DETERMINATION OF THE ENERGY EFFICIENT MODES FOR BARLEY SEEDS DRYING
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ВИЗНАЧЕННЯ ЕНЕРГОЕФЕКТИВНИХ РЕЖИМІВ СУШІННЯ НАСІННЯ ЯЧМЕНЮ

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ABSTRACT

For a more accurate study of the kinetics of the barley seeds drying, a convective drying stand with a computerized system of data acquisition and processing on the change in the mass and temperature of the sample from the drying time was used.

The kinetic curves of the drying process under the action of three factors were constructed: the temperature of the coolant, heating medium movement rate and the initial moisture content of the seeds. Studies were also conducted and the germination of barley seeds under the action of these factors was analysed.

Studies have shown that all factors affect the kinetics of the drying process, but the greatest influence on the germination of seed material comes from the influence of the temperature of the coolant. A three-factor effect on the germination of barley seeds on the 7th day of germination is presented, that indicates the need for low-temperature drying at a coolant temperature of 50°C.

In order to increase the intensification and energy efficiency of the drying process, the proposed two-stage drying mode is 65/50°C, which provides intensive heating and evaporation of moisture from the material at the initial stage of the process. Studies on the germination of barley seeds in a two-stage mode showed that the specified drying mode provides a high germination rate of the material up to 99%, an intensity of 83% and an energy efficiency of 62% compared to a rational single-stage drying mode of 50°C and can be recommended for drying barley seeds.

РЕЗЮМЕ

Для більш точного дослідження кінетики сушіння насіння ячменю був застосований конвективний сушильний стенд із комп'ютерною системою збору та обробки даних про зміну маси та температури зразка від часу сушіння.

Проведено побудова кривих кінетики процесу сушіння від дії трьох факторів: температури теплоносія, швидкості руху теплоносія та початкової вологості насіння. Також проведені дослідження та проаналізована схожість насіння ячменю від дії зазначених факторів

Дослідження показали, що всі фактори впливають на кінетику процесу сушіння, але найбільший вплив на схожість насіннєвого матеріалу відбувається від впливу температури теплоносія. Представлений трьохфакторний вплив на схожість насіння ячменю на 7 день пророщування вказує на необхідність низькотемпературного сушіння при температурі теплоносія 50ºC.

З метою підвищення інтенсифікації та енергоефективності процесу сушіння запропонований двохступеневий режим сушіння 65/50ºC, що забезпечує інтенсивне прогрівання та випаровування вологи з матеріалу на початковій стадії процесу. Проведені дослідження із схожості насіння ячменю в двохступеневому режимі вказали, що зазначений режим сушіння забезпечує високу схожість матеріалу до 99%, інтенсивність на 83% та енергоефективність процесу на 62% в порівнянні з раціональним одноступеневим режимом сушіння 50ºC і може бути рекомендований для сушіння насіння ячменю.

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INTRODUCTION

Drying is the main technological operation for bringing the seeds to a stable equilibrium condition. The technology of seed drying involves knowledge of the biological properties of the grain as the object for drying, the heat stability of the grain, patterns of moisture evaporation, determining the modes of drying and equipment for the implementation of the process.

The theoretical basis of the agricultural material drying techniques has been formed in the world for two and a half centuries. Nevertheless, despite the multitude of studies well presented in the literature, the industry still lacks universally recognized methods of design calculation for the majority of drying problems (*Bulgakov V., Bandura V., Arak M., Olt J., 2018).* Scientists are investigating different types of drying crops: active ventilation (*Gaponyuk O.I. Ostapchuk M.V, Stankevich G.M., 2014*), in a monolayer tray vibration dryer based on infrared radiation (*Bandura V., Mazur V., Yaroshenko L., Rubanenko O., 2019)*, by vibration dryer with electromagnetic energy sources (*Burdo O., Bandura V. , Zykov A., Zozulyak I., Levtrinskaya J. , Marenchenko E. 2017)*, intermitted drying *(Kumar C., Karim M. A., & Joardder M. U. H., 2014; Souza e Silva J. S., 2008)*, microwave convective drying *(Ahrné L. M., Pereira N. R., Staack N. & P. Floberg)*, a combination of a convective method of supplying heat with the introduction of ozone drying agent (*Tsurkan O. V. Necheporenko S. A., Blyznyuk M. Ya, 2013)*.

Having characterized the grain drying processes, we can roughly divide it into soft and rigid grain drying modes. The first is specified by the relatively low temperature and speed of the drying agent. In the soft mode, the processes of heating and drying the grain are relatively slow. For the rigid mode higher temperatures and the heating medium movement rates are characteristic *(Paziuk, V.M., Liubin, M.V., Yaropud, V.M., Tokarchuk, O.A., Tokarchuk, D.M., 2018).*

From the economic point of view, it is desirable to carry out the process of grain drying in a rigid mode with drying time reduction. However, under the rigid mode due to intensive heating and dehydration, grain quality deterioration takes place: cracking of seeds, discoloration, partial or complete destruction of the embryo, deformation of tissues.

The use of high temperatures at the beginning of the wet grain drying process leads to a rapid dehydration of its surface *(Matkivska I. Ja., Atamanyuk V. M., Symak D., 2014*), which makes the shell less permeable to moisture (the phenomenon of thermal "hardening" of the grain). Under such conditions, water vapor is formed in the surface layer, the output of which becomes difficult.

MATERIALS AND METHODS

Drying of seeds of different crops has certain restrictions. As it is known (*Lykov A.V., 1968; Stankevich G. M., Strahova T. V., Atanazevich V.I. , 1997; Paziuk V.M., Petrova Zh.O., Tokarchuk O.A., Yaropud V.M.; Shchitsov S.V., Tikhonchuk P.V., Krivuta Z.F., Kolzov A.V., 2016)*, high temperatures have negative effect on the quality of seeds, reducing their energy for germination and growth thus impairing the quality of material for technological purposes.

By the soft drying mode there is no full confidence in preserving seed properties of the grain, thus durable low temperature drying (depending on environmental parameters) may form the mould on the surface of the grain resulting in the seed material damage.

Soares M., Jorge L., Montanuci F. (2016) in their works studied the kinetics of the barley seeds drying process at a 40-80ºC temperature of the drying agent in continuous and periodic drying mode.

Continuous drying has the advantages of the drying time reduction due to elimination of the loading and unloading operations of the dryer. But it also has its disadvantages: in a continuous heat flow a difference between the moisture on the surface and inside the grain occurs.

In periodic dryers, the product passes through the dryer several times until fully dried. Thus, the grain is subjected to a short-repeated action of heat and rest during drying. During the rest, moisture is moved from the centre to the periphery of the grain, which reduces the occurrence of cracks due to a decrease of internal stresses in the grain.

Studies of the barley seeds drying kinetics described in the work of *Soares M. et al* showed that the maximum duration of drying at a 40ºC temperature of the heating medium for 12 hours corresponds to the 94-95% level of seeds germination. Increasing the temperature to 60-80ºC under different drying methods reduces duration of drying and the level of seed material germination

The influence of the coolant temperature in fluidized bed dryers and infrared radiation on drying kinetics and germination rates of barley seeds is demonstrated in the work of *Markowski M. et al (2007)* Drying of barley seeds in a fluidized bed dryer takes place at a 30-45ºC drying agent temperature, which corresponds to radiation in an infrared dryer with an intensity range of 0.048-0.107 W/cm^2, seed germination rate was at a 91-93% level.

Stankevich G.M. et al (1997) in their work recommend maximal allowable heating temperature for drying barley seeds in a mine-type dryer with a 40°C drying agent temperature, but does not give data on seed germination rate.

Various authors give recommendations on determining the optimal mode of drying, which need clarification.

Many of the approaches and methods for drying barley seeds are alternative to traditional convective drying. Modern drying equipment with computerized processing of the obtained data allows to determine more precisely the necessary drying modes on the base of germination properties of the seeds.

For determining the kinetics of barley seeds drying, a convective drying stand with a computerized data acquisition and processing system was used, which allows to read experimental data 6 times per minute *(Pazyuk V. Petrova Zn., Chepeliuk O., 2018).*

Data on the barley seeds heating temperature and the weight of the material changes during the studies were obtained. The graphs of the kinetics of the drying process were built and calculations of the drying rates of barley seeds were made.

RESULTS

Results of the authors' laboratory research on the barley seeds drying are presented in Fig. 1-3.

Shift in the temperature of the drying agent from 50 to 80°C reduces the drying time by 2.67 times.

The obtained temperature curves of heating inside the material caused by the drying agent temperature changes, indicate that it can be intensively heated for 10 minutes.

The increase in the intensity of heating of the material depends on the drying agent temperature increase, which directly affects barley seed properties (Fig. 1).

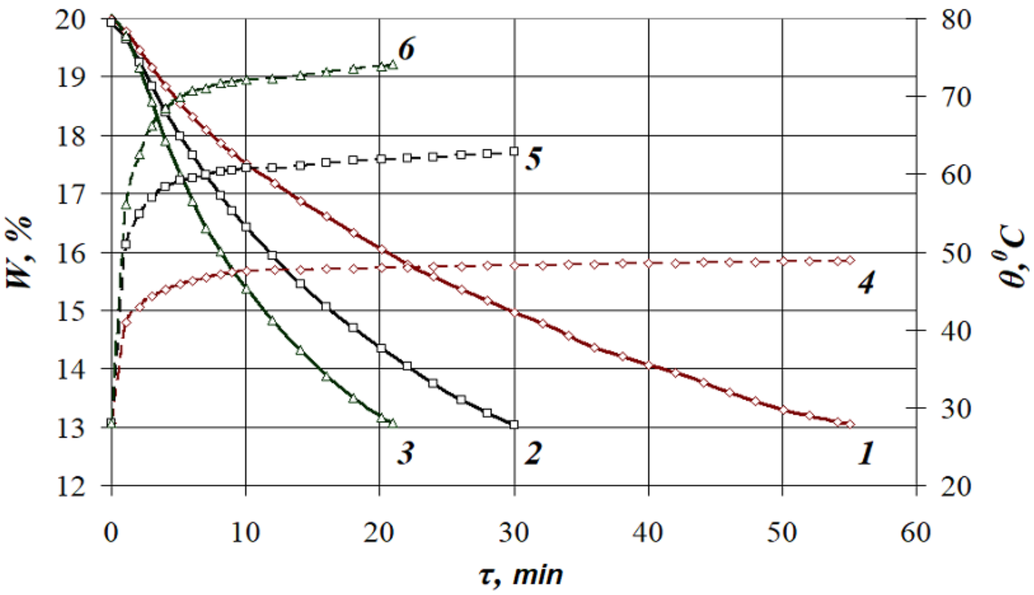

Fig. 1 - Effect of the coolant temperature and the temperature of the material heating on the duration of barley seeds drying

W_n (initial humidity) = 20%, V (velocity of the coolant) = 1.5 m/s, d (moisture content of dry air) = 10 g/kg d.a., δ (grain layer thickness) = 2 mm: 1.4 – 50ºC, 2.5 – 65ºC, 3.6 – 80ºC

The process of drying barley seeds occurs during the period of decreasing the drying rate on condition of the pre-heating of the material. The maximum drying rate at point K for the 50°C coolant temperature is 0.32% per min, and for the 80°C temperature – 0.63% per min (Fig. 2).

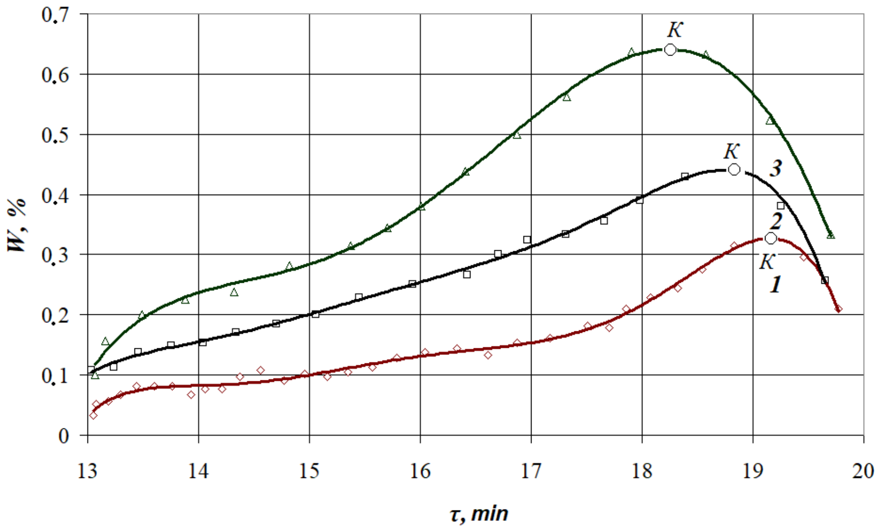

Fig. 2 - Effect of the coolant temperature on the barley seeds drying rate

W_n = 20%, V = 1.5 m/s, d = 10 g/kg d.a., δ = 2 mm

1 – 50°C, 2 – 65°C, 3 – 80°C

It has been established that the best germination rate of barley seeds is observed at a 50ºC heating medium temperature and 48.9ºC temperature of the material heating, namely 96%. Further increase of the drying agent temperature to 80ºC considerably reduces barley seed properties (Fig. 3).

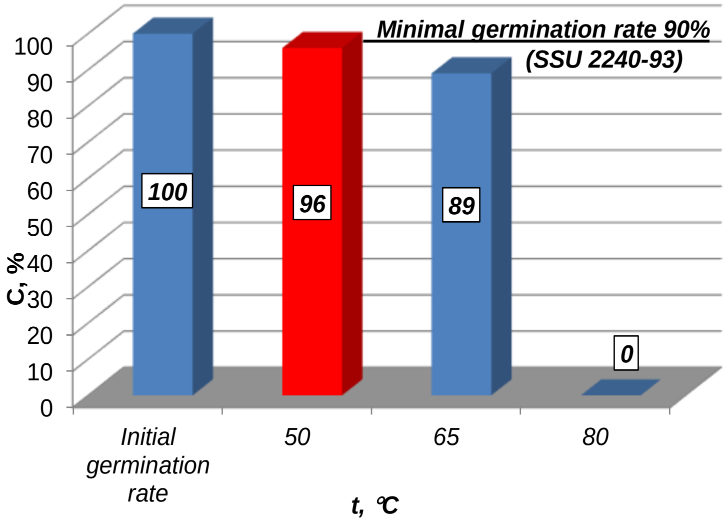

Fig. 3 - Effect of the coolant temperature on the germination rate of barley seeds on the 7th day of germination: *V = 1.5 m/s, W_n = 20%, d = 10 g/kg d.a.*

The results of the laboratory studies on the seed germination rate on the 7th day of germination can be seen in Fig. 4, they confirm the data of the experiment on the dependence of germination rates on the drying modes shown in Fig. 3.

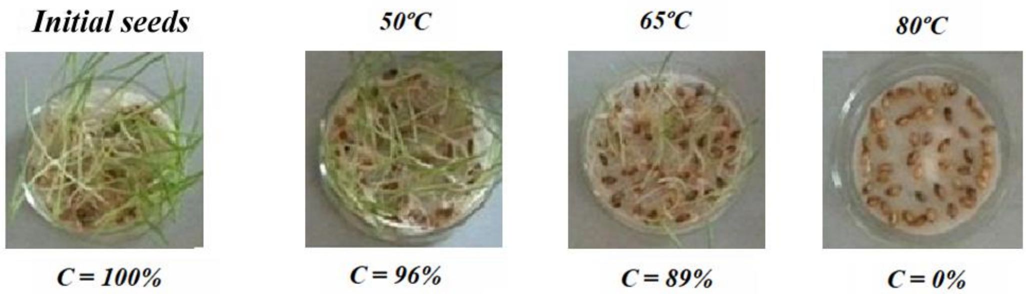

Fig. 4 - Barley seeds germination rates in accordance with drying modes

V = 1.5 m/s, W_n = 20%, d = 10 g/kg d.a.

Another factor that influences the kinetics of the drying process is the initial moisture content of barley seeds selected in the range of W=16-24%, which corresponds to the moisture content of the seeds when harvested under different climatic conditions.

Kinetics of the barley drying process shows that increase in the initial moisture content from 16% to 24% lengthens duration of drying by 3.29 times (Fig. 5).

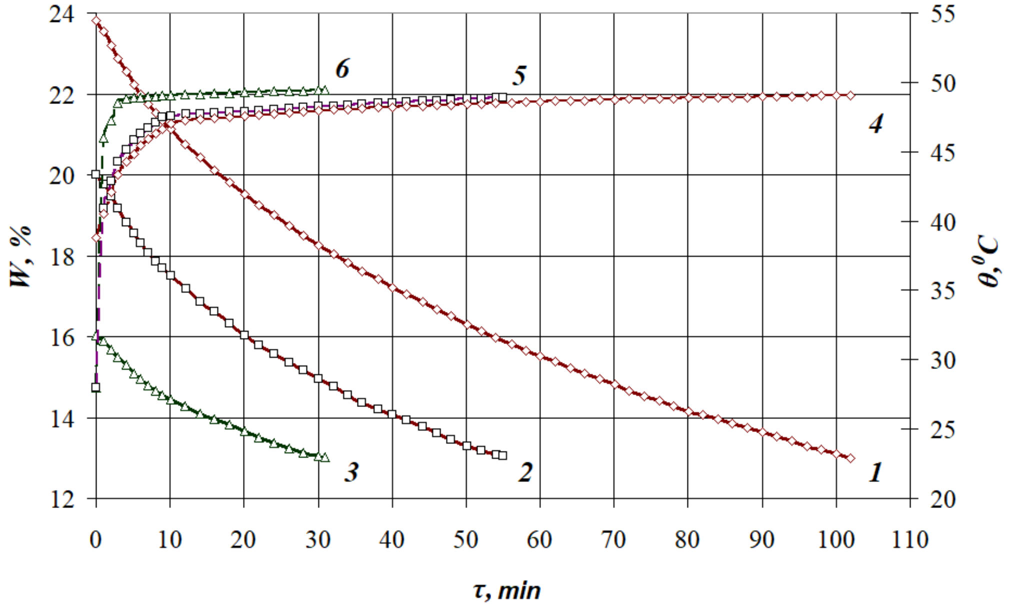

Fig. 5 - Effect of initial moisture content and material heating temperature on duration of barley seeds drying

t = 50ºC, V = 1.5 m/s, d = 10 g/kg d.a., δ = 2 mm:
1 – 24%; 2 – 20%; 3 – 16%

The final barley seeds heating temperature decreases as a result of the initial humidity of the material increase at a temperature of 50ºC and lies within the limits of 48.9-49.6ºC (Fig. 5).

The drying rate curves are similar to the drying curves shown in Fig.2. The rate of the barley seeds drying increases with the increase of the initial moisture content of the material (Fig. 6).

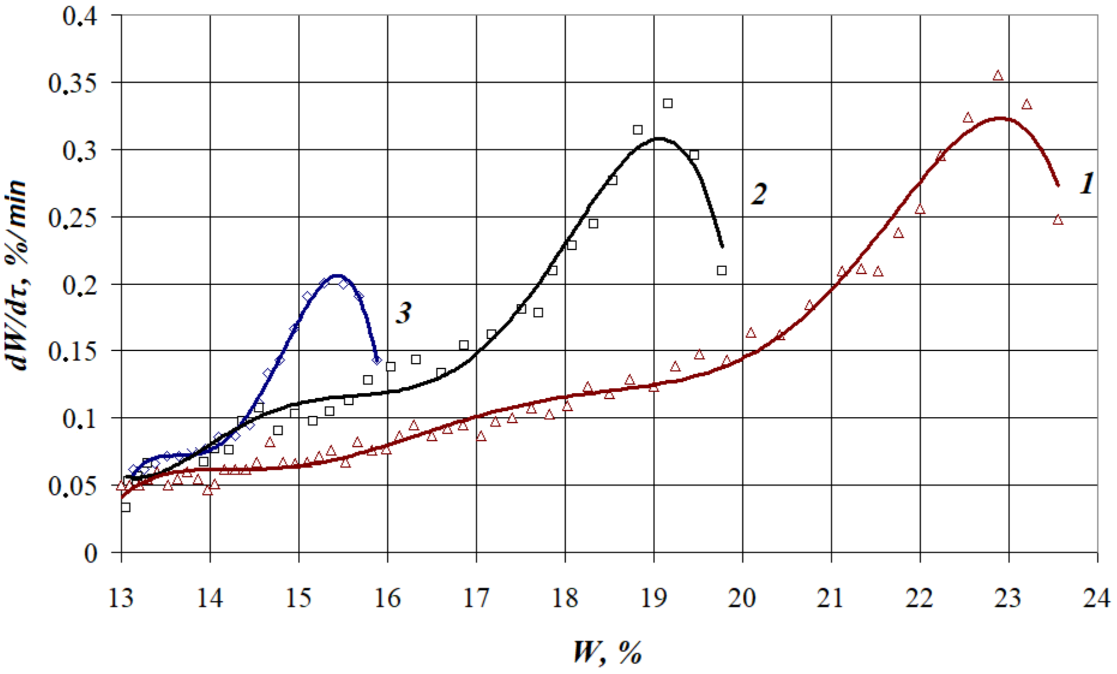

Fig. 6 - Influence of the material initial moisture content on the barley seeds drying rate

t = 50ºC, V = 1.5 m/s, d = 10 g/kg d.a., δ = 2 mm:
1 – 24%; 2 – 20%; 3 – 16%

Increase in the heating medium movement rate from 0.5 to 1.5 m/s increases duration of barley drying by 1.24 times (Fig. 7).

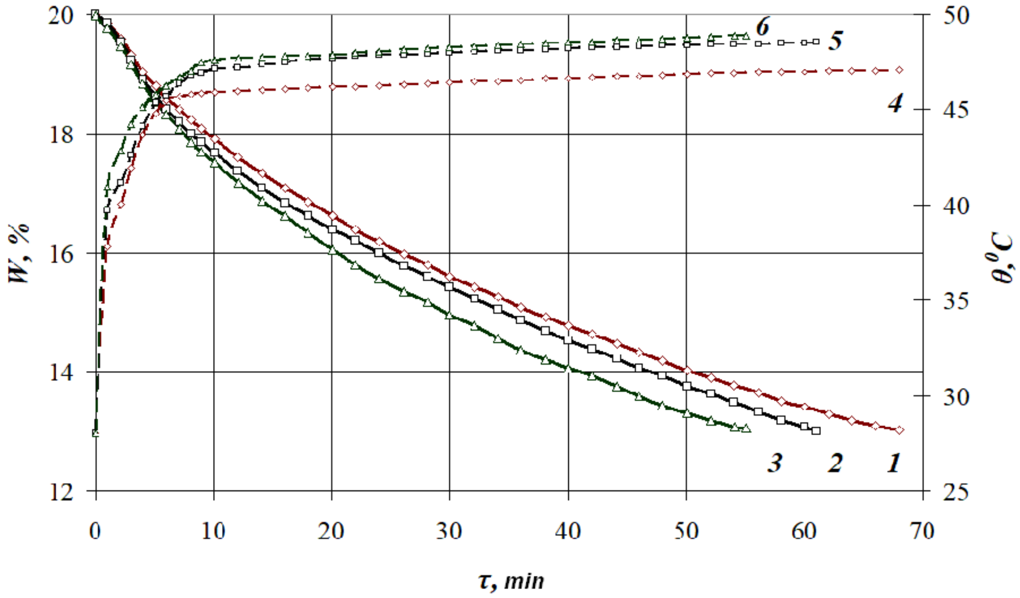

Fig. 7 - Influence of the heating medium movement rate and the material heating temperature on the barley seeds drying duration:
t = 50ºC, W_n = 20%, d = 10 g/kg d.a., δ = 2 mm:
1 – 0.5 m/s; 2 – 1.0 m/s; 3 – 1.5 m/s

When evaluating and selecting the drying mode, it is necessary to proceed from the qualitative characteristics of seed germination.

The three-factor effect on germination of barley seeds on the 7th day of germination is presented in Table 1.

Table 1

Influence of drying parameters on germination rates of barley seeds on the 7th day of germination

Drying parameters			Germination rates [%]
Temperature of the coolant, [ºC]	**Initial moisture content of the seeds [%]**	**Heating medium movement rate [m/s]**	
Output	-	-	100
50	16	1.5	98
50	20	0.5	98
50	20	1.5	98
50	24	1.5	96
65	16	1.5	95
65	20	0.5	90
65	20	1.5	90
65	24	1.5	89
80	16	1.5	18
80	20	0.5	18
80	20	1.5	18
80	24	1.5	0

Drying mode with high seed germination rate is a 50°C heating medium temperature, where the influence of initial moisture content and heating medium movement rate is not significant.

The temperature of the heating medium 65ºC at the initial moisture content above 16% is close to the minimum seed germination rate (92%) and is 89-90%, which does not meet the requirements for seed grain. The influence of the heating medium movement rate on the germination rate of seeds is more significant at the 80ºC temperature mode, and when the initial moisture content makes up 24%, all seed properties of grain disappear.

In order to increase energy efficiency of drying and to improve the rate of barley seeds germination, it is proposed to use a 65/50ºC temperature stepwise drying method. Comparison of the 65/50ºC drying mode with the one-stage modes is demonstrated in Fig. 8.

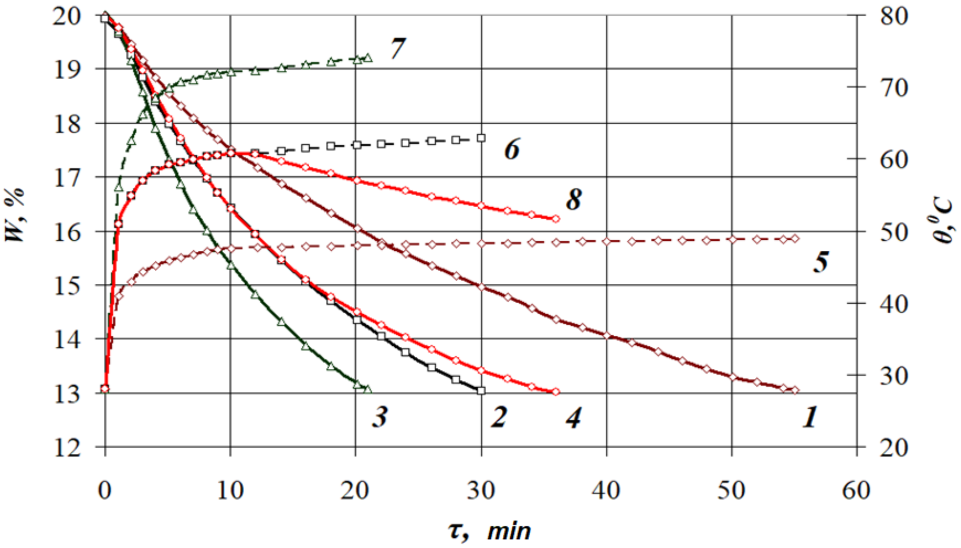

Fig. 8 - Influence of the heating medium temperature and the material heating temperature on duration of barley seeds drying
W_n = 20%, V = 1.5 m/s, d = 10 g/kg d.a., δ = 2 mm:
1.5 – 50ºC, 2.6 – 65ºC, 3.7 – 80ºC, 4.8 – 65/50ºC

As can be seen from Fig. 8, at the beginning of the drying process, the heating temperature of the barley seeds in the two-stage drying mode of 65/50ºC had been keeping for 5 minutes and after that the coolant temperature was sharply reduced to 50°C. The maximum temperature of the material heating at the beginning of the process at a 65°C coolant temperature was 59.18°C and then it gradually decreased to the 51.32°C final value.

Duration of the 65/50ºC two-stage drying process is reduced by 35% compared to the 50ºC drying mode. Low energy consumption for the drying process in the stepwise drying mode is associated with the rapid heating of the material in the drying chamber at a temperature of 65°C and a gradual decrease in the temperature of the coolant to a temperature of 5°C and in duration by 35% (Fig. 9).

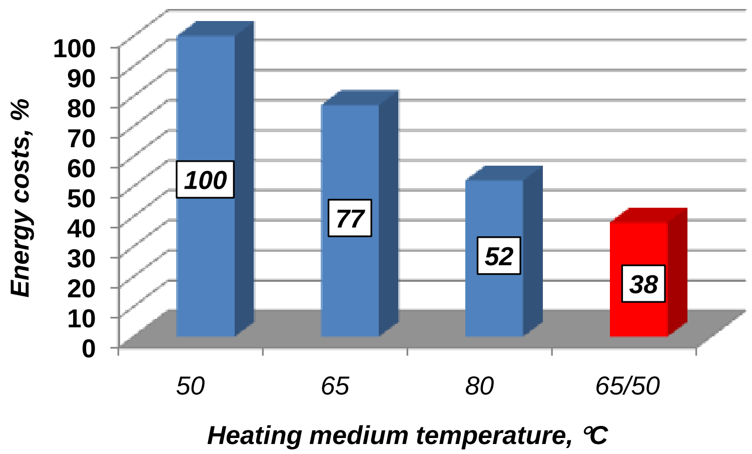

Fig. 9 - Dependence of the process of barley seeds drying energy consumption on the heating medium temperature:
W_n = 20%, V = 1.5 m/s, d = 10 g/kg d.a., δ = 2 mm

To evaluate objectively the stepwise drying modes for barley seed drying, the influence of 65/50, 80/65, and 80/resting/65ºC modes on the kinetics of the drying process and the qualitative characteristics of the seed material was investigated. The presented drying modes are within the proposed 50-80ºC range.

Kinetics of the barley seeds drying in stepwise modes indicates the peculiarity of the process and the rate of heating the material with a gradual temperature decrease (Fig. 10).

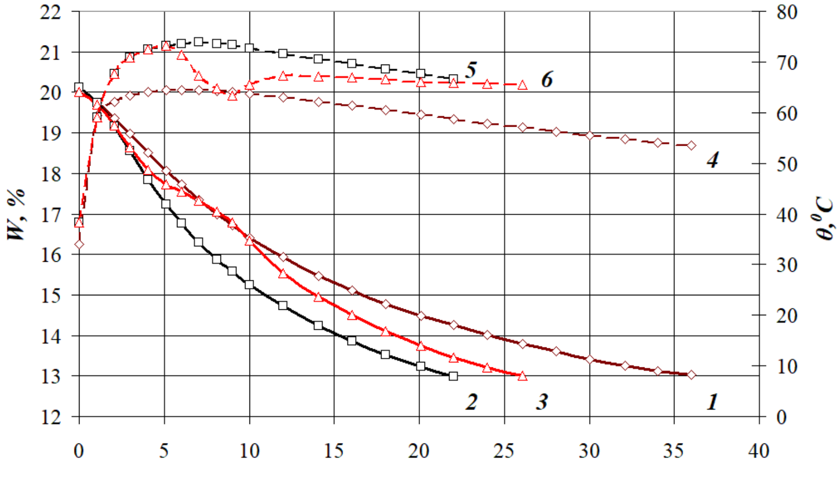

Fig. 10 - Influence of the heating medium temperature and the heating of the material temperature on barley seeds drying duration in stepwise modes:
W_n = 20%, V =1.5 m/s, d =10 g/kg d. a, δ = 2 mm:
1.4 – 65/50ºC, 2.5 – 80/65ºC, 3.6 – 80/resting/65ºC

The most intensive 80/65ºC stepwise drying mode differs from the 80/resting/65ºC drying mode by 5 minutes, that is, by the time of the seed resting. During the resting movement of the heating medium in the drying chamber stops and a significant slowdown in the removal of moisture from the seeds is observed, while redistribution of heat and moisture in the seed itself becomes the main process. It can also be seen that, in the resting mode, the drying kinetics curve shifts toward the 65/50ºC drying curve, into the area of high germination rates of the material.

In the 80°C/65°C stepwise drying mode in addition to the other processes, the process of resting is present, which is observed as a "temperature pit" on the curves, the decrease in temperature takes place from the 74ºC of the seed heating temperature by 15ºC after 5 min from the start. On the 9th minute it is switched to the 65ºC drying mode – the temperature rises sharply and then gradually decreases.

The curves of barley seeds drying rate in the stepwise drying modes are presented in Fig. 11.

The nature of the 65/50 and 80/65ºC drying curves does not differ from the previously described single-stage drying curves. The 80/65ºC drying mode is the most intensive one, it is more intensive than the 65/50ºC drying mode by 0.24% per min.

In the 80/resting/65ºC stepwise drying mode, there is a twofold fall in the heating period and the drying rate with a decrease in the drying rate with critical humidity K1-K3.

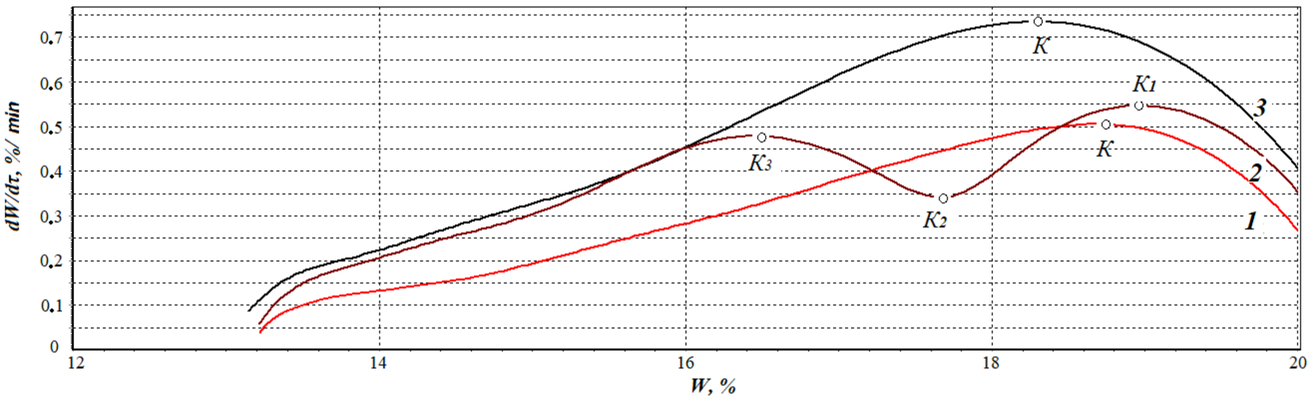

Fig. 11 - Influence of the heating medium temperature on the barley seeds drying rate in stepwise modes:
V = 1.5 m/s, d = 10 g/kg d.a., δ = 2 mm:
1 – 65/50ºC, 2 – 80/resting/65ºC, 3 – 80/65ºC

The barley seeds germination rates in the stepwise drying modes are shown in Fig. 12.

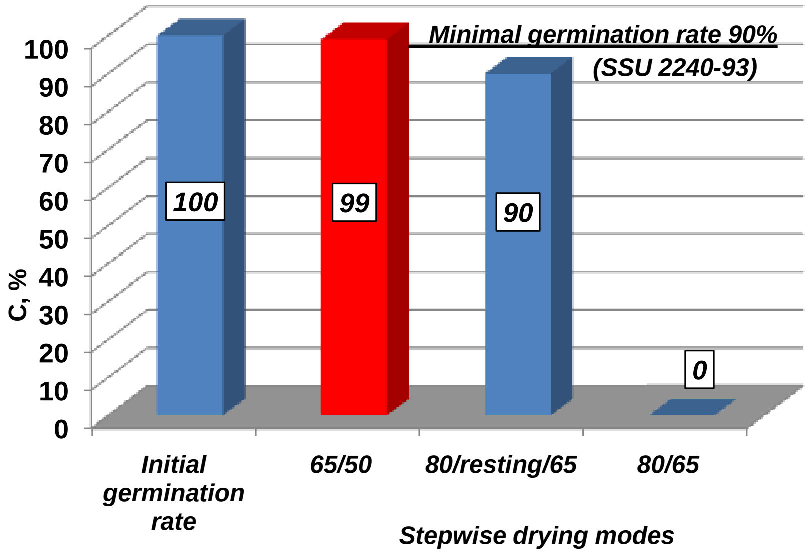

Fig. 12 - Influence of the stepwise drying modes on the barley seeds germination rates on the 7th day of germination:
V = 1.5 m/s, W_n = 24%, d = 10 g/kg d.a.

The results of germination rates prove the effectiveness of drying in the 65/50°C mode. After drying under the 80/65ºC mode the seeds of barley do not germinate, but after the stepwise 80/resting/65ºC mode of drying there was observed a rather high germination rate at the level of 90%, which testifies to the positive effect of resting on the seed properties of the material.

The strongest sprouts were observed in the 65/50ºC stepwise mode of drying. As can be seen from Fig. 13 all seed properties disappear in the 80/65ºC stepwise mode. An 80/65ºC stepwise drying mode shows that the influence of the 80ºC temperature heating medium for 10 minutes completely destroys all seed properties.

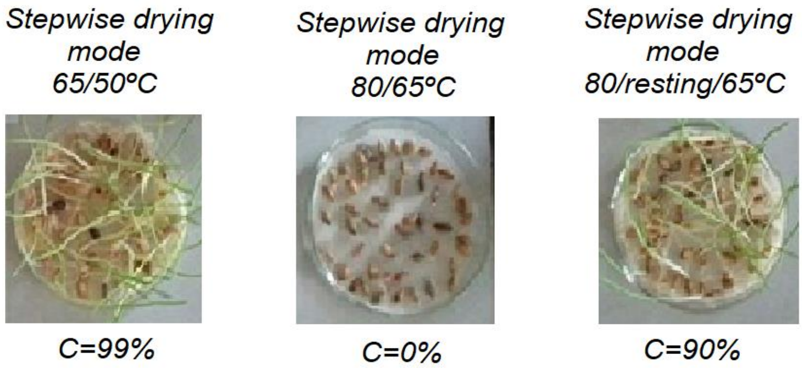

Fig. 13 - Germination rates of "Barvystyi" variety barley seeds depending on the drying mode on the 7th day of germination

CONCLUSIONS

The developed modes of drying allow making the drying of barley seeds more efficient with higher quality of seed material. The most appropriate mode for drying barley seeds is a two-stage drying mode 65/50ºC which differs from the drying mode 50ºC in that it increases the intensity of the process by 35%, germination rate – by 98% and reduces energy consumption by 62%.

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