SPECIAL ASPECTS OF SOYBEAN DRYING WITH HIGH SEEDLING VIGOR

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The complexity of soybean drying is caused by the structure of the bean, which consists of a shell and a kernel with different respective reaction to thermal effects.

Drying at low temperatures from 30 to 40ºC significantly increases the duration of the process, which can affect the quality characteristics of the material and substantially increase energy costs. Drying at high temperatures of a heating medium affects the seed properties of the material. Therefore, there is a need to develop the technological modes that will reduce the duration of the process while preserving high seedling vigor of the material.

In order to accomplish the assignment, we studied the process of drying a simple layer of soybean in a modern drying stand with computer processing of experimental findings.

Keywords: process of drying, soybean seeds, stepwise mode, kinetics for drying.

1. Introduction

Theoretical studies make it possible to calculate the kinetics of the drying process of soybean seeds in the second drying period by determining the corresponding coefficients and the necessary drying time at various temperature conditions.

The specificity of drying soybean is about the bean tending to give away moisture slowly and easily traumatized by mechanical impact. Soybean shell also dries out quicker than kernel, gets bigger in size and, being pushed out by the kernel, breaks off causing seed lobes to split apart. Soybeans are dried in aerated bins, drying towers, conveyor belt dryers and tunnel dryers.

Based on the findings of such authors as Broker D.B., J.B. Franca Neto, Krzyzanowski F.C., Afrakhteh S., G.M. Stankevich, V.I. Atanazevich, etc., the temperature, to which the material is heated, should not exceed 43°C. However, there are studies that demonstrate temperature increase up to 60°C [1-6].

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The experiments of drying soybean from the initial moisture of 22% to the final moisture of 12% at the heating medium temperature of 54.4ºC and 40% moisture show reduction in germination capacity, cracking and increased number of cracks on shells [4]. Overdrying problem may arise if percentage of air moisture is below 35-40%. Severe overdrying may cause reduction in seed viability and the increased crispiness [7]. In view of the above problems, an optimal combination of drying parameters needs to be found to minimize impairment of seed quality.

Therefore, we allow for the needed soybean drying temperature range of 40-60°C.

Modern drying equipment with computer processing of the data obtained allows for more precise definitions of drying modes based on the following seed germination studies [8-13]. We obtained experimental data of high accuracy regarding changes in temperatures of soybean heating and the weight of the material during the study. Research program provides for building diagrams to show the kinetics of the soybean drying process and drying speed.

2. Materials and method

It is most appropriate to determine the drying regime according to the biological properties of the grain.

Acceptable values of temperatures at different time values of impact on the grains, which does not affect the processes of life in it, depend on the moisture content of the grain – the higher the humidity, the lower the permissible values of temperatures.

The temperature change of the grain and the reduction of the material mass were determined using special devices and the developed program in an automatic mode on a convective drying stand (fig. 1). In order to assess the quality of the wheat seeds, the standard methods of research were provided by SS 4138 - 2002 and SS 2240 - 1993 (State Standard 4138 - 2002, 2003; State Standard 2240 - 1993, 1994).

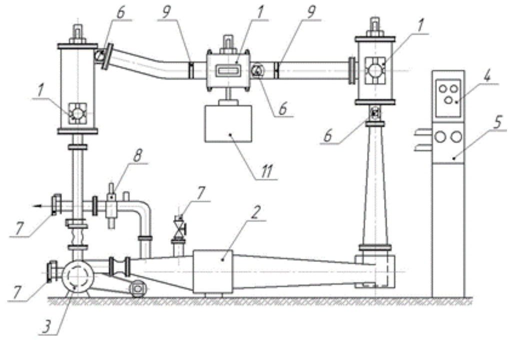

Fig. 1. Scheme of the experimental stand: 1 – drying chamber; 2 – heater; 3 – fan; 4 – temperature controller; 5 – control panel; 6 – thermometers; 7 – pipe fittings; 8 – psychrometer; 9 – special gratings; 10 – a bar of scales; 11 – scales

The research program involves removing the wheat drying kinetics by recording the changes in the mass of the material, temperatures of the coolant and in the middle of the material.

3. Paper contents

Findings of soybean drying studies are presented in fig. 2 – 4.

As the temperature increases the duration of soybean drying substantially decreases, i.e. with 20ºC temperature increase (from 40 to 60ºC) the duration drops by 100 min, or 70% total time (fig.2).

The intensity of the drying process can be achieved through the stepwise mode of 60/50ºC. Applicability of the stepwise mode is defined on the basis of quality indicators of the material.

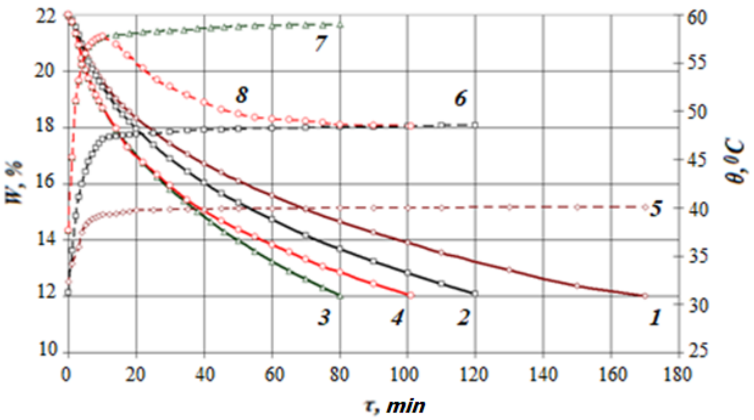

Fig. 2. Influence of heating medium temperature and soybeans heating temperature on the duration of drying: *Wn* = 22% (initial humidity), *V* = 1.5 m/s (velocity of the coolant), *d* = 10 g/kg d. a. (moisture content of dry air), δ = 2 mm (grain layer thickness): 1 – 40ºC, 2 – 50ºC, 3 – 60ºC, 4 – 60/50ºC

Implementation of the stepwise process allowed to reduce the heating medium temperature in the area of low moisture of the material which improves seed quality and allows to expedite the process by 23%.

During the stepwise drying process 60/50ºC the heating medium temperature changes in the following way: heating at temperature 60ºC – 8 min, transition from the temperature of 60 to 50ºC – 22 min, drying at the temperature of 50ºC – 71 min. Thus, 70% of the time is taken for drying at the heating medium temperature of 50ºC.

As the heating medium temperature increases, so does the maximum drying speed. Thus, with the temperature of 40ºC the drying speed is 0.3%/min. Temperature increase to 60ºC raises the drying speed to 0.47%/min. The critical point is also shifted with the temperature increase towards the moisture reduction from 21.1 – 20.7% (fig. 3).

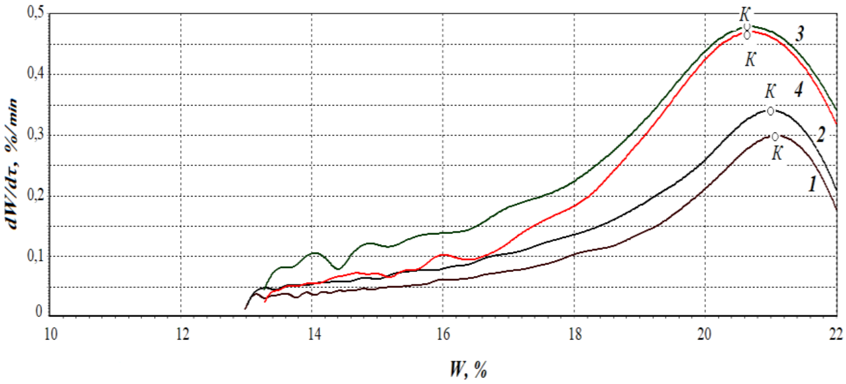

Fig. 3. Influence of heating medium temperature on soybeans drying speed: Wn = 22%, V = 1.5 m/s, d = 10 g/kg d. a., δ = 2 mm: 1 – 40ºC, 2 – 50 ºC, 3 – 60ºC, 4 – 60/50ºC

Fig. 4 shows researched correlations between seedling vigor and drying modes of soybeans, «Knyazhna» variety, on the 7th day of germination.

When analyzing the germination rate of «Knyazhna» variety we detect high (99%) germination in the stepwise mode 60/50ºC, with all other outlined modes the seedling vigor being lower. Even with the temperature of 40ºC germination rate is 96% which is 3% lower than the rate at stepwise mode 60/50ºC.

Visualization of germination capacity of «Knyazhna» variety is shown on fig. 5.

In the frame of fig. 4 we demonstrate changes in soybean germination influenced by heating medium temperature with the initial moisture of 22% and heating medium movement rate of 1.5 m/s. Visual estimation of germination gives higher rate than the initial one, meaning that heat processing under the stepwise mode of 60/50ºC improves seed capacity of the material.

We have also analyzed changes in seed material with heating medium temperature of 50ºC from the change in the initial moisture and heating medium movement rate.

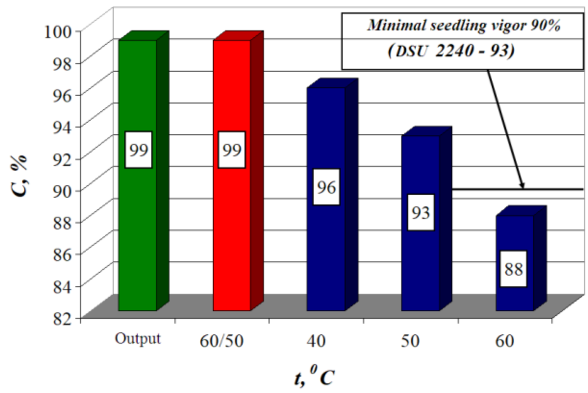

Fig. 4. Influence of heating medium temperature on the 7th day of soybeans germination: Wn = 22%, V = 1.5 m/s, d = 10 g/kg d.a.

10ºC increase in heating medium temperature within the temperature range of 40 - 60ºC reduces soybean germination by 3%. Initial moisture increase from 16 to 22% at the 50ºC heating medium temperature reduces germination by 2%, while movement rate change from 1.5 to 1.0 m/s does so by 1%. We used V.V. Krasnikov [9] method to calculate moisture exchange kinetics for drying soybean seeds.

Drying curves and drying speed curves of capillary-porous bodies, irrespectively of the variety of drying modes and differences in moisture and heat transference mechanisms within the wide range of heating medium temperatures, are basically the same.

The curves contain two periods, the second period being divided into two or three parts, critical points W_{K1}, W_{K2} and W_{K3} are identified. The difference is in quantities. Similar analogy is also identified in comparison of drying curves and drying speed curves of the material with different drying methods, i.e. the differences in drying modes and methods don't result in changes of drying curves and drying speed curves for this material.

In view of the above, the empirical coefficient values, that arise from the material properties, should be taken into account at mathematical description of the moisture exchange dynamics during the second phase of drying. Normally, those coefficients are defined directly during the experimental drying of the material.

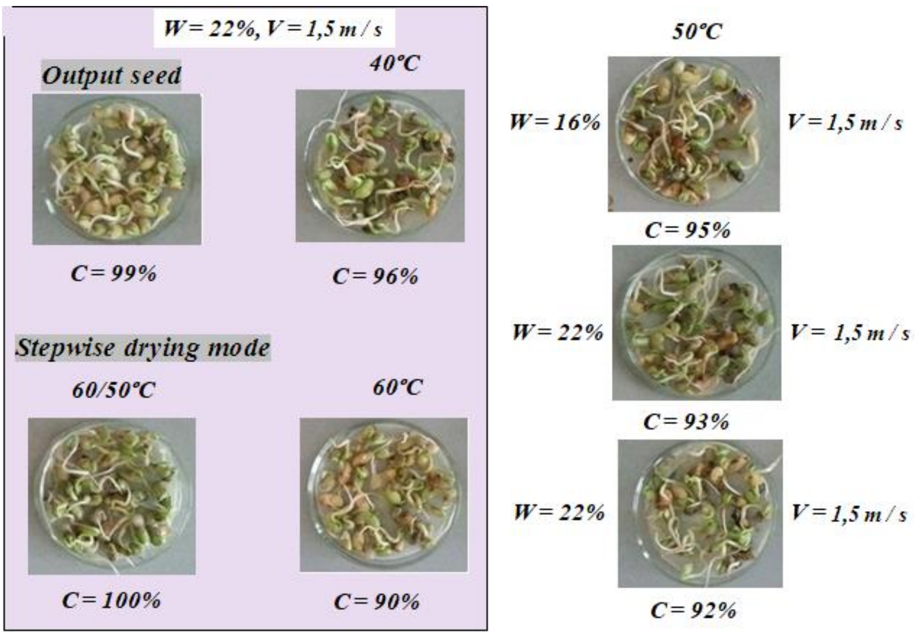

Fig. 5. The pictures of germination rates of soybean seeds, «Knyazhna» variety, on the 7th day of germination under various drying modes

Drying curve equation for the first phase is written as:

$$W = Wn - N\tau \qquad (1)$$

The second drying phase starts at all $W\kappa_1$ modes and time τ, equal to the duration of the first drying phase.

The equation for the first part of the second phase is written as:

$$\lg(W - Wp) = \lg(W\kappa_1 - Wp) - K_1\tau_1 \qquad (2)$$

$$W\kappa_1 \geq W \geq W\kappa_2,$$

where K_1 – is drying coefficient of the 1st part of the second phase;

τ_1 – time, starting from the beginning of the 1st part of the second phase.

The equation for the second part of the second phase is written as:

$$\lg(W - Wp) = \lg(W\kappa_2 - Wp) - K_2\tau_2 \qquad (3)$$

$$W\kappa_2 \geq W \geq W\kappa_3,$$

where K_2 – is drying coefficient of the 2nd part of the second phase;

τ_2 – time, starting from the beginning of the 2nd part of the second phase.

The equation for the third part of the second phase is written as:

$$\lg(W - Wp) = \lg(W\kappa_3 - Wp) - K_3\tau_3 \qquad (4)$$

$$W\kappa_3 \geq W \geq W\kappa,$$

where K_3 – is drying coefficient of the 3rd part of the second phase;

τ_3 – time, starting from the beginning of the 3rd part of the second phase;

Wp – represents the equilibrium moisture content of the material;

$W\kappa$ – defines final moisture content of the material dried.

Coefficients K_1, K_2 and K_3 – are the coefficients of drying, that are numerically equal to tangents of the angles of slope of the rectilinear segments to the axis τ in semilogarithmical anamorphosis. The value of these coefficients depends on the kind of wet material, its properties, drying mode and method.

The influence of the mode on the coefficients K_1, K_2 and K_3 can be expressed by N – the maximum drying rate of the material under the given mode in the first drying phase (or the maximum drying speed under the given Wn if the first phase is absent). This is possible because N is a generalized value, which reflects impact of all parameters that influence the material drying speed and applies to the second drying phase.

$$K_1 = \chi_1 \cdot N \qquad (5)$$

$$K_2 = \chi_2 \cdot N \qquad (6)$$

$$K_3 = \chi_3 \cdot N \qquad (7)$$

The values χ_1, χ_2, χ_3 – are relative drying coefficients and are different in two (three) parts of the second phase. They are defined by the form the moisture is connected to the material, its structure and drying method, but do not depend on the mode.

Relative drying coefficients are easily defined on the basis of research curve under the following formula:

$$\chi_1 = \frac{\lg(W\kappa_1 - Wp) = \lg(W\kappa_2 - Wp)}{N\max\cdot\tau_1} \tag{8}$$

$$\chi_2 = \frac{\lg(W\kappa_2 - Wp) = \lg(W\kappa_3 - Wp)}{N\max\cdot\tau_2} \tag{9}$$

$$\chi_3 = \frac{\lg(W\kappa_3 - Wp) = \lg(W\kappa_4 - Wp)}{N\max\cdot\tau_3} \tag{10}$$

Total duration of the drying process τ_T (excluding warm-up phase) consists of the drying duration in the first phase τ_1, and the second phase, which is divided into parts (τ_2, τ_3 and τ_4):

$$\tau_T = \tau_1 + \tau_2 + \tau_3 + \tau_4 \tag{11}$$

By solving equations (1) - (4) regarding τ and using the formulas (5) - (7) we come up with the formula that calculates the duration of the drying process in every part of the process.

Drying duration in the first phase is equal to:

$$\tau_1 = \frac{Wn - W\kappa_1}{N} \tag{12}$$

Drying duration in the 1st part of the second phase:

$$\tau_1 = \frac{1}{\chi_1 N}\lg\frac{W\kappa_1 - Wp}{W\kappa_2 - Wp} \tag{13}$$

Drying duration in the 2nd part of the second phase:

$$\tau_2 = \frac{1}{\chi_2 N}\lg\frac{W\kappa_2 - Wp}{W\kappa_3 - Wp} \tag{14}$$

Drying duration in the 3rd part of the second phase:

$$\tau_3 = \frac{1}{\chi_3 N}\lg\frac{W\kappa_3 - Wp}{W\kappa\ \ - Wp} \tag{15}$$

The total duration of drying grain, oil, vegetable and technical crops (excluding the first drying phase) comprises:

$$\tau_{\text{est}} = \frac{1}{N}\left(\frac{1}{\chi_1}\lg\frac{W\kappa_1 - Wp}{W\kappa_2 - Wp} + \frac{1}{\chi_2}\lg\frac{W\kappa_2 - Wp}{W\kappa_3 - Wp} + \frac{1}{\chi_3}\lg\frac{W\kappa_3 - Wp}{W\kappa_4 - Wp}\right) \tag{16}$$

To study soybean drying kinetics we built graph in the system of semi logarithmical axes lg(W-Wp) based on the timing of the experiment (fig. 6).

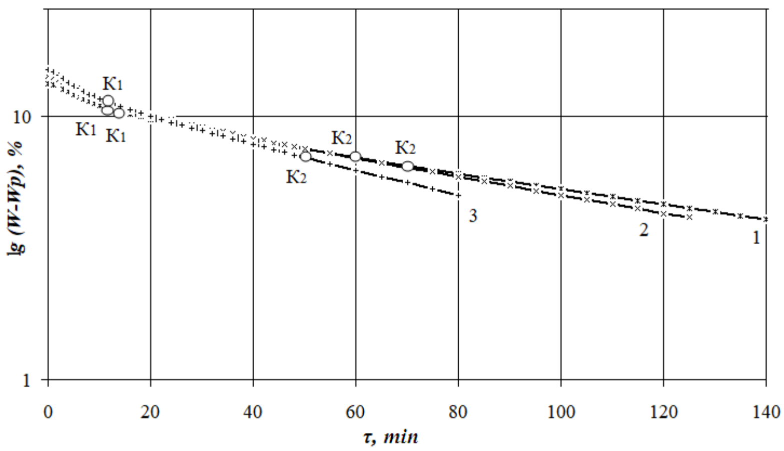

Fig. 6. Influence of the heating medium temperature on the duration of soybean seeds drying in the semi logarithmic axes of coordinates: V = 1,5 m/s, d = 10 g/kg d. a.:
1 – 40ºC; 2 –50ºC; 3 – 60ºC

The soybean drying curves in the semi logarithmic axis of coordinates (fig. 6) indicate that the second phase consists of two parts with critical points of $К_1$ and $К_2$. The lower the heating medium temperature, the later the critical points achieve their values and the slower is the process.

The analysis of the generalized drying modes curve indicates that all drying modes fall into one curve with errors not exceeding 10% (fig. 7).

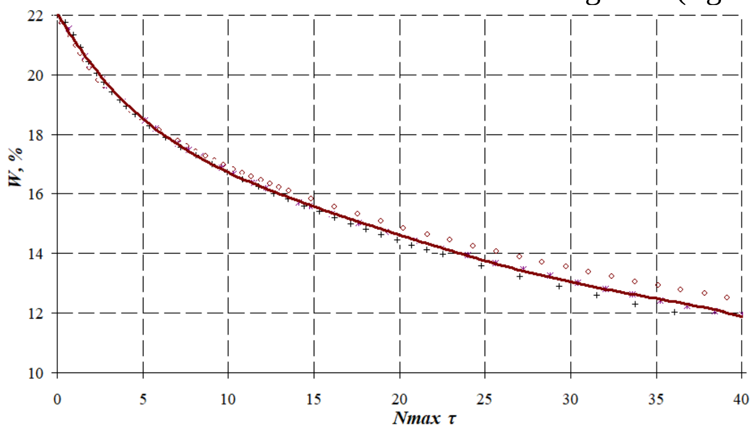

Fig. 7. Generalized soybean drying curves in the system of axis $W – N_{max}\,\tau$

We define relative and kinetic coefficients of drying on the basis of the formulas (5 - 10) and introduce them into the table 1.

Table 1

Relative and kinetic coefficients of soybean drying

Seed	Critical moisture range, %	Relative drying coefficients			Kinetic drying coefficients		
		χ_1	χ_2	χ_3	K_1	K_2	K_3
Soybean	20.94 – 17.38	0.012	-	-	0.006	-	-
	17.38 – 12.02	-	0.0052	-	-	0.0017	-

The total drying duration is calculated according to the formula (16) and aggregated into the table 2.

Table 2

Soybean drying duration

Seed	Estimated drying duration, min
Soybean	$\tau = \dfrac{39.22}{N}$

Fig. 8 shows comparison of experimental τ_{exp} and estimated τ_{est} duration of soybean seeds drying under various drying modes.

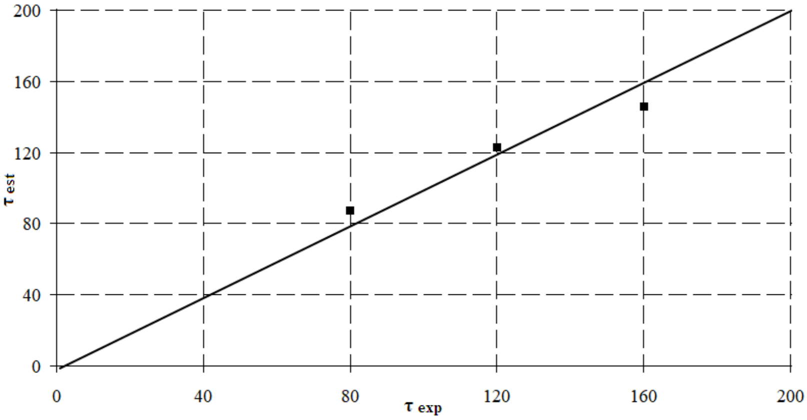

Fig. 8. Comparison of experimental and estimated duration of soybean seeds drying τ_{est}, τ_{exp}

The error between the experimental and estimated duration of drying doesn't exceed 10%.

4. Conclusions

We have done a number of research on the impact of three factors: the temperature of the heating medium, its flow velocity and initial moisture content of soybean. There is a substantial influence of heating medium temperature.

The developed drying modes allow for more effective drying of soybean seeds with higher quality of seed material. The most appropriate drying mode for soybean seeds is a two-step drying mode of 65/50ºC. It is different from 50ºC mode with its 23% increased process intensity while seedling vigor reaches 99%.

Theoretical studies allowed us to build general theoretical drying curve based on various drying modes as well as identify the overall duration of soybean seeds drying. The deviation between the researched and theoretical duration does not exceed 10%.

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