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Substantiation of technical and operational characteristics of the device to sort corn cobs

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Abstract. The paper presents a method to substantiate the technical and technological parameters of the device to sort corn cobs, which takes into account the biometric and physical-mechanical properties of the treated plant objects. The method of basic parameters substantiation involves determining the overall dimensions of the device, the geometric and technological parameters of the working bodies, as well as the energy for operation.

1 Introduction

Corn is one of the world's leading crops of the agro-industrial complex. The Russian Federation is one of the most significant world corn producers along with the United States, China, Brazil, the countries of the European Union and some other states. In Russia, the traditionally leading regions for the collection of corn are the Krasnodar Krai (17.1 % of the total), the Kabardino-Balkaria Republic, Kursk, Voronezh, Belgorod, Rostov oblasts, and the Stavropol Krai. According to the State Statistics Service, the gross harvest of corn in Russia in 2018 was at the level of 11,162.6 thousand tons. The total sown area of the Russian Federation under corn in 2018 amounted to 2,452.2 thousand ha. Despite a slight downward trend in the area occupied by corn in the last 2 years, the general trend shows some increase in the popularity of this crop among agricultural producers. So, over the past 10 years (relative to 2008), the area under corn has grown by 35.5 % (by 0.64 million hectares). Moreover, in relation to 2001, the area grew by more than 3 times (by 1.79 million hectares). At the same time, the yield of corn in different regions varies significantly. So, in 2018, the average yield in Kursk region exceeded 80 kg/ha, in Kabardino-Balkaria – 60 kg/ha, in the Krasnodar Territory amounted to 33.9 kg/ha and in Voronezh region – 49.1 kg/ha. Obviously, such differences are caused not only by regional characteristics, but also by the level of agricultural technology, as well as the quality of the seed material used. Thus, it is obvious that ensuring stable corn production is of strategic importance for the Russian Federation.

The stability and increase in the gross harvest of corn grain in Russia requires corresponding volumes of seed material that can be provided by domestic producers. Getting good seed material is associated not only with breeders but with the technical support of all operations included in this technology [1].

Technical support of technological operations for the production of high-quality crop production involves the use of a complex of machines and equipment with the necessary performance. An integral part of such a complex for the production of corn for seed production is the equipment for sorting the cobs in accordance with the established requirements.

In accordance with the state requirements of the Russian Federation (GOST 13634 "Corn. Requirements for procurement and supply") the total harvest of the cobs, when harvesting corn with cleaning, should be at least 98.5 %. The degree of cobs cleaning from boots should not be less than 95 %, the purity of cobs should not be less than 99.7 %, grain peeling – no more than 2 %, damage to cob grains – no more than 1 % and broken cores of the cobs – no more than 2 %. Additional cleaning of cobs at the facility should be at least 98 %. The content of weed impurities should not exceed 0.5 %, the amount of cobs broken into pieces and the presence of free grain in a pile of peeled cobs should not exceed 0.5 %. The number of cobs with a damaged surface should be no more than 1.5 %. Purification of seed corn requires the total removal of the boot, with the possible presence of one leaf covering the cob on 12–15 % of the surface. Corn cobs containing no more than one boot leaf are also recognized as clean [1].

As a result of investigations [2] the following works were carried out:

- based on an analysis of the currently existing technologies and mechanization tools for separating corn cobs and peculiarities of their biometric and physical-mechanical properties, a generalized technological scheme of the plant for sorting cobs into cleaned and unpeeled was developed;
- the process of corn cobs interaction with the working surface of the variable curvature of the sorting plant was theoretically substantiated, investigated and optimized;

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- the biometric and physical-mechanical properties of corn cobs were investigated in specific soil, climatic and industrial conditions;
- a technique for recognizing peeled and unpeeled ears by color codes has been developed;
- the process of sorting ears on a plant with a working surface of variable curvature and code recognition depending on the degree of cleaning was experimentally investigated;
- field studies of a prototype cob sorting plant were conducted, and the cost-effectiveness of the proposed solutions was evaluated.

According to the results of scientific work, the technical and technological substantiation of the proposed solution was done and a device (Figure) was developed to sort cobs, which remains an important element in the technology for producing seed material. The device to sort cobs of seed corn contains the following main elements: a bunker, a dosing device, an inclined surface, a control unit, an actuator, a bunker for peeled cobs and a bunker for unpeeled cobs [3]. The development of a methodology for substantiating the parameters of the developed device to sort cobs of seed corn, prior to the design and manufacture of a prototype, was an important scientific and practical task.

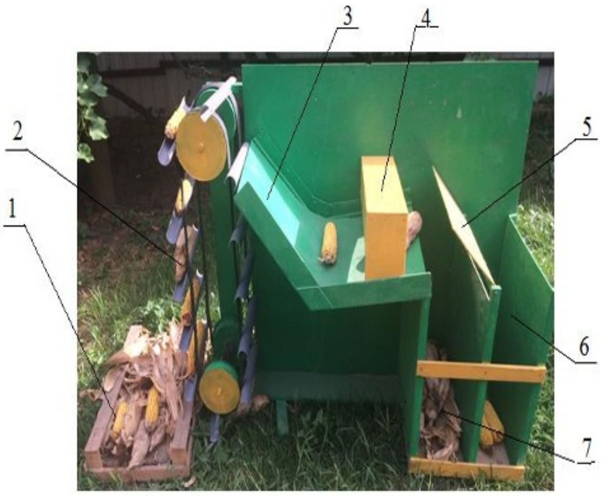

Fig. 1. The device to sort cobs of seed corn. 1 – a bunker; 2 − a dosing device; 3 − an inclined surface; 4 − a control unit; 5 − an actuator; 6 − a bunker for peeled cobs; 7 − a bunker for unpeeled cobs

2 Materials and methods

As a rule, studies on the substantiation of structural technological parameters of machinery and equipment in crop production are preceded by reception and analysis of data on biometric (which include part of the morphological and size-mass characteristics) and physical-mechanical (which include strength parameters, friction coefficients, etc.) properties of plant varieties. That is an essential condition for the development of structures and determining the parameters of the working bodies of apparatuses and machines for cleaning and post-harvest processing. Knowledge of these parameters makes it possible to clarify the design features of the working bodies and machines and optimize their parameters, which ensure the destruction of individual parts of plants while observing the full or partial integrity of others, which is regulated by the corresponding initial requirements.

The founder of agricultural mechanics V.P. Goryachkin emphasized the need for a more complete and comprehensive study of the properties of processed plant objects in order to determine the difference between varieties on the one hand, and assess the degree of evenness of individual varieties on the other.

At present, in the Russian Federation, a dimensional characteristic of maize varieties and hybrids has been adopted, including four cob parameters: length, diameter, weight and mass of 1,000 grains. These parameters (in full or partially) are usually included in studies of the physical-mechanical properties of corn cobs.

Comparing the values of the length, diameter and mass of corn cobs, the mass of 1,000 grains obtained for different varieties and hybrids of corn, it can be noted that the intervals of the parameters remained practically unchanged and amounted to 0.17–0.35 m, 0.035–0.055 m, and 0.15–0.4 kg, 0.2–0.38 kg, respectively. Since hybrids of maxi sizes up to 0.6 m long and mini-sizes about 0.05 m long (Baby Corn) are currently cultivated, the difference in the three main dimensional parameters of cobs in different hybrids can be 3–7 times [2].

N. Tulaykov formulated the optimal characteristics of cobs suitable for mechanized harvesting. They are 1) approximately the same thickness along the entire length; 2) a slight narrowing to the top of the cob; 3) the ratio of the length of the cob to its circumference at a distance of 1/3 from the base 4 : 3; 4) the rows of grains are even, without close fit and without strong separation; 5) the cob rod is average with deep-seated grains; 6) the grain is 1.5 times longer in length than in width and of the same thickness.

The range of investigated and generalized parameters of biometric and physical-mechanical properties is constantly expanding and supplemented. This is due to

- the variability of parameters of plant objects associated with objective reasons (uncharacteristic seasons by temperature, precipitation, etc.);
- the emergence of new varieties and hybrids, the biometric properties of which, thanks to the successes of modern genetics, are as close as possible to the requirements of mass mechanized processing;
- advances in the field of modern electronics, which 10–15 years ago were not considered for use in agriculture.

Therefore, each researcher repeats and supplies the database of biometric and physical-mechanical properties of processed plant objects, in particular, corn cobs.

The classification principle used to select the biometric and physical-mechanical properties of corn cobs is based on the following provisions [2]. First, the cob was considered as a complex biological object, clearly divided into several heterogeneous zones.

Secondly, some physical-mechanical properties of the cobs undergo significant changes during processing. Thirdly, the properties of some working bodies in the process of interaction with the cob change. As a result of processing, changes occur in the anatomical structure, size-mass and physical-mechanical parameters of the cobs. Therefore, their properties are investigated in the dynamics of the corresponding process, taking into account design solutions.

The analysis [2] shows that such data on the study of the biometric and physical-mechanical properties of corn are presented in the works of M.F. Burmistrova, A.I. Buyanov, Y. Grushka, I.T. Osmak, A.F. Sokolov, V.G. Ivashkov, V.S. Kravchenko, V.S. Kurasov, E.V. Truflyak, as well as practically all developers of the design of working bodies of corn-harvesting machines and post-harvest processing facilities both in Russia and abroad. The data obtained by the authors listed above [1, 4–9], as well as the results of own investigations [2], were used in the research as initial data.

The scientific substantiation of the basic parameters of the device to sort cobs of seed corn and the engineering calculation of these parameters were carried out according to the following procedure. We take into account that it is necessary to ensure the substantiation of the overall dimensions of the device, the geometric and technological parameters of the working bodies, as well as the energy costs of the operation [10].

The method involves the rationale of parameters in stages of cob processing, ranging from loading and completing the separation. In addition to the description of the method itself, an example of the calculation of plant parameters for sorting seed material with reference to specific conditions is provided to clarify the features of its use.

Technical and operational parameters are obtained for:

- basic parameters of the device, including overall and dynamic characteristics;
- the device performance;
- energy.

Overall parameters of the receiving bunker in the form of an inverted pyramid are:

- capacity

$$V_{\text{b}} = \frac{h}{6}\left(ab + (a + a_1)(b + b_1) + a_1 b_1\right), \tag{1}$$

where V_b is the receiving bunker capacity, m^3;
h is the bunker height, m;
a is the length of the receiving bunker, m;
b is the bunker width, m:
a_1 is the base length, m;
b_1 is the base width, m.

$$V_b = 1.17 \text{ m}^3;$$

- working capacity

$$V_{\text{wb}} = \alpha_n \cdot n \cdot V_n, \tag{2}$$

where α_n is the bunker fill factor, α_n = 1.20–1.35;
n is the number of cobs in the party, n = 300 pcs.;
V_{n} is the maximum capacity size of the cob, V_{n} = 0.003 m^3.

$$V_{wb} = 1.17 \text{ m}^3.$$

Elevator parameters:

- bucket capacity

$$V_e = \alpha_e \cdot V_n, \tag{3}$$

where V_e is the elevator bucket capacity, m^3;
α_e is the fill factor of the elevator bucket, α_e = 1.1–1.2.

$$V_e = 3.45 \cdot 10^{-3} \text{ m}^3,$$

- the bucket length

$$L_e = \alpha_{\text{c}} \cdot L_{\text{c}}, \tag{4}$$

where L_e is the elevator bucket length, m;
α_{c} is the bucket length utilization factor, α_{c} = 1.18–1.25;
L_{c} is the maximum cob length, m.

$$L_e = 0.42 \text{ m};$$

- the bucket width

$$B_e = \alpha_w \cdot d_{\max}, \tag{5}$$

where B_e is the elevator bucket width, m;
α_w is the bucket width utilization factor, α_w = 1.05–1.15;
$d_{\max}$ is the maximum cob diameter, m.

$$B_e = 6.6 \cdot 10^{-2} \text{ m};$$

- the elevator height

$$H_e = \alpha_e \cdot h, \tag{6}$$

where H_e is the elevator height, m;
α_e is the elevator design factor, α_e = 1.2–1.4;

$$H_e = 1.44 \text{ m};$$

- the working branch width

$$B_{ew} = \alpha_{ew} \cdot B_e, \tag{7}$$

where B_{ew} is the elevator width, m;
α_{ew} is the elevator width design factor, α_{ew} = 1.15–1.25.

$$B_{ew} = 5.04 \cdot 10^{-1} \text{ m};$$

- the belt speed

$$v_{\text{b}} = gt\cos\Theta\left(tg\Theta - tg\varphi - \frac{f_k}{r}\right) + v\sqrt{\sin^2\Theta + k^2\cos^2\Theta}, \tag{8}$$

where t is cob rolling time along the guide, t = 0.2 s;
Θ is the guide elevation angle, Θ = 30°;
φ is the sliding friction angle, φ = 24°;
f_k is the rolling friction coefficient, f_k = 0.008 m;
r is the cob radius, r = 0.032 m;
k is the recovery factor, k = 0.35;
v is the speed of the cob at the time of contact with the guide, v = 0.44 m / s;

$$v_{\text{b}} = 4.58 \cdot 10^{-1} \text{ m/s}.$$

The parameters of the working surface of variable curvature:

- the length of the descending plane

$$L_{\text{d}} = \frac{1}{2}gt^2\cos\Theta\left(tg\Theta - tg\varphi - \frac{f_k}{r}\right) + vt\sqrt{\sin^2\Theta + k^2\cos^2\Theta}, \tag{9}$$

$$L_{\text{d}} = 4.19 \cdot 10^{-1} \text{ m};$$

- the cob center of gravity acceleration

$$\omega = \frac{2}{3} g \sin\Theta, \tag{10}$$

$$\omega = 5.56 \text{ m/s}^2;$$

- cob speed at the lowest point of the descending plane

$$v_{\text{c}} = v + gt\sin\Theta, \tag{11}$$

$$v_c = 2.07 \cdot 10^{-1} \text{ m/s}$$

- kinetic energy of the cob on the descending surface

$$T = \frac{3}{4}mv^2, \tag{12}$$

$$T = 9.64 \cdot 10^{-3} \text{ J};$$

- cob speed on the ascending surface

$$v_{\text{t}} = v - gt\sin\beta, \tag{13}$$

where v_t is the cob speed at a moment t, m/s;
β is the slope angle of the ascending branch, degrees.

$$v_t = -8.3\cdot10^{-2}\ \text{m/s};$$

- the length of the ascending surface

$$L_{\text{AS}} = \frac{3\alpha_{\text{AS}} v_c^2}{4g\left(\sin\beta + \dfrac{f_k}{r}\cos\beta\right)}, \tag{14}$$

where α_{AS} is the ratio of the length of the ascending surface, α_{AS} = 0.5–0.65.

$$L_{AS} = 0.5\ \text{m}.$$

The performance of the device is determined based on the availability of the truck in the form of an elevator.

$$Q_{\text{el}} = 3.6\alpha_{\text{el}} n_{\text{el}} v_{\text{el}} m_c, \tag{15}$$

where α_{el} is the elevator use ratio, α_{el} = 0.85–0.94; n_{el} is the number of buckets per 1 long meter, n_{el} = 5 pcs.; v_{el} is the elevator belt speed, v_{el} = 0.44 m/s; m_c is the cob weight, m_c = 0.3 kg.

$$Q_{\text{el}} = 2.067\ \text{t / h}$$

Energy is determined as the power to drive the elevator

$$N_{\text{el}} = (1.1 - 1.3)\,(N_{\text{e}} + N_{\text{xk}}), \tag{16}$$

where N_{el} is the motor power, W; N_{e} is the power to drive the elevator, W; N_{xk} is the idling power, W; 1.1–1.3 are dynamic coefficients.

$$N_{\text{el}} = 499.35\ \text{W}$$

$$N_{\text{e}} = N_{\text{fr}} + N_b, \tag{17}$$

where N_{fr} is the power to overcome the friction forces of the cob on a pile, W.

$$N_{\text{fr}} = (1.1 - 1.3)\cdot P\cdot v_b, \tag{18}$$

where P is the preload force of the pile to the elevator belt, P = 150−450 N; v_b is the elevator belt speed, m/s; N_{b} is the power to move the belt, W.

$$N_{\text{fr}} = 237.6\ \text{W},$$

$$N_{\text{xx}} = A\omega_{\text{p}} + B\omega_{\text{p}}^3, \tag{19}$$

where A and B are coefficients depending on geometric parameters,

$$A = 0.3\cdot10^2\ \text{N·m},\ B = 0.68\cdot10^{-1}\ \text{N·m·s}^2;$$

ω_{p} is the cob angular speed, c^{-1}.
N_{b} is the power to overcome friction when the cob is raised by an elevator, W,

$$N_{\text{b}} = f\cdot P\cdot v_{\text{e}} = 0.46\cdot450\cdot0.44 = 91.08\ \text{W}, \tag{20}$$

where f is the friction coefficient, f = 0.46–0.57,
v_e is the speed of the elevator,
N_{b} = 91.08 W,
N_{xx} = 170.67 Wт.

The presence of buckets fixed at 120 mm intervals on the elevator was taken as the initial design data. The transition of the inclined working plane to the ascending branch was carried out through a section with 150 mm radius of curvature. The slope of the ascending part of the sorting plane was adjustable in height.

3 Results and discussion

The calculation algorithm is based on the use of the results of theoretical studies of corn cobs rolling along an inclined surface of variable curvature and experimental studies of biometric and physical-mechanical properties of corn cobs. To calculate parameters, both the average and extreme values of cobs parameters and the operating modes of the separator were selected.

As a result of the investigations, it was found that the proposed method allows scientific and engineering substantiation of specific structural, technological and energy parameters of the device to sort cobs of seed corn.

The use of the technique makes it possible to substantiate the following parameters: theoretical capacity of the receiving bunker, its actual "useful" capacity (it is assumed that the bunker has the shape of an inverted pyramid, which is most appropriate from a technological point of view), the main design parameters of the bucket elevator (capacity, rational length and width of buckets, elevator height, width of its working branch and belt speed), surface parameters of variable curvature (the length of the descending plane taking into account the parameters of acceleration of the center of gravity of the cob, the speed of the cob at the lowest point of the descending plane, the kinetic energy of the cob on the descending plane, and the length of the ascending surface taking into account the speed of the cob and the angle of inclination of the ascending branch) and the power required to operate the device.

It has been established that specifically for the device to sort cobs of seed corn with a capacity of 2 t/h, the following rational values of parameters were substantiated: the capacity of the receiving bunker, having the shape of an inverted pyramid, is 1.17 m^3, the capacity of the elevator bucket is $3.45\cdot10^{-3}$ m^3 with a length of 0.42 m and a width of $6.6\cdot10^{-2}$ m, a height of the elevator is 1.44 m with a width of its working branch equal to $5.04\cdot10^{-1}$ m and a belt speed of 0.44 m/s, the length of the descending $4.19\cdot10^{-1}$ plane, the required power for the operation of the device is 0.5 kW.

The proposed method provides the possibility of substantiating the above parameters for similar devices of different performance with the introduction of appropriate changes in values of the input source data.

According to the data of field studies [2] and the economic inspection, the device with scientifically sound parameters ensures the sorting of cleaned and uncleaned cobs in accordance with initial requirements for this operation.

4 Conclusion

As a result of the conducted research, it was established that the proposed method allows scientific and engineering substantiation of specific structural, technological and energy parameters of the device to sort cobs of seed corn. The use of the technique allows substantiating the following parameters: theoretical capacity of the receiving bunker, its actual "useful" capacity, the main design parameters of the bucket elevator (capacity, rational length and width of buckets, elevator height, width of its working branch and belt speed), surface parameters of variable curvature (the length of the descending plane and the length of the ascending surface), the performance of the device, taking into account the availability of a lifting vehicle in the form of an elevator, energy consumption and power necessary for the device operation. According to the data of field studies and economic inspection, the device with scientifically sound parameters ensures sorting of cleaned and uncleaned cobs in accordance with the initial requirements for this operation. It has been established that the required stable operation capacity of the device, intended for sorting cobs of seed corn, with a capacity of 2 t/h, does not exceed 0.5 kW.

The parameters of the working bodies of the sorting plant proposed in the work can be used by design organizations in the development of fully mechanized production lines for processing corn cobs. The developed constructive solution of the device for sorting corn cobs can be used in the activities of seed plants and farms in breeding and in primary seed production.

In further applied research aimed at improving the efficiency of using the cob sorting plant, it is promising to improve its technological capabilities using both static and dynamic inclined surfaces in combination with electronic recognition by color scheme

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