Всеукраїнський науково-технічний журнал
All-Ukrainian Scientific & Technical Journal
ISSN 2520-6168 (Print)
DOI:10.37128/2520-6168-2024-4

Machinery
Energetics
Transport
of Agribusiness

№4 (127)

2024

ТЕХНІКА ЕНЕРГЕТИКА ТРАНСПОРТ АПК

Науковий журнал

ТЕХНІКА, ЕНЕРГЕТИКА, ТРАНСПОРТ АПК

№ 4 (127) / 2024

м. Вінниця – 2024

Scientific Journal

Engineering, Energy, Transport AIC

Vol 127, № 4 / 2024

Vinnytsia – 2024

ТЕХНІКА, ЕНЕРГЕТИКА, ТРАНСПОРТ АПК

Журнал науково-виробничого та навчального спрямування
Видавець: Вінницький національний аграрний університет

Заснований у 1997 році під назвою «Вісник Вінницького державного сільськогосподарського інституту».
Правонаступник видання: Збірник наукових праць Вінницького національного аграрного університету. Серія: Технічні науки.
Свідоцтво про державну реєстрацію засобів масової інформації
КВ № 16644–5116 ПР від 30.04.2010 р.

Науковий журнал «Техніка, енергетика, транспорт АПК» / Редколегія: Токарчук О.А. (головний редактор) та інші. Вінниця, 2024. № 4 (127). С. 1-99.

Друкується за рішенням Вченої ради Вінницького національного аграрного університету (протокол № 6 від 24.12.2024 р.)

Свідоцтво про державну реєстрацію засобів масової інформації №21906-11806 Р від 12.03.2016р.

Журнал «Техніка, енергетика, транспорт АПК» включено до переліку наукових фахових видань України з технічних наук (Категорія «Б», Наказ Міністерства освіти і науки України від 02.07.2020 року №886).

Згідно рішення Національної ради України з питань телебачення та радіомовлення від 25.04.2024 р. №1337 науковому журналу «Техніка, енергетика, транспорт АПК» присвоєно ідентифікатор медіа R30-05173.

Журналу «Техніка, енергетика, транспорт АПК» присвоєно ідентифікатор цифрового об'єкта (Digital Object Identifier – DOI).

Журнал включений до міжнародних наукометричних баз і каталогів наукових праць:

- ***Index Copernicus Value з 2018 року, сайт: https://journals.indexcopernicus.com/search/details?id=47074;***
- ***Національної бібліотеки України ім. В.І. Вернадського, сайт: http://www.irbis-nbuv.gov.ua;***
- ***Google Академія, сайт: https://scholar.google.com.ua/citations?user=A5layLAAAAAJ&hl=uk;***
- ***CrossRef, сайт: https://www.crossref.org.***

відповідальний секретар редакції – **Полєвода Ю.А.** к.т.н., доцент,
літературний редактор української та іноземних мов – **Погранична Н.М.,**
Адреса редакції: 21008, Вінниця, вул. Сонячна 3, Вінницький національний аграрний університет, тел. (0432) 46– 00– 03
Сайт журналу: http://tetapk.vsau.org/ **Електронна адреса: pophv@ukr.net**

Journal of scientific, industrial and educational direction
Publisher: Vinnytsia National Agrarian University

ENGINEERING, ENERGY, TRANSPORT AIC

It was founded in 1997 under the name "Bulletin of the Vinnytsia State Agricultural Institute".
Successor publication: Collection of Scientific Works of the Vinnytsia National Agrarian University. Series: Technical sciences.
Certificate of state registration of mass media
KV No. 16644–5116 PR dated 04/30/2010

Scientific journal "Technology, Energy, Transport AIC" / Editorial board: Tokarchuk O.A. (chief editor) and others. Vinnytsia, 2024. Vol. 127, № 4, P. 1-99.

Printed by decision of the Academic Council of the Vinnytsia National Agrarian University (protocol №. 6 dated December 24, 2024)

Certificate of state registration of mass media No. 21906-11806 R dated March 12, 2016.

The journal "Technology, Energy, Transport AIC" is included in the list of technical scientific publications of Ukraine (Category "B", Order of the Ministry of Education and Science of Ukraine dated 07.02.2020 No. 886).

According to the decision of the National Council of Ukraine on Television and Radio Broadcasting dated 04/25/2024 No. 1337, the scientific journal " Technology, Energy, Transport AIC " was assigned the media identifier R30-05173.

The journal " Technology, Energy, Transport AIC " has been assigned a digital object identifier (DOI).

The journal is included in the international scientometric bases and catalogs of scientific works:

- Index Copernicus Value since 2018, website: https://journals.indexcopernicus.com/search/details?id=47074;

- National Library of Ukraine named after V.I. Vernadskyi, website: http://www.irbis-nbuv.gov.ua;

- Google Academy, website: https://scholar.google.com.ua/citations?user=A5layLAAAAAJ&hl=uk;

- CrossRef, website: https://www.crossref.org.

editor-in-chief – ***Yurii POLIEVODA***, Candidate of Technical Sciences, Associate Professor,
literary editor of Ukrainian and foreign languages – ***Natalia POGRANICHNA***
Address of the editorial office: 21008, Vinnytsia, str. Sonyakna 3, Vinnytsia National Agrarian University, tel. (0432)46-00-03
The magazine's website: ***http://tetapk.vsau.org/*** **E-mail address:** ***pophv@ukr.net***

ЗМІСТ

I. ПРИКЛАДНА МЕХАНІКА. МАТЕРІАЛОЗНАВСТВО. ГАЛУЗЕВЕ МАШИНОБУДУВАННЯ

II. АГРОІНЖЕНЕРІЯ

III. ЕЛЕКТРОЕНЕРГЕТИКА, ЕЛЕКТРОТЕХНІКА ТА ЕЛЕКТРОМЕХАНІКА

CONTENTS

I. APPLIED MECHANICS. MATERIALS SCIENCE. INDUSTRY MACHINERY BUILDING

II. AGROENGINEERING

III. ELECTRICAL ENERGY, ELECTRICAL ENGINEERING AND ELECTROMECHANICS

UDC 631.356.24
DOI: 10.37128/2520-6168-2024-4-3

ANALYSIS OF DESIGN AND TECHNOLOGICAL ASPECTS OF FUNCTIONING OF CHICORY ROOT DIGGERS

Olena TRUKHANSKA, Candidate of Technical Sciences, Associate Professor
Maksym HADAICHUK, Recipient of the Third Educational and Scientific Level
Vinnytsia National Agrarian University

ТРУХАНСЬКА Олена Олександрівна, к.т.н., доцент
ГАДАЙЧУК Максим Юрійович, здобувач третього освітньо-наукового рівня
Вінницький національний аграрний університет

An analysis of the design features and technological processes of the functioning of working bodies intended for digging chicory root crops is given. Based on the identification of structural models of digging working bodies, a classification of root crop diggers was developed according to the accepted systematization criteria. Among many types of industrial crops, including root crops, only root chicory ensures the production of strategic raw materials from which, in the process of its processing, the raw product of processing inulin is obtained, from which an important medicinal product - insulin is subsequently produced.

The existing technical means of harvesting chicory roots do not provide the necessary indicators of the quality of digging root crops according to the agrotechnical requirements for root harvesting machines. At the same time, the average rate of loss of root crops is 3.5...7.5%, depending on the harvesting conditions, and damage to chicory roots exceeds 2.5...3.5 times the value of the index of agrotechnical requirements. The characteristic structural and technological shortcomings of the main existing types of excavating working bodies are analyzed. The main trends in the development of disc diggers and directions for improvement of combined digging systems of chicory root crops using a spherical disc are substantiated.

The reduction of losses of root crops and their damage is ensured by the use of a combined single-disk spherical digger, which combines a spherical disk and a loosener placed behind it and in the area of its action, installed on the riser of the disk. The obtained research results are a partial addition to the existing method of further calculation and substantiation of the rational parameters of the spherical disc and the technological parameters of the working processes of root harvesting machines.

Key words: *root crops, digger, spherical disk, loosener, soil layer, classification.*
Eq. 4. Fig. 5. Ref. 15.

1. Problem formulation

The main criterion for the further intensification of modern agricultural production is the material and technical basis for the mechanization of all production processes through the introduction of resource-saving technologies for harvesting crops. One of the main features that characterizes advanced technology is a significant reduction in energy resources inherent in the technological operation of digging root crops.

The main design and technological criteria that determine the unsatisfactory operational and technological efficiency of the use of existing root harvesters is the separate performance of two related technological operations - removal of the remains of tops from the heads of root crops and their subsequent digging. This leads to additional costs of material and energy resources [1].

2. Analysis of recent research and publications

The technological efficiency of chicory root crops digging largely depends on the design and layout scheme and the quality of diggers' work, while the loss of root crops should not exceed 2.5 %, while observing the permissible values of damage to root crops and residual tops, respectively, not more than 15 % and 4 % according to the initial requirements for root harvesting machines [2].

However, insufficient adaptation of the known designs of diggers to a significant variation in the operating conditions of root harvesting machines [3] does not provide the established agrotechnical indicators in extreme harvesting conditions - root crop losses increase by 1.5...2.0 times due to the breakage of the underground (tail) part of chicory roots, and damage to root crops increases to 20...30 % [4].

Therefore, increasing the technological level of diggers, or reducing the ratio of losses and damage to root crops to their harvested mass, remains a scientifically relevant problem in terms of further development of technology.

The development of the concept and algorithm for constructing rational outlines of modern machines is possible on the basis of further phased analysis of the world experience in improving the process of harvesting root crops, or on the basis of in-depth identification of the functioning of the working bodies of transport and technological systems for digging root crops.

The results of scientific research are known and are presented in [5, 6, 7], as a rule, characterize only the general aspects of the functioning of excavating working bodies without an accentuated analysis of the directions of improving the technological efficiency of their work.

3. The purpose of the article

The purpose of the experimental research is to improve the quality indicators of root harvesting machines by intensifying the process of digging root crops.

4. Results of the researches

Solving the scientific problem of improving the agrotechnical quality indicators and technological performance of root harvesting machines, or reducing the degree of loss and damage to chicory root crops is possible by developing and substantiating the parameters and modes of operation of digging working bodies that ensure simultaneous digging and removal of the remains of tops from the heads of root crops as part of a combined digger. This research is a further development of the technological principles of the functioning of transport and technological systems of digging tines of root harvesters.

The technological progress of the beginning of the XXI century has led to the further development of agricultural engineering - new highly efficient root harvesting complexes are being introduced into mass production, built on the basis of original technological and layout schemes and design solutions of working bodies.

The technological process of chicory root harvesting is regulated mainly by the agrotechnical characteristics of the crop, the design of working bodies and layout diagrams of transport and technological systems of machines. The first stage of the development of root harvesting machinery should be based on the systematization of existing machines for harvesting root crops with their subsequent taxonomy according to certain classification criteria, which will allow the identification of the design schemes of machines and technological processes of root crops harvesting.

According to the functional purpose (performance of technological harvesting operations), root harvesting equipment (Fig. 1) is divided into tops harvesting machines (modules), root head cleaners from tops residues, root harvesting machines, root loaders.

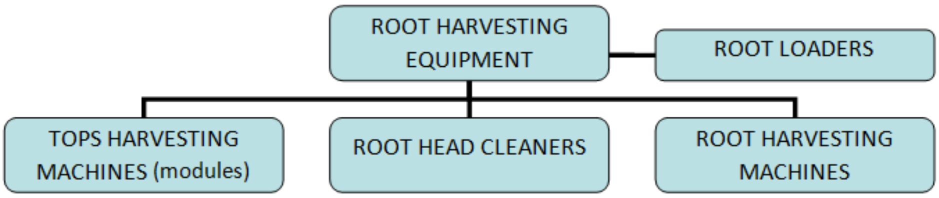

Fig. 1. Classification of root harvesting equipment

Mechanized technologies for harvesting root crops combine complex production and technological operations - harvesting tops and roots according to different technological schemes: cutting the main mass of root crop tops; removing the remains of tops from the heads of root crops; digging root crops with simultaneous further cleaning of the heap from impurities or laying them in a windrow with further selection and cleaning; loading and transportation of root crops and tops [8].

The principles of the evolution of technical means intended for harvesting root crops are closely related to the main general trends in the development of technologies and methods of harvesting, as well as the improvement of individual basic technological operations. Among them, a special role belongs to such operations as harvesting the main mass of tops and trimming its residues on the heads of root crops, digging root crops, cleaning the dug heap of root crops from impurities, loading the cleaned root crops into a vehicle or a harvester hopper, forming large field piles with their subsequent loading into a vehicle.

The basis for the further formation of the scientific outlook of the developers of working bodies for digging chicory roots, i.e., the further development of the general concept of the process of digging roots, should be the hypothesis about the possibility of simultaneously combining the operations of pruning the remains of tops and digging roots with combined diggers [8].

Diggers are one of the basic structures of transport and technological systems of modern root harvesting machines, since the quality of their technological process ultimately determines the efficiency of the use of the structural and layout scheme of the entire root harvesting complex and the quality of root crops harvesting. The mechanical and technological principle of the diggers' operation is to destroy the bonds of root crops with the soil and create a pulling force for their subsequent movement along the surface of the working body and transfer of the dug roots to further machine systems.

As a rule, the working bodies of the diggers cut the soil layer together with the root crops with a wedge blade or their working surface at the digging depth and move the excavated heap along the digger channel to the cleaner zone for further separation of soil and plant impurities from the root crops. At the same time, the working bodies of the diggers must ensure sufficient disruption of the root crops bonds with the soil, the necessary completeness of their excavation with satisfactory damage indicators and minimization of the supply of free and adherent soil to the cleaning systems [1, 8].

These indicators determine the technological efficiency of the diggers, which, in addition to these factors, is also regulated by the applied design and layout scheme of the digger, the choice of their adjustable parameters and modes of operation of the working bodies of the digger and the root harvester as a whole, agrophysical parameters of root crop plantations, soil and climatic conditions of harvesting, etc.

There are many variants of root crop diggers, which differ from each other not only in design but also in the technological principle of operation. This is due to both the natural development of structures and the variety of soil and climatic conditions for digging root crops and the agrobiological properties and characteristics of root crop plantations. The general fundamental disadvantages of the existing and technically realized types of diggers (ploughshare, fork, double-disc, vibratory), which are mainly equipped with mounted, trailed and self-propelled root harvesting machines, are as follows a relatively significant second supply of free and adhering soil on the surface of the root crop body (7... 10 kg/s), residues of tops on the heads of root crops (from 0.5 to 1.5 kg/s) from one running meter of the row at a working speed of 1.6 m/s, with up to 70 % of the total amount being the mass of free and adhering soil, up to 10 % - residues of tops on the heads of root crops, which led to an increase in the length and constructive complexity of cleaning systems [8]. At the same time, double-disc diggers have one significant drawback - they pinch intact clods and feed them to the following machine systems, which significantly reduces the quality indicators established by agrotechnical requirements, the quality of work.

In addition, the analysis of the design and technological processes of the machines showed that the objective reason for the technological imperfection of existing diggers is that they are structurally and technologically impossible to simultaneously combine two technological operations into one during harvesting - digging and cleaning root crops with the simultaneous removal of the remains of tops on their heads.

Of all the varieties of diggers, single-disc spherical, or the so-called “Eurodisk” (Fig. 2. a) have a simple design, are the least metal- and energy-intensive compared to other types of diggers, and have a wide range of applications for digging root crops with satisfactory performance. The axis of rotation 2 of the spherical disk 1 of the digger forms an angle of attack α in the horizontal plane relative to the axis of the root crop row.

Significant disadvantages of their work, which consist in unsatisfactory deepening of the working edge of the disk into the soil at low soil moisture, the absence of removal of the remains of tops on their heads simultaneously with the digging of root crops, can be predictably eliminated by further structural and technological improvement of this type of digger [8].

Increasing the technological and quality indicators of the existing root crop diggers, and in general - the entire root harvester, is solved by using the basic version of the combined digger (Fig. 2.b), or by additional installation in the front zone of the spherical disk 1 of the root guide 3 and the horizontal cleaning shaft 4, on which the flanges 5 are radially fixed. Between the flanges along their circumference, parallel axes 6 are successively installed, which are rotated relative to the axis of the cleaning shaft at an acute angle. Flat elastic blade sections 7 are pivotally mounted on the parallel axes. During the movement of the digger, the root guide shifts the root crops, previously knocked out during the cutting of the tops by the working bodies of the tops harvester, from the row to its center, and the spherical disk digs out the root crops. Simultaneously with the digging of root crops with a spherical disk, due to the rotation of the cleaning shaft, flat elastic blades contact the heads of root crops, cleaning their heads from the remains of tops on them due to their contact interaction with the remains of tops. The rotation of the parallel axes at an acute angle relative to the axis of the cleaning shaft allows the flat elastic blades to strike the root heads from the side of the row, which improves the cleaning of root crops of different heights, while the tall root crop does not cover the low root crop from an oblique impact. In addition, the flat elastic blades also interact with clods of soil, destroying the clods of soil and pushing the dug heap of roots to the next systems of the machine, which increases its technological capabilities.

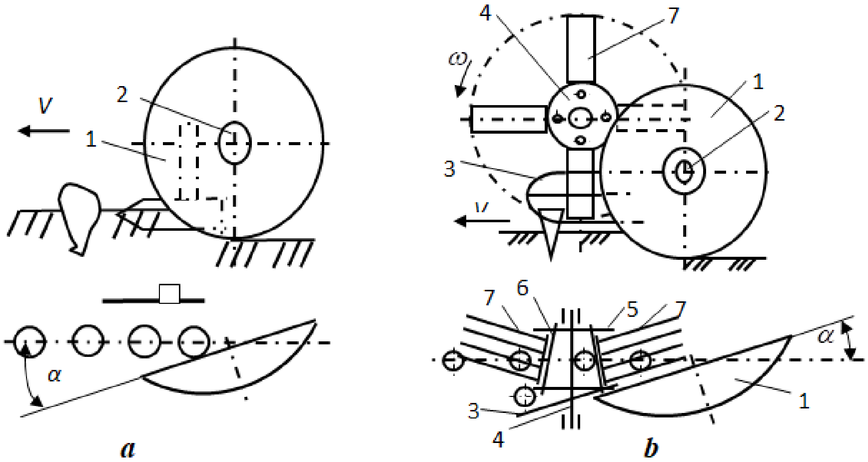

Fig. 2. Diagrams of single-disc diggers: a – single-disc digger; b – combined digger

When digging root crops in dry hard soil conditions, the tail part of the root crops is damaged due to their breakage due to insufficient vertical force of root crops pushing, which leads to their significant losses. To eliminate the breakage of the tail part of the root crops or their losses, the spherical disk 1 (Fig. 3.a) is installed at an acute angle *φ*, and the flanges 5 - at an angle *δ* to the vertical plane, while the axis 6, which occupies the extreme lower position on the flange, forms an angle ε, equal or close to 90^0. with the plane passing through the blade of the spherical disk. The one-sided spherical disk digs up root crops by lifting them upwards due to the additional projection of the lateral pushing force that occurs, which is directed to the vertical plane. At the moment of impact of flat elastic blades on the root crop head, they rotate around their axes and in the plane of impact due to the installation of flanges at an angle φ to the vertical and with their axes rotated at an angle relative to the shaft axis. Since the axes in the lower position are perpendicular to the plane that passes through the blade of the spherical disk, or inclined to it at an angle close to straight, the flat elastic blades in the lower position are parallel to this plane and do not contact the surface of the spherical disk, which reduces their wear [10].

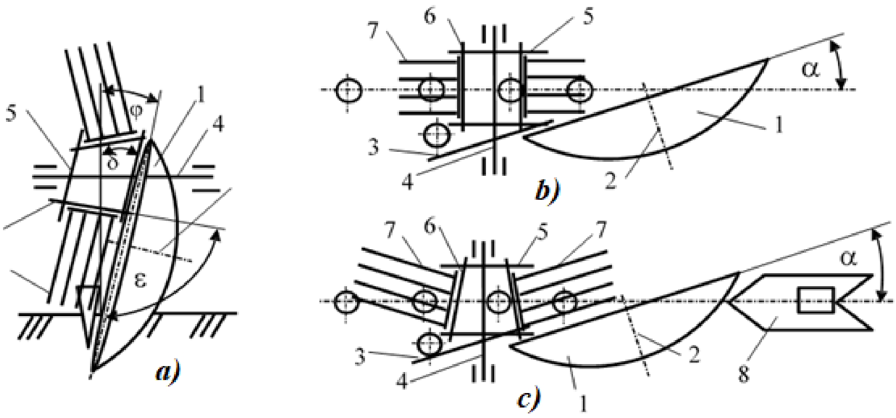

Fig. 3. Schemes of combined diggersflow velocity of rapeseed and pea at the outlet of the boot

To increase the degree of separation of the residual tops from the heads of root crops and the degree of destruction of soil clods, by increasing the force of contact interaction (force of direct central impact) of flat elastic blades on the head of root crops and soil clods, parallel to the axis 6 (Fig. 3. b), which are located on the flanges 5 of the horizontal cleaning shaft 4 and on which flat elastic blades 7 are fixed, are set parallel to the axis of rotation of the cleaning shaft. Simultaneously with the digging of root crops, due to the rotation of the cleaning shaft, flat elastic blades interact with the heads of root crops and clods of soil, while a direct impact of flat elastic blades occurs with the subsequent removal of the remains of tops from the heads of root crops and the destruction of clods of soil [11].

For digging root crops that lie deep relative to the soil surface, rippers 8 are used, installed behind the stroke of the spherical disk 1 (Fig. 3. c), which can be made in the form of a cultivator foot or a chisel. In the process, the ripper preliminarily digs up the root crops, thus breaking the bonds of the root crops with the soil, i.e., preliminary crumbling of the soil layer occurs. Root crops, whose connection with the soil is broken, are then easily dug out of the crumbled soil by a spherical disk and displaced by it in the direction of the plane that passes through the blade of the spherical disk. At the same time, we have the opportunity to deepen the disk to a rational depth in such a way as not to lose root crops and to crush a minimum of soil and plant impurities onto the cleaners of the machine [12].

However, the mechanized harvesting of chicory roots by such diggers also leads to significant losses of chicory roots (up to 45...60 %) due to the breakage of the underground tail part due to the improper depth of the working bodies, which significantly reduces the profitability of the management conditions [13].

The development and substantiation of the parameters of working bodies for digging chicory roots with their minimum losses will lead to an increase in economic, technical and operational indicators and a significant increase in the efficiency of production in general.

To increase the efficiency of chicory root crops digging, an improved combined digger was proposed, the design scheme of which is shown in Fig. 4.

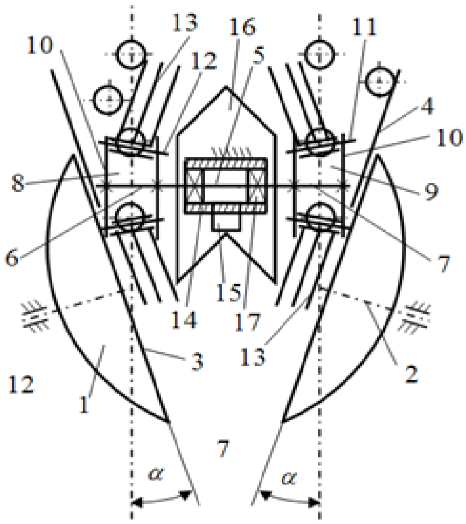

Fig. 4. Design scheme of the combined digger

The combined digger consists of two spherical disks 1 installed at an angle α to the row axis of root crops, two spherical disks 1, which are freely planted on their axes of rotation 2. A root guide 4 is installed in the front zone of the working edge 3 of each of the two spherical disks. Above the two spherical disks, perpendicular to the row of root crops, or the direction of the working speed V_k of the digger, a horizontal drive shaft 5 is installed. On the end edges 6 and 7 of the shaft are fixed separate drums 8 and 9, which are made in the form of radial flanges 10 mounted on the shaft 5. Between the flanges of each of the drums, axes 11, 12 are fixed in series and in parallel along their formative parts, on which flat elastic elements 13 are placed. The axes are rotated relative to the shaft axis at an acute angle. A hollow tube 14 is horizontally mounted in front of the area of the working edges of the spherical disks and between them, on which a riser 15 is fixed. A loosening device 16 is mounted on the riser, which is placed in the row of root crops. Bearings 17 are installed inside the hollow tube, on which a horizontal drive shaft is mounted. The depth of the loosening device is greater than the depth of the spherical disks. The direction of rotation of the horizontal drive shaft is the same as the direction of movement of the combined chicory root digger.

The combined chicory root digger works as follows.

During the movement of the combined digger, the loosening device 16 destroys the bonds of chicory roots with the soil at the depth of their occurrence, that is, loosens the soil environment and partially digs up the roots. At the same time, simultaneously with the digging of root crops by the ripper, two related operations take place - the final digging of chicory root crops with spherical disks 1 and cleaning the heads of root crops from the remains of tops from two adjacent rows of root crops due to the rotation of drums 8 and 9 of the shaft 5, or the interaction of elastic elements 13 with the heads of root crops. The root guide 4 shifts the chicory roots previously knocked out of the row to its center, and the spherical disks 1 pick up the roots knocked out of the soil. In addition, flat elastic elements 13 also destroy clods of earth and simultaneously push the heap that is in the space of the spherical disks 1, accelerating its supply to the next technological systems of the root harvester.

The use of a ripper can reduce the breakage of the underground tail part of root crops, or reduce damage and loss of root crops.

However, the location of the ripper in the front zone of movement of the spherical disks significantly hinders the passage of the dug heap, which reduces the technological efficiency or productivity of the digger, i.e. the root harvester as a whole.

To improve the technological efficiency of the process of harvesting chicory root crops, we have proposed a technical tool for digging up root crops (Fig. 5), which will allow to increase the completeness of digging up root crops and reduce their damage due to the intensification of the process of destruction of the peri-fruit environment and the occurrence of additional dynamic effects that ensure an increase in the force of pushing out root crops from the ground.

The combined working body for digging chicory root crops consists of a one-sided spherical disc 2, which is located at a certain angle relative to the row of root crops.

The disk is freely seated on the axis 3 of the disk rotation, which is mounted in a riser (not shown in Fig. 5), rigidly fixed on the frame 9 of the digger. Also, a bracket 5 is mounted on the riser, which can be moved along the riser and fixed on it with the help of fixing pairs of bolts and nuts.

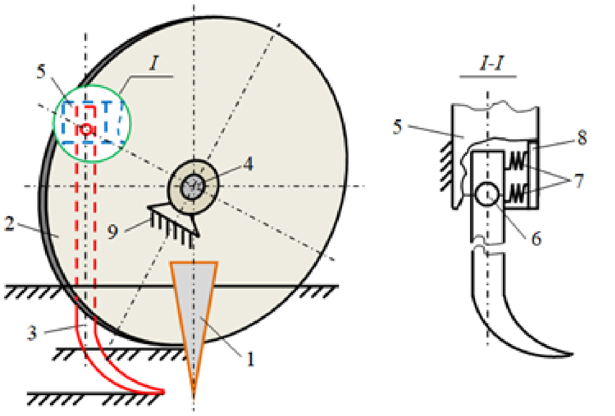

Fig. 5. Construction diagram of a combined digger:
1 – root crop; 2 – spherical disc; 3 – loosener; 4 – disk rotation axis; 5 – bracket for fastening the loosener; 6 – axis of rotation of the loosener; 7 – spring; 8 – thrust plate; 9 – frame

The bracket 5 can be moved along the riser and fixed to it with the help of a bolt-nut fixing pair. The bracket has an axis 6 on which the ripper 3 is mounted. With the help of springs 7, which are connected to the ripper at one end and rest against the stop plate 8 at the other end, the riser of the ripper is made spring-loaded.

During the movement of the combined digger along the rows of chicory root crops, the ripper 3 and the spherical disk 2 destroy the pericarp soil environment and the bonds of the root crop in it due to the rotation of the spherical disk with an angular velocity $\omega_д = dV_д / dt$ and the movement of the ripper (i.e., the disk) with a translational speed $V_д$. At the same time phenomenon (process) occurs, such as the movement of the excavated soil layer along the spherical surface of the disk and, accordingly, its further movement to the subsequent working bodies of the root harvester.

To determine the moment of the amount of movement of the soil that enters the disc per unit of time, or the moment M_s of the amount of movement of the soil layer, it is necessary to determine the average force of the reaction N_d of the disc on the falling layer. At the same time, the average force of the reaction N_d will depend on the value of the mass ms and the velocity vector $\vec{\vartheta}$ of the falling layer of soil on the disc, as well as on the contact area (area of the disc S_d, m^2) on which the layer of soil falls.

The mass of soil that falls on the disc is determined:

$$m_s = \rho_s V_г \quad (1)$$

where ρ_s – the specific mass (density) of the soil, kg/m^3; V_s – the volume of soil that falls on the disc, m^3.

The volume of soil V_s that falls on the disc can be determined according to [8], taking into account the area of the disc S_d on which the soil falls and the unit vector $\vec{n}$, which determines the instantaneous value of the thickness of the layer of soil that falls on the disc, or:

$$V_s = \int_{S_d} n dS_d \quad (2)$$

Then the average reaction force N_d will be determined by the formula:

$$N_d = -\int_{S_d} \rho_s \vartheta_n \left(\vec{\vartheta} \times \vec{n} \right) n dS_d \qquad (3)$$

where $\vec{n}$ – a unit vector that is directed to the point of contact (fall) of the soil layer on the disc.

The volume V_k (m^3) of the soil layer, which s excavated by a spherical disc, or the second supply of the volume of soil, which subsequently enters the following working organs of the root harvester, is determined by the formula:

$$V_k = \vartheta_d S_k = \frac{1}{\rho_s} M_s = 8\vartheta_d D_s^2 \theta_3 \sin\alpha \qquad (4)$$

Thus, the use of the proposed combined digger will increase the technological efficiency of the harvesting process of chicory root crops by increasing the working speed of the root harvester with satisfactory digging quality indicators.

5. Conclusions

From the analysis of the digger working bodies, it was found that the problem of additional loosening of the soil layer in front of chicory root crops during their excavation by single-disc diggers is relevant. Therefore, a promising direction is the improvement of combined diggers, which will ensure effective simultaneous digging and separation of the remains of tops, loose and adhering soil, plant residues from the roots with minimal damage.

The study emphasizes the importance of combining multiple technological operations, such as digging and cleaning, within a single working body to reduce crop losses and minimize damage. The proposed combined digger with a spherical disk and integrated loosener ensures better separation of soil and residual tops, reduces mechanical stress on root crops, and adapts to various soil conditions. These advancements contribute to the efficiency and reliability of modern root harvesting technologies, offering practical solutions for achieving agrotechnical requirements and minimizing resource consumption.

References

1. Baranovskyj, V.M. (2017). The main stages and general principles of current trends of root crop machinery. *Scientific magazine. Visnyk TNTU, 11 (2).* 67–75. [in English].
2. Baranovsky, V., Truhanska, O., Pankiv, M., Bandura, V. (2020). Research of a contact impact of a root crop with a screw auger. *Research in Agricultural Engineering*, *66 (1),* 33–42. URL: https://www.agriculturejournals.cz/web/rae.htm?type=article&id=75_2017-RAE. [in English].
3. Trukhanska, O.O., Shvets, L.V. (2017). Matematychne modeliuvannia protsesu tekhnolohichnoi vzaiemodii koreneplodiv z shnekovoiu poverkhneiu [Mathematical modeling of the process of technological interaction of root crops with the screw surface]. *Machinery, energy, transport of agro-industrial complex, 4 (99)*, 128–132. [in Ukrainian].
4. Trukhanska, O. (2018). Technological interaction of the roots with the screw surface of the cleaning system. *Vibration in engineering and technology, 4 (91),* 63–68. URL: http://vibrojournal.vsau.org/storage/articles/February2020/FfgnmaiE5dbAU20EVl0P.pdf. [in English].
5. Trukhanska, O. (2022). Research of the working process of the cleaning system of machines for harvesting root crops. *Vibration in engineering and technology, 1 (104),* 106–116. DOI: 10.37128/2306-8744-2022-1-13. [in English].
6. Hadaichuk, M. (2024). The process of digging chicory roots with a combined digger. *Scientific Journal of the Ternopil National Technical University, 3 (115),* 62–72. DOI: https://doi.org/10.33108/visnyk_tntu2024.03.062. [in English].
7. Pohorilyi, M.L. (2004). *Buriakozbyralni mashyny: istoriia, konstruktsiia, teoriia, prohnoz [Beet harvesting machines: history, design, theory, forecast*]. K.: Feniks. [in Ukrainian].
8. Trukhanska, O.O., Baranovskyi, V.M. (2014). Eksperymentalni doslidzhennia protsesu vidmynannia hychky vid koreneplodiv [Experimental study of the process of discarding hooks from root crops]. *Scientific review, 6 (7),* 76–84. [in Ukrainian].
9. Baranovskyi, V., Pidhurskyi, M., Dubchak, N., Trukhanska, O. (2011). Eksperymentalni doslidzhennia poshkodzhennia koreneplodiv [Experimental study of root crop damage]. *Bulletin of Ternopil National Technical University, 16 (3),* 95–101. [in Ukrainian].
10. Baranovskyi, V.M., Pidhurskyi, M.I., Pankiv, M.R., Herasymchuk, H.A. (2006). Pat. № 19526 Ukraina. MPK A01D 25/04. Prystrii dlia vykopuvannia koreneplodiv. zaiavnyk i vlasnyk Ternopilskyi natsion. tekhnich. un-t im. I. Puliuia. № u200607381; zaiavl. 03.07.2006; opubl. 15.12.2006. Biul. № 12. [in Ukrainian].

11. Pankiv, M.R., Herasymchuk, H.A. Baranovskyi, V.M., Ramsh, V.Yu. (2009). Pat. № 44747 Ukraina. MPK A01D 25/04. Prystrii dlia vykopuvannia koreneplodiv. zaiavnyk i vlasnyk Ternopilskyi derzhavn. tekhnich. un-t im. I. Puliuia. № u200905065; zaiavl. 22.05.2009 ; opubl. 12.10.2009. Biul. № 19. [in Ukrainian].
12. Baranovskyi, V.M., Pidhurskyi, M.I., Pankiv, M.R., Herasymchuk, H.A. (2011). Pat. № 62598 Ukraina. MPK A01D 25/04. Prystrii dlia vykopuvannia koreneplodiv. zaiavnyk i vlasnyk Ternopilskyi natsion. tekhnich. un-t im. I. Puliuia. № u201014901 ; zaiavl. 10.12.2010 ; opubl. 12.09.2011. Biul. № 17. [in Ukrainian].
13. Kravchenko, I.Ie., Baranovskyi, V.M., Trukhanska, O.O., Pidhurskyi, M.I., Pankiv, M.R. (2013). Pat. № 77568 Ukraina. MPK A01D 25/04. Kombinovanyi kopach koreneplodiv. zaiavnyk i vlasnyk Vinnytskyi natsionalnyi ahrarnyi universytet. opublik. 25.02.2013, biul. №4. [in Ukrainian].
14. Baranovskyi, V.M., Kravchenko, I.Ie., Trukhanska, O.O., Pankiv, M.R. Pankiv, V.R. (2014). Pat. № 92362 Ukraina. MPK A01D 25/04. Kopach koreneplodiv. zaiavnyk i vlasnyk Vinnytskyi natsionalnyi ahrarnyi universytet. opublik. 11.08.2014, biul. №15. [in Ukrainian].
15. Humentyk, M.Ya. (2013). Osoblyvosti tsykoriiu korenevoho i ahrotekhnika yoho vyroshchuvannia [Peculiarities of chicory root and agricultural technology of its cultivation]. *Collection of scientific works ITsB UAAN, 18 (02),* 339–341. [in Ukrainian].

АНАЛІЗ КОНСТРУКТИВНО-ТЕХНОЛОГІЧНИХ АСПЕКТІВ ФУНКЦІОНУВАННЯ КОПАЧІВ КОРЕНЕПЛОДІВ ЦИКОРІЮ

Наведено аналіз конструктивних особливостей і технологічних процесів функціонування робочих органів, призначених для викопування коренеплодів цикорію. На основі ідентифікації структурних моделей викопувальних робочих органів розроблено класифікацію копачів коренеплодів за прийнятими критеріями систематизації.

Проаналізовано характерні конструктивно-технологічні недоліки основних існуючих типів викопувальних робочих органів. Обґрунтовано основні тенденції розвитку дискових копачів і напрямки вдосконалення комбінованих викопувальних систем коренеплодів цикорію з використанням сферичного диска.

Запропонований комбінований викопувач коренеплодів цикорію покращить якісні показники викопування коренеплодів, які відносяться до показників повноти викопування, або зменшення втрат коренеплодів та їх пошкодження.

Отримані аналітичні залежності дають змогу обґрунтувати основні параметри робочого органу та параметри процесу викопування коренеплодів цикорію одностороннім сферичним диском без використання чисельних методів розрахунку, що значно спрощує вирішення завдань дослідження.

Зменшення втрат коренеплодів та їх пошкодження забезпечується застосуванням комбінованого однодискового сферичного копача, який поєднує в собі сферичний диск і розпушувач, розміщений за ним і в зоні його дії, встановлений на стояку диска. Отримані результати досліджень є частковим доповненням до існуючої методики подальшого розрахунку та обґрунтування раціональних параметрів сферичного диска та технологічних параметрів робочих процесів корензбиральних машин.

Ключові слова: *коренеплоди, копач, сферичний диск, розрихлювач, шар ґрунту, класифікація.*
Ф. 4. Рис. 5. Літ. 15.

INFORMATION ABOUT THE AUTHORS

Olena TRUKHANSKA – Candidate of Technical Sciences, Associate Professor, Associate Professor of the Department of Agroengineering and Technical Service of Vinnytsia National Agrarian University (Soniachna Str., 3, Vinnytsia, 21008, Ukraine, e-mail: seaswallow@ukr.net, https://orcid.org/0000-0001-8481-8878).
Maksym HADAICHUK – Recipient of the Third Educational and Scientific Level Department of Agroengineering and Technical Service of Vinnytsia National Agrarian University (Soniachna Str., 3, Vinnytsia, 21008, Ukraine, e-mail: max3novmac@gmail.com, https://orcid.org/0009-0008-8967-8171).

ТРУХАНСЬКА Олена Олександрівна – кандидат технічних наук, доцент, доцент кафедри агроінженерії та технічного сервісу Вінницького національного аграрного університету (ВНАУ, вул. Сонячна, 3, м. Вінниця, Україна, 21008, e-mail: seaswallow@ukr.net, https://orcid.org/0000-0001-8481-8878).
ГАДАЙЧУК Максим Юрійович – здобувач третього освітньо-наукового рівня, кафедри агроінженерії та технічного сервісу Вінницького національного аграрного університету (ВНАУ, вул. Сонячна, 3, м. Вінниця, Україна, 21008, e-mail: max3novmac@gmail.com, https://orcid.org/0009-0008-8967-8171).