INVESTIGATION OF DEGREE OF DAMAGE TO TABLE BEET ROOTS DURING CLEANING WITH SPIRAL CLEANER

Volodymyr Bulgakov[1], Ivan Holovach[1], Volodymyr Martyniuk[1], Oleksandra Trokhaniak[1], Aivars Aboltins[2], Adolfs Rucins[2]
[1]National University of Life and Environmental Sciences of Ukraine, Ukraine;
[2]Latvia University of Life Sciences and Technologies, Latvia
adolfs.rucins@lbtu.lv

Abstract. Efficient cleaning of table beet roots to remove soil impurities and plant debris while minimizing damage to the roots, particularly when using a spiral cleaner – is a pressing scientific and technical challenge in vegetable crop production. Successful addressing this important issue will help improve the quality of the harvested table beet, ensure its high marketability and long-term storage capacity, and reduce the amount of the fertile soil, removed from the field during harvesting operations. Even with high-quality cleaning of the roots to remove impurities, inevitable yield losses occur if their outer surfaces are damaged. This occurs because, during the necessary long-term storage of table beets, rot develops; due to damage, diseases and infections penetrate the interior of the roots, affecting even the undamaged ones. The aim of the study is to improve the quality of cleaning table beet roots of residues, specifically, to reduce the degree of damage by determining optimal design and technological parameters for a spiral cleaner. The article presents a new, more advanced design of a spiral cleaner that makes it possible to reduce the degree of damage to table beetroots during their cleaning. Based on laboratory experimental studies and statistical analysis of measurement results, graphs were constructed showing the relationship between the changes in the degree of damage to table beetroots and changes in the design and technological parameters of the cleaner, specifically, the diameter and mass of the table beet at different drop heights into the cleaning channel of the spiral cleaner. Analysis of the obtained graphs revealed that, as the mass and diameter of the table beetroot increase, damage to its outer surfaces increases. It was also found that, as the drop height of the table beet root into the working channel of the spiral cleaner increases, damage to it inevitably increases. Based on the results of the laboratory experimental study, a graph was constructed showing the distribution of damage types in table beets during cleaning with a newly designed spiral cleaner for a sample of at least 100 roots of varying mass and diameter. The obtained dependences may be used to substantiate the inlet geometry and operating mode of spiral cleaners; for the tested design, the rational drop height should not exceed 14 cm.

Keywords: table beet, spiral cleaner, root vegetable, removal of impurities, mechanical damage, statistical analysis, equivalent diameter, drop height.

Introduction

Cleaning table beetroots, using a spiral cleaner with minimal damage, improves the quality of the harvested crop and reduces the amount of the fertile soil removed from the field during the cleaning operations.

Theoretical and experimental investigations of the root cleaning processes have enabled the selection of an efficient design, kinematic and dynamic parameters for the working parts of the spiral cleaners and their operating modes [1-3].

During the research, particular attention was paid to the degree of cleaning and the degree of damage to the root crops during their separation, using various cleaners [4-6]. However, the analysis of numerous investigations has shown that the existing potato harvesters, equipped with cleaning mechanisms, based on different operating principles, do not fully meet the above requirements. This is primarily because the cleaning components become clogged with soil and plant debris, as the soil often has a high moisture content and plasticity during potato harvesting. Significant damage to the tubers can also occur increasing crop losses.

Analysis of the existing studies has shown that the variety of harvesting conditions, in particular changes in the soil moisture and hardness in the bed area, the presence of stony inclusions, compacted soil formations and plant residues, as well as variations in the mass, size and shape of the crop material, necessitate the adjustment of the technical and technological parameters of the specified separator to ensure stability of the cleaning process [7]. Furthermore, methods that can be used in laboratory conditions do not provide a comprehensive assessment of functioning of the working parts and machines, as a whole, and can only be used for a comparative assessment of the degree of damage and separation of the root crops [7-10].

Studies on sugar beet, which is the closest crop in terms of botanical origin and root structure, show that the impact of loading, cleaning intensity, root tissue strength and the harvesting system significantly affect damage formation and subsequent storage losses [11-20]. In particular, stronger impacts and more aggressive harvesting and cleaning conditions increase the probability of scratches, skin removal, cracking and internal tissue failure [12-14; 17; 18].

At the same time objective assessment of root damage requires clear classification criteria and reproducible measurement procedures. Methods for determining the textural and impact-related properties of beetroots [20; 21] and modern approaches to bruise and damage identification [19; 22] provide a methodological basis for such research.

However, published data specifically on table beets during cleaning in spiral cleaners are limited. Previous studies of spiral separators and related cleaning devices [8] are useful for developing the machine concept, but they cannot replace direct experimental substantiation for table beets because the root mass, diameter, shape and tissue strength substantially influence the damage susceptibility [11; 13; 16; 18; 20].

A review of the literature and an analysis of the performance of the cleaning units in beet- and potato-harvesting machinery have shown that the existing designs and configurations of these units do not fully achieve the required degree of root separation while preventing critical damage to the roots. Although some varieties of table beets resemble potatoes in shape and size (i.e. they are either nearly spherical or slightly elongated), table beets require a separate cleaner design, specifically one that has been developed and is being tested by us.

Therefore, it is essential to develop and further improve new designs for table beet root cleaners and to justify their structural and technological parameters, particularly those of spiral cleaners, which will ensure minimal damage to the roots while maintaining high cleaning efficiency and productivity.

The aim of this study is to improve the quality of cleaning table beets of residues, specifically, to reduce the degree of damage to them, by determining optimal design and technological parameters for a spiral cleaner.

Materials and methods

With the aim of reducing the degree of damage to table beet roots during cleaning by a spiral cleaner, a new design of a laboratory setup has been developed, a general view of which is shown in Fig 1.

The spiral peeler operates as follows. A pile of table beetroots, dug out of the soil (and therefore containing a lot of soil impurities, rootstocks and plant residues), is fed from above onto the cleaning trough, which is constructed in the form of cantilevered spiral springs 10 that are forced to rotate in one direction, and cleaning brushes 14, which are mounted on frames 9 at appropriate intervals and at identical angles of inclination to the horizontal. As a result, all parts of the pile are essentially located inside the cleaning channel in the form of a trapezium, with the upper part pointing downwards. It is precisely this design that ensures that, in the event of the root crops striking the cleaning trough and bouncing, they will inevitably be returned to the interior of this cleaning trough, coming into contact only with the upper parts of the drive cleaning brushes 14.

For the laboratory studies table beets of a variety with a predominantly regular spherical shape were pre-harvested; the tops had already been trimmed, and the roots were extracted from the soil using standard harvesting tools. Cleaning tools were not used in this process. The table beetroots were carefully collected and delivered to the laboratory without any contact with other roots (each root was delivered to the laboratory in the same condition as when it was dug out of the soil). During the experimental studies, the table beets were selected without any mechanical damage, and the weight and diameter of each root were subsequently measured. The weight of each table beetroot was determined using electronic scales (with an accuracy of 0.1 g), and the diameter was measured using a caliper (with an accuracy of 0.1 mm). For the laboratory studies, the root crops weighing 135 g, 205 g, 275 g, 345 g and 415 g were selected, with a permissible deviation of ± 5 g. The diameters of the table beets, selected for the experiments, were 65 mm, 72 mm, 79 mm, 86 mm and 93 mm.

To ensure the purity of the experiment, root crops were used that had been completely cleared of adhering soil, which made it possible to determine the maximum depth of damage to the beetroot, based on the height from which it fell into the cleaning channel of the spiral cleaner.

The drop height of the root vegetable was determined using a ruler, mounted on the spiral cleaner (the measurement accuracy was up to 0.1 mm). During the laboratory studies, the table beet roots were dropped into the cleaning trough of the spiral cleaner from three fixed heights of 14 cm, 22 cm and 30 cm.

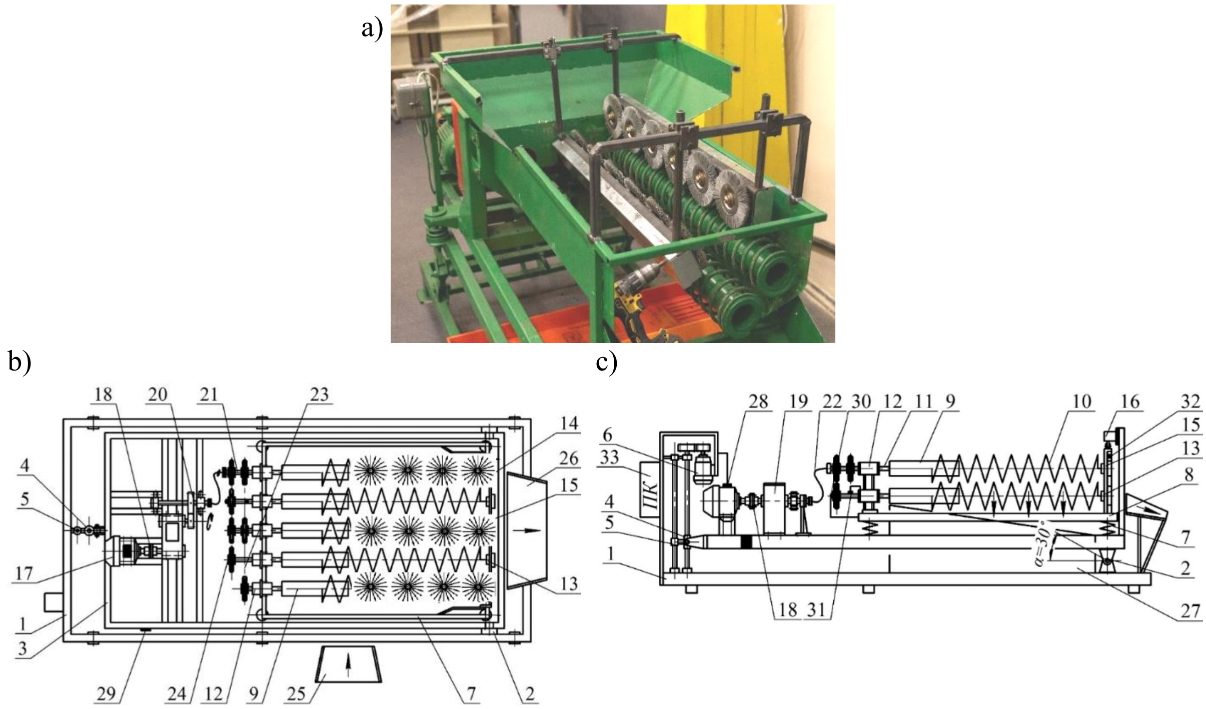

Fig. 1. **General view of a laboratory setup for studying root and tuber crop cleaners (a), its schematic diagram, top view (b) and side view (c):** 1 – main frame; 2 – hinge; 3 – middle frame; 4 – screw pair; 5 – guide; 6 – drive; 7 – elastic supports; 8 – frame; 9 – frames; 10 – cylindrical spring; 11 – shaft; 12 – bearing housing; 13 – bracket; 14 – cleaning brushes; 15 – movable stand; 16 – vibrator; 17 – electric motor; 18 – coupling; 19 – variator; 20 – cylindrical gear; 21 – drive shaft; 22 – flexible shaft; 23, 24 – chain drive; 25 – feed chute; 26 – discharge chute; 27 – soil chute; 28–32 – sensors; 33 – control panel

During the experiments the table beetroots entered the cleaning channel of the spiral cleaner and were transported to the discharge zone. From there they fell onto the discharge chute, were carried outside the cleaner, and were "gently" caught. Thus, during these laboratory experiments, damage to the beetroot tubers could only occur if they fell into the working channel and were transported within it, coming into contact with the cleaning mechanisms. Afterwards, they were inspected to determine the presence of damage and its type (minor scratches, peeled skin, deep scratches, damage to the root itself with fragments breaking off). The depth of damage to the table beet roots was determined using a caliper.

Fig. 2 shows the appearance of damage to the table beets after cleaning on a spiral cleaner.

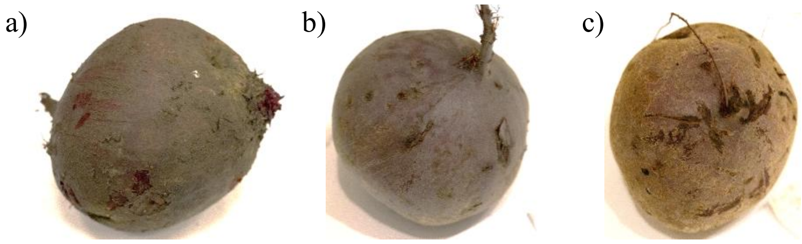

Fig. 2. **Appearance of damage to table beet roots:** a – shallow scratches; b – scraped skin; c – deep scratches

The procedure for measuring the extent of damage to the outer surfaces of the table beets after passing through the cleaning channel of the spiral cleaner and their contact with the cleaning working parts was as follows. Each root was carefully inspected to assess the presence of any damage across its entire spherical surface. In the same manner, i.e. purely visually, the type of each damage was determined. For each root vegetable, information regarding the presence of damage was recorded in the laboratory research log, and the parameters of each type of damage were then carefully determined, and a database was created. Thus, areas of peeled skin were assessed, based on their surface area. To do this, the specified areas were photographed, digitized, and the areas of the scratches were determined using a computer program on PC. If there were scratches on the spherical surface of the beetroot in the form of narrow “thread-like” lines, their lengths were determined in a similar manner. Chips and deep scratches on the roots of table beets were assessed and measured manually (linear dimensions, shape, depth). However, such significant damage was rare.

Statistical analysis of the measurement results, performed using a computer program, developed for PC, made it possible to conduct a realistic evaluation of the measurement results. Based on the results of the laboratory experiments, the operating conditions and parameters of the spiral peeler were determined to ensure that damage to the table beet roots during peeling remains within acceptable limits.

Results and discussion

Based on the results of the experimental research, measurement data were obtained, organized, and subsequently analyzed, using statistical methods with the aid of a computer. As a result, graphs were plotted, showing variation in the damage to the table beetroots as a function of their weight and diameter at different drop heights, as shown in Fig. 3 and Fig. 4.

Analysis of the graphs shows that damage to the table beets increases as their root mass increases; specifically, when the mass ranges from 135 g to 415 g, damage increases by 23-27%. It was also found that the damage to the table beets increases as the drop height of the root increases. Within the range of the table beet drop height from 14 cm to 30 cm, the damage increases by 2-2.7 times.

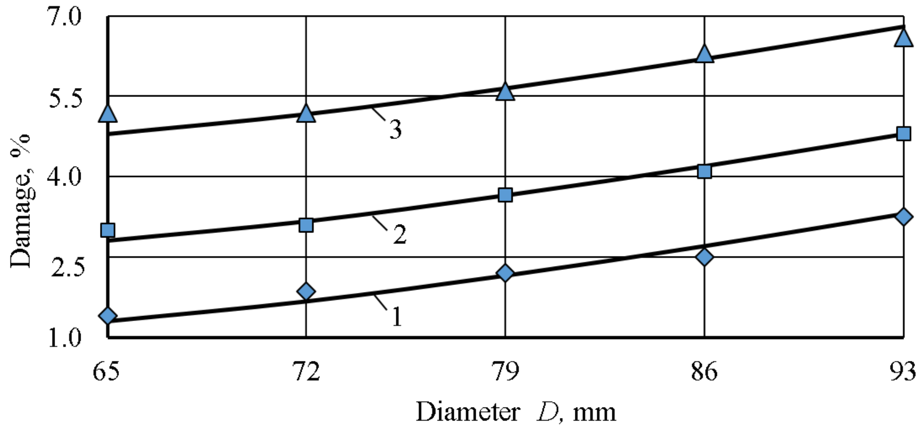

Fig. 3. **Relationship between the degree of damage to the table beetroots and their weight at different drop heights:** 1 – h = 14 cm; 2 – h = 22 cm; 3 – h = 30 cm

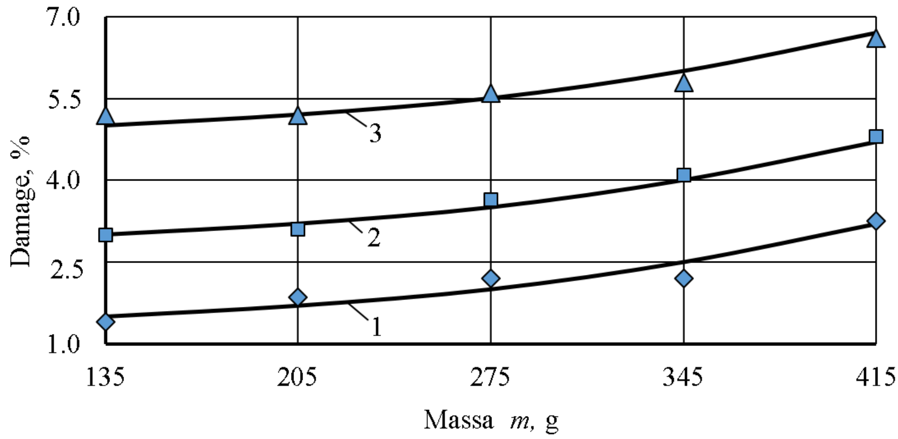

Fig. 4. **Relationship between the degree of damage to the table beetroots and their diameter at different drop heights:** 1 – h = 14 cm; 2 – h = 22 cm; 3 – h = 30 cm

Analysis of the graphs shows that, as the diameter of the table beet root increases, damage to them also increases, specifically, when the diameter of the beets changes from 65 mm to 93 mm, the damage increases by 22.5-26.5%. It was also found that, as the drop height of the table beet root increases, the damage to the root increases. Within the range of drop heights for the table beet from 14 cm to 30 cm, the damage increases, on average, by 2.0-2.7 times.

The obtained tendencies agree with published results for beet crops, according to which the impact severity, harvesting system and root tissue strength significantly affect the formation of surface injuries and subsequent storage losses [12-18; 20; 23]. The predominance of surface defects at a lower impact intensity and the growth of more severe defects at stronger impacts are also consistent with general approaches to bruise and mechanical-damage assessment for horticultural produce [22]. Compared with the previous studies that focused mainly on sugar beet, the present work provides experimental data specifically for table beetroots and for the operating conditions of a spiral cleaner.

Fig. 5 also shows a graph of the distribution of the damage types in table beets during cleaning by a spiral separator for a sample of 100 root vegetables of different weights and diameters at drop heights of 14 cm, 22 cm and 30 cm.

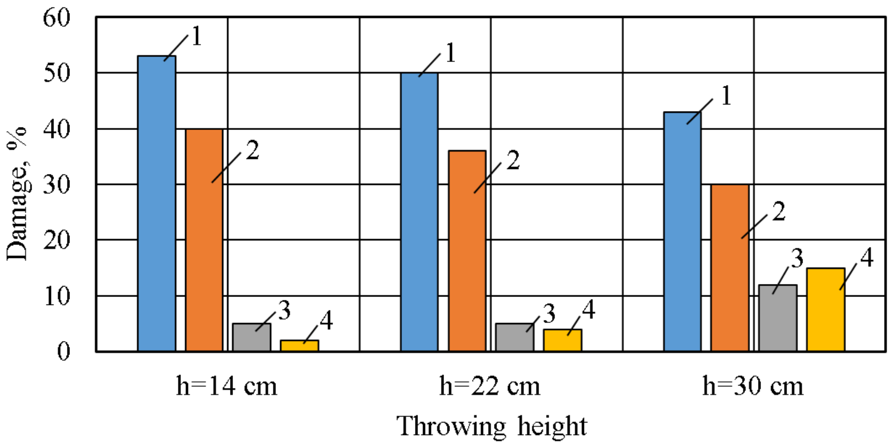

Fig. 5. **Distribution of damage types in the table beets during cleaning using a spiral separator for different drop heights:** 1 – no damage; 2 – minor scratches; 3 – skin scraped off; 4 – deep scratches

The distribution shown indicates that the most severe damage (the presence of deep scratches on the outer surfaces of the root crops) occurs when the drop height of the root crops into the cleaning trough of the spiral cleaner increases. This can be achieved by developing a new design for the loading mechanism of the cleaner that will ensure the specified reduction.

In addition, the graphs of damage to the table beets during cleaning by the spiral separator, obtained and presented in Fig. 3-5, provide grounds for identifying ways how to further improve the cleaning process and the design of the developed spiral cleaner. Thus, for each average diameter range of spherical table beet roots, the linear dimensions of the cleaning channel of the spiral cleaner itself must be adjusted.

If soil adheres to the spherical surfaces of the table beetroots, the degree of damage can be reduced to 5-7%. However, soil adhering to the smooth spherical surfaces of the root vegetables is possible if the total moisture content of the soil in which the root vegetables were located prior to harvesting was 21% or higher. Undoubtedly, the operation of the harvesting machines in this case will be very difficult.

Based on the results of these laboratory experiments, other optimal parameters for the root crop cleaner can be selected, which will improve the cleaning quality of table beets using a spiral cleaner and significantly reduce damage to the roots.

Conclusions

1. The article presents the design diagram and general view of a newly developed experimental setup for cleaning table beet roots of soil impurities and plant debris, which has made it possible to significantly improve the cleaning quality and reduce the degree of damage.

2. Based on laboratory experiments and the statistical analysis of their results using a computer, graphs were plotted, showing how the degree of damage to the root crops varies with changes in the diameter and weight of the table beet root crops at different drop heights into the working channel of a spiral cleaner.
3. Analysis of the graphs obtained revealed that, as the weight of the table beetroot increases, the damage increases, the extent of damage also increases; specifically, when the weight of the beet ranges from 135 g to 415 g, the damage increases by 23-27%.
4. An analysis of the graphs also shows that as the diameter of the table beet root increases, the extent of its damage increases, specifically, when the diameter of the beet changes from 65 mm to 93 mm, its damage increases by 22.5-26.5%.
5. It has been established that, as the drop height of the table beetroots increases, the extent of their damage also increases. Within the range of drop heights from 14 cm to 30 cm, their damage increases by a factor of 2 to 2.7. The graph presented, showing the distribution of damage types in the table beets during cleaning by a spiral separator for a sample of 100 roots of various weights and diameters, indicates that significant damage can be avoided by reducing the drop height of the table beet roots into the cleaning channel of the spiral cleaner. This requires the development of a loading mechanism design for the cleaner that takes this circumstance into account. Additionally, for each average diameter range of spherical table beetroots, the linear dimensions of the cleaning channel of the spiral cleaner must be adjusted.

Author contributions

Conceptualization, V.B. and I.H.; methodology, V.B., I.H. and V.M.; investigation, I.H., V.M. and O.T.; formal analysis, V.B., I.H. and A.A.; visualization, V.M. and O.T.; writing – original draft preparation, I.H. and V.B.; writing – review and editing, A.A., A.R. and V.B.; supervision, V.B.; project administration, V.B. All authors have read and agreed to the published version of the manuscript.

References

[1] Bratucu Gh., Paunescu D. D. Establishing the Optimum Operating Mode of Sugar Beet Head Cutting Equipment Using a Cylindrical Palpator. Bulletin of the Transilvania University of Braşov, Romania, Series II, vol. 8, 2015, pp. 51-56.
[2] Trokhaniak O.M., Hevko R.B., Lyashuk O.L., Dovbush T.A., Pohrishchuk B.V., Dobizha N.V. Research of the of bulk material movement process in the inactive zone between screw sections. INMATEH - Agricultural Engineering, 60 (1), 2020, pp. 261-268.
[3] Ichiki H., Nguyen Van N., Yoshinaga K. Stone-clod separation and its application to potato in Hokkaido. Engineering in Agriculture Environment and Food, 6 (2), 2013, pp. 77-85.
[4] Guo W., Campanella O. H. A relaxation model based on the application of fractional calculus for describing the viscoelastic behavior of potato tubers. Transactions of the ASABE, 60 (1), 2017, pp. 259-264.
[5] Bulgakov V., Nikolaenko S., Adamchuk V., Ruzhylo Z., Olt J. Theory of retaining potato bodies during operation of spiral separator. Agronomy Research, 16 (1), 2018, pp. 41-51.
[6] Bulgakov V., Nikolaenko S., Adamchuk V., Ruzhylo Z., Olt J. Theory of impact interaction between potato bodies and rebounding conveyor. Agronomy Research, 16 (1), 2018, pp. 52-64. DOI: 10.15159/AR.18.037.
[7] Olt J., Bulgakov V., Trokhaniak O., Klendii M., Gadzalo I. A., Ptashnik M., Tkachenko M. Harrow with screw-type operating tools: Optimisation of design and process parameters. Agronomy Research, 20 (4), 2022, pp. 751-763.
[8] Bulgakov V., Ivanovs S., Adamchuk V., Ihnatiev Y. Investigation of the parameters of the experimental spiral potato heap separator on the quality of work. Agronomy Research, 15 (1), 2017, pp. 44-54.
[9] Bulgakov V., Nikolaenko S., Adamchuk V., Ruzhylo Z., Olt J. Mathematical model of cleaning potatoes on surface of spiral separator. Agronomy Research, 16 (4), 2018, pp. 1590-1606. DOI: 10.15159/AR.18.173.11.

[10] Jin X., Du X., Wang S., Ji J., Dong S., Wang D. Design and Experiment of Stems Cutting Device for Carrot Harvester [J]. Transactions of the Chinese Society for Agricultural Machinery, vol. 47 (3), 2016, pp. 82-89.
[11] Alizadeh H., Segerlind L. J. Some Material Properties of Sugar Beet Roots. Applied Engineering in Agriculture, 13 (4), 1997, pp. 507-510. DOI: 10.13031/2013.21619.
[12] Bentini M., Caprara C., Rondelli V. The Use of an Electronic Beet to Evaluate Sugar Beet Damage at Various Forward Speeds of a Mechanical Harvester. Transactions of the ASAE, 45 (3), 2002, pp. 547-552. DOI: 10.13031/2013.8848.
[13] Bentini M., Caprara C., Rondelli V. Mechanical Properties of Sugar Beet Roots. Transactions of the ASAE, 48 (4), 2005, pp. 1429-1439. DOI: 10.13031/2013.19168.
[14] Hoffmann C. M., Engelhardt M., Gallmeier M., Gruber M., Märländer B. Importance of harvesting system and variety for storage losses of sugar beet. Sugar Industry, 143 (8), 2018, pp. 474-484. DOI: 10.36961/si19782.
[15] Hoffmann C. M., Leijdekkers M., Ekelöf J., Vancutsem, F. Patterns for improved storability of sugar beet - importance of marc content and damage susceptibility of varieties in different environments. European Journal of Agronomy, 101, 2018, pp. 30-37. DOI: 10.1016/j.eja.2018.08.004.
[16] Kleuker G., Hoffmann C. M. Influence of tissue strength on root damage and storage losses of sugar beet. Sugar Industry, 145 (7), 2020, pp. 435-443. DOI: 10.36961/si24556.
[17] Kołodziej P., Gołacki K., Boryga M. Impact characteristics of sugar beet root during postharvest storage. International Agrophysics, 33 (3), 2019, pp. 355-361. DOI: 10.31545/intagr/110810.
[18] Kołodziej P., Stropek Z., Gołacki K. Mechanical Properties of Sugar Beet Roots under Impact Loading Conditions. Materials, 16 (3), 2023, 1281. DOI: 10.3390/ma16031281.
[19] Nasirahmadi A., Wilczek U., Hensel O. Sugar Beet Damage Detection during Harvesting Using Different Convolutional Neural Network Models. Agriculture, 11 (11), 2021, 1111.
[20] Nedomová Š., Kumbár V., Pytel R., Buchar J. Mechanical properties of sugar beet root during storage. International Agrophysics, 31 (4), 2017, pp. 507-513. DOI: 10.1515/intag-2016-0081.
[21] Kleuker G., Hoffmann C. M. Method development for the determination of textural properties of sugar beet roots. Sugar Industry, 144 (7), 2019, pp. 392-400. DOI: 10.36961/si23306.
[22] Opara U. L., Pathare P. B. Bruise damage measurement and analysis of fresh horticultural produce - A review. Postharvest Biology and Technology, 91, 2014, pp. 9-24. DOI: 10.1016/j.postharvbio.2013.12.009.
[23] Vaccari G., Marzola M. G., Mantovani G., Bentini M., Baraldi G., Spettoli P. Chemical and enzymatic changes in strongly damaged beets. Food Chemistry, 27 (3), 1988, pp. 203-211. DOI: 10.1016/0308-8146(88)90063-5.