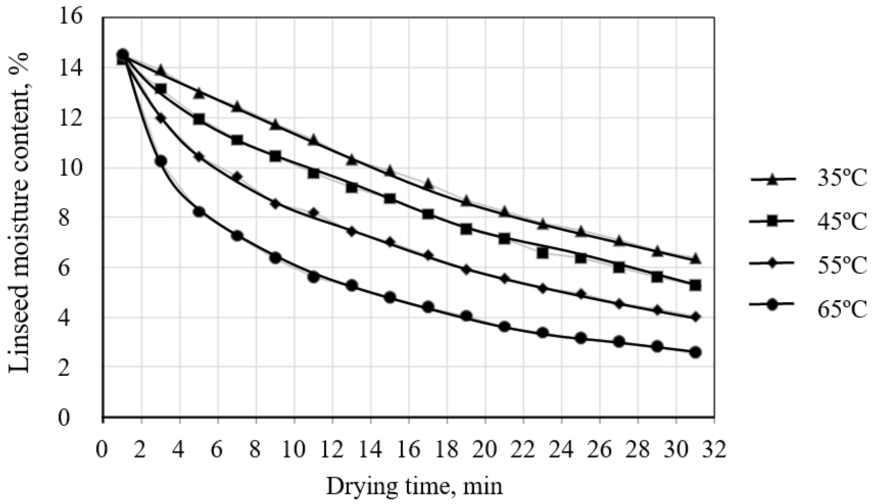
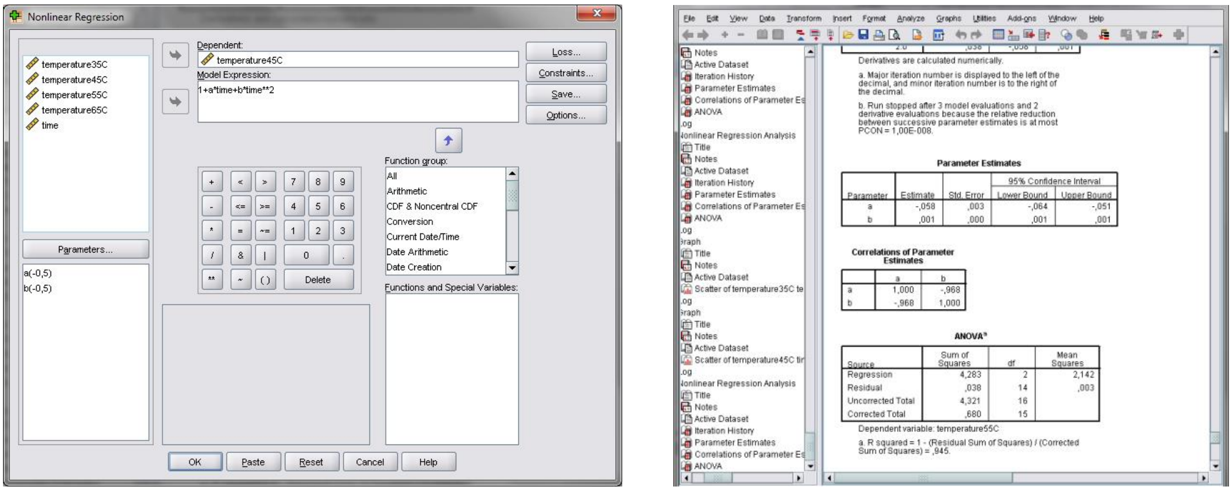


Fig. 2 – Diagram of linseed moisture content during the drying process at different drying agent temperatures

Table 1 –Mathematical models of drying process of bulk materials

Mathematical models of drying process	Model equation
1	2
Newton	$MR = e^{-kt}$
Henderson-Pabis	$MR = ae^{-kt}$
Page	$MR = e^{-kt^n}$
Modified Page	$MR = e^{-(kt)^n}$
Logarithmic	$MR = ae^{-kt} + c$
Wang and Singh	$MR = 1 + at + bt^2$
Midilli	$MR = ae^{-kt^n} + bt$



a b

Fig. 3 – Calculation of the coefficients of the drying process models using the SPSS 17 software:
a – setting the calculation parameters; b – calculation results

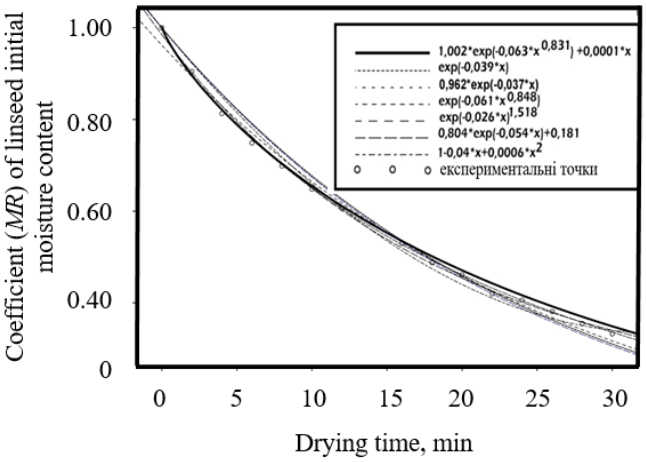


Fig. 4 – Diagrams obtained from different linseed drying process models
at a drying agent temperature of 45°C

The accuracy of drying process models and their comparison was assessed using three indicators: coefficient of determination, sum of squared errors and standard mean square error. As a result of the comparison, the Midilli model was found to be the most accurate in this case. The calculated accuracy indicators for the Midilli model are shown in **Table 2**.

Coefficient of determination was calculated by Equation:

$$R^2 = 1 - \left(\frac{\sum_{i=1}^{N} (MR_{cal.,i} - MR_{ex.,i})^2}{\sum_{i=1}^{N} (MR_p - MR_{ex.av.,i})^2} \right), \qquad (2)$$

where $MR_{cal.,i}$ – calculated quantity; $MR_{ex.,i}$ – experimental quantity; $MR_{ex.av.,i}$ – experimental average quantity; N – observation number.

Sum of squared errors was calculated by Equation:

$$SSE = 1 - \left(\frac{\sum_{i=1}^{N} (MR_{cal.,i} - MR_{ex.,i})^2}{N} \right). \qquad (3)$$

Standard mean square error was calculated by Equation:

$$RMSE = \left(\frac{1}{N} \sum_{i=1}^{N} \left(MR_{cal.,i} - MR_{ex.i} \right)^2 \right)^{\frac{1}{2}}. \qquad (4)$$

The coefficients (a, b, k, n) of the Midilli model, which accurately reproduces the kinetics of the linseed drying process, are summarized in **Table 3**.

The results of numerical modeling (**Fig. 5**) showed that the Midilli model reproduces possible drying modes. The simplicity of the modelling makes it possible to use modelling for a wide class of tasks in the management of drying processes in convective dryers.

Table 2 – Calculated accuracy indicators for the Midilli model

Mathematical model	Temperature of drying agent, °C	Coefficient of determination R^2	Sum of squared errors *SSE*	Standard mean square error *RMSE*
1	2	3	4	5
Midilli	35	0.999	0.567	0.000
	45	0.999	0.616	0.000
	55	0.999	0.680	0.001
	65	0.999	0.755	0.001

Table 3 – Coefficients of the Midilli model

Temperature of drying agent, °C	Coefficients of the Midilli model $MR = ae^{-kt^n} + bt$			
	a	*b*	*k*	*n*
1	2	3	4	5
35	1.000	0.003	0.029	1.088
45	1.002	0.001	0.063	0.831
55	1.001	0.001	0.148	0.643
65	1.001	0.001	0.284	0.567

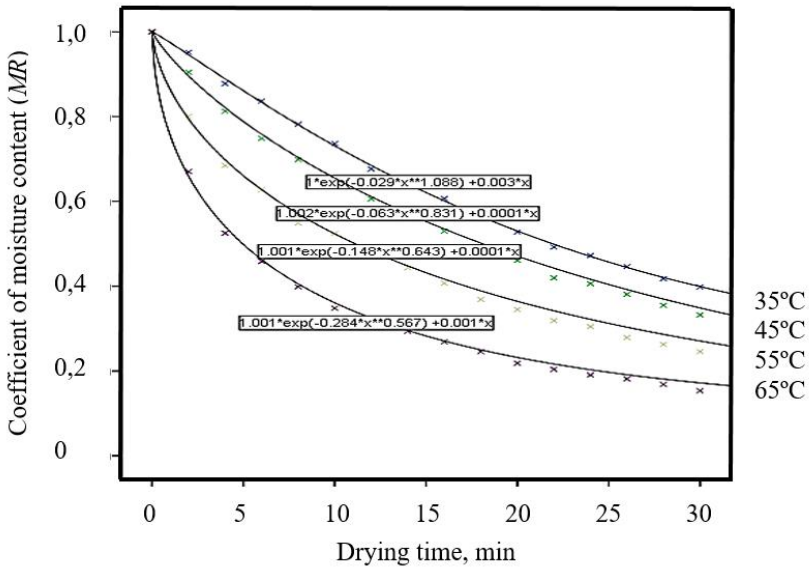


Fig. 5 – Results of numerical modeling of the linseed drying process using the Midilli model at different drying agent temperatures

CONCLUSIONS

The obtained mathematical model of the linseed drying process takes into account the following parameters: type of drying, interaction of the seed with the drying agent, moisture content of the seed layer. The characteristics of the model must be agreed with the experimental results. Temperature, humidity and speed of the drying agent affect the duration of seed drying. It is necessary to find such a drying mode, that the best technological properties of the seeds can be obtained with the minimum drying time and the lowest heat consumption.

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