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CONFIGURATION OF THE BASIC SCHEME OF CLEANING MACHINES IN THE TECHNOLOGICAL FLOW OF SEED CONDITIONING FOR AGRICULTURAL CROPS AND MATHEMATICAL MODELING OF THE CLEANING PROCESS

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Abstract

The quality of seeds, designated as biological material for the establishment of new crop generations, is largely determined by their physical characteristics, achieved through conditioning and preservation. Proper exploitation equipment and configuration of cleaning machines in the technological seed conditioning flow include: number of cleaning machines (z), optimal feeding rate (q), combinations of sieves with different hole types (g) used in a single operation, as demonstrated in this article, can ensure the final quality of wheat seeds belonging to the biological category of the batch while also contributing to energy saving. Through utilization of well-known statistical techniques it was possible the interpretation of results, which highlighted significant differences between cleaning machines variants regarding technological flow, which affected in the final the most important parameters of seeds like purity (Ƥ) and germination (G) but also the seed technical processing efficiency (η_t*). By using the active experimental planning method (AEPM) and the orthogonal central composite design (OCCD) of the second order, a multidimensional mathematical model Ƥ = f (q, g, z), was developed to describe the efficiency of conditioning process.*

Key words: *cleaning machines*, *conditioning*, *mathematical model*.

INTRODUCTION

Mitigating the effects of climate change and developing agricultural production to ensure food security while conserving biodiversity are priority research directions in this field.

The promotion of sustainable agricultural technologies with a favourable environmental impact, protection of agricultural landscapes, introduction of high-performance varieties well adapted to ecological conditions, and the use of high cultural value seeds ensured through conditioning and preservation are the most reliable ways to increase productivity, quality, and stability in agricultural production. Seeds, as biological material for establishing new crop generations, represent the first step in improving cultivation technologies for obtain high-quality and quantitatively superior yields. The literature contains many studies where authors highlight the importance and influence of seed quality as biological material on yields obtained in most cultivated species. MacGuire (2005) states: "Seed is a crucial input for agricultural production and the most affordable external input for smallholder farmers". Biemond (2013), in his doctoral thesis, confirms: "Improving the availability of high-quality seed of well-adapted varieties is important to boost agricultural productivity, leading to higher farmers' income and improved food security". Also, Abdoulaye et al. (2009), Morris & Heisey (2003) and Evenson & Gollin (2003) confirm this. After harvesting, the final product obtained is a mixture composed of grains of the main crop, weed seeds, and various mineral or organic impurities (dust, straw, chaff). Additionally, the main crop's seeds are heterogeneous and contain small, medium, and large grains, immature seeds, unfilled/semi-filled grains, large pinched seeds-residues, damaged grains, and components with low germination potential. The seeds used as biological material for sowing, besides maintaining their biological value unaltered, must have high cultural value and this can be obtained by removing all unwanted components, performing legal quality standards. The quality of seed conditioning process is very important in every agricultural crop, ensuring genetic quality of varieties adapted in cultivated areas and also high cultural value. Khishigjargal (2022) said: "One of the most important factors in maximizing crop yields is planting high-quality seed". Physical purity, which characterizes the final quality of seed batches before sowing/storage, is achieved through a series of operations: pre-cleaning, basic cleaning, dimensional sorting, and gravity sorting. Conditioning is the process of bringing the harvested product to a specific state of moisture, temperature, purity, etc., ensuring long-term preservation of its initial properties while meeting agrotechnical requirements (Barbos & Moldovan, 2014). Boyd (1983) defines this process as: "These various operations/processes are termed seed conditioning". The conditioning process involve well-defined quantitative and qualitative modifications that can be measured, evaluated, and managed, all contributing to the improvement of seed quality and uniformity (Frecăuțeanu, 2009). Pre-cleaning is the first operation in preparing seeds for conditioning or storage, being crucial in preventing negative consequences by eliminating impurities such as weed seeds, organic residues (straw, chaff, dust, stems), and even small and broken seeds of the main crop. Basic cleaning is the main seed processing operation, performed by using cleaning machines equipped with sieves and air aspiration, continuing the selection process by removing small seeds, unfilled/semi-filled grains, deteriorated grains, dust, and materials larger than the main crop's seed.

Basic cleaning brings seeds to an acceptable quality level for commercial use as biological material for sowing, but to achieve the highest possible physical purity standard, further fine cleaning operations is necessary. Fine cleaning is usually required when processing seeds from higher categories (base, pre-base), and seed laws impose superior quality standards, or when hard to separate impurities remain. Commonly used machines for this purpose include sorting machines with combined action (calibrated sieves and air aspiration) and gravity separators (Barbos & Moldovan, 2014). The agricultural quality of seeds is determined by their genetic and cultural value, and health status.

MATERIALS AND METHODS

The seed processing, an essential component of cultivation technology is complex, involving various operations: pre-cleaning, basic cleaning, dimensional and gravity sorting, treatment, and packaging, with well-established sequences. Seeds follow safe processing routes to avoid physical contamination. Physical purity, an attribute of cultural value, is ensured through conditioning, aiming to achieve a final physical purity of seed batches at a high standard and uniform dimensionality. In agriculture, physical purity analysis determines seed lot sowing value, and its results are directly used to calculate sowing rates. According to the International Seed Testing Association (ISTA) and Romanian standard SR7713/1999, purity analysis is determined in the laboratory and contains a mixture of different components: pure seeds, seeds of other crops, weed seeds, and inert matter. Pure seed belong to main crop and include securely grains identified belonging to analysed species which can be different as size: small, medium, and large grains, immature seeds, unfilled/semi-filled grains, damaged grains, and broken seeds with the size only 1/2 of the original size. The importance of physical purity is also emphasized by McGuire (2005), which said: "High physical quality of seed is essential to establish a sufficient plant stand, directly affecting the yield". Compared to small seeds, medium and large seeds have a better developed embryo that leading to increased seedling growth rate and faster vegetative development (Bucurescu et al., 1992). Mishra, (2020) highlights the importance of the conditioning process: "The basic objective of seed processing is to achieve maximum physical purity, germination and uniformity of seed size in economical way”.

While many researchers have focused on improving individual construction and functional characteristics of cleaning machines (Bazaluk et al., 2022), it was observed an insufficient research on their configuration in a combined system within the technological processing flow, customized according to species and their physical-mechanical characteristics.

The conditioning technology flow can be simple or more complex depending on various factors: seed destination, requirements, the range of machines available, but it cannot be conceived without a minimum set of equipment ensuring cleaning and sorting based on their aerodynamic properties, dimensional principles, and differences in shape and specific weight. In this context, deepening experimental research on selection process of seeds becomes necessary and opportune.

The experimental research was conducted at the Specialized Seed Processing Center of Agricultural Research and Development Station Turda (ARDS Turda), where exist technical equipment, which allowed the development of various combined machine systems for seed conditioning.

Figure 1 presents the basic configuration of machines from conditioning flow.

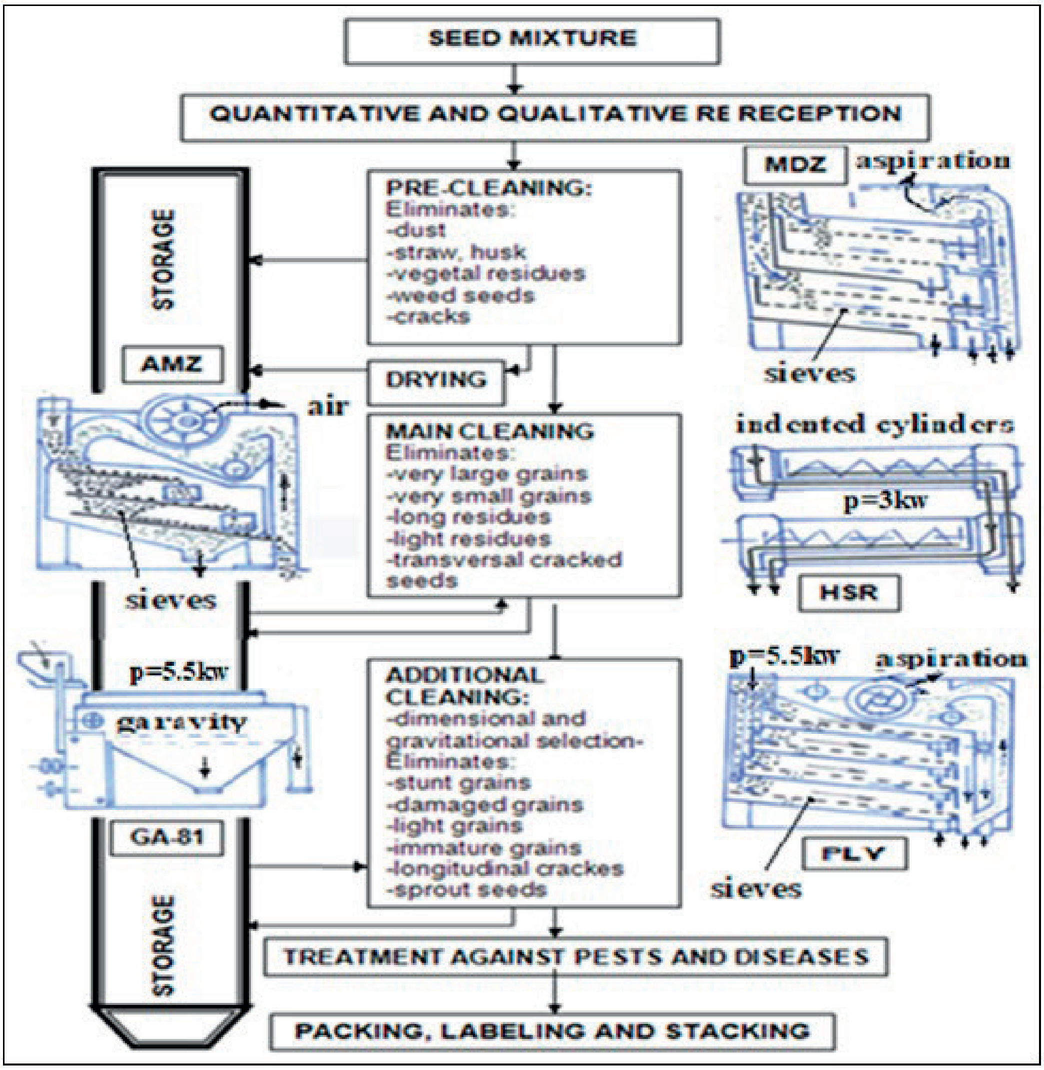

Figure 1. Conditioning technology for crop seeds (ARDS Turda)

In the first phase of the study, research was conducted on the influence of different conditioning technology flow configurations using standard-equipped cleaning machines, operating at nominal feeding rates, on physical purity (P), germination (G) and technical processing efficiency (η_t), in the case of a batch of wheat. In the pre-cleaning process, the MDZ machine (Figure 1), operating through the combined action of sieve movement and air suction, was equipped like: the upper sieve with round holes, diameter = 10 mm, the lower sieve with slotted holes, width = 1.6 mm.

The AMZ and PLV machines, which are part of the basic cleaning phase and operate through the combined action of sieve movement and air suction, were equipped with: the upper sieve with round holes, diameter = 5.5 mm, the lower sieve with slotted holes, width = 2.1 mm.

The indent cylinder separator (HSR), used for separating unwanted long or short impurities, had the following specifications: upper cylinder, indent diameter = 5.5 mm and lower cylinder, indent diameter = 9.5 mm (Figure 2).

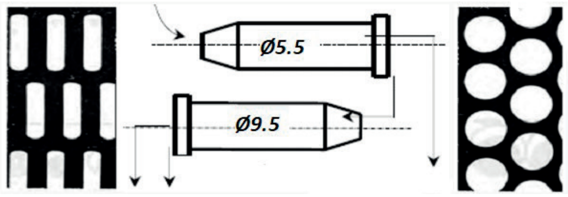

Figure 2. Basic equipment of the cleaning machines in the process flow

In practice, a complete separation of the mixture into its components does not occur. This means that in the material discharged as sieve refuse, there will be particles smaller than the sieve openings.

Additionally, in the mass of impurities removed through the combined sieve-air suction action, good seeds may be present due to their dimensions and consistency.

Assuming that the seeds of the main crop are present in quantity M_b in the material entering the equipment, the loss of good seeds, p_b (%), is calculated using the formula:

$$\mathrm{p}_b = \frac{\mathrm{m}_b}{\mathrm{M}_b}\ 100 \qquad (1)$$

m_b represent mass of good seeds founded in the output material classified as impurities.

This estimator, the loss of good seeds p_b is very difficult to quantify due to the suction action of the airflow, which can reach the floating velocity of wheat seeds, causing them to be carried along with other impurities into the cyclone separators.

To evaluate both the individual and total capacity of the machines to effectively separate seeds from unwanted materials and to establish the optimal basic machine configuration for achieving the highest selection level while maintaining low costs, a new indicator was introduced: the technical processing efficiency (η_t) of the system. This indicator is determined as the product of the partial technical efficiencies of the machines in the system:

$$\eta_t = \eta_{AMZ} \cdot \eta_{PLV} \cdot \eta_{HSR} \cdot \eta_{GA81}\ ; \qquad (2)$$

The technical processing efficiency of machine (%) is determined using the following relation:

$$\eta_t = \frac{Q_{mf}}{Q_{mi}}\ 100\ ; \qquad (3)$$

where:

Q_{mf} - mass of the material after passing through the cleaning machine;

Q_{mi} - mass of the material before passing through the cleaning machine.

The technical processing efficiency depends on the weight and quality of the raw seeds processed at the Conditioning Station.

During the conditioning process, quantitative and qualitative changes occur, which can be measured. We can calculate the components of the conditioning process, using the follow relation:

$$Q_{mi} = m_v + m_f + m_n + p_t\ \ [kg] \qquad (4)$$

The components are expressed as percent (%) of initial mass:

m_v - valuable final product;

m_f - by-products (generally fodder);

m_n - unusable products;

p_t - standardized technical losses.

To determine physical purity (P_i) of the final product, is calculated the percentage content of each category: pure seed (x_1), impurities (x_2), weed seeds (x_3), inert materials (x_4) using the formula:

$$x_i = \frac{\mathrm{m_i} \cdot 100}{\Sigma\,\mathrm{m_i}}\,\mathrm{k}\ [\%] \qquad (5)$$

where:

m_i - mass of impurity category "i", in grams;

$\sum m_i$- total mass of all components in the analyzed sample in grams;

k - correction coefficient (if applicable).

The percentages of all fractions are summed and must total 100%. If this sum does not equal 100%, then a maximum adjustment of ± 0.1% is applied to the highest fraction value (SR 7713/1999).

The separation index represents the percentage of impurities and foreign bodies removed from the seed mass during a single pass through the cleaning machine. It is determined using the formula:

$$\grave{\imath}_t = \frac{[(q_{ii} - \ q_{if})]\cdot 100}{q_{ii}} \ \lfloor\%\rfloor \qquad (6)$$

where:

q_{ii} - total impurity content at machine input (%).

q_{if} - residual impurity content at machine output (%)

The working capacity (C) was determined using the formula:

$$C = \frac{Q_{mi}}{t} \ [\text{to/h}] \qquad (7)$$

where:

Q_{mi} - weight mass of product in a period of time required [to];

t - time of product [h].

The factors involved in the conditioning process can be grouped into two main categories:

(I) physiological and physical-mechanical characteristics of seeds and impurities;

(II) constructive and functional characteristics of the cleaning machines.

Most mathematical models proposed in scientific literature to describe the separation process are based on simplifying of assumptions for reduce the number of influencing factors to a manageable level, thereby decreasing complexity (Simonyan, 2006).

An a priori analysis was conducted to identify the most influential factors for developing a mathematical model describing the efficiency of the cleaning process.

The following key factors were selected: feed rate, type of sieve and indented cylinder separator configuration; number of cleaning machines included in the conditioning process flow.

For quantitatively evaluate the influence of these factors on the conditioning process and reduce the number of experiments in this multifactorial study, the active experimental planning method (AEPM) was used.

The orthogonal central composite design (OCCD) of the second order was applied to describe the processing efficiency of the combined system, as shown in Table 1.

The experimental matrix presents, in coded form, the conditions for each planned experiments.

Since the covariance matrix for second-order designs is diagonal, an appropriate choice of the axial point "α" and a special transformation of the quadratic effects, orthogonality is preserved (Voznesensky, 1981):

$$x_i^* = x_i^2 - \frac{\sum x_{ij}^2}{N} = x_i^2 - \bar{x}_i^{\,2};$$

$$Y = b_0 + \sum_{i=1}^{n} b_i .\, x_i + \sum_{i<j}^{n} b_{ij} .\, x_i x_j$$
$$+ \sum_{i=1}^{n} b_{ii} .\, (x_i^2 - \bar{x}_i^{\,2}) \qquad (8)$$

where:

y - goal function;

b_0, b_i, b_{ij}, b_{ii}- coefficients of the regression equation;

$$b_0^*, b_i, b_{ij} = \frac{1}{\sum x_{ij}^2} \sum x_{ij} \ \bar{y}_i \ ; \quad b_{ii} = \frac{1}{\sum x_i^{*2}} \sum x_i^* \ \bar{y}_i$$

$$b_0 = b_0^* - b_{11} \bar{x}_1^2 - b_{22} \bar{x}_2^2 - b_{33} \bar{x}_3^2 \ ; \qquad (9)$$

Table 1. The orthogonal central compositional design

No Exp.	*Independent factors*				$x_1^2 - 0.73$	$x_2^2 - 0.73$	$x_3^2 - 0.73$	x_1x_2	x_1x_3	x_2x_3	y_{i1}	y_{i2}	y_{i3}	$\bar{y}_i$
	x_0	x_1	x_2	x_3										
1	+1	+1	+1	+1	0.27	0.27	0.27	+1	+1	+1	y_{11}	y_{12}	y_{13}	$\bar{y}_1$
2	+1	+1	+1	-1	0.27	0.27	0.27	+1	-1	-1	y_{21}	y_{22}	y_{23}	$\bar{y}_2$
3	+1	+1	-1	+1	0.27	0.27	0.27	-1	+1	-1	y_{31}	y_{32}	y_{33}	$\bar{y}_3$
4	+1	+1	-1	-1	0.27	0.27	0.27	-1	-1	+1	y_{41}	y_{42}	y_{43}	$\bar{y}_4$
5	+1	-1	+1	+1	0.27	0.27	0.27	-1	-1	+1	y_{51}	y_{52}	y_{53}	$\bar{y}_5$
6	+1	-1	+1	-1	0.27	0.27	0.27	-1	+1	-1	y_{61}	y_{62}	y_{63}	$\bar{y}_6$
7	+1	-1	-1	+1	0.27	0.27	0.27	+1	-1	-1	y_{71}	y_{72}	y_{73}	$\bar{y}_7$
8	+1	-1	-1	-1	0.27	0.27	0.27	+1	+1	+1	y_{81}	y_{82}	y_{83}	$\bar{y}_8$
9	+1	-1.215	0	0	0.745	-0.73	-0.73	0	0	0	y_{91}	y_{92}	y_{93}	$\bar{y}_9$
10	+1	+1.215	0	0	0.745	-0.73	-0.73	0	0	0	y_{101}	y_{102}	y_{103}	$\bar{y}_{10}$
11	+1	0	-1.215	0	-0.73	0.745	-0.73	0	0	0	y_{111}	y_{112}	y_{113}	$\bar{y}_{11}$
12	+1	0	+1.215	0	-0.73	0.745	-0.73	0	0	0	y_{121}	y_{122}	y_{123}	$\bar{y}_{12}$
13	+1	0	0	-1.215	-0.73	-0.73	0.745	0	0	0	y_{131}	y_{132}	y_{133}	$\bar{y}_{13}$
14	+1	0	0	+1.215	-0.73	-0.73	0.745	0	0	0	y_{141}	y_{142}	y_{143}	$\bar{y}_{14}$
15	+1	0	0	0	-0.73	-0.73	-0.73	0	0	0	y_{151}	y_{152}	y_{153}	$\bar{y}_{15}$

RESULTS AND DISCUSSIONS

The experimental research was conducted at the Specialized Seed Processing Center of the Agricultural Research and Development Station Turda (ARDS Turda). Previous research performed by Moldovan et al. (2015), in a monofactorial experiment with seven combinations of cleaning machines, highlighted the strong effect of the double indented cylinder separator and the gravity separator in the conditioning process. Based on these results, the current study focused on three different configurations of cleaning machines, with all configurations including the double indented cylinder separator (HSR). The condition of wheat batch after pre-cleaning, which was used in this study, is presented in Table 2.

Table 2. Analysis sheet of the crop

Sample no.	Humidity [%]	Test weight [kg/hl]	Classification of components				
			-small cracks of the main crops. -scraps minerals [%]	large scraps -pinched [%]	shriveled grains [%]	small grains [%]	medium and large grains [%]
Mean	13.4	80.5	2.50	0.88	2.40	6.3	87.92

The wheat crop was affected by drought, which coincided with the grain filling and ripening stages, leading to an increased presence of shriveled grains in the harvested material. Additionally, the presence of shriveled grains and high breakage was recorded as components that are still considered part of pure seed according to SR 7713/1999. To select the configuration that ensures the best seed quality while minimizing energy consumption, laboratory samples were collected at both input and output of each cleaning machine.

The technological effect of each machine was quantified, as well as the cumulative effect of the entire conditioning system. The results regarding the influence of different conditioning systems on germination and purity are presented in Table 3.

Table 3. Results concerning the influence of conditioning systems on germination and purity

Variant	Conditioning variants	Mean of Germination [%]	Significance	Mean of physical purity [%]	Significance	Small grains [%]
1	AMZ+HSR	89.60	Control	98.80	Control	1.05
2	AMZ +HSR+PLV	93.00	*	99.34	**	0.35
3	AMZ+PLV+HSR+GA-81	95.00	**	99.82	**	0.40
		LSD 5% LSD 1%	2.56 3.48	LSD 5% LSD 1%	0.25 0.42	

The differences in germination values across the conditioning variants (over 5%) and the significant differences in purity clearly highlight the substantial influence of different machine configurations in the conditioning process on the final purity of the seed (Table 3). The analysis of processing variants reveals the high efficiency of the double indented cylinder separator in removing small seeds and transverse seed breakages, relative to their initial proportion. Analyzing the results, it is evident that all variants ensure the appropriate final seed quality, meeting the standards for certified biological categories. Variant V_1 which utilizes a reduced number of machines, also contributes to energy savings.

With the introduction of GA-81 gravity separator, which operates based on specific weight separation, there is a considerable improvement in all quality indices, though its effect on small and healthy seeds is less pronounced. The low germination potential (G) of broken grains (49%), small grains (86%), and large breakages (7%), present in varying proportions in the final product due to the applied conditioning system, considered as seeds pure, negatively impacts the quality of the seed, and was emphasized before by

Moldovan et al. (2015). Broken and shriveled grains have low resistance to diseases and pests, particularly toxigenic fungi, and their presence in the final seed reduces quality, increases seeding rates (germinating seeds per m²), and ultimately contributes to the spread of diseases when mixed with healthy seeds intended for planting. Haque (2007) similarly states, "High-quality seed should be free from diseases to avoid seedling mortality or introduction of diseases". Small seeds produce weak plants, many of which do not survive, and those that survive have low production potential (Bucurescu et al., 1992; Rukavina, 2002; Khishigjargal, 2022). To continue the study for modeling the processing procedure, all three working variants were retained based on their performance. Different seed batches, even of the same variety, may exhibit major differences in the initial mixture composition. In further study for the development of a mathematical model of the processing procedure, the most influential factors were selected: x_1 - average feeding rate (t/h), x_2 - the size of the slotted (oblong) holes of the sieves (mm), x_3 - the number of cleaning machines included in the conditioning process flow. For active experimental planning (AEPM) using the orthogonal central composite design (OCCD), the range of variation for the natural factors and their coding were selected (Table 4).

Table 4. Factors, natural values and coding levels

Factors	U.M.	Fact. code	Natural values					Coding levels		
			−α	Lower	Center	Upper	+α	Lower	Center	Upper
Average feeding rate	kg/s	x1	1.6	2	4	6	6.4	−1	0	+1
Slotted holes	mm	x2	1.7	1.8	2.1	2.3	2.4	−1	0	+1
Number of machines		x3	2 (1.78)	2	3	4	4(4.2)	−1	0	+1
Star (axial) point	OCCD	α						−1.215	−	−1.215

Quantitative analysis and modeling of the processing procedure require adopting an appropriate model, described by equation (8). Dependent variable in the model described by equation (8), $Y = f(x_1, x_2, x_3)$, represents the objective function, specifically the physical purity of the final product. Purity, analyzed in the Seed Testing Laboratory, refers to determination of different components: pure seeds, seeds of other crops, weed seeds, and inert matter. The primary objective of seed testing laboratories is to provide real information about seed lot quality to producers, consumers, and the seed industry, enabling informed decisions regarding the timing, location, and method of seed utilization. Each row in the experimental matrix (Table 1) represents an experimental variant for which the response to y_i, is measured, which may differ from the true response due to experimental error, $Э_i$. The last column of the matrix records the mean value of three repetitions. Developing the second-order model (8) for this multifactorial experiment, the mathematical model of the processing procedure in its coded form is:

$$Y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 \quad (10)$$

The coefficients: b_0, b_1, b_2, b_3, b_{11}, b_{22}, b_{33}, b_{12}, b_{23}, b_{33} are determined independently using the methodology known in the orthogonal central composite design (relation 9).

By substituting the calculated coefficients into the mathematical model (10), the final second-order regression equation, considering factor interactions, is obtained:

$$Y = 98.97 - 0.6x_1 + 0.27x_2 + 0.56x_3 - 0.15x_1^2 - 0.11x_3^2 + 0.03x_1x_2 + 0.23x_1x_3 - 0.02x_2x_3 \quad (11)$$

The experimental matrix does not contain repeated trials at the experiment center thus, the direct calculation method is used to assess model adaptability, considering:

$$SP_{rez} = SP_{на},$$

where SP_{rez} represent residual variance (sum of squares of theoretical values, $\hat{y}_i$ relative to empirical values y_i) and $SP_{на}$ - sum of squares characterizing model mismatch.

$SP_{rez} = \sum(\hat{y}_1 - \bar{y}_1)^2 = 0.135$, with $f_{\text{Н}\,a} =$ N - λ =15 – 9 = 6

– degrees of freedom (N - total number of variants, λ - number of significant regression coefficients) .

Applying Fisher's criterion, model mismatch is determined as follows:

$$F_c = \frac{SP_{rez}/f_{\text{Н}\,a}}{SP_{\text{Э}}/f_{\text{Э}}} = 2.12 < F_t = 2.42 \ (f_1 = 6 \,;\, f_2 = 30\,)$$

where: $SP_{\text{Э}}$ represent the sum of squares characterizing experimental error, with degrees of freedom $f_{\text{Э}}$ = N (k-1)=15 (3-1) = 30; k-number of repetitions.

The result of the inequality: $F_c < F_t$ imposes the rejection of hypothesis H_0, more precisely the hypothesis of mismatch (non-adaptability). Thus, the model must be accepted as *adequate*. Geometrically, in space, regression represents a hypersurface. Sometimes, it is technically, economically or technologically interesting to know the shape of this surface around extra points, which can be achieved through a canonical transformation of the model. In this study, the variation interval of the factors is narrow, which may result in the center of the surface being located outside the experimental zone. We will calculate the gradient components of the response function that represent the partial derivatives of the function Y in relation to the studied factors: x_1, x_2, x_3, as follows:

$$\frac{\partial Y}{\partial x_1} = -0.3\,x_1 + 0.03\,x_2 + 0.23\,x_3 - 0.6$$

$$\frac{\partial Y}{\partial x_2} = 0.03\,x_1 - 0.02\,x_3 + 0.27 \qquad (12)$$

$$\frac{\partial Y}{\partial x_3} = 0.23\,x_1 - 0.02\,x_2 - 0.22\,x_3 + 0.56$$

The best combination that maximizes the function within the limits of the experimental domain is given by the solution of the system, (10) under the conditions of the restrictions: -1 < x_i < 1. The solution of the system respecting the imposed constraints is: $x_1 = -1$; $x_2 = 1$; $x_3 = 1$,, values that determine a local maximum of the function, $Y_{max} = 99.86$.

From the examination of the regression coefficients of the mathematical model, it results that within the range of values of the considered factors, the following information are obtained:

- the feeding rate (x_1) and the number of cleaning machines combined in the flow (x_3) according to the size of the regression coefficients, had a much greater influence on the final quality (purity) of the seed intended for biological material than the size of the sieve holes (x_2);
- increasing the feeding rate, (x_1) adds a decrease in quality and final purity of the seed, as indicated by its negative sign;
- although the factor the size of the slotted (oblong) holes of the sieve, x_2, has a smaller regression coefficient than factors x_1 and x_3 it is still very important. The positive sign of the regression coefficient indicates a positive effect on the final quality of the seed;
- the interactions between the studied factors are highlighted, particularly the strong effect of the double interaction, x_1x_3 (feeding rate × number of machines), assessed based on the magnitude of the regression coefficients. After decoding the factors, the real form of the mathematical model is obtained:

$$Ƥ = 96.07 - 0.468\,q + 1.08\,g + 0.924\,z - 0.0375\,q^2 - 0.11\,z^2 + 0.06\,q\,g + 0.115\,q\,z - 0.08\,g\,z \qquad (13)$$

where:

q - optimal feeding rate (t/h);

g - combinations of sieves with different hole types (mm);

z - number of cleaning machines.

To illustrate the adequacy of the generated model in predicting the obtained purity, we assign the following values to the studied factors: q = 6 to/h; g = 1.8 mm; z = 4;

Substituting these values into model (13), the predicted purity value is: *Ƥ=98.62%.* The actual purity value obtained in the experimental variant was: *Ƥ=98.70%* with a technical processing efficiency of η_t = *90.5%* and the following percentage values for the components:

$$m_f = 7.3\% \,;\ m_n = 2.2\% \,;\ p_t \cong 0$$

The final purity value of $\mathcal{P}=98.62\%$ is appropriate for processing certified category seeds, where the minimum required seed lot purity is $\mathcal{P}=98\%$. However, if the processing flow includes seeds from higher biological categories (basic, pre-basic), Law 266/2002 (updated) requires a minimum final seed purity of Ƥ=99%. In this case, another processing variant is needed. For example, if, in the previous processing variant, the cleaning machines were equipped with sieves with slotted holes of size $\neq 2.3$ *mm*, substituting this value into equation (11) results in a predicted purity of $\mathcal{P}=99.17\%$. The actual purity value obtained in this experimental variant was: $\mathcal{P}=99.25\%$ with a technical processing efficiency of, $\eta_t = 88.7\%$. In another variant, at a feeding rate of 2 to/h, processing variant is needed. The regression equation predicts a seed lot purity of Ƥ=99.86%. Final quality, specifically the purity of the seed lot, decreases as the feeding rate increases. This can be explained by the fact that the material on the sieves forms a thicker layer, reducing screening efficiency and making it more difficult for air aspiration to remove impurities. By combining sieves with different types of holes in a single operation, superior final quality can be achieved, bringing the seeds to quality indices that meet the standard requirements for the biological category of the respective lot without reducing the feeding rate for productivity reasons. The Food and Agriculture Organization of the United Nations and Africa Seeds (Rome, 2018) recommend, in the wheat seed selection process, a top screen with round holes (diameter: 4.5-6.00 mm) and a bottom screen with slotted holes (width: 2.1-2.3 mm). Several studies highlight the importance of seed size on harvested production. Khishigjargal (2022) states, "Cultivating wheat seed with size above >2.2 mm is definitely an important factor in seed production".

CONCLUSIONS

The valorisation of the results obtained from the conducted experiment, using known statistical techniques, has revealed a series of technical aspects of conditioning systems with significant influences on all quality indicators that define the cultural value of biological material intended for sowing. Seed conditioning stations are required to ensure not only the high quality of seeds characterized by purity (Ƥ) and the established technical efficiency (η_t).

Currently, discussions focus on seed dynamics, uniform field emergence, the growth speed of young plants, and the potential guarantees for achieving high quantitative and qualitative production levels, which can only be ensured through proper conditioning and seed preparation.

The technological operations associated with crop conditioning, considering initial state characteristics, the optimal configuration of the technological flow with cleaning machines, the combinations of sieves with different types of holes used in a single operation, and the selection of kinematic regimes of working elements, as demonstrated in this article, can ensure the appropriate final seed quality for different biological categories while also contributing to energy savings.

The differences in germination values between conditioning variants (over 5%) and the significant differences in final product purity clearly highlight the significant influence of different machine configurations in the conditioning flow on the final seed quality. Small, shriveled, damaged, or large broken seeds, present in varying percentages in the final product, although considered pure as part of the basic seed category, still have defects and previous research has demonstrated the poor performance of these components.

For an analytical description of the conditioning process's efficiency, a multidimensional mathematical model was developed using the active experimental planning (AEPM) method with a central composite orthogonal experimental design (OCCD). This developed model could be useful for professionals in the seed processing industry, providing a better understanding of the conditioning process and aiding decision-making regarding the configuration and equipping of combined machine systems to achieve the desired final quality.

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