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MATHEMATICAL MODELLING OF THE TECHNOLOGY OF PROCESSING THE SEED MASS OF VEGETABLES AND MELONS

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Abstract. Designing modern seed processing machines requires a study of the regularities of technological processes, dynamics and conditions of operation. To determine the control parameters and their optimum values, it is necessary to use high-precision mathematical models of technologies of processing the vegetable and melon seed mass. A method has been suggested of modelling the technology of processing the seed mass of vegetables and melons based on nonlinear canonical decomposition of a random sequence of changes in the technological process parameters. The method of modelling the technology of processing the seed mass of vegetables and melons can be used to determine the optimum values of design and operation parameters of seed separating machines. This method allows obtaining mathematical models of technological processes for an arbitrary number of input parameters used to evaluate the characteristics of seeds, the degree of nonlinearity, and the peculiarities of stochastic connections. The method consists of the following stages: collection of statistical data; calculation parameters in the mathematical model; evaluation of the values of the parameters; calculation of the input parameters. The mathematical model of the processing technology of the seed mass of vegetables and melons does not impose any restrictions on the properties of the random sequence of input and output parameters (linearity, stationarity, monotonicity, scalarity, etc.). It allows taking into account the features of seed processing and, as a result, achieving the maximum quality of separation of vegetable and melon seeds. The method has been approved on the basis of the experimental installation of a separating machine. The results of the experimental studies have confirmed the high accuracy of the suggested method. The application of the suggested models reduces the average error of determination of seed losses. Statistic data for calculating mathematical model parameters have been obtained in the course of processing melons and cucumbers on an experimental installation. The results of the experimental studies have confirmed the high accuracy of the suggested method.

Key words: vegetables and melons, seed mass, processing technology, random sequence, canonical decomposition.

Introduction. Formulation of the problem

The natural and climatic conditions of the South of Ukraine are the most suitable to grow vegetables and melons. When the seeds are separated according to known technological schemes, some of the seed mass is lost together with the technological mass consisting of the pulp of the seeds, husks, pomace, inclusions of mucilage, etc. These by-products are responsible for 20% of lost certified seeds, with certain technologies used (whereas, according to the established agrotechnical requirements, the loss should not be more than 5–6%) [1]. Minimizing the loss of seeds is only possible by creating a modern complex of machines to implement the mechanized technology of separating the seeds of vegetables and melons. This is a topical issue for the development of the seed industry of Ukraine. Designing modern seed separating machines requires a deeper study of the interaction of the working elements with the object of their action, the technological mass. It is necessary to know the laws of technological processes, dynamics, and operating conditions. To determine the complex of the control parameters and their optimum values, it is important to use high-precision mathematical models of the technologies of processing the seed mass of vegetables and melons. At the present stage, developing mathematical models of technological processes is a labourious procedure based on the theory of experiment planning [2,3]. But such models, firstly, take into account but a small number of parameters and stochastic connections, and secondly, after a minor change in the machine in order to improve it, the equation parameters need to be re-calculated. The limited possibilities of the experiment planning technology do not allow the formation of high-precision models of technological processes, and as a consequence, the application of such models in practice results in significant seed losses (5–15%) [1]. The development and design of modern engineering models requires taking into account a greater number of factors, the diversity of their combination, and the study of the impact on the operating parameters of the process equipment. Thus, the development of a general method of simulation, which takes into account the peculiarities of the technology of processing seed mass, is an urgent problem.

Analysis of recent research and publications

Of all branches of the agro-industrial complex, processing seeds of vegetables and melons is the least mechanized and does not meet the requirements of modern production. Scientists from the Mykolayiv branch of the Main Specialized Design Office for vegetable growing machines worked on developing technological lines for separation, washing, and drying of tomato seeds (LST-10) and seeds of cucumbers and melons (LSB-20). Also, the design of some machines for processing melon seeds was developed by engineers from the Kyiv Design Bureau. The designs of machines for processing and refinement of seeds of vegetables and melons MPD-1.5, INT-1.5, NSC-5M, MOS-300 are unproductive and allow large losses of seeds, and the technological process on these lines is far from perfect [4]. To develop and give reasons for the constructive and operating parameters of machines and working elements, it is necessary to study the object such as the technological mass of vegetable and melon cultures (cucumber, watermelon, melon). Acting with the working elements on the object processed pursues two purposes: changing the initial state of the seed mass, and the maximum prevention of damaging the seeds [5]. The publications by foreign authors about seed processing mostly consider the properties of the technological mass (husks, juice, and seeds) [6]. Better separation of vegetable and melon seeds is determined by the geometric and operating parameters of the working elements, as well as by the physical and technological properties of the raw material processed. But it would be more effective to develop a general method of simulating the technology of processing the seed mass of vegetables and melons.

The purpose of the research was to develop a method of mathematical modelling of the technology of processing the seed mass of vegetables and melons in order to determine the optimum structural and operating parameters of seed separating machines. The use of machines with the optimum parameters will improve the quality of separation of melon (watermelon, muskmelon) and cucumber seeds. To achieve this purpose, it was necessary to:

– substantiate the application of mathematical methods to synthesize models of the technology of processing vegetable and melon seed mass;

– develop a method of modelling the technological processes of separation of vegetable and melon seed mass, and algorithms for calculating its characteristics;

– mathematically model the technological process of vegetable and melon seed separation using an experimental separating machine.

Research materials and methods

Modelling the technological process of seed separation refers to the problems of nonlinear extrapolation of random sequences. Artificial intelligence methods used to predict random sequences have limited precision characteristics and are generally used for small volumes of static data [7-9]. The number of experiments on the separation of seed mass is virtually unlimited, so it is advisable to use deductive methods of prediction based on the maximum volume of information to form mathematical models. The most general extrapolation form to solve nonlinear extrapolation problems is the Kolmogorov-Gabor polynomial [10]. But finding the parameters of the Kolmogorov-Gabor model for a large number of known values and the degree of the nonlinear connection used is a rather complicated and time-consuming process. So, for 11 known values and degree of nonlinearity 4, it is necessary to obtain and solve 1819 equations of partial derivatives of the mean squared extrapolation error. That is why, when forming prediction algorithms to be implemented in practice, different simplifications and restrictions are used for the properties of a random sequence. For example, in [11-14], a number of suboptimal nonlinear extrapolation methods with a bounded order of stochastic connection are suggested. They are based on approximation of the a posteriori probabilities using orthogonal decomposition by Hermite polynomials or in the form of an Edgeworth series. The non-stationary Kolmogorov equation [15] (a special case of the Stratonovich differential equation for the description of Markov processes) is solved with the wear coefficient being a linear function of the state, and the diffusion coefficient being a constant. There is an exhaustive solution to the problem of optimal linear extrapolation for various classes of random sequences and different levels of information provision of the prediction problem (Kolmogorov's equation for stationary random sequences measured without errors; Kalman's method [16] for Markov noise random sequences; the Wiener–Hopf extrapolation filter [17] for stationary sequences on condition that there are measurement errors; V. Kudrytsky's optimal linear extrapolation algorithms [18] based on V. Pugachev's linear decomposition, etc.). However, the maximum prediction accuracy with the help of linear extrapolation methods can only be achieved for Gaussian random sequences [19]. The most universal as for the restrictions (linearity, Markovian character, stationary, monotonicity, scalarity, etc.) on the properties of random variables sequences is the method [20] based on nonlinear canonical decomposition. This method takes into account all features and aspects of the technology of seed mass processing, and allows achieving the maximum quality of separation of vegetable and melon seeds.

Results of the research and their discussion

The research object is the random vector $\overrightarrow{X}=\left\{X(1),...,X(k),X(k+1),...,X(J)\right\}$, in which $X(j),\ j=\overline{1,k}$ are input parameters of the model (the physical parameters of the working elements, parts, operating modes of the machine), $X(j)$, $\mathrm{j}=\overline{k+1,J}$ are output parameters (characteristics of the seeds). For this vector, the nonlinear canonical decomposition has the form [21]:

$$X(j)=M\left[X(j)\right]+\sum_{U=1}^{j-1}\sum_{\xi_1^{(1)}=1}^{N-1}U_{\xi_1^{(1)}}(u)\psi_{\xi_1^{(1)}}^{(1)}(u,j)+U_1(j)+$$
$$+\sum_{u=1}^{j-1}\sum_{l=2}^{M(u)}\sum_{p_1^{(l)}=1}^{p'^{(l)}_1}\cdots\sum_{p_{l-1}^{(l)}=p_{l-2}^{(l)}+1}^{p'^{(l)}_{l-1}}\sum_{\xi_1^{(l)}=1}^{\xi'^{(l)}_1}\cdots\sum_{\xi_l^{(l)}=1}^{\xi'^{(l)}_l}U_{p_1^{(l)}...p_{l-1;}^{(l)}\xi_1^{(l)}...\xi_l^{(l)}}(u)\psi^{(1)}_{p_1^{(l)}...p_{l-1;}^{(l)}\xi_1^{(l)}...\xi_l^{(l)}}(u,j),\ j=\overline{1,J}. \tag{1}$$

The expression to determine the variance $D_{\beta_1,...\beta_{n-1};\alpha_1,...\alpha_n}(u)$ of the random coefficients $U_{\beta_1,...\beta_{n-1};\alpha_1,...\alpha_n}(u)$ has the following form:

$$D_{\beta_1,...\beta_{n-1};\alpha_1,...\alpha_n}(u)=M\left[X^{2\alpha_n}(u-\beta_{n-1})...X^{2\alpha_1}(u)\right]-$$
$$M^2\left[X^{\alpha_n}(u-\beta_{n-1})...X^{\alpha_1}(u)\right]-\sum_{\eta=1}^{u-1}\sum_{\xi_1^{(1)}=1}^{N-1}D_{\xi_1^{(1)}}(\eta)\left\{\psi_{\xi_1^{(1)}}^{(\beta_1,...\beta_{n-1};\alpha_1,...\alpha_n)}(\eta,u)\right\}^2-$$
$$\sum_{\eta=1}^{u-1}\sum_{l=2}^{M(\eta)}\sum_{p_1^{(l)}=1}^{p'^{(l)}_1}\cdots\sum_{p_{l-1}^{(l)}=p_{l-2}^{(l)}+1}^{p'^{(l)}_{l-1}}\sum_{\xi_1^{(l)}=1}^{\xi'^{(l)}_1}\cdots\sum_{\xi_l^{(l)}=1}^{\xi'^{(l)}_l}D_{p_1^{(l)}...p_{l-1;}^{(l)}\xi_1^{(l)}...\xi_l^{(l)}}(\eta)\left\{\psi^{(\beta_1,...\beta_{n-1};\alpha_1,...\alpha_n)}_{p_1^{(l)}...p_{l-1;}^{(l)}\xi_1^{(l)}...\xi_l^{(l)}}(\eta,u)\right\}^2-$$
$$-\sum_{l=2}^{n-1}\sum_{p_1^{(l)}=1}^{p'^{(l)}_1}\cdots\sum_{p_{l-1}^{(l)}=p_{l-2}^{(l)}+1}^{p'^{(l)}_{l-1}}\sum_{\xi_1^{(l)}=1}^{\xi'^{(l)}_1}\cdots\sum_{\xi_l^{(l)}=1}^{\xi'^{(l)}_l}D_{p_1^{(l)}...p_{l-1;}^{(l)}\xi_1^{(l)}...\xi_l^{(l)}}(u)\left\{\psi^{(\beta_1,...\beta_{n-1};\alpha_1,...\alpha_n)}_{p_1^{(l)}...p_{l-1;}^{(l)}\xi_1^{(l)}...\xi_l^{(l)}}(u,u)\right\}^2-$$
$$-\sum_{p_1^{(n)}=1}^{p_1^{*(n)}}\cdots\sum_{p_{l-1}^{(n)}=p_{l-2}^{(n)}+1}^{p_{n-1}^{*(n)}}\sum_{\xi_1^{(n)}=1}^{\xi_1^{*(n)}}\cdots\sum_{\xi_n^{(n)}=1}^{\xi_n^{*(n)}}D_{p_1^{(n)}...p_{n-1;}^{(n)}\xi_1^{(n)}...\xi_n^{(n)}}(u)\left\{\psi^{(\beta_1,...\beta_{n-1};\alpha_1,...\alpha_n)}_{p_1^{(n)}...p_{n-1;}^{(n)}\xi_1^{(n)}...\xi_n^{(n)}}(u,u)\right\}^2,u=\overline{1,J}. \tag{2}$$

The coordinate functions $\psi_{\beta_1,...\beta_{n-1};\alpha_1,...\alpha_n}^{(b_1,...b_{m-1};a_1,...a_m)}(u,j)$ of the canonical decomposition (1) are determined by the relations:

$$\psi_{\beta_1,...\beta_{n-1};\alpha_1,...\alpha_n}^{(b_1,...b_{m-1};a_1,...a_m)}(u,j)=\frac{1}{D_{\beta_1,...\beta_{n-1};\alpha_1,...\alpha_n}(u)}\left\{M\left[X^{\alpha_n}(u-\beta_{n-1})...X^{\alpha_1}(u)\times X^{a_m}(j-b_{m-1})...X^{a_1}(j)\right]-\right.$$

$$-\sum_{\eta=1}^{u-1}\sum_{\xi_1^{(1)}=1}^{N-1} D_{\xi_1^{(1)}}^{(g)}(\eta)\psi_{\xi_1^{(1)}}^{(\beta_1,\ldots\beta_{n-1};\alpha_1,\ldots\alpha_n)}(\eta,u)\psi_{\xi_1^{(1)}}^{(b_1\ldots b_{m-1};a_1\ldots a_m)}(\eta,j)-$$

$$\sum_{\eta=1}^{u-1}\sum_{l=2}^{M(\eta)}\sum_{p_1^{(l)}=1}^{p'^{(l)}_1}\cdots\sum_{p_{l-1}^{(l)}=p_{l-2}^{(l)}+1}^{p'^{(l)}_{l-1}}\sum_{\xi_1^{(l)}=1}^{\xi'^{(l)}_1}\cdots\sum_{\xi_l^{(l)}=1}^{\xi'^{(l)}_l} D_{p_1^{(l)}\ldots p_{l-1;}^{(l)}\xi_1^{(l)}\ldots\xi_l^{(l)}}(\eta)\times$$

$$\times\psi_{p_1^{(l)}\ldots p_{l-1;}^{(l)}\xi_1^{(l)}\ldots\xi_l^{(l)}}^{(\beta_1,\ldots\beta_{n-1};\alpha_1,\ldots\alpha_n)}(\eta,u)\psi_{p_1^{(l)}\ldots p_{l-1;}^{(l)}\xi_1^{(l)}\ldots\xi_l^{(l)}}^{(b_1,\ldots b_{m-1};a_1,\ldots a_m)}(\eta,j)-\sum_{l=2}^{n-1}\sum_{p_1^{(l)}=1}^{p'^{(l)}_1}\cdots\sum_{p_{l-1}^{(l)}=p_{l-2}^{(l)}+1}^{p'^{(l)}_{l-1}}\sum_{\xi_1^{(l)}=1}^{\xi'^{(l)}_1}\cdots\sum_{\xi_l^{(l)}=1}^{\xi'^{(l)}_l} D_{p_1^{(l)}\ldots p_{l-1;}^{(l)}\xi_1^{(l)}\ldots\xi_l^{(l)}}(u)\times$$

$$\times\psi_{p_1^{(l)}\ldots p_{l-1;}^{(l)}\xi_1^{(l)}\ldots\xi_l^{(l)}}^{(\beta_1,\ldots\beta_{n-1};\alpha_1,\ldots\alpha_n)}(u,u)\psi_{p_1^{(l)}\ldots p_{l-1;}^{(l)}\xi_1^{(l)}\ldots\xi_l^{(l)}}^{(b_1,\ldots b_{m-1};a_1,\ldots a_m)}(u,j)-\sum_{p_1^{(n)}=1}^{p_1^{*(n)}}\cdots\sum_{p_{l-1}^{(n)}=p_{l-2}^{(n)}+1}^{p_{n-1}^{*(n)}}\sum_{\xi_1^{(n)}=1}^{\xi_1^{*(n)}}\cdots\sum_{\xi_n^{(n)}=1}^{\xi_n^{*(n)}} D_{p_1^{(n)}\ldots p_{n-1;}^{(n)}\xi_1^{(n)}\ldots\xi_n^{(n)}}(u)\times$$

$$\times\psi_{p_1^{(n)}\ldots p_{n-1;}^{(n)}\xi_1^{(n)}\ldots\xi_n^{(n)}}^{(\beta_1,\ldots\beta_{n-1};\alpha_1,\ldots\alpha_n)}(u,u)\psi_{p_1^{(n)}\ldots p_{n-1;}^{(n)}\xi_1^{(n)}\ldots\xi_n^{(n)}}^{(b_1,\ldots b_{m-1};a_1,\ldots a_m)}(u,j)\Big\},\ u=\overline{1,J}. \quad (3)$$

In (3), the parameters $p_1^{*(n)},\ldots,p_{n-1}^{*(n)};\ \xi_1^{*(n)},\ldots,\xi_n^{*(n)}$ are calculated using the following expressions:

$$p_\mu^{*(n)}=\begin{cases} p''_\mu,\ \text{if}\ (\mu=1)\vee\left(p_{\mu-1}^{(n)}=p''_{\mu-1},\ \mu=\overline{2,n}\right);\\ u-n+\mu,\quad \text{if}\ \ p_{\mu-1}^{(n)}\neq p''_{\mu-1},\ \mu=\overline{2,n}.\end{cases}$$

$$\xi_j^{*(n)}=\begin{cases} \xi''_j,\ \text{if}\ (j=1)\vee\left(\xi_{j-1}^{(n)}=\xi''_{j-1},\ \mathrm{j}=\overline{2,n}\right);\\ N-1-n+j-\sum\limits_{j=1}^{j-1}\xi_j^{(n)},\ \text{if}\ \xi_{j-1}^{(n)}\neq\xi''_{j=1},\ \mathrm{j}=\overline{2,n}.\end{cases}$$

The values $p''_\mu,\ \mu=\overline{1,n-1};\ \xi''j,\ \mathrm{j}=\overline{1,n},$ are the indices of the random coefficient $U_{p''_1\ldots p''_{n-1};\xi''_1\ldots\xi''_n}(u)$ that precedes $U_{\beta_1\ldots\beta_{n-1};\alpha_1\ldots\alpha_n}(u)$ in the canonical expansion (1) for the section u and n of the indices α_j:

$$1.\ p''_\mu=\beta_\mu,\ \mu=\overline{1,n-1};\ \xi''_j=\alpha_j,\ j=\overline{1,k-1};\ \xi''_k=\alpha_k-1;\xi''_g=$$
$$N-1-n+g-\sum_{m=1}^{g-1}\xi''_m,\ g=\overline{k+1,n};$$
$$if\ \ \alpha_k>1,\alpha_g=1,g=\overline{k+1,n};\xi''_g=$$
$$N-1-n+g-\sum_{m=1}^{g-1}\xi''_m,\ g=\overline{k+1,n};\ \alpha_k>1,\alpha_g=1,g=\overline{k+1,n};$$

$$2.\ p''_\mu=\beta_\mu,\mu=\overline{1,k-1};\ p''_k=\beta_k-1;\ p''_g=u-n+g,\ g=\overline{k+1,n-1};\xi''_j=$$
$$N-1-n+j-\sum_{m=1}^{g-1}\xi''_m,\ \mathrm{j}=\overline{1,n},$$
$$if\ \ \alpha_j=1,\ \mathrm{j}=\overline{1,n};\ \beta_k>\beta_{k-1}+1;\beta_g=\beta_{g-1}+1;\mathrm{g}=\overline{k+1,n-1};$$

$$3.\ p''_\mu=0;\ \xi''_j=0;\ U_{p''_1\ldots p''_{n-1};\xi''_1\ldots\xi''_n}=0,\ if\,\beta_\mu=\mu,\ \mu=\overline{1,n-1};\ \alpha_j=1,\ j=\overline{1,n}.$$

The values $b_1 \ldots b_{m-1}; a_1 \ldots a_m$ vary in the intervals $b_\mu \in \left[b_{\mu-1}^{(m)}; b_\mu^{'(m)} \right]$ and $a_\mu \in \left[1; a_\mu^{'(m)} \right]$, $m = \overline{1-N}$. The right-hand limits of the intervals are determined by the formulae

$$b_\mu^{'(m)} = \begin{cases} 0, \ \left(\mu \neq \overline{1, m-1} \right) \vee \ (m=1); \\ j - m + \mu, \ \mu = \overline{1, m-1}, \ m > 1; \end{cases} \quad a_\mu^{'(m)} = N - 1 - m + \mu - \sum_{g=1}^{\mu-1} a_g^{(m)}, \mu = \overline{1, m}.$$

The algorithm predicting seed characteristics based on the expansion (1) has the form [22, 23]:

$$m_x^{(\beta_1 \ldots \beta_{n-1}; \alpha_1 \ldots \alpha_n, u)} \left(b_1 \ldots b_{m-1}; a_1 \ldots a_m, j \right) = \begin{cases} m_x^{(\beta^*_1 \ldots \beta^*_{n-1}; \alpha^*_1 \ldots \ldots \alpha^*_n, u)} \left(b_1 \ldots b_{m-1}; a_1 \ldots a_m, j \right) + \\ \left[x^{\alpha_n} \left(u - \beta_{n-1} \right) \ldots x^{\alpha_1} (u) - \right. \\ \left. - m_x^{(\beta^*_1 \ldots \beta^*_{n-1}; \alpha^*_1 \ldots \ldots \alpha^*_n, u)} \left(\beta_1 \ldots \beta_{n-1}; \alpha_1 \ldots \alpha_n, u \right) \right] \times \psi_{\beta_1 \ldots \beta_{n-1}; \alpha_1 \ldots \ldots \alpha_n}^{(b_1 \ldots b_{m-1}; a_1 \ldots a_m)} (u, j), \alpha^*_i \neq 0; \\ m_x^{(p_1^{'(n-1)} \ldots p_{n-2}^{'(n-1)}; \xi_1^{'(n-1)} \ldots \xi_{n-1}^{'(n-1)}, \nu)} \left(b_1 \ldots b_{m-1}; a_1 \ldots a_m, j \right) + \\ \left[x^{\alpha_n} \left(u - \beta_{n-1} \right) \ldots x^{\alpha_1} (u) - \right. \\ \left. - m_x^{(p_1^{'(n-1)} \ldots p_{n-2}^{'(n-1)}; \xi_1^{'(n-1)} \ldots \xi_{n-1}^{'(n-1)}, u)} \left(\beta_1 \ldots \beta_{n-1}; \alpha_1 \ldots \alpha_n, u \right) \right] \times \psi_{\beta_1 \ldots \beta_{n-1}; \alpha_1 \ldots \ldots \alpha_n}^{(b_1 \ldots b_{m-1}; a_1 \ldots a_m)} (u, j), \alpha^*_i = 0. \end{cases}$$

(5)

The expression $m_x^{(\beta_1 \ldots \beta_{n-1}; \alpha_1 \ldots \alpha_n, u)} \left(b_1 \ldots b_{m-1}; a_1 \ldots a_m, j \right)$ is the optimum estimate of the coordinates $X(j)$, $j = \overline{k+1, J}$ (seed characteristics) of the random vector $\vec{X}$.

The mean squared error is for k input values of $x(g)$, $g = \overline{1, k}$ and the degree of nonlinearity N will be written as:

$$E^{(k,N)}(j) = M\left[\left\{ X(j) - M\left[X(j) \right] \right\}^2 \right] - \sum_{u=1}^{k} \sum_{\xi_1^{(1)}=1}^{N-1} D_{\xi_1^{(1)}}(u) \left\{ \psi_{\xi_1^{(1)}}^{(1)}(u, j) \right\}^2 -$$

$$\sum_{u=2}^{k} \sum_{l=2}^{M(u)} \sum_{p_1^{(l)}=1}^{p_1^{'(l)}} \ldots \sum_{p_{l-1}^{(l)}=p_{l-2}^{(l)}+1}^{p_{l-1}^{'(l)}} \sum_{\xi_1^{(l)}=1}^{\xi_1^{'(l)}} \ldots \sum_{\xi_l^{(l)}=1}^{\xi_l^{'(l)}} D_{p_1^{(l)} \ldots p_{l-1;}^{(l)} \xi_1^{(l)} \ldots \xi_l^{(l)}}(u) \left\{ \psi_{p_1^{(l)} \ldots p_{l-1;}^{(l)} \xi_1^{(l)} \ldots \xi_l^{(l)}}^{(1)}(u, j) \right\}^2 j = \overline{k+1, J}. \quad (6)$$

The method consists of the following stages:

1. Collection of statistical information about the random vector $\vec{X}$ on the basis of repeated research on the experimental installation.
2. Estimation of the moment functions $M\left[X^l(u) X^p(\mu) \ldots X^s(j) \right]$ on the basis of accumulated realizations of the random vector.
3. Formation of canonical decomposition (1) using the expressions (2), (3).
4. Calculation of the parameters of the mathematical model (5).
5. Estimation of the values of the output parameters $X(j)$, $j = \overline{k+1, J}$ (seed characteristics) based on the predictive model (10).
6. Assessing the quality of the solution of the problem of predicting seeds characteristics using the expression (6).

Testing the research results. The simulation method was tested, when studying the technological process of separating the vegetable and melon seed mass, on an experimental installation. Its general scheme is presented in Fig. 1. It works in the following way. The melon and cucumber seed mass moves along the conveyor 6, then falls on the slide tray 7, from where it moves into the gap between the drum 1 and the deck plate 2. The fruit are crushed as they are squeezed into the gap that becomes narrower between the sieve plate and the drum. In this case, the undersize products (seeds, pomace, juice) are separated from the crust and pulp by passing through the openings of the sieve 2. Further, the seeds are retained on the mesh surface of the tray 8, and the juice and other jelly-like wastes flow to its bottom. The oversize products (fragments of crust and pulp) are driven off through the slide tray 3 onto the waste conveyor 4. Statistical data for calculating the parameters of mathematical models were obtained as a result of processing of 2 tons of cucumbers of the variety *Competitor* and 1.5 tons of the variety *Kolhospnytsia* on the experimental installation.

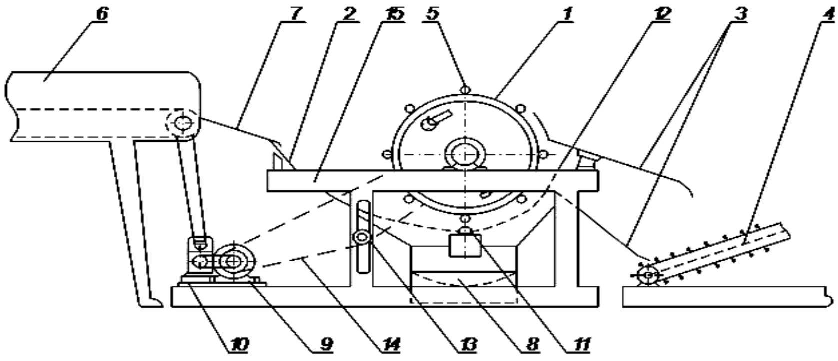

Fig. 1. General scheme of the experimental installation

1 – drum; 2 – deck plate; 3 – slide tray; 4 – waste conveyor; 5 – beaters; 6 – feed conveyor; 7 – slide tray; 8 – tray; 9 – belt transmission; 10 – gear motor; 11 – screw conveyor; 12 – deck plate extension; 13 – tension sprocket; 14 – chain drive; 15 – frame.

Among the possible parameters of the machine that effect on the purity of the seeds and on their loss, the following were selected: X (1) – the speed of the drum; X (2) – the volume of the technological mass that was fed; X (3) – the size of the gap between the beaters and the sieve; X (4) – the size of the meshes in the sieve; X (5) – the angle of span of the deck plate extension around the drum. Some parameters were rejected due to their insignificant influence on the results of the work machine (for example, the coefficient of the cross section of the sieve, the moisture content of the crushed mass, the slope angle, the material of the sieve, the size of the seeds, the number of the beaters, the diameter of the drum). The processing of the statistical experimental data with a computer program based on the algorithm (5) allowed us to obtain third-order mathematical models for the purity of the seeds X (6) and their losses X (7). In the following equations, the third order of a nonlinear stochastic connection was used [20].

For cucumbers:

– according to the seed loss criterion:

$$\begin{gathered}
X_{cucumber}(6)=5,43+0,55X(1)+0,36X(2)+0,1X(3)+0,21X(4)-1,1X(5)+0,48X(1)X(2)+0,74X(1)X(3)-\\
-0,197X(1)X(4)-0,095X(1)X(5)++0,215X(2)X(3)-0,090X(2)X(4)-1,369X(2)X(5)-\\
-0,162X(3)X(4)++0,006X(3)X(5)+0,241X(4)X(5)+0,973X^2(1)+0,957X^2(2)+0,407X^2(3)+\\
+0,423X^2(4)+2,023X^2(5)+1,111X^3(1)+0,722X^3(2)+0,200X^3(3)+0,411X^3(4)-2,056X^3(5)+\\
0,23X^2(1)X(2)+0,06X^2(1)X(3)-0,01X^2(1)X(4)+0,1X^2(1)X(5)+0,13X^2(2)X(3)-0,019X^2(2)X(4)+\\
+0,243X^2(2)X(5)-0,031X^2(3)X(4)++0,406X^2(3)X(5)+0,619X^2(3)X(5)+0,117X(1)X^2(2)+\\
0,234X(1)X^2(3)++0,390X(1)X^2(4)+0,595X(1)X^2(5)+0,451X(2)X^2(3)+0,752X(2)X^2(4)+\\
+1,148X(2)X^2(5)+0,216X(3)X^2(4)+0,329X(3)X^2(5)-0,047X(4)X^2(5)++0,482X(1)X(2)X(3)+\\
+0,1X(1)X(2)X(4)-0,32X(1)X(2)X(5)-0,2X(2)X(3)X(4)-0,4X(2)X(3)X(5)+0,9X(3)X(4)X(5);
\end{gathered}\tag{7}$$

–according to the seed purity criterion:

$$\begin{gathered}
X_{cucumber}(7)=96,620-0,783X(1)+0,150X(2)+0,267X(3)+0,094X(4)-0,444X(5)+0,067X(1)X(2)+\\
+0,137X(1)X(3)-0,011X(1)X(4)+0,247X(1)X(5)-0,146X(2)X(3)-0,300X(2)X(4)+0,125X(2)X(5)+\\
+0,007X(3)X(4)-0,032X(3)X(5)+0,092X(4)X(5)-0,336X^2(1)+0,597X^2(2)-0,119X^2(3)-0,136X^2(4)+\\
+0,314X^2(5)-1,567X^3(1)+0,300X^3(2)+0,533X^3(3)+0,189X^3(4)-0,9X^3(5)-0,04X^2(1)X(2)-\\
-0,05X^2(1)X(3)-0,01X^2(1)X(4)+0,06X^2(1)X(5)-0,11X^2(2)X(3)-0,02X^2(2)X(4)+0,12X^2(2)X(5)-\\
-0,028X^2(3)X(4)+0,201X^2(3)X(5)+0,306X^2(4)X(5)+0,138X(1)X^2(2)+0,275X(1)X^2(3)+\\
+0,458X(1)X^2(4)+0,700X(1)X^2(5)-0,087X(2)X^2(3)-0,145X(2)X^2(4)-0,221X(2)X^2(5)-\\
-0,178X(3)X^2(4)-0,271X(3)X^2(5)-0,043X(4)X^2(5)+0,183X(1)X(2)X(3)-0,064X(1)X(2)X(4)+\\
+0,014X(1)X(2)X(5)-0,494X(2)X(3)X(4)-0,022X(2)X(3)X(5)+0,133X(3)X(4)X(5);
\end{gathered}\tag{8}$$

For melons:

– according to the seed loss criterion:

$$X_{melon}(6)=4,67+0,55X(1)+0,36X(2)+0,1X(3)-0,28X(4)-1,028X(5)+0,049X(1)X(2)+2,04X(1)X(3)+$$
$$+0,195X(1)X(4)-0,487X(1)X(5)-0,96X(2)X(3)-1,39X(2)X(4)-0,065X(2)X(5)+0,273X(3)X(4)-$$
$$-0,428X(3)X(5)-0,15X(4)X(5)+1,61X^2(1)+1,59X^2(2)+1,047X^2(3)-0,4X^2(4)+2,664X^2(5)+1,1X^3(1)+$$
$$+0,7X^3(2)+0,2X^3(3)-0,56X^3(4)-2,1X^3(5)+0,1X^2(1)X(2)+0,18X^2(1)X(3)+0,2X^2(1)X(4)+ \quad (9)$$
$$+0,02X^2(1)X(5)+0,358X^2(2)X(3)+0,444X^2(2)X(4)+0,038X^2(2)X(5)+0,740X^2(3)X(4)+$$
$$+0,063X^2(3)X(5)+0,096X^2(4)X(5)+0,220X(1)X^2(2)+0,440X(1)X^2(3)+0,733X(1)X^2(4)+$$
$$+1,118X(1)X+0,223X(2)X^2(3)+0,372X(2)X^2(4)++0,567X(2)X^2(5)+0,596X(3)X^2(4)+$$
$$+0,910X(3)X^2(5)+1,129X(4)X^2(5)-0,301X(1)X(2)X(3)-0,857X(1)X(2)X(4)+$$
$$+0,546X(1)X(2)X(5)-0,974X(2)X(3)X(4)+0,390X(2)X(3)X(5)+0,099X(3)X(4)X(5);$$

– according to the seed purity criterion:

$$X_{melon}(7)=96,2-0,85X(1)+0,15X(2)+0,26X(3)+0,09X(4)-0,44X(5)+0,1X(1)X(2)+0,13X(1)X(3)+$$
$$+0,002X(1)X(4)-0,24X(1)X(5)-0,185X(2)X(3)-0,465X(2)X(4)+0,17X(2)X(5)+0,02X(3)X(4)+$$
$$-0,09X(3)X(5)+0,078X(4)X(5)-0,436X^2(1)+0,63X^2(2)-0,086X^2(3)+0,103X^2(4)+0,34X^2(5)-$$
$$-1,7X^3(1)+0,300X^3(2)+0,533X^3(3)+0,189X^3(4)-0,9X^3(5)-0,03X^2(1)X(2)-0,05X^2(1)X(3)- \quad (10)$$
$$-0,01X^2(1)X(4)+0,1X^2(1)X(5)-0,1X^2(2)X(3)-0,01X^2(2)X(4)+0,12X^2(2)X(5)-0,02X^2(3)X(4)+$$
$$+0,200X^2(3)X(5)+0,305X^2(4)X(5)+0,155X(1)X^2(2)+0,311X(1)X^2(3)+0,517X(1)X^2(4)+$$
$$+0,790X(1)X-0,065X(2)X^2(3)-0,109X(2)X^2(4)-0,166X(2)X^2(5)-0,178X(3)X^2(4)-$$
$$-0,272X(3)X^2(5)-0,025X(4)\ X^2(5)++0,157X(1)X(2)X(3)-0,174X(1)X(2)X(4)+$$
$$+0,043X(1)X(2)X(5)-0,496X(2)X(3)X(4)+0,004X(2)X(3)X(5)+0,215X(3)X(4)X(5).$$

The application of the models (8) – (10) reduces the average error of determination of seed losses by 2.9–3.7 % compared to the second order equations formed using the experiment planning technology. The gain in predicting the purity of the seeds is 2.7–3.6%. Compared with linear models, the increase in the prediction accuracy is 5.1–5.5% and 5–5.3%, respectively. For a higher accuracy of the process description, the nonlinear order of the equations (8)–(10) can be easily increased. This modification of equations is practically impossible to implement with the tools of the experiment planning technology as the latter involve a sharp increase of the number of intermediate calculations.

Conclusions

The analysis of the constructions of pressure type machines for separation of vegetable and melon seeds indicates their low efficiency. The main reason for the low quality of seed separation is the fact that there are no adequate studies of the technological process that would determine the optimum parameters of the machines. The experiment planning technology, which is used at the present stage to analyze the stochastic features of the technology of processing vegetable and melon seeds, has but limited possibilities. Models that can be synthesized on the basis of this technology have few parameters and a low order of stochastic connection (no higher than the second). To solve this problem, an analysis of existing methods of predicting random sequences was performed and the use of the method based on nonlinear canonical random decomposition of random sequence has been substantiated. The mathematical methods of canonical decompositions do not impose any restrictions (linearity, stationary, monotonicity, scalars, etc.) on a random sequence of changes in the values of the parameters of seed separation. A method of modelling the technology of processing vegetable and melon seeds has been suggested. It is based on the canonical decomposition technology. The method consists of the following stages: collection of statistical data; calculation of the parameters of the mathematical model; estimation of the values of the output parameters; calculation of the error of determining the input parameters. Processing the vegetable and melon seed mass with the use of an experimental separating machine has been mathematically modelled. The results of the experiment with the use of this machine has shown the high quality of the suggested modelling method. Unlike the experiment planning technology, the use of synthesized models of the third order increases the accuracy of determining the losses of seeds and their purity by 2.9–3.7% and 2.7–3.6%, respectively. To improve the accuracy of the process description, the nonlinear order of the equations can be increased. It should be noted that the suggested method can be used to simulate arbitrary technological processes that have stochastic properties.

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МАТЕМАТИЧНЕ МОДЕЛЮВАННЯ ТЕХНОЛОГІЧНОГО ПРОЦЕСУ ОБРОБКИ НАСІННЄВОЇ МАСИ ОВОЧЕ-БАШТАНИХ КУЛЬТУР

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Анотація. Проектування машин для обробки насіннєвої маси овоче-баштанних культур потребує дослідження закономірностей технологічних процесів, динаміки і умов функціонування. Для визначення управляючих параметрів та їхніх оптимальних значень необхідно використовувати високоточні математичні моделі технологічних процесів обробки насіннєвої маси овоче-баштаних культур. Запропоновано метод моделювання технологічного процесу переробки насіннєвої маси овочів та баштанних культур, що ґрунтується на нелінійному канонічному розкладі випадкової послідовності змін параметрів технологічного процесу. Метод математичного моделювання технологічного процесу обробки насіннєвої маси овоче-баштанних культур можна використовувати для визначення оптимальних значень конструктивних та режимних параметрів насіннєвідокремлювальних машин. Цей метод дозволяє отримати математичні моделі технологічних процесів для довільної кількості вхідних параметрів, які використовуються для оцінки характеристик насіння, порядку нелінійності та особливостей стохастичних зв'язків. Метод складається з наступних етапів: накопичення статистичних даних; параметри обчислення в математичній моделі; оцінка значення параметрів; обчислення вхідних параметрів. Математична модель технологічного процесу переробки насіннєвої маси овочів та баштан не накладає жодних обмежень на властивості випадкової послідовності вхідних та вихідних параметрів (лінійність, стаціонарність, монотонність, скалярність тощо), дозволяє взяти врахувати особливості переробки насіння і, як результат, досягти максимальної якості поділу насіння овочевих та баштанних. Метод був затверджений на основі експериментальної установки відокремлювальної машини. Результати експериментальних досліджень підтвердили високу точність запропонованого способу. Застосування запропонованих моделей зменшує середню похибку визначення втрат насіння. Статистичні данні для обчислення параметрів математичних моделей були отримані в результаті переробки на експериментальній установці таких культур як диня та огірок. Результати експериментальних досліджень підтвердили високу точність запропонованого методу.

Ключові слова: овоче-баштанні культури, насіннєва маса, технологічний процес, випадкова послідовність, канонічний розклад.

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