Development of a method for carrying out a multi-factory experiment on cleaning root crops from soil and vegetable impurities

Zinoviy Ruzhylo[1]; Volodymyr Bulgakov[1*]; Ivan Holovach[1]; Oleksandra Trokhaniak[1]; Myroslav Budzanivskyi[2]
[1]National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine
[2]Institute of Mechanics and Automation of Agricultural Production of the National Academy of Agrarian Sciences of Ukraine, Ukraine
[*]E-mail: vbulgakov@meta.ua

Abstract. *Cleaning of root and tuber crops, in particular potato tubers, from soil impurities and plant residues when they are excavated from the soil is an important and urgent problem in the agricultural industry. This article discusses a new construction of a vibrating spiral root and tuber cleaner and a new experimental setup that makes it possible to study the influence of the main structural and kinematic factors on the operation of a spiral type cleaner, as well as to substantiate its rational structural and kinematic parameters. The main constructional difference of the developed cleaner is that the technological process of cleaning root and tuber crops from soil and plant impurities is carried out by moving the heap with coils of cantilevered spiral springs rotating at a certain angular speed and forced oscillatory movements of the ends of the spiral springs themselves in the longitudinal-vertical plane. In this case, soil and plant impurities are effectively sifted not only through the separating gaps and coils of the spirals, but are also significantly destroyed due to oscillatory movements. At the same time, the root and tuber bodies are guaranteed to be transported by the spiral coils themselves towards the unloading conveyor. In the case of covering the spiral coils with a rubber coating, there is no damage to the bodies of root and tuberous crops. The article also presents the developed methodology for conducting a multifactorial experiment on cleaning root and tuber crops from soil impurities and plant residues.*

KEYWORDS: *POTATO, SOIL RESIDUES, CLEANER, EXPERIMENT, METHODOLOGY.*

1. Introduction

Cleaning root and tuber crops from soil impurities, in particular potato tubers, during harvesting is a very complex, labor-intensive and energy-consuming operation. This is primarily due to the fact that the application of excessive combing forces to the bodies of root and tuber crops will be large, which will significantly improve their quality, but will contribute to damage to their outer surfaces and will be too excessive, which is unacceptable. The technological process of cleaning root and tuber crops should be carried out under the condition that a significant mass of soil and other components of the heap (remains of tops, roots, other plant residues) are immediately separated from the root and tuber crops. This cleaning process, in particular when harvesting potatoes, takes place directly during the process of digging up the entire potato layer or immediately after it is removed from the soil and lifted. And then a significant mass of the dug up heap can get inside the root harvester along with the tubers. This problem is especially acute when digging root and tuber crops out of wet (20% moisture) soil. Therefore, many engineering developments and scientific studies have been devoted to the research and creation of highly efficient and reliable potato heap cleaners, which have been published in the following works [1-9]. At the same time, the analysis of the content of these published works shows that most of the existing constructions of potato harvesters, both domestic and foreign, which operate on different principles of operation of cleaning working bodies, are not always capable of reproducing the process with high quality indicators. That is, not all soil and climatic conditions can achieve a high degree of cleaning of the lateral surfaces of root and tuber bodies from adhering soil and guaranteed and rapid removal of free soil and plant residues from the heap. This is due to soil and plant residues sticking to the separation gaps, as the soil can be very moist and plastic during harvesting. Even under such conditions, significant damage to tubers is observed, and, accordingly, yield losses increase.

Based on the above, we have developed a new root and tuber vegetable cleaner, the construction of which provides for self-cleaning of the cleaning working bodies from adhering soil and plant residues. This is achieved by applying the vibration principles of operation of its working cleaning bodies.

This root and tuber vegetable cleaner from soil impurities and plant residues consists of five cleaning rollers, which are made in the form of cantilever spiral springs connected to the drive in rotational motion, with mutual overlap and separating gaps between the spirals. The cleaning surface formed by the spiral springs performs forced oscillatory movements with appropriate amplitudes and frequencies.

To study the cleaning of root and tuber crops from soil impurities and plant residues, we have created a laboratory experimental installation with five wavy cantilevered cleaning spirals, which allows to expand the working area of separation, improve the quality of cleaning potato tubers from soil impurities and plant residues and, as a result, increase the productivity of the potato heap separator.

Modern methods of planning multifactorial experiments were used in the laboratory experimental studies. The results obtained from the experimental measurements were further calculated using modern statistical methods on a PC.

The aim of this study is to develop a methodology for conducting a laboratory multifactorial experiment on cleaning root and tuber crops from soil and plant residues using a new construction of a spiral cleaner.

2. Results and discussions

To increase the efficiency of separation of potato heaps dug from the soil, we used a new construction of a root and tuber crop cleaner from impurities, for which we received a patent for an invention [9].

Based on experimental studies, it was found that the dominant factors affecting the operation of the cleaner were oscillations of the separators in the vertical plane; changes in the slope of the working surface of the separators, the speed of rotation of the drive and driven shafts of the separators.

In order to determine the intensity of the influence of these factors on the degree of purification of root and tuberous fruits from impurities on this cleaner, a multifactorial experiment of the BFE P^k was conducted, where P – is the number of levels of variation of the factor; k is the number of factors present in the experiment.

Fig. 1 shows a diagram and general view of the laboratory setup, which was constructed and manufactured specifically for conducting experimental studies of root and tuber crops cleaners from impurities.

The construction of the installation provides for the implementation of a number of factors that actively influence the process of separation of soil impurities and plant residues: frequency and amplitude of oscillatory movements of cleaning spirals in the longitudinal-vertical plane; change in the angle of inclination of the working surface of cleaning spirals, rotation speed of the drive shafts of cleaning spirals.

To measure and record the kinematic parameters of the developed new spiral cleaner, the following sensors are provided in the construction of the laboratory experimental setup. Sensor 29 – the angle of inclination of the cleaning working spiral surface; sensors 30 and 31 – the speed of rotation of the drive shafts of the cleaning spirals; sensor 32 – the frequency and amplitude of oscillations of the working surface formed by the cleaning spirals 10.

To obtain a regression model of the optimization parameter, which was taken in the form of the functional $Y = f(x_1;\ x_2;\ x_3)$, where Y – is the degree of purification of root and tuberous fruits from impurities: x_1; x_2; …; x_i – natural independent variable factors, we chose the appropriate conditional plan of a multifactorial experiment, the implementation of which was carried out in the following sequence.

To determine the degree of cleaning Y of root and tuber crops from impurities, the following independent variable factors were taken as independent factors: the frequency of oscillations of cleaning spirals in the longitudinal-vertical plane, which was coded by the index X_1, the angle of inclination of the working surface of the spirals α, which was coded by the index X_2, the angular velocity ω of rotation of the drive shafts of the cleaning spirals, which was coded by the index X_3.

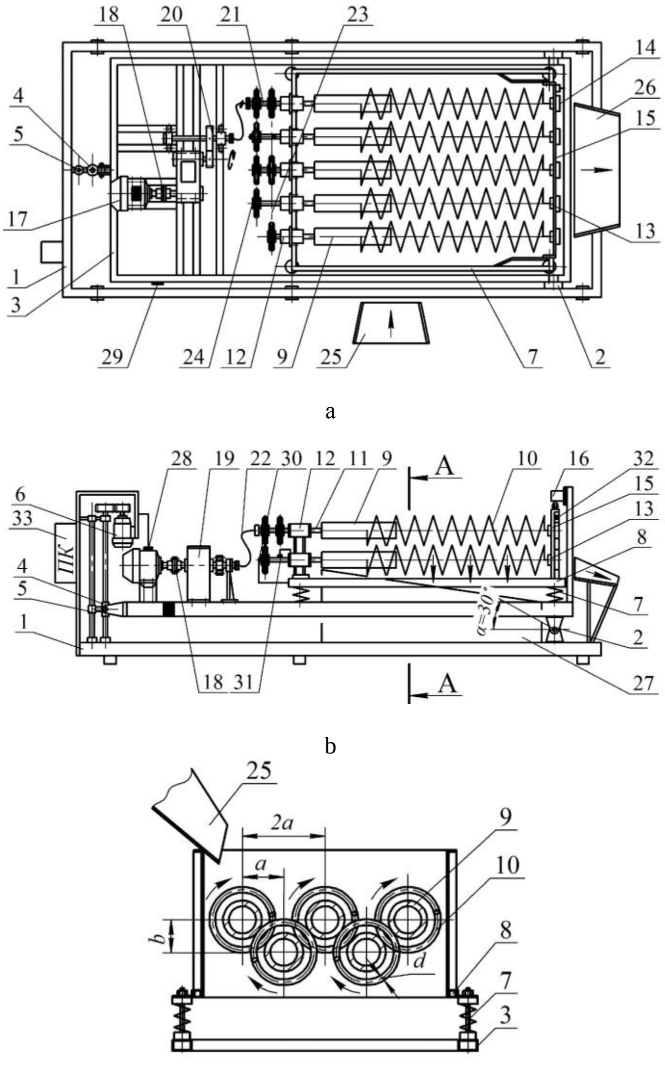

Figure 1. *Scheme of the laboratory experimental setup for the study of root and tuber crops cleaners from impurities:*
a – top view of the laboratory installation;
b – side view of the laboratory installation;
c – cross-sectional view A-A:
1 – main frame; 2 – joint; 3 – middle frame; 4 – screw pair; 5 – guide; 6 – drive; 7 – elastic supports; 8 – frame; 9 –drum; 10 – cleaning spirals; 11 – shaft; 12 – bearing housing; 13 – bracket; 14 – plain bearing; 15 – movable stand; 16 – vibrator; 17 – electric motor; 18 – coupling; 19 – variator; 20 – spur gear; 21 – drive shaft; 22 – flexible shaft; 23, 24 – chain transmission; 25 – loading tray; 26 – unloading tray; 27 – tray for collecting soil impurities; 28-32 – sensors; 33 – control panel

Fig. 1 shows the main linear and angular dimensions of the spiral root and tuber crop cleaner from impurities.

Next, a mathematical model of a multivariate experiment on cleaning root and tuberous crops from soil impurities was built.

It is well known that when coding factors, the factor space is linearly transformed – the origin is moved to the center of the experiment, and the scale along the axes is chosen in units of factor variation. To code the factors, we used the following relationship:

$$X_i = \frac{2(x_i - x_{i0})}{x_{\max} - x_{\min}}, \qquad (1)$$

where X_i – coded value of the factor (dimensionless value); x_i – value of the factor in named (natural) units; x_{i0} – is the natural value of the factor at the zero level; $x_{\max}$, $x_{\min}$ – the maximum and minimum values of the factor, respectively.

Next, it was necessary to build a plan-matrix of the multifactorial experiment. When constructing the plan-matrix of the multifactorial experiment, we introduced coded designations for the upper, lower, and zero levels of variation by each factor, which were respectively designated as (+1), (–1), (0). The results of coding the variable factors and their levels of variation are shown in Table.

Table. Results of coding factors and their levels of variation of the multivariate experiment - PFE 3^3

Factors	Designation		Levels of variation, natural/coded		
	Code.	Nat.			
Oscillation frequency of the cleaning spirals in the longitudinal-vertical plane, s^{-1}	X_1	x_1			
The angle of inclination of the working surface of the cleaning spirals α, deg	X_2	x_2			
Angular speed of rotation of the drive shafts of the cleaning spirals ω, $rad \cdot s^{-1}$	X_3	x_3			

After coding the factors, a plan-matrix of the corresponding multifactorial experiment of the PFE 3^3 type was drawn up for the total number of experiments $N = 3^3$.

n order to reliably assess the quality of the root and tuber vegetable cleaner during laboratory experimental studies, the required number of measurements of the controlled parameters (repetition of experiments) was carried out in six replications.

When implementing the compiled plan matrices, to eliminate the influence of uncontrolled and unregulated factors on the results obtained, the plan matrix was randomized by the random balance method, which was implemented randomly.

The processing of the experimental data obtained after the implementation of the planned experiments was carried out in the following order.

The response function (optimization parameter) was taken in the form of an approximating mathematical model of a full square polynomial describing the real experimental process:

$$Y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + \\ + b_{123}x_1x_2x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2, \qquad (2)$$

where Y – experimental value of the output parameter;

$b_0, b_1, b_2, b_3, b_{12}, b_{13}, b_{23}, b_{123}, b_{11}, b_{22}, b_{33}$ – regression coefficients of the corresponding values of the input factors x_i; x_1, x_2, x_3 – input coded factors.

The coefficients of the approximating polynomial, represented as a full quadratic equation, under the condition of orthogonality and symmetry, were determined by the corresponding general formulas:

– free term b_0 and coefficients b_i i-th factor:

$$b_i = \frac{\sum_{u=1}^{N} x_{iu}\bar{y}_u}{\sum_{u=1}^{N} x_{iu}^2} = \frac{\sum_{u=1}^{N} x_{iu}\bar{y}_u}{N}; \quad (3)$$

– interaction coefficients b_{ij}:

$$b_{ij} = \frac{\sum_{u=1}^{N} x_{iu}x_{ju}\bar{y}_u}{N}, \qquad b_{ij} = \frac{\sum_{u=1}^{N} x_{iu}x_{ju}x_{ku}\bar{y}_u}{N}, \quad (4)$$

where x_{iu}, x_{ju}, x_{ku} – the value of the coded variable in the corresponding column of the experiment plan;

$\bar{y}_u$ – average result of the u-th experiment;

u – serial number of the experiment;

i – number of the factor;

j, k – number of the factor, different from the *i*-th;

N – number of conducted experiments.

The reproducibility of the obtained values of the experimental array with an identical number of repetitions for each experiment was checked by the Cochrane criterion:

$$G = \frac{S_{v\max}}{\sum_{u=1}^{n} S_v}, \quad (5)$$

where G – the calculated value of the Cochrane criterion;

$S_{v\max}$ – is the numerical value of the maximum variance at the *u*-th point;

S_v – is the variance that characterizes the scattering of the results of the *u*-th experiment.

The variance of the reproducibility of the experiments was determined using the following formula:

$$S^2(Y) = \frac{\sum_{u=1}^{N}\left(Y_{ui} - \overline{Y_u}\right)^2}{N(m-1)}, \quad (6)$$

where Y_{ui} – is the numerical value of the *i*-th response of the *u*-th experiment;

$\overline{Y_u}$ – is the arithmetic mean of the response of the *u*-th experiment;

m – is the number of repetitions of each *u*-th experiment.

The calculated values of the Cochran criterion were compared with the tabulated values. If the condition $G \le G_T$ is met, and the variances are considered homogeneous, it means that the process is reproducible. Otherwise, it is necessary to increase the number of experiments, i.e., to implement the plan-matrix again or several times.

The statistical significance of the coefficients b_i of the regression equation was tested by the Student's *t*-test and determined in the following sequence:

– determine the variance of experimental errors in the lines of the multifactorial experiment plan:

$$S^2(b) = \frac{1}{N \cdot m} S^2(Y); \quad (7)$$

– determine the reproduction error:

$$S(b) = \sqrt{S^2(Y)}; \quad (8)$$

– determine the condition of significance of the coefficients $b_{i(jk)}$ of the regression equation:

$$b_{i(jk)} > t_T S(b), \quad (9)$$

where t_T – the table value of the Student's coefficient, which is selected from the table depending on the degree of freedom of correspondence f and the level of significance.

The degree of freedom of compliance is equal to:

$$f = (m-1)N.$$

If the condition of significance is not met, then such a coefficient b_i of the regression equation was taken to be insignificant (equal to zero), and the corresponding term x_i of the regression equation was excluded.

The adequacy of the selected mathematical model to the experimental data, i.e., the correspondence of the mathematical model to the real process, was checked by the Fisher's F-criterion as follows

- the variance of adequacy was determined:

$$S_{ag}^2 = \frac{m}{N - g'} \sum_{u=1}^{N} (\overline{Y_u} - \tilde{y}_u)^2, \quad (11)$$

where $N - g'$ – is the number of degrees of freedom of the variance of adequacy;

g' – number of significant coefficients in the regression equation;

$\overline{Y_u}$ – is the average response value in the u-th experiment;

$\tilde{y}_u$ – is the response value at the u-th point of the plan, calculated by the regression equation;

– determine the calculated Fisher's conformity criterion F_p:

$$F_p = \frac{S_{ag}^2}{S^2(Y)}, \quad (12)$$

where $S^2(Y)$ – variance of the experiment reproduction;

– determine the table value of the Fisher's criterion F_T or a given level of significance and two degrees of compliance:

$f_{ag} = N - g$ and $f_y = N(n-1)$.

The condition of the adequacy of the chosen mathematical model was checked according to the inequality:

$$F_p < F_T.$$

The obtained value F_p was compared with the table value F_T.

Thus, if the condition of adequacy of the chosen mathematical model is met, that is, the regression equation of a multivariate experiment is adequate to the experimental data. If the adequacy condition is not met, the model is inadequate. It is necessary to repeat the experiments in whole or in part under different conditions.

Next, the multiple correlation coefficient was also determined by the formula:

$$R = \sqrt{1 - \frac{\sum_{u=1}^{N}(\overline{Y_u} - \tilde{y}_u)^2}{\sum_{u=1}^{N}(\overline{Y_u} - \overline{Y})^2}}, \quad (13)$$

where $\overline{Y}$ – the average value of the function values determined from the experimental data.

Thus, almost all the conditions for drawing up a regression equation that will reflect the dependence of soil residues (output parameter) on the surfaces of potato tubers that have been cleaned with a spiral-type root and tuber cleaner on independent (input) parameters were obtained. Subsequently, using a computer, it is necessary to perform numerical calculations and obtain graphical dependencies.

3. Conclusion

1. To study the technological process of cleaning root and tuber crops from soil impurities and plant residues, a laboratory experimental setup was created. This installation has five cantilevered cleaning spirals arranged in a transverse-vertical plane, forming a separation zone with two cleaning channels. This allows to improve the quality of cleaning potato tubers from soil impurities and plant residues and, as a result, to increase the productivity of the potato heap separator.
2. The use of this experimental setup with a new potato heap cleaner makes it possible to study the influence of the main structural and kinematic factors on the operation of spiral-type cleaners, as well as to substantiate its rational structural and kinematic parameters.
3. A new methodology for conducting a multifactorial experiment to study the cleaning of root and tuber crops from soil impurities and plant residues has been developed.

4. References

1. Z. Ruzhylo, V. Bulgakov, O. Trokhaniak, I. Holovach. Justification of the improved technological process and development of the construction of the cleaner of root tubers from impurities. International scientific journal «Mechanization in agriculture & conserving of the resources». Year LXVIII ISSUE 3 / 2022. pp. 91-93.
2. Batyaev, F.I. Automatic separation of impurities from tubers (to the mechanization of potato harvesting). Potatoes and vegetables, vol. 6, 1967, p. 16-17.
3. Batyaev, F.I., Karev, E.B., Petrov, G.D. Condition and prospects for the development of working tools for separating potato tubers from impurities in combine harvest. VISCHOM, 1972, 63 p.
4. Vereschagin, N.I., Pshechenkov, K.A. Working tools for cultivation, harvesting and sorting of potatoes, publishing by Machinebuilding, 1965, 241 p.
5. Maslennikov, I.N. Research and comparative evaluation of potato rotary separators for potato harvesters. Abstract of diss. Cand. tech. Sciences, 1974, 28 p.
6. Petrov, G.D. Potato harvesters. Machinebuilding, 1984, 320 p.
7. Kropotov, E.I., Egoshin, A.V. On the issue of separating potato tubers from impurities and rottenness. Study of machines and implements for cultivation and harvesting of potatoes, vegetables and cereals: Sat. Scientific Tr. Nizhny Novgorod SHI, N. Novgorod, 1991, p. 55-57.
8. Kolchin, N.N., Furletov, V.M., Arsenev, D.A. Condition and prospects for the development of the separators of potato and vegetable impurities for post-harvest processing. VISCHOM, 1986, 65 p.
9. Karwowski, T. Teoria i konstrukcia maszyn rolniczych. Part 3. Warszawa: PWRiL, 1982, 429 p.
10. Bulgakov, V., Holovach, I., Ruzhylo, Z. and others. Purifier of root tubers from impurities. Patent of Ukraine №120234, A 01 D 33/08. Published 25.10.2019, bulletin №20.