

Investigation of the influence of the parameters of the experimental spiral potato heap separator on the quality of work

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Abstract: The known designs of potato heap cleaners have a series of disadvantages, particularly on sticky soils. In the newly developed and patented potato heap cleaner of a spiral type there is used the vibration effect and other technical solutions which ensure efficient self-cleaning of the rollers. Laboratory-field equipment was worked out and made for the investigations which had a spiral potato heap cleaner of a new design mounted on it. Under the field conditions the real technological process of digging and cleaning of the potato tubers from the soil admixtures was simulated in one row of the potato plantation. By using the developed methodology of a multi-factor experiment dependencies were obtained characterising the impact of the design and kinematic parameters of the cleaner itself upon the quality indicators of its operation (the soil separation efficiency, the cleanness of the heap, the damage and losses of the tubers), allowing optimisation of the design.

Key words: potatoes, harvesting, separator, spiral tool, multi-factor experiment.

INTRODUCTION

Potatoes are an important food and fodder crop in the countries of Eastern Europe and the Baltic States, and improvement of the methods of their cultivation and harvesting is a pressing scientific and practical problem (Shpaar, 2004). One of the important problems of potato harvesting is cleaning of the extracted heap (the mass of potato tubers, soil and plant residues) from the soil and plant admixtures. After combine harvesting, fertile soil (up to 3–5% of the mass of potatoes) is carried away from the field together with the potatoes (Kanafojski, 1997; Barwicki et al., 2012). For instance, it is estimated that during only three years in Russia, which is one of the biggest producers of potatoes in the world, more than 11 million tons of fertile soil have been carried off the fields (Byshov, 2000). The basic reason for this is the fact that in mechanised potato harvesting a significant volume of soil is dug out and raised together with the tubers, in which the potato tubers themselves constitute only several percent.

Moreover, depending on the condition of the plantation at the moment of their harvesting, the humidity of the soil is from 7% to 20%. The systems of the separating tools used on the serial potato combine harvesters not always ensure a high separation degree from the admixtures (Petrov, 2004). Most often this happens as a result of intense sticking of the surfaces of the separating tools with humid soil (Pastuhov, 2014). The technical systems of more intense coercion upon the soil separation lead to increased undesired damage of the tubers. Separators of the potato heap should not only ensure reliable and qualitative execution of the technological process but also constantly carry out a self-cleaning operation during the working process. There is no doubt that the degree of damage of the potato tubers has to be as small as possible. There are many researchers and designers who have worked on the problem how to create efficient and reliable separators of the potato heap at the moment of its extraction, as well as on stationary potato cleaning sites (Byshov, 2000; Petrov, 2004; Wei et al., 2013; Norten Equipment, 2016). However, in spite of the great variety of the technological processes of cleaning the potato heap at the moment of its extraction, for the time present there are only relatively few investigations about the optimisation of spiral separators.

The aim of the work was experimental investigation of the operation of the spiral potato heap separator of a new design in order to optimise its parameters and improve the quality indicators of cleaning the potato tubers from the soil admixtures.

MATERIALS AND METHODS

A new design scheme (Fig. 1) of a spiral potato heap separator (Bulgakov et al., 2002, Bulgakov et al., 2013) has been developed, consisting of three serially arranged spiral driving shafts 1, which are executed as cantilever (i.e. fixed only from one side) springs 2, fastened to hubs 3 and joined with the driving shafts 4 ensuring their rotary movement with a pre-set frequency. In order to avoid clogging of the sieving gaps with humid soil, spirals 2 are arranged overlapping each other but intensification of the heap separation and additional destruction of the lumps of soil is effected by means of eccentric fixation of the shafts 1 to the hubs 3.

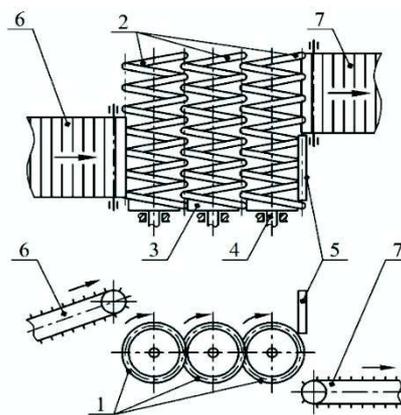


Figure 1. A design scheme of the spiral potato heap separator: 1 – spiral driving shafts; 2 – cantilever spiral springs; 3 – hubs; 4 – driving shafts; 5 – a flat screen; 6 – the feeding (input) conveyor; 7 – the discharge (output) conveyor.

The design of the spiral potato heap separator also provides for a feeding (input) rod chain conveyor 6 and a discharge (output) rod chain conveyor 7, the feeding (input) conveyor 6 being installed from the side of the hubs 3 of the spiral springs 2 and the discharge (output) conveyor 7 – from the side of the cantilever ends of the springs 2. Opposite the feeding (input) conveyor 6, with the outer side of the third roller there is installed a flat screen 5.

The technological process of operation of the improved spiral potato heap separator proceeds in the following manner. At first the potato heap is conveyed onto the first driving shaft 1 where an impact contact of the heap with the spiral spring 2 occurs. Yet this impact interaction does not induce any essential damage to the potato tubers because the surface of the spiral spring 2 which receives the impact is not an entirely solid surface (on the contrary, it is a surface with alternating projecting rods and empty gaps). Since the spiral springs 2 are to the hubs 3 only from one side, their ends are able to commit oscillatory movements in longitudinal vertical planes, which also mitigate the impact interaction. The tiny soil admixtures and the plant residues are immediately sifted down (outside the area of the separator) through the coils of the spring and the gaps between separate spiral springs. The potato tubers, left on top the active wavy surface formed by the spiral springs and inclined at a certain angle, are immediately involved in a complex movement both in a radial and an axial direction. As the spiral springs 2 are eccentrically mounted on hubs 3, the surface on which the potato tubers are situated commit compulsory wave-like movements over its entire surface with small amplitude, which promotes intense turning of the tubers and efficient sifting down of the soil residues outside the area of the separator. Here an important moment is that the spiral springs 2, due to their overlapping, clean themselves efficiently from the stuck soil. In the area of the third shaft further movement of the tubers is limited by a flat screen 5, and the tubers are directed towards the output conveyor 7. By means of the last spiral spring 2 the tiny soil admixtures and soil residues are conveyed outside the area of the cleaner into a gap between the last spiral spring 2 and the flat screen 5.

In order to conduct the research, laboratory experimental equipment was developed and made, on which a specimen of the new spiral potato heap separator was mounted. The amount of the soil and the soil residues sifted through the separator, the existence of soil stuck on the tubers of the potatoes and the degree of their damage were estimated according to a common methodology (Adamchuk et al., 2016). The design and kinematic parameters of the operation of the spiral separator were recorded in the process of investigation by means of sensors connected to the PC. The speed of the movement of the experimental equipment across the field was measured with the help of the track measuring wheel, also connected to the PC (Adamchuk et al., 2016). The design and kinematic parameters of the spiral separator of a new design (inclination of the separator in relation to the horizon, the peripheral speed of its spirals, the eccentricity dimensions of the adjacent spirals) were changed at the expense of different combinations of the dimensions of cogwheels, and controlled by sensors of revolutions. The amount of the potato heap to be fed into the spiral separator for cleaning was varied by changing the speed of the forward movement of the experimental equipment across the field. Under laboratory conditions, the input of the heap to be cleaned was estimated using preliminarily prepared and carefully weighed samples (there were prepared soil-tuber samples of standard dimensions). The condition of the potato plantation (the type of the soil, the crop capacity of the tubers, etc.) during the experimental research on the field was

evaluated by the standard methodology (Standard UA7794).

To conduct experimental investigations of the spiral separator under laboratory conditions, one-row experimental equipment was made, equipped with a digging tool used on the standard potato digger L-651 and provided with two serially arranged rod chain conveyors having vibrators. Besides, on the rear part of the equipment (after the second rod chain conveyor) there was a spiral separator of a new design installed. The laboratory equipment consists of a tracer roller 1 (with lateral cutting disks), a sectional digging share 2, the first 3 and the second 4 rod chain shaking conveyors, a spiral separator 5 of a new design, a blade 6 for receiving samples of the soil and plant admixtures at the output from the spiral separator 5, a blade 7 for receiving samples of soil and the plant residues sifted through the separator, a supporting wheel 8 (Fig. 2).

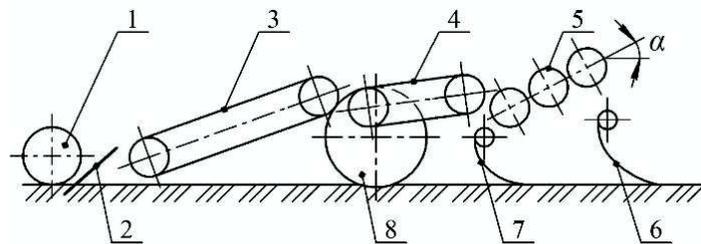


Figure 2. A design scheme of the experimental equipment: 1 – roller; 2 – a digging share; 3 – the first elevator; 4 – the second elevator; 5 – a spiral separator; 6 – a blade for receiving the mass of soil removed by the separator; 7 – a blade for receiving samples of soil passed through the separator; 8 – a supporting wheel.

When experimental investigations were carried out under stationary conditions, the experimental equipment was joined to the drive system by means of an electric motor and a transmission but the prepared samples of the heap of a corresponding fractional content were conveyed to the cleaning area. In addition, a task was posed to determine the impact of separate parameters of the cleaning technological process upon the operation quality of the separator. In accordance with the methodology, the limits of variation of the input parameters during the investigations were the following: the inclination angle $\alpha - 0...20^\circ$, the peripheral speed of the helicoidal surface of the shafts $V - 1.81...2.37 \text{ m s}^{-1}$, eccentricity $e - 0...10 \text{ mm}$, feeding of the potato heap $Q - 15...25 \text{ kg s}^{-1}$. The other design parameters of the spiral separator were assumed during the experiments as constant. They included: the external diameter of the separator spirals – 133 mm, the inclination angle of the helical line of the spirals – 25° , the diameter of the metal coiling rod – 17 mm, the pitch of the coiling – 48 mm, the covering of the adjacent spirals – 6...8 mm, the minimal number of spirals – 3, the length of the spiral per one row of the harvested potatoes – 500 mm. The mode of the forward movement of the experimental equipment during the potato harvesting technological process was selected by means of different transmissions of the aggregated wheeled tractor; it was controlled using a track measuring wheel mounted on the experimental equipment and connected to the PC; it corresponded to such values: 0.53; 0.67; 0.83; 1.11 m s^{-1} . In each mode of speed of the experimental equipment the research was repeated five times. Using analytical calculations, on the basis of initial parameters of the row and conditions of digging (the digging depth – 27 cm; the width of the dug out

layer – 55 mm; bulk density of the potato heap – 1,300 kg m⁻³) the feeding rate of the heap into the middle of the experimental equipment per second were determined.

In the year 2016 the field experimental research was carried out on the experimental plot of the Ukrainian National Academy of Agricultural Sciences National Science Centre ‘Institute of Mechanization and Electrification of Agriculture’. Harvesting proceeded from one row of the potato plantation, the widespread sort ‘Lugovskoy’. The crop capacity of potatoes on the experimental plot was 40.35 t ha⁻¹; the potatoes were planted in ridges with 0.7 m row spacing. At the moment of the experimental research the characteristics of the potato field was: black soil, with a medium humus content, medium loamy; the average humidity of the soil 11% (in the top layer 6...8%, in the horizon 10 cm, and lower – 12...16%); hardness of the soil in the tuber-bearing layer – 0.3...0.5 MPa, weediness of the plot 1.8 t ha⁻¹ (mainly haulm and stones).

According to the methodology of (Standard UA7794) under the field conditions, determination of the quality indicators was carried out while changing the forward speed, and a comparative evaluation of the heap purity in comparison with a serial machine without a separator was made.

The separation intensity was determined by the following formula:

$$q = \frac{\Delta m}{\tau \cdot S}, \text{ (kg s}^{-1} \text{ m}^{-2}\text{)} \quad (1)$$

where Δm – mass of the sifted soil (kg); τ – separation time (s); S – area of the separating surface (m²).

The efficiency of separation is estimated as percentage of the sifted soil, and in the research it was determined according to the formula:

$$q = \frac{\Delta m}{m} \cdot 100\%. \quad (2)$$

where m – mass of the soil that enters the separator (kg).

RESULTS AND DISCUSSION

Preliminary investigations indicated that the greatest part of the soil in the experimental equipment was sifted onto the rod chain conveyors-separators but the operating area of the spiral separator was reached by approximately 30...32% of the total mass seized by the digging tools of the potato harvester. Besides, the fractional content of the potato heap was: the tubers – 43...62%, the soil admixtures – 25...40%, the plant admixtures – 11...25%.

At the first stage of the experimental research of the fractional factorial experiment an impact of separate factors was studied upon the operation quality indicators of the separator (Box et al., 2005). By using statistical processing of the results of experimental investigations for four factors mathematical models of the process were obtained in the form of linear regressions. At natural values they have the following appearance:

$$Y_1 = 118.396 + 0.25125\alpha - 12.2768V + 0.5325e - 0.3175Q \quad (3)$$

$$Y_2 = 126.3339 + 1.08\alpha - 43.107V + 0. +974e - 0.3081Q, \quad (4)$$

where Y_1 – percentage of the sifted (separated) soil, (%); Y_2 – the separation intensity, (kg s⁻¹ m⁻²); α – the inclination angle to the horizon of the spiral separator, (deg); V – the

peripheral speed of the rotary movement of the spiral shafts, (m s^{-1}); e – the installation eccentricity of the separator spirals, (mm); Q – feeding of the potato heap onto the spiral separator, (kg s^{-1}).

After completion of the regressive analysis (Bingham & John, 2010) of these equations one can draw a conclusion that the maximal effect upon the soil sifting and separation intensity is caused by the peripheral speed V of the separator spirals but the minimal effect – by feeding of the potato heap Q .

Increasing the inclination angle α of the separator and eccentricity e , sifting of the soil and the separation intensity increases. Consequently, in order to raise the percentage of the sifted soil and the separation intensity by the spiral separator, it is necessary to ensure reduction in speed V and feeding Q .

The following experimental studies had an aim to examine the soil sifting relationships as a function of the inclination angle α of the separator spirals to the horizon and the peripheral speed V of its spirals. After completion of the experimental investigations a multivariate regression analysis was carried out on the basis of the obtained results. By investigating the percentage of the sifted soil the separation intensity the following models were obtained in the form of a multivariate polynomial of the second degree (at the probability $P = 0.95$, and the value of the critical Student distribution point, equal to $t_a = 2.176$):

$$Y_1 = 66.9523 + 34.755V - 0.0227\alpha^2 + 0.3868\alpha V - 11.56669V^2 \quad (5)$$

$$Y_2 = 141.6031 + 3.7093\alpha - 49.9049V - 0.0999\alpha^2 \quad (6)$$

On the basis of this mathematical simulation and data, obtained during the experimental research, graphs were built of the dependencies of the separated soil percentage and the separation intensity upon the inclination angle α of the spiral separator to the horizon and upon the peripheral speed V of its spirals (Figs. 3 and 4).

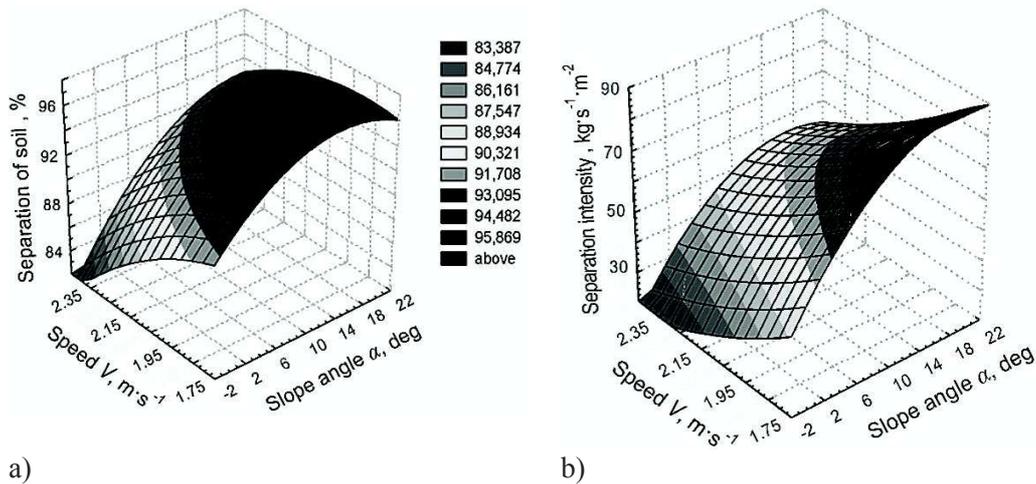


Figure 3. A response surface of the inclination angle α of the spiral separator and the peripheral speed V of the rotary movement of the spirals: a) upon the percentage of the sifted soil; b) upon the separation intensity.

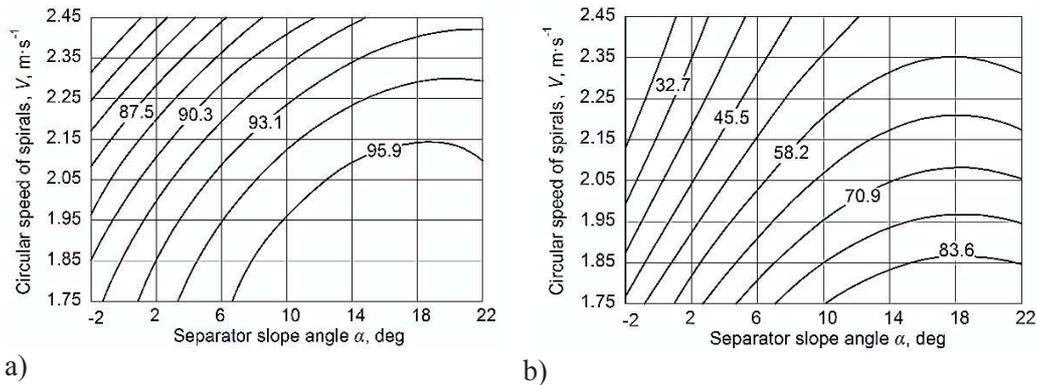


Figure 4. A two-dimensional cross-section of the response surface of the inclination angle α of the separator and the peripheral speed V of the rotary movement of the spirals: a) upon the percentage of the sifted soil; b) upon the separation intensity.

At a constant value of the peripheral speed V (1.81 m s^{-1}) and change of the inclination angle α there were conducted investigations of the technological process of the separator operation for various soil humidities (Fig. 5).

The data obtained as a result of the research witness that, increasing humidity, the sifting process on the spiral separator takes place more slowly, which leads to increased soil contents in the cleaned heap in contrast to the heap of lesser humidity.

As it is evident from the dependency (Fig. 6, a), when the inclination angle is raised from 0 to 15° , an essential increase in the percentage of the sifted soil is observed. Yet after the following raising of the value of the inclination angle α of the spiral separator to the horizon, the variations of this indicator are not essential.

Increasing the peripheral speed of the spirals to 2 m s^{-1} (Fig. 6, b), the percentage of the sifted soil decreases slowly, but then rapid decrease is observed. This can be explained by the fact that, increasing the peripheral speed, the time of contact of the delivered mass with the operating tools of the separator diminishes, and the greatest part of the soil clods fly through the separator. The percentage of the sifted soil reaches its maximum value at the peripheral speed 1.81 m s^{-1} and the inclination angle of the separator to the horizon $15\text{--}19^\circ$.

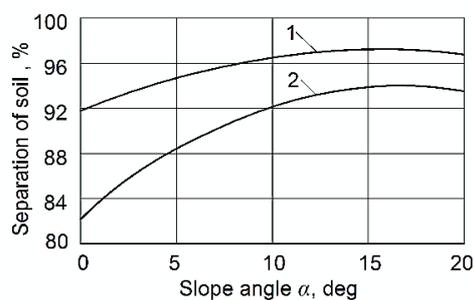


Figure 5. The impact of the inclination angle α of the spiral separator upon the percentage of the sifted soil at its humidity: 1) 7.0%; 2) 12.5%.

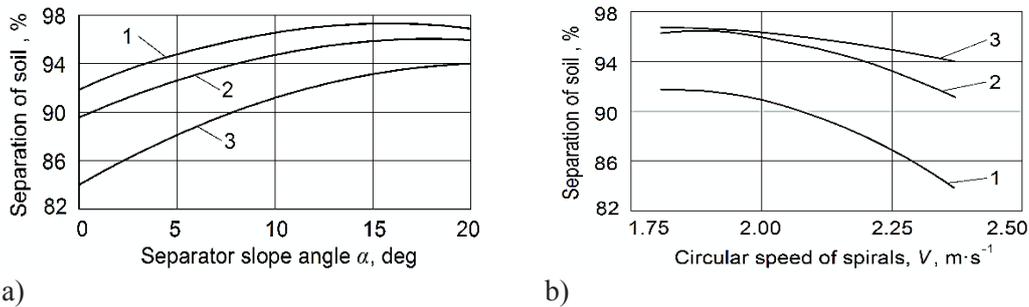


Figure 6. Dependencies of the percentage of the sifted soil upon: a) inclination of the angle α to the horizon at the following values of the peripheral speed V of the spirals: 1) 1.82 m s^{-1} , 2) 2.09 m s^{-1} , 3) 2.37 m s^{-1} ; b) the peripheral speed V of the spirals at the following values of the inclination angle α of the separator to the horizon: 1) 0° ; 2) 10° ; 3) 20° .

Dependencies of the separation intensity on the inclination angle α of the spiral separator to the horizon and on the peripheral speed V its spirals are presented in Fig. 7. As evident from the graphs, the dependencies mentioned above have an appearance close to the linear one.

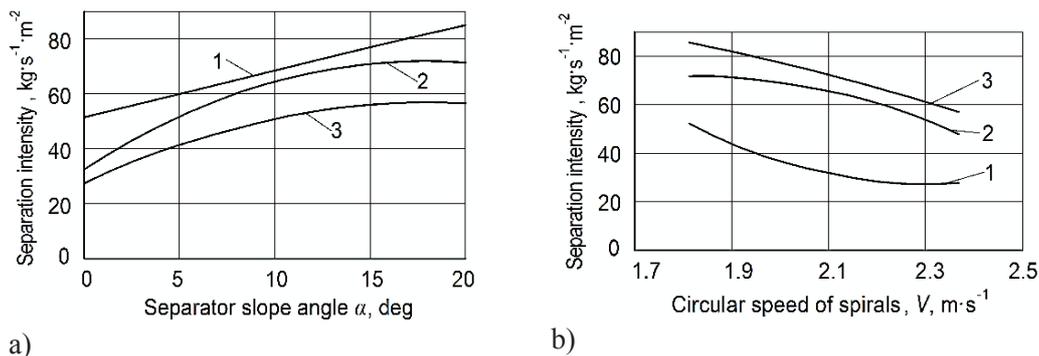


Figure 7. The intensity of the separation depending on: a) angle a of the the separator inclination to the horizon: 1) 0° ; 2) 10° ; 3) 20° ; b) circular speed V of spirals: 1) 1.82 m s^{-1} ; 2) 2.09 m s^{-1} ; 3) 2.37 m s^{-1} .

By using the results of laboratory investigations, optimal values of the parameters were determined for the work under field conditions (for the speed of the movement of the experimental equipment $0.5\text{--}2.0 \text{ m s}^{-1}$): the inclination angle α of the separator to the horizon was accepted as equal to 15° , the peripheral speed V of the spirals was equal to 1.92 m s^{-1} , eccentricity $e - 10 \text{ mm}$.

On the basis of the obtained structural parameters of the machine, a sample machine was made for the work on the field. Under the field conditions, determination of the quality indicators of operation was carried out while changing the forward speed, and a comparative evaluation was made with a potato digger which is popular among the potato breeders (Standard UA7794).

The dependency graphs of the separation efficiency of the potato heap, its frequency, losses and damage of potatoes are presented in Fig. 8–9. When the speed of the forward movement of the experimental equipment is increased, feeding of the potato heap (at constant values of the section of the dug up layer) increases. According to the results of the experimental investigations (Fig. 8), increase in the forward speed has an unequal effect on the agrotechnical indicators of the operation of the harvesting aggregate. Thus, the separation efficiency (Fig. 8, curve 2) in the region of the changing speed of the movement to 0.67 m s^{-1} increases gradually but, when the speed is changed from 0.67 m s^{-1} to 0.83 m s^{-1} , its slow falling is observed. Further increase in the forward speed of the experimental equipment leads to significant diminution of this quality indicator, and at the speed 1.11 m s^{-1} the separation efficiency is, on the average, 33.31%. In a similar way a change in the purity of the potato heap takes place (Fig. 8, Curve 1) since the purity of the cleaned potato heap also depends on the separation efficiency. In addition, when the speed of the movement is increased, damage of the potato tubers decreases (Fig. 9, curve 2). First of all this is due to the fact that the operating tools of the separator receive a greater amount of soil, which promotes reduction in the contact time of the root crops with the metal surface of the cleaner. The losses of the potato tubers (Fig. 9, curve 1) constitute 0.68% at the speed of the machine 0.67 m s^{-1} , but its further increase evidently leads to successive increase in their damage. When the speed of the movement of the experimental equipment is equal to 1.11 m s^{-1} , the losses constitute 2.23%.

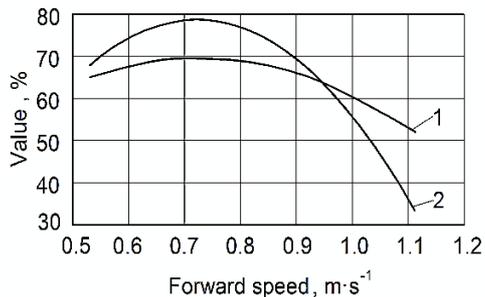


Figure 8. Influence of the forward speed of the experimental machine on the heap purity (1) and the percentage of the sifted soil (2).

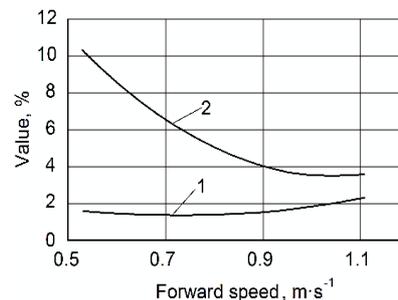


Figure 9. Influence of the forward speed of the experimental machine on the losses of tubers (1) and their damage (2).

As a result of the field experimental investigations on cleaning the potato heap, sort ‘Lugovskoy’, the crop capacity 40.35 t ha^{-1} , in the black soil, with a medium humus content, medium loamy; the average humidity of the soil 11% and hardness 0.3–0.5 MPa, weediness of the plot 1.8 t ha^{-1} , it was established that, using a potato digger with a spiral separator, there are losses of the potato tubers – 1.8%, and the total damage of the tubers up to 6.4%.

A statistical analysis of the research results of the damage caused to the potatoes by the spiral separator was also executed. Fig. 10 presents a distribution diagram of the types and degree of (%) damage of the potato tubers interacting with the spiral separator. As it is evident from the presented diagram, the greatest injuries (about 50%) are due to stripping the outer surface (skin) from $\frac{1}{4}$ of the tubers, the minimum (2.17%) – due to

damage of the pulp of the tubers, which does not exceed the allowed norms. It is evident that it will be possible to lower the degree of damage of the potato tubers by rubberising the separator spirals envisaged by further plans.

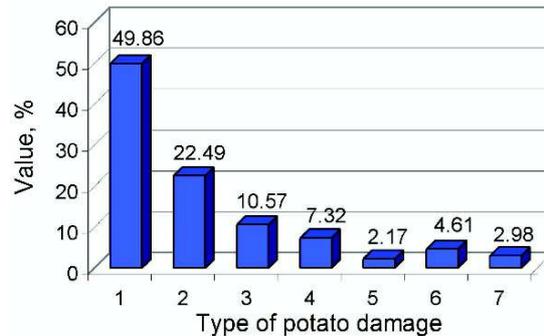


Figure 10. A distribution diagram of damage (%) of the potato tubers by their types: 1 – stripping of the outer (up to $\frac{1}{4}$) surface of the skin; 2 – stripping from $\frac{1}{4}$ to $\frac{1}{2}$ of the outer surface of the skin; 3 – cracks 10...20 mm; 4 – damage of the pulp less than 2 mm; 5 – damage of the pulp to the depth 2...5 mm; 6 – traumas with the diameters of spots 5...10 mm; 7 – traumas with the diameters of spots 10...15 mm.

According to practitioners, in Ukraine the potato digger L-651 is considered one of the best machines of this purpose. Therefore, in 2016, evaluation of the the heap purity of the experimental machine was carried out also in comparison with the serial potato-digger L-651 (without a separator); which showed that the inclusion of the separator in the potato-digger construction ensures an increase in the purity of the potato heap by 27%. The conducted field experimental investigations confirm the high quality indicators of the potato heap separation using the new design of a spiral separator, and the possibility of its application in the designs of the contemporary potato harvesting machines. In the future, after completion of industrial testing (for the reliability of the design, etc.), it is envisaged to introduce the discussed design of the separator into the systems of the potato harvesting combines of areal application.

CONCLUSIONS

1) On the basis of the research results, using the method of a fractional factorial experiment and statistical processing of the results, mathematical models have been obtained which characterise the impact of the design, kinematic and technological parameters of the new spiral separator of the potato heap per cent of the sifted soil and the separation intensity of admixtures.

2) For the experimental spiral separator the optimal parameters are: the peripheral speed of rotation of the spirals 1.75–2.0 m s⁻¹, the inclination angle of the separator to the horizon 15–19°, the installation eccentricity of the spirals – 5–10 mm, the recommended speed of the movement 0.6–0.8 m s⁻¹.

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