EXPERIMENTAL STUDIES ON DRYING CONDITIONS OF GRAIN CROPS WITH HIGH MOISTURE CONTENT IN LOW-PRESSURE ENVIRONMENT

/

ЕКСПЕРИМЕНТАЛЬНІ ДОСЛІДЖЕННЯ РЕЖИМІВ СУШІННЯ НАСІННЯ ЗЕРНОВИХ КУЛЬТУР ІЗ ВИСОКОЮ ВОЛОГІСТЮ В СЕРЕДОВИЩІ НИЗЬКОГО ТИСКУ

Prof. Ph.D. Eng. Rogovskii I.L.[1], Senior lecturer Ph.D. Eng. Titova L.L.[1],
Senior lecturer Ph.D. Eng. Trokhaniak V.I.[1], Assoc. Prof. Ph.D. Eng. Solomka O.V.[1],
Senior lecturer Ph.D. Eng. Popyk P.S.[1], Ph.D. Eng. Shvidia V.O.[2], Ph.D. Eng. Stepanenko S.P.[2]
[1] National University of Life and Environmental Sciences of Ukraine;
[2] National Scientific Centre "Institute of Mechanization and Electrification of Agriculture", Ukraine
Tel: +380673513082; E-mail: Trohaniak.v@gmail.com

Keywords: *seed, heating temperature, drying exposure, laboratory germination, thermal damage*

ABSTRACT

During the experimental studies of drying grain crops with high moisture content in a low-pressure environment, the influence of residual pressure in a peri-seed environment and seed heating temperature on drying exposure and laboratory germination have been investigated. These experimental studies have been carried out by means of the experimental facility and its attachments that make it possible to provide residual pressure within the range of 10 – 80 kPa and seed heating temperature of +20 – +40 °C.

Having processed the experimental data, regression equations of drying exposure and laboratory germination of grain crops with high moisture content by the example of corn seeds have been derived. The characteristic curves plotted based on the regression equations show that the minimum drying exposure and, simultaneously, the maximum laboratory germination can be achieved by applying residual pressure of 45 kPa and seed heating temperature of no more than +30 °C.

РЕЗЮМЕ

Під час проведення експериментальних досліджень сушіння насіння зернових культур із високою вологістю в середовищі низького тиску досліджувався вплив залишкового тиску навколонасіннєвого середовища, температури нагріву насіння на експозицію сушіння та лабораторну схожість. Дані експериментальні дослідження були реалізовані на експериментальній установці та пристосуваннях до неї, які дали можливість забезпечити залишковий тиск у діапазоні 10 – 80 кПа, температуру нагріву насіння +20 – +40 °С.

Після оброблення експериментальних даних були побудовані рівняння регресії експозиції сушіння та лабораторної схожості насіння зернових культур високої вологості, в якості якого використовувалося насіння кукурудзи. Графічні залежності, побудовані на основі рівнянь регресії, показують, що найменшої експозиції сушіння та, одночасно, високої лабораторної схожості можливо досягти, застосовуючи залишковий тиск на рівні 45 кПа, температуру нагріву насіння, що не перевищує +30 °С.

INTRODUCTION

In order to dry seeds with high moisture content, convection drying in a fixed, slow-moving and pseudo-fluidized bed is currently used in seed farming and breeding. It is implemented in chamber, conveyer, hopper and column dryers.

In order to stimulate moisture transfer in a seed, heating, which is provided by an air flow at the temperature of no more than 65°C, is used. The upper temperature value is determined by the fact that at this temperature level there is intensive exudation of moisture, but seed proteins are not denaturized. There are mild temperature conditions developed for various crops, which are necessary to follow during seed drying in different convection dryers, in order to reduce the risk of thermal damage.

In spite of the developed measures for reducing thermal damage of seeds during drying, dried seeds have lower germinating ability and germinating power and even less germination compared to the undried ones. It can be explained by the difference in the properties of individual seeds and non-linear behaviour of the temperature conductivity of a seed bed, which results in overheating and under-drying of individual seeds. In order to improve sowing qualities of seeds, it is necessary to decrease their thermal damage after drying by means of reducing the influence or avoiding a temperature field as well as increasing the uniformity of seed drying.

Investigations *(Kotov B.I. et al., 2018; Kuznetsov Y.A. et al., 2018)* show that drying without seed damage is possible, if seed heating temperature of most grain crops does not exceed 40 – 45°C. At the same time, the change in moisture content does not exceed 5 – 6% in one technological cycle, since, if drying rate is higher, cracks can appear in a seed *(Zahoranová A. et al., 2016)*. In addition, it has been determined that if there is an increase in the initial moisture content of a seed, there is a decrease in the maximum acceptable temperature of seed heating *(Gorobets V.G. et al. 2018; Gorobets V.G. et al. 2018)*. In order to prevent seed damage during drying, the author *(Kuznetsov Y.A. et al. 2017)* suggests using mild drying temperature conditions. However, mild temperature conditions may result in under-drying of seeds. In addition, the existing heat generators do not always provide the required stable temperature conditions *(Dobrin D. et al. 2015)*.

One of the advanced methods of drying seeds is drying in a low-pressure environment *(Kotov B. et al. 2015)*. In this case, seed drying is even more and heating temperature is lower, compared to the one used in a convection method *(Kroulík M. et al. 2016)*.

Research *(Paziuk, V.M. et al. 2018; Bogaert L. et al. 2018)* shows that intensive moist removal can be provided during continued seed heating to the temperature, which is close to the permissible one. Other researchers suggest using a vacuum-pulse method, in order to improve drying rate *(Lukaszuk J. et al. 2008)*. However, the use of these methods may result in seed thermal damage *(Rekas A. et al. 2017)*.

Scientific papers *(Gorji A. et al. 2010)* present the idea that intensive moist removal in a low-pressure medium is possible during cyclic heating, vacuum treatment and blowing under air-pressure through a heat-exchange apparatus *(Gorobets V.G. et al. 2018)*. However, these papers do not consider the influence of operating conditions on the sowing qualities of seeds.

Most of the above-mentioned papers do not consider the influence of the operating conditions of drying in a low-pressure environment both on the sowing qualities of seeds and on their drying exposure simultaneously. That is why, it is necessary to substantiate the parameters, which provide drying in a low-pressure environment with minimum exposure and maximum germinating ability after drying.

MATERIALS AND METHODS

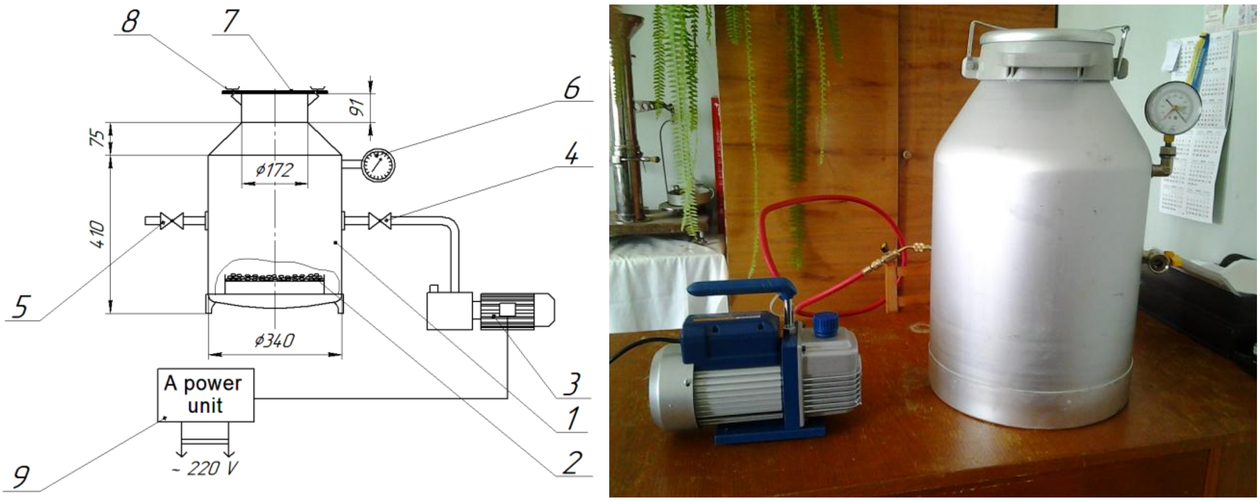
In order to investigate the mutual influence of operating conditions and optimize the number of experiments, a multi-factor experiment procedure *(Paziuk, V.M. et al. 2018; Bogaert L. et al. 2018)* was used. The planning matrix of the experiments was conducted according to D-optimal second-order plans *(Lukaszuk J. et al. 2008)*, based on the theory of joint efficient estimates, which was developed by an American statistician J. Kiefer. At the same time, Box-Behnken design (B–B3) was used for a three-factor experiment.

Drying exposure was determined by measuring the time, during which moisture content of the pre-moistened seed was changed by 6%. Such a change in moisture content was registered by periodic weighing of the seed mass that was used in the experiments. The level of thermal damage was evaluated based on laboratory germination, which was determined according to State Standards of Ukraine 4138-2002.

Regression coefficients, their relevance, adequacy, reproducibility and the homogeneity of the regression equations were determined by means of Wolfram Mathematica 13 software. Graphical interpretation of the regression equations was realized in MathCad 13 software environment.

In order to substantiate drying conditions of seeds in a low-pressure environment with minimum exposure and maximum generating ability after drying, a simple laboratory-scale plant, which is a cylindrical vessel, where residual pressure up to 2 kPa (Fig. 1) can be created inside, was developed. The heating of seeds was performed by means of Rotex RAS15-H infra-red heater with off system of protection from falling outside a drying chamber. Rotex RAS15-H infra-red heater was arranged above a plastic vessel and seed batching lasted for 5 minutes. During seed batch heating by the heater, it was thoroughly mixed to level the temperature. The temperature of seed heating was regulated by the level of infra-red heater arrangement above a seed batch.

Since the seeds of every grain crop have their own individual drying characteristics, the determination of the common patterns of their drying in a low-pressure environment requires a great number of experimental studies. In order to decrease the number of experimental tests, it was decided to use a batch of the variety of corn seeds called Liubava 279 MV weighting 715 g and having 20% initial moisture content as an example, since, to some approximation, its characteristics can be considered as ones which are typical of the seeds of most grain crops that need drying.



a) b)

Fig. 1 - Laboratory-scale plant design (a) and its general view (b)

1 – a drying chamber; 2 – corn seeds; 3 – a rotary vane-type vacuum low-pressure pump; 4 – a vacuum pressure tap; 5 – a tap for releasing vacuum; 6 – a vacuum meter; 7 – a lid with a seal; 8 – a locking mechanism; 9 – a power unit

The following independent factors, which are the main operating parameters of seed drying in a low-pressure environment, were chosen: *p* – residual pressure in a drying chamber, kPa; *t* – seed heating temperature, ^{o}C.

Their values and variability interval are represented in Table 1.

Table 1

Values and coding of independent factors levels during experimental investigation of the operating conditions of drying moist seeds in low-pressure environment

Variability level	**Independent factors**	
	Residual pressure, *p*, kPa	**Seed heating temperature, *t*, °C**
Low (-1)	10	20
Medium (0)	45	30
High (+1)	80	40
Variability interval	35	10

As mentioned above, a plastic vessel with a batch of corn seeds was heated at regular intervals to the required temperature during 5 min and then it was put into a drying chamber, where it was exposed to low air pressure for 10 min. At the end of each period, sample mass was measured and the amount of the evaporated moisture was determined. The measurement of sample mass and the amount of the evaporated moisture was conducted until the change in moisture content of corn seeds reached 6 %.

RESULTS

Implementation of a D-optimal plan, according to the data presented in Table 1, resulted in the derivation of the regression equations of drying exposure and seed germinating ability. Having conducted the analysis for regression coefficients, their adequacy, reproducibility and correspondence to a certain dependence, the regression equations acquire the following form.

Regression equation of drying exposure, τ_{ex}:

$$\tau_{ex} = 608.151 + 1.06 \cdot p - 13.73 \cdot t\,. \tag{1}$$

Regression equation of laboratory germination of seeds:

$$K_{ger} = 81.37 + 0.12 \cdot p + 0.972 \cdot t - 0.028 \cdot t^2\,. \tag{2}$$

In the equations (1) and (2): p - residual pressure in a drying chamber, kPa; t — heating temperature of a seed batch, °C.

The analysis of the regression equations (1) and (2) shows that drying exposure is greatly affected by heating temperature t and laboratory germination is influenced both by seed heating temperature t and residual pressure in a drying chamber p.

Based on the equation (1), drying exposure τ_{ex} was plotted versus residual pressure p without airflow. (Fig. 2).

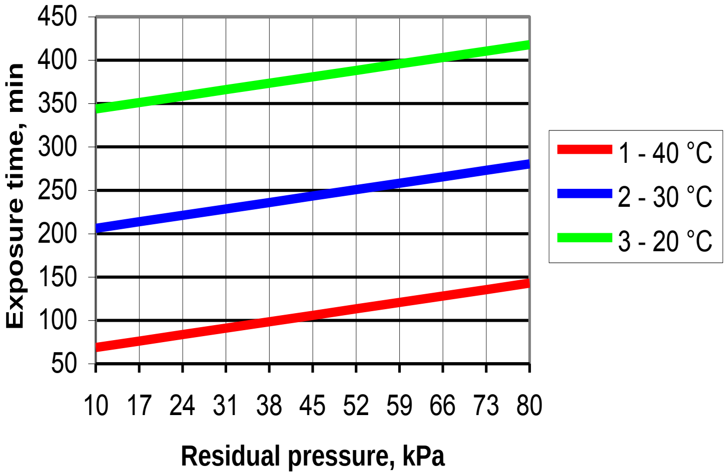


Fig. 2 - Drying exposure-vs-residual pressure characteristic curves at various temperature without airflow:
1 – 40 °C, 2 – 30 °C, 3 – 20 °C

Fig. 3 presents the comparison of laboratory germination-vs-temperature curves at vacuum and convectional drying. According to the characteristic curves presented in Fig. 3, drying exposure τ_{ex} linearly depends on residual pressure p. The decrease in residual pressure p results in the linear decrease of drying exposure τ_{ex}. If seed heating temperature t is reduced, drying exposure τ_{ex} increases. These characteristic curves show that the minimum drying exposure (69.6 min) can be achieved at the lowest level of residual pressure p = 10 kPa and the seed heating temperature of t = 40°C. The significant influence of seed heating temperature t on drying exposure τ_{ex} can be explained by the fact that, during seed drying in a low-pressure environment, it is cooled down due to the evaporation of seed surface moisture with simultaneous decrease of moisture diffusion rate. That is why, seed heating reduces exposure.

In addition, seed heating temperature t is a significant factor that influences laboratory germination and therefore, it affects the level of thermal damage of seeds (equation (2). It is shown in Fig. 3. The dependence of laboratory germination at convectional drying was plotted based on the data *(Kyrpa M.Ya. et al., 2015).*

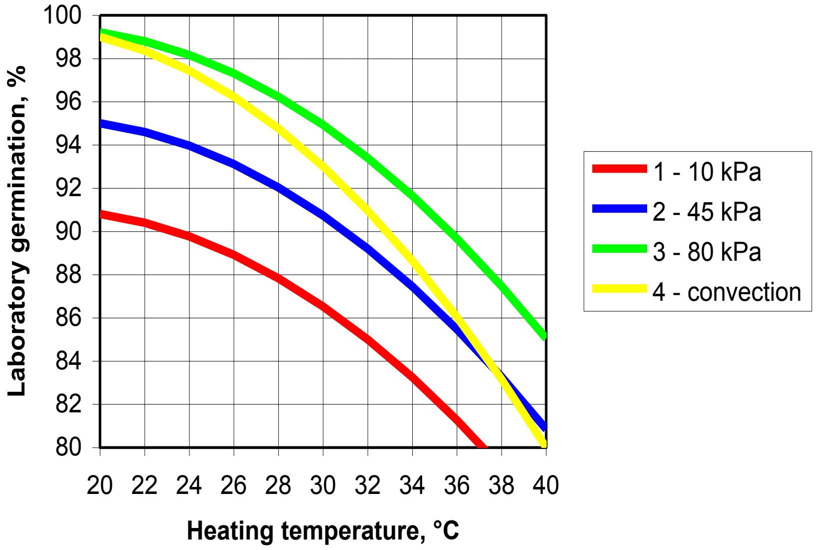


Fig. 3 - Laboratory germination-vs-seed heating temperature curves at various residual pressure and convectional drying
1 – 10 kPa, 2 – 45 kPa, 3 – 80 kPa; 4 – convectional drying

According to the curves presented in Fig. 3, at the same seed heating temperature, vacuum drying makes it possible to dry seeds providing better laboratory germination. It can be explained by the fact that, if drying is performed in a low-pressure environment, the heat supplied to seeds is spent on water evaporation and to only a small extend it is spent on heating seed cells, which reduces thermal influence on seeds.

The increase of seed heating temperature *t* and the decrease of residual pressure *p* result in the reduction of seed laboratory germination Kgerm. This is due to the fact that there is an increase of possible degradation of seed protein structures, if seed heating temperature *t* increases.

The increase of seed heating temperature *t* and the decrease of residual pressure *p* result in the reduction of laboratory germination of seeds Kgerm and simultaneous decrease in drying exposure τex. In order to find rational values of the operating conditions of drying in a low-pressure environment, drying exposure and laboratory germination-vs-seed heating temperature curves at different residual pressure were plotted in one of the graphs (Fig. 4). Their cross point defines the minimum value of drying exposure and the maximum value of the laboratory germination of seeds.

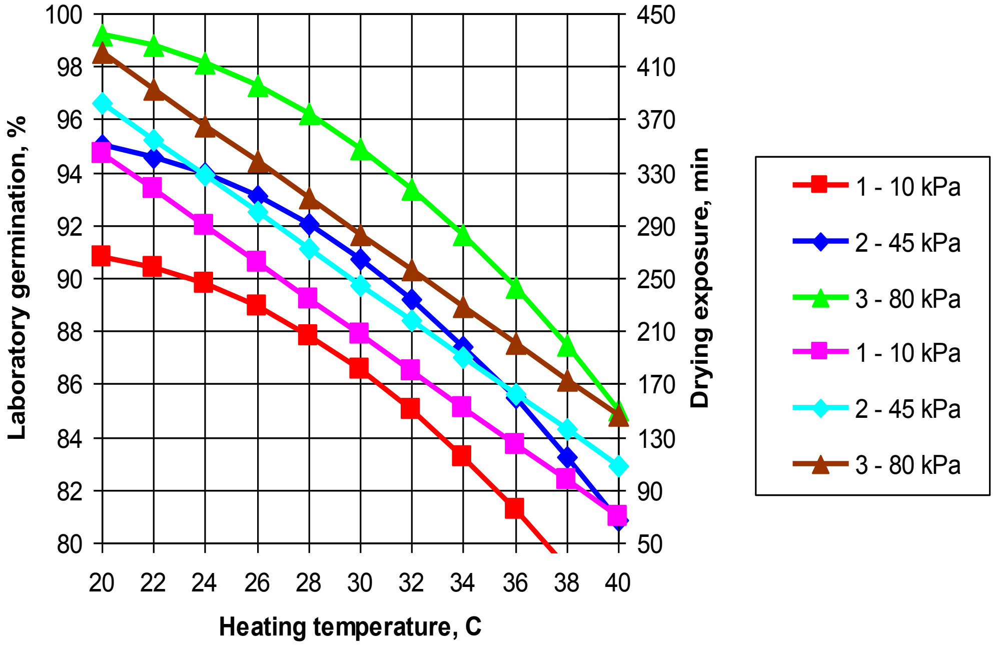


Fig. 4 - Laboratory germination and drying exposure-vs-seed heating temperature curves at various residual pressure:
1 – 10 kPa, 2 – 45 kPa, 3 – 80 kPa

According to the curves presented in Fig. 4, the minimum drying exposure with the lowest level of thermal damage, which is expressed as laboratory germination, can be achieved at seed heating temperature of no more than 30^{o}C and at residual pressure being equal to 45 kPa.

In case of corn seeds with initial moisture content of 20%, the minimum drying exposure is equal to 240 min and laboratory germination is 91.8%. It means that intensive drying in a low-pressure environment can be conducted at the temperature levels, which are 10 – 15^{o}C lower than those used during convection drying, ensuring germinating conditions.

CONCLUSIONS

Experimental research on drying the seeds of grain crops by the example of corn seeds in a low-pressure environment has been conducted. As a result of the conducted experimental investigations, regression equations have been obtained based on which drying exposure-vs-seed laboratory germination curves have been plotted. It has been determined that drying in a low-pressure environment makes it possible to provide high laboratory germination due to the fact that the heat, which is supplied to seeds, is spent on water evaporation mostly and to only a small extend it is spent on heating seed cells. Laboratory germination of 92-95% can be achieved at drying exposure of 200-240 m, at pressure in a peri-seed environment of 30–45 kPa and seed heating temperature of +25–+30 °C during drying.

REFERENCES

[1] Bogaert L., Mathieu H., Mhemdi H., Vorobiev E., (2018), Characterization of oilseeds mechanical expression in an instrumented pilot screw press, *Industrial Crops and Products*, vol. 121, pp.106-113. Wageningen/Netherlands;

[2] Dobrin D., Magureanu M., Mandache N.B., Ionita M.D., (2015), The effect of non-thermal plasma treatment on wheat germination and early growth, *Innovative Food Science & Emerging Technologies*, vol. 29, pp. 255-260, https://doi.org/10.1016/j.ifset.2015.02.006, Seville/Spain;

[3] Gorji A., Rajabipour A., Tavakoli H., (2010), Fracture resistance of wheat grain as a function of moisture content, loading rate and grain orientation, *Australian Journal of Crop Science*, vol. 4, pp. 448–452, Southern Cross/Australia;

[4] Gorobets V.G., Bohdan Yu.O., Trokhaniak V.I., Antypov I.O., (2018), Experimental studies and numerical modelling of heat and mass transfer process in shell-and-tube heat exchangers with compact arrangements of tube bundles, Paper presented at the *MATEC Web of Conferences*, vol. 240, 02006, https://doi.org/10.1051/matecconf/201824002006, Cracow/Poland;

[5] Gorobets V.G., Trokhaniak V.I., Antypov I.O., Bohdan Yu.O., (2018), The numerical simulation of heat and mass transfer processes in tunnelling air ventilation system in poultry houses, *INMATEH: Agricultural Engineering*, vol.55, no.2, pp.87-96, Bucharest/Romania;

[6] Gorobets, V.G., Trokhaniak, V.I., Rogovskii, I.L., Titova, L.L., Lendiel, T.I., Dudnyk, A.O., Masiuk, M.Y., (2018), The numerical simulation of hydrodynamics and mass transfer processes for ventilating system effective location, *INMATEH: Agricultural Engineering*, vol. 56, no 3, pp. 185-192, Bucharest/Romania;

[8] Kotov B., Kalinichenko R., Spirin A., (2015), Mathematical modeling of heat and mass transfer process under heat treatment of grain materials in dense layer, *TEKA, Commission of Motorization and Energetics in Agriculture*, Vol.17, Issue 5, pp.54-57, Lublin/Poland;

[9] Kotov B.I., Spirin A.B., Tverdokhlib I.V., Polyevoda Y.A., Hryshchenko V.O., Kalinichenko R.A., (2018), Theoretical researches of cooling process regularity of the grain material in the layer, *INMATEH: Agricultural Engineering*, vol. 54, no 1, pp. 87-94, Bucharest/Romania;

[10] Kroulík M., Húla J., Rybka A., Honzík I., (2016), Pneumatic conveying characteristics of seeds in a vertical ascending airstream, *Research in Agricultural Engineering*, vol.62, no. 2, pp.56-63, Prague/Czech Republic;

[11] Kuznetsov Y.A., Volzhentsev A.V., Kolomeichenko A.V., Kalashnikova L.V., (2017), Grounding of construction parameters of pseudofluidized layer dryer working chamber, *INMATEH: Agricultural Engineering*, vol. 52, no. 2, pp. 33-38, Bucharest/Romania;

[12] Kuznetsov Y.A., Volzhentsev A.V., Kolomeichenko A.V., Kalashnikova L.V., (2018), Influence of technological parameters of pseudofluidized layer grain dryer on the grain drying quality, *INMATEH: Agricultural Engineering*, vol. 54, no 1, pp. 81-86, Bucharest/Romania;

[13] Kyrpa M.Ya., Stiurko M.O., Bondar L.M., Bazilieva Yu.S., (2015), Thermal resistance of the seeds of corn hybrids and peculiarities of their post-harvest processing (Термостійкість насіння гібридів кукурудзи та особливості їх післязбиральної обробки), *Bulletin of Dnipropetrovsk state agrarian and economic university (Вісник Дніпропетровського державного аграрно-економічного університету),* vol. 3, no. 37, pp. 58–63., Dnipropetrovsk/Ukraine;

[14] Lukaszuk J., Molenda M., Horabik J., Szot B., Montross M.D., (2008), Air flow resistance of wheat bedding as influenced by the filling method, *Research in Agricultural Engineering*, vol. 54, no. 2, pp.50-57, Prague/Czech Republic;

[16] Paziuk, V.M., Liubin, M.V., Yaropud, V.M., Tokarchuk, O.A., Tokarchuk, D.M., (2018), Research on the rational regimes of wheat seeds drying, *INMATEH: Agricultural Engineering*, vol. 56, no 3, pp. 39-48, Bucharest/Romania;

[17] Rekas A., Scibisz I., Siger A., Wroniak M., (2017), The effect of microwave pre-treatment of seeds on the stability and degradation kinetics of phenolic compounds in rapeseed oil during long-term storage, *Food Chemistry*, vol. 222, pp. 43-52, Leiden/Netherlands;

[19] Zahoranová A., Henselová M., Hudecová D., Kaliňáková B., Kováčik D., Medvecká V., Černák M., (2016), Effect of Cold Atmospheric Pressure Plasma on the Wheat Seedlings Vigour and on the Inactivation of Microorganisms on the Seeds Surface, *Plasma Chemistry and Plasma Processing*, vol. 36, no. 1, pp. 397-414, https://doi.org/10.1007/s11090-015-9684-z, Bern/Switzerland.