Advanced machine for sorting potatoes tubers

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Abstract. The article provided the results of studies to improve the design of a machine for potato sorting, the working surface of which consists of belts at different speeds. The aim of the work is to increase the accuracy of potato sorting according to their external dimensions, without damage. Using theoretical, one-factor, and multi-factor experiments and experiments in production conditions, the following optimal parameters of the improved patented machine for sorting potato were established: - the speed of a slow-moving belt of 0.4 m/s; - the speed of a fast-moving belt 0.6 m/s; - the angle between adjacent belts 0.46°/26. With these values of the factors, the accuracy of the criteria of the sorting machine is 95%. An experimental model of the machine tested on the fields of farms of the Ferghana region of the Republic of Uzbekistan.

In the process of potato sorting, it was revealed that the indicator of damage to potato in the course of the experiments did not exceed 0.5%. It was found that to achieve 95% accuracy of sorting, at a feed speed of potato heap onto the belt surface of the machine 4.5 kg per second, the angle between the belts should be 0.46°26, the speed of the slow-moving belt should be 0.4 m/s and the speed of the second should be 0.6 m/s.

1. Introduction

Potatoes are cultivated in 130 countries of the world on an area of over 18 million hectares, where more than 300 million tons of tubers are harvested annually [1, 2, 3].

Worldwide, measures are being taken to prevent the loss of food and its waste throughout the value chain [4]. Currently, potato sorting in farms accounts for significant labour costs due to low mechanization and automation of the process.

Consequently, many scientific works are devoted to the study of problems and solutions for sorting fruits and vegetables. Non-destructive quality control systems for mechanized or robotic sorting systems are relevant [5]. There is a technical review of optical non-destructive quality control for robotic systems for sorting fruits and vegetables [6], an acoustic sorting system for detecting a hollow heart in potato tubers has been investigated [4], using laser backscattering of light, the classification of potato tubers was performed [7]. Recent advances in computer vision (computer vision) have allowed the use of a wide variety of applications in all areas of life [8].

To determine the potato damage from shock, the creep behavior of potato tubers was studied [9]. There is a review of the mechanical condition of the soil and the development of an inexpensive stone block separator for a new potato cultivation system [10].
Scientific work is undertaken to mechanization and automation the sorting of various vegetables and fruits. A field machine was developed and investigated for sorting fruits, sorting, and filling bins during harvesting [11]. There is also an automatic sorting system for fresh porcini mushrooms based on image processing. The system consists of a transportation mechanism, an image acquisition system, a control module, and an actuator [12].

A mobile sorting machine for citrus has been developed [13].

It is known that to evaluate the quality of potatoes in a non-destructive way, the method of ultrasonic testing under water was used without pressing ultrasonic sensors to the potatoes. The possibility of developing an underwater ultrasonic sorting machine for potatoes was investigated. Graphic programming software was used to collect ultrasonic signals, calculate the spectral moment, and build functions for classifying potatoes. The research results were used to control the mechanism for sorting potatoes [14].

Among the electronic methods that were used to track and quickly measure the qualitative characteristics of potatoes, visual and spectral analysis systems showed the most promising applicability, reliability, and stable performance. The detection of external and internal defects associated with potatoes during harvesting and handling operations has become possible using non-destructive methods. Commercial electronic systems used to sort tubers and potato products are being introduced into the potato industry and are discussed and discussed in detail in connection with operating theories and performance [15].

The distinction between potato tubers and lumps is the first step in developing an automatic separation system for potato harvesters. In this study, an acoustic intelligent system was developed for high-speed discrimination between potato tubers and soil lumps [16].

An acoustic sorting system was developed to detect hollow hearts in potato tubers. The system includes a microphone, equipment for digital signal processing, and equipment for processing materials. When struck with a steel plate, it was found that solid potato tubers produce sounds of a higher magnitude than hollow tubers. One of the distinguishing features was the integrated absolute value of the microphone output signal. Two other characteristics were the number of data points in the digitized microphone signal after impact, which has slopes and values below predetermined threshold levels. The classification accuracy of this system was approximately 98% [17], [18].

Processing potato tubers at all stages of the production chain are of great importance since it can have a strong impact on the final quality of products derived from potatoes. Potato tubers can vary greatly in size, shape, and regularity. A product with a good appearance, size, and uniform shape will always be preferred by most consumers and will have the best selling appeal. Consequently, sorting processes will ensure that products meet certain quality requirements.

There is a real need for standardization of the analysis of potatoes, especially since the quality assessment depends on the acceptance or rejection of the submitted batches of potatoes. In this sense, automation is desirable because it can ensure consistent product quality and handle large volumes. A fully automated inspection station requires the inclusion of machine vision and automation in a system consisting of appropriate hardware and software, both for product processing and evaluation. The paper describes the process of how potatoes are sorted automatically in industry, and what basic characteristics of potatoes and surface defects determine the strategies that must be applied for proper classification [19].

Volume is one of the important parameters for assessing the quality of potatoes. To automatically determine the volume of potato tubers, this method is known for measuring the volume of potatoes based on the RGB-D camera. The new method was developed to measure the volume of potatoes and built using a new image processing algorithm for deep images. The experiment was conducted with a depth of image collection and determination of the volume of 120 potatoes. According to the observation of the form, the selected potatoes were empirically divided into a group of regular and irregular shapes. 60 potatoes with the best appearance and spheroidal shape were marked as ordinary potatoes, and 60 potatoes with the worst appearance and curved shape were marked as irregular potatoes. When checking the algorithmic feasibility of the system and the accuracy of the
measurement results, the results show that: the forecast error of 60 normal potatoes is 9%; the forecast error of 60 irregular potatoes is 30%, which can be used to measure the volume of potatoes without damage [20].

Based on the abovementioned the aim of the study is to develop the design of a machine for sorting potato tubers with an improved sorting surface and high efficiency, designed to separate into several fractions according to the external dimensions of the potato tubers. The object of the study is potato tubers, the belt surface of the machine for sorting potatoes according to the external dimensions of the tubers.

The subject of the study is the ratio of the belt speeds of the machine with the geometric dimensions of the tubers, the mathematical relationship characterizing the relationship with the angle between the belts, the regression equations and the laws of movement of tubers along the sorting surface.

2. Methods
In this regard, the creation of machines for sorting potatoes with high technical and economic indicators is an urgent task [21].

The world is undergoing a transition to machine-technological cultivation of the bulk of the potato crop using highly efficient technology. In the leading countries of the European Union for potato growing, this process is almost complete. To reduce manual labor and improve the quality of goods in potato growing, various foreign companies produce a complex of special equipment [22].

To qualitatively sort the potatoes by their external dimensions, taking into account the size and mass properties of the tubers of the cultivated potato varieties we propose a new design of the sorting machine [23].

The potato sorting machine comprises a conveyor 1 for loading tubers, a sorting surface 2, and conveyors 3-7 for carrying out tubers selected for size fractions. Sorting surface 2 is formed of infinitely closed flexible elements (belts) enveloping pulleys 8-11 of the same diameter mounted on shafts with the possibility of axial movement (figure 1).

During the operation of the machine, it was revealed that the accuracy of the sorting of tubers depends on the angle between the belts of the working surface $\alpha$, the speed $v_1$ of the slowly moving belt-1, the speed $v_2$ of the belt-2, and studies were conducted to identify their optimal value.

A distinctive feature of the design of the developed machine is the different speed of the belts forming its working surface. Due to the difference in speed of the belts, the tubers make a complex movement along the sorting surface and adjust to the holes between the belts. This method improves the accuracy of sorting. To achieve the goal theoretical studies were carried out to determine an acceptable value for the ratio of speeds of machine belts depending on the size of the tubers being sorted.

![Figure 1. Scheme of the proposed machine.](image-url)
The mathematical relationship between the belt speeds depending on the geometric dimensions of the potato tubers, the distance between the belts, the angle between the belts, the velocity vector at the point where the tuber touches the belt and the angle changes between the belt velocity vector is as follows (figures 2, 3).

\[
\frac{v_2}{v_1} = \left( \frac{h_1 \sqrt{k^2 - 1} + \sqrt{(kh_1)^2 - h_2^2}}{x_2 \cos(\alpha + \beta) \cos \beta} \right) + 1,
\]

where \( k \) is the ratio of potato tuber length to thickness.

This expression allows us to determine the optimal value of the ratio of belt speeds depending on the size of the potato tubers, the established requirements for sorting, and the angles between the belts. If we take into account that \( h_1 = 35 \text{ mm}, h_2 = 45 \text{ mm}, k_{\text{max}} = 1.5 \), from figure 3 \( \alpha = \arctan \left( \frac{45 - 35}{667} \right) = \arctan 0.0135 = 0^\circ 48' \), the value of \( \beta \) is 60°, \( X_2 \approx 667 \text{ mm} \), it can be determined that the ratio of belt speeds of the sorting machine is \( v_2 / v_1 = 1.41 \) [24], [25].

![Figure 2. The position of the potato tuber on the working surface and velocity vectors.](image)

![Figure 3. The movement pattern of potato tubers on the surface.](image)

Experimental studies were conducted, and the parameters and the optimal value of the operating modes of the sorting machine were substantiated in the next stage [26], [27].

The movement of potato tubers and the determination of the parameters of the sorting machine were carried out in a specially organized laboratory at the Margilan Mechanical Plant. To conduct a one-factor experiment 30 pieces of potato tubers of one fraction were laid out on a sorting surface. The speed of the low-speed belt at a different speed of the fast-moving belt was set. As a result of successive experiments the following results were obtained: A low-speed belt 1 was set at 0.4 m/s. The distance between the belts increases from 30 mm to 45 mm. The length of the part of the sorting surface of the experiment is 60 cm. From the potato heap 30 longest tubers suitable for the experimental fractions were selected. The distance between the belts was adjusted according to the thickness of the potato tubers. High-speed belt 2 is set to an initial speed of 0.45 m/s. Potato tubers
were located at the beginning of the sorting surface of the experiment, as shown in figure 3.

The machine was driven. All potato tubers fell through the corresponding section of the sorting surface. Then the speed of the belt 2 gradually increased and the movement of potato tubers was observed. With a belt speed of 2 equal to 0.6 m/s, almost all potato tubers fell through the belts in the corresponding section of the sorting surface. When reaching a belt 2 speed of 0.7 m/s, an early rotation of the potato tubers and a jam between the belts were observed. The angle between the belts is set to 0°46′48 ″.

Thus, one of the main values for further research was determined. Therefore, as revealed by theoretical studies, the ratio of the speeds of 2 and 1 belts should be 1.4-1.6, or the difference between them should be 0.2 m/s (figure 4).

To study the size and mass properties of potato tubers, 45 kg of potatoes were selected. The sizes and weights of each potato tuber were measured, and using the computer program the following regression equation was formulated, which reflects the dependence of the thickness, width, and length of potato tubers on mass:

\[
m_{\text{small}} = 0.59l + 0.88b + 0.72c - 33; \\
m_{\text{medium}} = 0.83l + 0.89b + 1.36c - 52; \\
m_{\text{large}} = 1.69l + 1.99b + 3.01c - 235. \\
\]

(2)

According to agrotechnical requirements, when separating tubers into fractions, the main criterion is to sort them by weight. From the dependencies between the size and mass of potato tubers, with a change in the average and large size of the thickness of the tubers, the largest mass change was observed in comparison with other sizes [28].

At a belt speed of 0.45 m/s, and a speed difference between 2 and 1 belts of 0.2 m/s, an angle between the belts of 0°46′26″ was a good sorting (figure 5).
The next stages of the experiment were carried out at a belt speed of 1.045 m/s, the difference between the speeds of belts 2 and 1 was 0.2 m/s, and the angle between the belts was from 0°45′ to 0°48′.

After image processing and analysis, it was confirmed that the acceptable angle between the belts should be 0°46′26″ (figure 6).

As a result of the research, the parameters and the operating mode were established that provide the highest accuracy of sorting the belt sorting machine: belt speed 1 – 0.45 m/s, belt speed difference – 0.2 m/s, the angle between belts - 0°46′26″, when a potato embankment is fed for 1 s at a speed of q = 4.5 kg/s onto the sorting surface, 95% of the sorting accuracy is ensured [29].

The optimal values of the studied parameters in theoretical studies and one-factor experiments of the sorting machine were determined using the methods of mathematical planning of multi-factor experiments.

\[
Y = 84.75 - 1.6x_1 - 1.2x_2 - 2.3x_3 - 5.75x_1^2 + 2.25x_1x_2 + 0.75x_1x_3 - 7.75x_2^2 + 2x_1x_3 + 7.75x_3^2.
\]  
(3)

An analysis of the obtained regression equation shows that all factors significantly affect the evaluation criteria.

From equation (3) we can see that the accuracy of the sorting machine is difficult to depend on variable factors. As belts increase in speed, sorting accuracy decreases. Also, increasing the angle between the belts reduces the accuracy of sorting.

The operating speed of the machine is related to the speed of the belts. However, higher belt speeds result in less sorting accuracy. To ensure maximum operating speed during the experiments, maximum belt speeds were obtained.

From the regression equation (3) the condition is accepted that the criterion "Y" should have a maximum value. This problem was solved using the “search for solutions” action of the Excel program on a Pentium IV PC, the optimal values of the volatile factors in encoded form were obtained, and the encoded values were converted to natural values (table 1).
Table 1. Optimal sorting machine parameters.

| Factors                  | unit of measurement | Symbol | Encoded value | Actual value |
|--------------------------|---------------------|--------|---------------|--------------|
| Slow belt speed, \(v_1\) | m/s                 | \(x_1\) | -0.252        | 0.4122       |
| Belt speed, \(v_2\)     | m/s                 | \(x_2\) | -0.243        | 0.6135       |
| The angle between the belts, \(\alpha\) | degree | \(x_3\) | -1            | 0°45'36''    |

3. Results and discussion

Thus, the optimal parameters of the sorting machine that ensure the fulfillment of the above conditions are determined:
- the speed of a slowly moving belt of 0.4 m/s;
- speed of a fast-moving belt 0.6 m/s;
- the angle between adjacent belts 0°45'36''.

With these values of the factors, the accuracy of the criteria of the sorting machine is respectively 95%.

An experimental copy of the created sorting machine was tested on the fields of farms of the Ferghana region of the Republic of Uzbekistan.

In the experiment, the speed of belt 1 was 0.4 m/s, the difference in the speed of belts 2 and 1 was 0.2 m/s, that is, the speed of belt 2 was 0.6 m/s, the angle between the belts was 0°46'26''. The feed rate of potato piles to the sorting surface is set at \(q = 4.5\) kg/s. The working process of the sorting surface was evaluated by the smooth movement and sorting of a pile of potatoes on the surface.

An analysis of the video records showed that, at the given parameter values, the sorting process was carried out stably.

Then, during one cycle of the machine, the sorting process is investigated. Moreover, the accuracy of sorting was 95%.

From experiments it was found that the sorting machine does not change its characteristics under any conditions.

To determine the damage indicators in the process of sorting potato tubers, it was revealed that the indicator of damage to potato tubers in the course of the experiments did not exceed 0.5%.

The experimental model of the machine reliably performed the technological process specified in the tests, and its performance indicators fully comply with the established requirements.

Having ensured the accuracy of the sorting machine for potato tubers, after collecting potato tubers in the sorting process due to labor-saving by sorting 10 tons of potato crop, this machine achieved significant economic efficiency

4. Conclusions

As a result of the study, the design of a machine for sorting potato tubers with an improved sorting surface and high efficiency was developed. The machine is designed to separate potato tubers into several fractions according to their external dimensions.

Based on the studies and experimental data conducted on the experimental model of the machine, the following conclusions are made:
1. The developed machine for sorting potato tubers will ensure the sorting of potato tubers with an accuracy of 95% with almost no damage.
2. The optimal parameters of the improved machine for sorting potato tubers are established.
3. It has been experimentally established that the damage index of potato tuber machines does not exceed 0.5%.
4. The geometric shapes and size and weight indicators of the tubers of various varieties of potatoes made it possible to determine the feasibility of using a machine for sorting potato tubers.
5. It was found that to achieve 95% accuracy of sorting the machine, at a feed speed of potato heap to the surface of the machine 4.5 kg per second, the angle between the strips should be 0.46°26', the
speed of the slowly moving belt should be 0.4 m/s, and the speed of the second should be equal to 0.6 m/s.

6. Experimental studies have shown that the developed machine for sorting potato tubers reliably performs an established technological process, and its performance indicators fully comply with agrotechnical requirements and technical conditions.

7. Using the machine for sorting potato tubers yields 900000-1000000 Uzb soums of economic efficiency per 10 tons of potatoes by reducing labor costs for sorting potatoes.

The achieved results will be used in the manufacturing of industrial design of the machine.

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