DESIGN OF CUTTING DEVICE FOR DECAPITATION OF POTATO SHOOTS

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Abstract. Potatoes are one of the most popular agricultural crops. One of the eco-friendly ways to increase the yield of potatoes is to use the internal potential of the plant, or rather, to artificially redirect the vector of its development. Such methods include a technique called “decapitation”, which consists in stimulating the development of tubers by increasing the area of the leaf surface of the tops. The process of decapitation consists in the mechanical removal of the upper part of the plant in the early stages of its growth. For decapitation of potato shoots it is proposed to use a mechanized device, one of the main elements of which is a rotary cutting device, which has a fairly simple design of the cutting part and the drive. For devices of this type the main factor that affects the cutting process is the speed of the knife. As a result of laboratory studies, it was determined that in order to ensure the free cutting of potato shoots, the knife of the cutting device must have a linear speed of more than 5.5 $m \cdot s^{-1}$. The obtained values allowed us to conclude that the main problem when using the cutting device in the potato decapitation device will not be the cut of the shoots, but its interaction with other systems of the device: pneumatic boot lift and disinfection system. To ensure normal joint operation of these systems, it is proposed to use a disk knife with a smooth blade for cutting plants. The possibility of cutting plants with such a device was proved experimentally at a circumferential disk speed of 6 and 18 $m \cdot s^{-1}$. It is concluded that in order to achieve a guaranteed cut of shoots with a disc knife it may be necessary to install support elements that exclude bending of the cut part of the plant and to determine the optimal design and technological parameters of the disc knife it is necessary to perform field studies.

Keywords: potatoes, decapitation, cutting device, supportless cutting, cut quality.

Introduction

Potatoes are one of the most popular agricultural crops cultivated in Russia, both in private plots and on an industrial scale. Consumption of this vegetable in the country per capita is at the level of 110-120 kg per year. Potato consumers focus on the quality of the product, the presence of useful and absence of harmful substances in it. Potato growers are more interested in the yield of the crop, its resistance to diseases, exactingness to the cultivation conditions and suitability for mechanized harvesting. In order to ensure that the wishes of consumers and producers are satisfied, potato production technologies should be applied that will allow for a high yield with the proper quality of the product obtained and the minimum cost.

In the course of the long history of plant cultivation man has created many ways to increase their productivity and improve the quality of the products obtained. Carefully observing the growth of plants, it was found that the removal of its individual parts, which at first glance should lead to negative consequences for the plant and, ultimately, to a decrease in the amount of production obtained, on the contrary, has a positive effect on the vital activity of the plant and contributes to an increase in and (or) improving the quality of the resulting products [1-4]. The correct (scientifically grounded and technologically verified) change in the natural balance between the aboveground part and the root system of a plant, by mechanically removing individual fragments of its aboveground part, is able to mobilize, which has become unnecessary for a while, the potential of the root system, directing it in the right direction. This initiates a number of biochemical processes caused by stress, which ultimately lead to a rejuvenating effect [5].

One of the environmentally friendly ways to increase the yield of potatoes is to use the internal potential of the plant, or rather the artificial redirection of the vector of its development. These methods include a technique called “decapitation”, which consists in stimulating the development of tubers by increasing the leaf surface area of the tops, which is possible when the apical dominance of the apical bud is removed. The decapitation process consists in the mechanical removal of the upper part of the plant in the early stages of its growth.

When observing the further growth of plants exposed to this effect, some scientists conclusively note a number of positive effects: intensive formation of high photosynthetic activity of plants, accompanied by an increase in the area (mass) of tops and, as a consequence, yield by 20-30%; healing of potato plants, due to the fact that the flowering of plants does not occur, the total duration of the

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growth period and the total duration of the growing season increase, while inhibition of viruses in plant cells occurs [5-6]; reducing the susceptibility of tubers to fungal infections (rhizoctonia and silver scab), which allows decapitation to be considered as a promising environmentally safe method of protecting potato seed material in elite and reproductive seed culture [7].

Materials and methods

To achieve a significant effect from decapitation, at least 40% of potato shoots must be subjected to this procedure. To accomplish this task, at the level of the invention, a device for mechanized decapitation of potato shoots was proposed [8], which performs their preliminary vertical alignment using an ascending air flow and a non-supporting cut with a knife, which is treated with a disinfectant solution and provides simultaneous disinfection of the cut site, which reduces the likelihood of damage plants with viruses. It is proposed to apply the solution to the knife by feeding it in a fine droplet state, using a standard slot spray gun.

In the considered device, for decapitation of potato shoots, it is proposed to use a rotary cutter, which has a rather simple design of the cutting part and drive, in contrast to the retaining cut apparatus [9]. This will simplify the design of the device in a multi-row design, since it will require an individual drive for each working section to adapt to the height of the cultivated plants located in adjacent rows.

One of the parameters required for choosing the design and operating mode of this device is the value of the knife speed, which provides a high-quality and guaranteed cut of the plant. In [10], it was assumed that this value of the rate will be less than for a significant number of herbaceous plants, since potato shoots in the early stages of growth have low mechanical strength.

Experimental studies were carried out to determine the speed of the knife required for the unsupported cut of potato shoots. For this, a pendulum head was made (Fig. 1) at the end of the rod, at a distance of 2.26 m from the swing axis there was a plate knife 4. On the copra rod, there were also loads 3 with a total weight of 20 kg, with the possibility of their longitudinal movement along the rod and fixing in the required position.

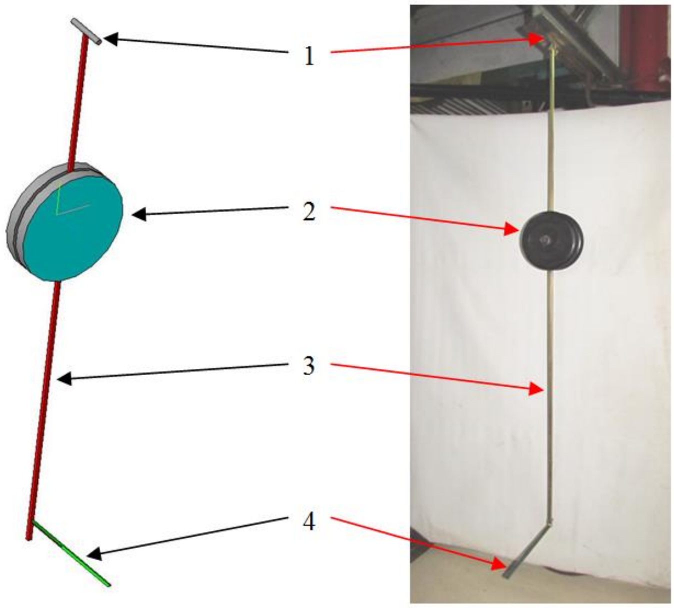

Fig. 1. **Diagram and general view of the device:** 1 – suspension axis; 2 – rod; 3 – weight system; 4 – knife

To determine the parameters of the pile driver and the speed of the knife at the moment of contact with the plant, we used the theory of a physical pendulum set forth in works [10-12], according to which the linear velocity of the pendulum at the lowest point of its stroke is determined based on the law of conservation of energy for rotational motion according to the dependence.

$$\upsilon = R\sqrt{\frac{2\sum m_i g r_i}{J}(1-\cos\varphi_0)}\text{ , m·s}^{-1} \quad (1)$$

where R – shoulder of the knife location relative to the suspension axis of the rod, m;
m_i – mass of the i-th part of the copra, kg;
g – acceleration of gravity, m·s^{-2};
r_i – distance of the center of gravity of the i-th part from the axis of the suspension of the rod, m;
J – moment of inertia of the pile driver relative to the suspension axis, Nm·s^{-2};
φ_0 – initial deflection angle of the rod.

In accordance with this relationship, obtaining high knife speeds will be ensured, when the center of gravity of the pile driver is shifted to the axis of its suspension and the initial angle of deflection of the rod from the vertical position is increased.

In addition, the speed of the knife is influenced by the value of the moment of inertia of the copra equipment hammer, which for significant angles of deflection of the physical pendulum is determined by dependence

$$J = \frac{T^2}{(4K)^2} mgr, \text{ Nm·s}^{-2}; \quad (2)$$

where T – period of oscillation of the pendulum, s;
K – complete elliptic integral of the first kind;
m – total mass of the pendulum, kg;
r – distance from the center of mass of the pendulum to the axis of its suspension, m.

The value of K depends on the initial angle of deviation of the pendulum from the vertical [11] and can be determined from the dependence

$$K = \int_0^{\frac{\pi}{2}} \frac{d\xi}{\sqrt{1 - \sin^2\frac{\varphi_0}{2}\sin^2\xi}}. \quad (3)$$

Also, the value of K for some values of the angles φ_0 can be determined using the tables presented in [11].

Taking into account the considered dependencies, formula 1 for calculating the linear speed of the knife fixed on the pile driver rod will take the form

$$\upsilon = \frac{(4K)R}{T}\sqrt{2(1 - \cos\varphi_0)}. \quad (4)$$

Based on the obtained dependence, in order to determine the linear speed of the knife fixed on the rod of the copra at the lowest point of its stroke, it is necessary to know the pile driver oscillation period, the knife distance from the suspension point R and the initial angle of deflection of the rod from the vertical φ_0.

The period of oscillation was determined experimentally, for which the rod of the copra was deviated at a certain angle from the vertical position and oscillated under its own weight. With the help of a stopwatch, the duration of 20 oscillations (t, s) was measured and the period of one full oscillation was calculated ($T = t/20$, s).

Results and discussion

The results of the experimental studies have shown that a high-quality unsupported cut of potato shoots is possible at a linear knife speed of more than 5.5 m·s^{-1}. The obtained value confirms the assumption made in [10] and allows us to conclude that the cut of the plant is not a problematic point in the operation of the considered device for decapitation of potatoes, since the obtained values of the knife speed are much lower than that of cutting devices of the same type in existing harvesting machines [13-15].

The main problem in using the cutter bar in a decapitation device will not be the cut of the shoots, but the interaction with other systems, i.e. with the pneumatic topper and the disinfection system.

When considering the interaction of the cutting device with a pneumatic topper, one should bear in mind the fact that the presence of the knife in the area of the suction channel will lead to a change in the spectrum of air flow rates, since it will partially block the channel, which may affect the efficiency of vertical alignment of the shoots. The degree of influence will depend on how much area the cutterbar elements will occupy within the air channel. Hence, it follows that the elements of the cutting device should not be massive and numerous. It can be concluded that in the device under consideration it would be advisable to use a plate knife with two cutting edges, since it will occupy the minimum channel area [9].

However, the use of such a knife can have a negative impact on the operation of the pneumatic topper lifter and the point of view of interaction with the disinfecting system, which is proposed to be performed [7] in the form of a sprayer supplying the working solution to the knife. Since the supply of the solution is supposed to be constant, as a result of which only a small part of the solution will fall directly on the knife. The rest will fall into the air channel, moistening its walls, which will contribute to the adhesion of the cut plant fragments to the air ducts, the impeller and the fan housing, and hence reduce the reliability of the workflow.

From the point of view of the interaction of the cutting device with the disinfecting system, it seems more rational to use a disc-type knife with a working surface in the form of a smooth disc. This design will provide a constant supply of disinfectant to the cutting edge, which means it will improve the quality of processing of the cut point. To reduce the degree of overlapping of the air channel, the disk core can be made in the form of a hub with several thin spokes.

Experimental studies were carried out to assess the possibility of using such a design. The tool is shown in Fig. 2. The disc of the cutting device with the diameter of 230 mm was driven into rotation by an electric motor with the possibility of changing the rotation frequency.

Fig. 2. **Circular knife attachment**

Using this device, several attempts were made to cut plant shoots. Based on the results of the experiments, it was concluded that the process of unsupported cutting of potato shoots using a disc cutter is possible.

The shear capability was determined at a disk rotation speed of 500 and 1500 min^{-1}, which corresponded to a disk circumferential speed of 6 and 18 ms^{-1}. It was noted that at a high speed of the disc, longitudinal cutting of the stem can be observed. In addition, in some cases, when the circular knife interacted with the stem, the effect of the latter bouncing in the direction of the disc rotation was observed, especially if the contact point was in the zone where the vector of the peripheral speed of the disc has a component directed towards the movement of the device.

To eliminate these situations, an additional element was installed above the cutting disk of the device (Fig. 2), on which longitudinal rods were located, which play the role of supports for the cut parts of the shoots (Fig. 3).

The presence of supporting elements above the cutting disc made it possible to cut the shoots, and with this arrangement the supports do not interact with the part of the shoot located below the plane of the knife, do not injure it and do not allow it to bend in the vertical plane.

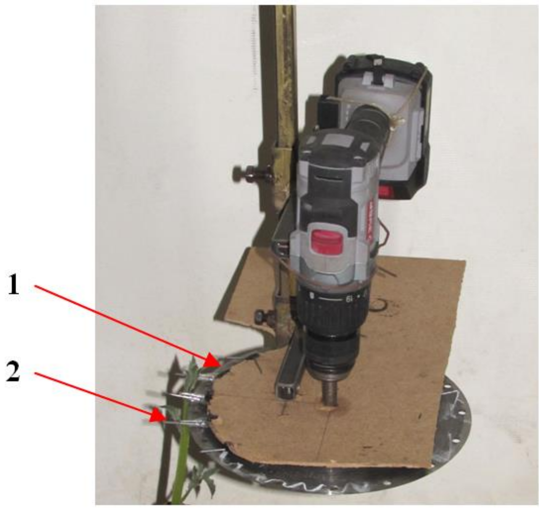

Fig. 3. **Device with a disc knife 1, equipped with support elements 2**

Conclusions

1. The data obtained as a result of laboratory studies showed the possibility of cutting potato shoots during decapitation with a disc-type cutter.
2. To eliminate the likelihood of the plant stem bouncing off the circular knife into the structure of the device, it should be equipped with supporting plates in contact with the plants above the plane of the cutting disc.
3. To confirm the obtained data, it is planned to conduct field studies of the operation of the cutting apparatus on plants of different vegetation periods in order to determine the optimal modes of its operation.

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