RESEARCH ON INCLINATION OF FLAX STALKS THAT DO NOT INTERACT WITH DIVIDERS OF PULLING APPARATUS

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Abstract. The effect of the dividers of the pulling apparatus on stalked flax consists in dividing the standing stalks into separate strips and sending them to the mouths of the pulling streams. The side rods of the dividers interact with the stalks, causing them inclination. However, flax plants that are located in the center opposite the pulling stream enter the mouth of the pulling stream and do not come into contact with the side rods of the dividers. These central stalks will also incline. This inclination is caused by the stalks that interact with the side rods of the dividers, through some support of the stalks and the entangling of their tops. Reducing the angle of inclination of the central stalks, which do not interact with the dividers, is a positive phenomenon, as it reduces the stretch and skew of the stalks in the belt. The more inclined the pulling apparatus to the field surface, the smaller the angle of the stalks that are led to the pulling streams. The article presents the results of a study on inclination of flax stalks that do not directly interact with the side rods of dividers. Using a developed methodology, experiments were conducted in laboratory conditions to determine the influence of the plant density, the width of the gap between the side rods of adjacent dividers, and the height of the divider's lift on the inclination angle of central stalks that do not directly interact with the divider rods. The experiments were conducted using a mathematical method for planning a three-factor experiment. According to the obtained regression equation for the angle of inclination of the central stalk, it is possible to adjust the gap between the the side bars of dividers from 35 to 75 mm and the installation height of the dividers from 6 to 26 cm for the appropriate plant density of 1000 to 2200 stalks per m^2. For a plant density of 1000...2200 stalks per m^2, it is possible to reduce the angle of inclination of the central stalks to 57°...68°.

Keywords: flax, stalk, dividers, side rods, inclination.

Introduction

Flax has many important applications, which makes its cultivation profitable for agriculture and the economy as a whole. Flax is an environmentally friendly crop, as it does not require a significant amount of pesticides and herbicides as it is resistant to many diseases and pests. It has a high ability to fix nitrogen in the soil, which reduces the need for chemical fertilisers. Flax also helps improve the soil structure. Flax is the main source of flax fibre, which is used to make clothes, bed linen and various industrial fabrics. Flax contains beneficial omega-3 fatty acids, fibre and antioxidants that promote human health. Flaxseed is widely used in food (as an additive to products) and in medicine to support cardiovascular health, improve digestion and lower cholesterol. In addition to textile production, flax is used to make biodiesel, paper, and in construction (for example, as insulation). Flaxseed has a high profitability when grown properly [1-3].

The production of long fibre has always been the main goal of flax growing. An analysis of the flax industry has shown that in the ranking of unfavourable circumstances, one of the leading places is occupied by excessively high losses of the fibre part during its separation from the trust at the flax mill [4]. Most often, the unsatisfactory result is the result of excessive stretching of the stalks in the belt.

The first technological process in the harvesting cycle that affects the stretch is pulling, which is carried out by the pulling apparatus of flax harvesters. The front of the pulling apparatus is equipped with flax stalk dividers designed to separate the flax stalks into separate strips and bring them to the pulling streams.

The dividers are multi-faceted long wedges made of steel bars and tubes with noses that are bent at the top. They are hinged to the machine frame. The lower working rods of the dividers do the main work of bringing the stalks in. The dividers affect the quality of the machine, in particular the stretch and kink of the flax stalks and the reliability of the machine [5; 6].

A proposed [7] new design of the spring-loaded divider shown in Fig. 1. This splitter is attached to the frame of the pulling apparatus with a bracket 1. The central branch of the divider consists of a head 2, into which a rod 3 is screwed, with a shoulder at the end. The rod 3 slides freely in the sleeve 4, which fits into the tube 6 and is secured in it by an elastic ring 5. The shoulder of the rod 3 is in contact with the spring 7, which is located in the tube 6 and rests against the sock 9 through the washer 8. The sock

9 is rigidly attached to the tube 6 with rivets. The toe 9 also has a slot into which the side rod 10 fits so that a hinged connection is formed. The ends of the bar 10 and the head 2 are pivotally mounted on the bracket 1.

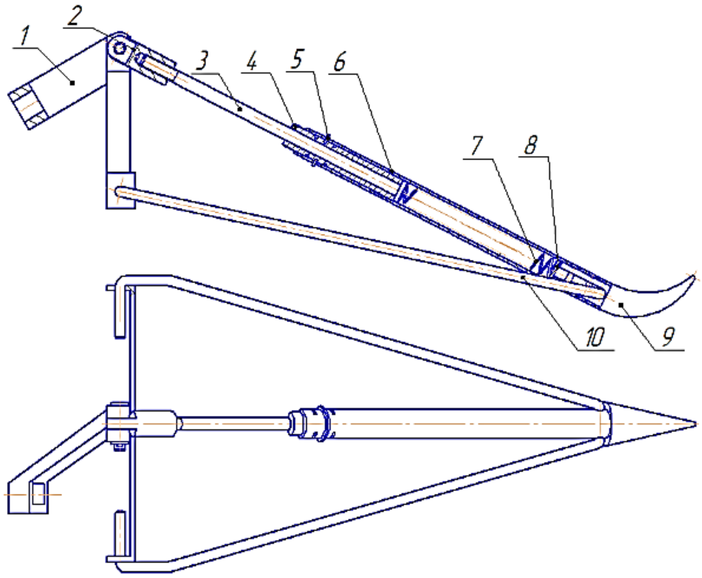

Fig. 1. **Spring-loaded divider:** 1 – bracket; 2 – head; 3 – rod; 4 – sleeve; 5 – ring; 6 – tube; 7 – spring; 8 – washer; 9 – toe; 10 – side rod

Adjustment of the height of the toe 9 of the divider is ensured by repositioning the ring 5 in the slots on the tube 6 (three slots are provided) and by threading the rod 3 and head 2.

When hitting an obstacle, the toe 9 of the divider together with the tube 6 will rise upwards, the spring 7 will compress and, after crossing the obstacle, straighten and return the divider to its original position.

In Fig. 2, in the spatial coordinate, we consider the process of interaction of the side bar of the divider with flax stalks 1, 2. Here, the vertical plane of symmetry of the divider coincides with the *XOZ* plane, and the surface of the field with the *XOY* plane. The side bar *AB* forms on the coordinate planes the projections $A_{XZ}B_{XZ}$, $A_{XY}B_{XY}$ and is characterised by the following parameters: length– l, angle with the projection $A_{XZ}B_{XZ}$ – β, angle of inclination to the horizon – α, height – h.

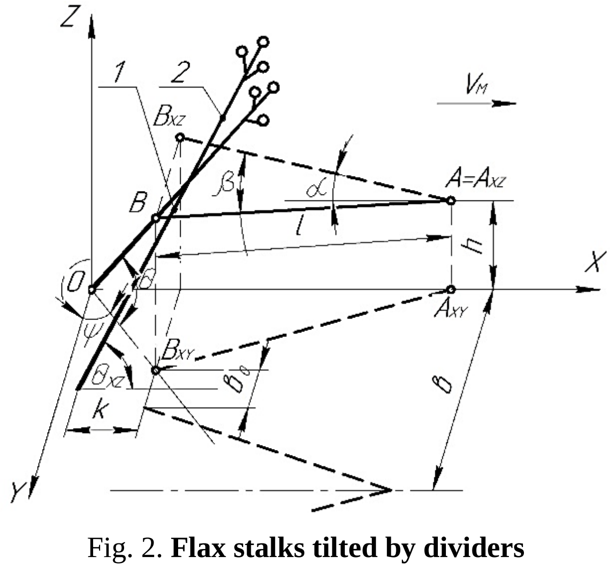

Fig. 2. **Flax stalks tilted by dividers**

Under the action of the divisor, the stalk 1 (Fig. 2) is tilted by the angle θ, the sine of which is obtained from formula [8]:

$$\sin\theta = \frac{1}{\sqrt{1+\dfrac{(\cos\alpha ctg\beta + tg\psi)^2(1+tg^2\psi)}{\{\dfrac{2h}{b-b_o}tg\psi + [\sin\alpha(\cos\alpha ctg\beta + tg\psi) + \dfrac{2h}{b-b_o}\cos\alpha]ctg\beta\}^2}}}, \qquad (1)$$

where ψ is the angle between the projection of OB_{XY} and the OY axis.

The relative stretch of the stalks is determined by formula [8]:

$$\lambda_O = (1-\sin\theta)/\sin\theta . \qquad (2)$$

However, it should be noted that in theoretical studies, the tilting under the action of the divider of the outermost flax stalks in the elementary bundle, which are in the vertical plane of symmetry of the divider (stalk 1 of Fig. 2), is considered, assuming that the stalks that do not directly interact with the side bars of the divider, i.e. whose roots are in the zone of width b_o, are brought to the mouth of the pulling stream in a vertical position. In reality, the outermost stalks, being tilted by the divider, act in a certain way through some support of the stalks and the adhesion of their tops on these stalks, causing their tilt. Stalks with roots located in the zone with a width of b_o – the gap between the side bars of neighbouring dividers – will deviate both towards the central vertical plane of the elementary bundle and in the direction of the machine movement. The central stalks of the elementary bundle, i.e. the stalks that are located in the central vertical plane, will tilt only in this plane in the direction of the machine movement. Fig. 2 shows the central stalk 2 tilted forward in the direction of the machine movement by a certain angle θ_{xz}. The angle of inclination of these stalks will be the largest.

The difference in angles of the stalks falling into the pulling stream to the surface of the field gives rise to stretching and skewing of the stalks and the stalk belt. The greater this angle difference, the greater the stretch and skew of the stalks in the belt. That is, you need to adjust the dividers to reduce the angle of inclination of the central stalks to the field surface.

It is also worth noting that the inclination of the stalks by the dividers must be coordinated with the inclination to the surface of the pulling apparatus. The stalks that are brought to the mouth of the pulling stream must be clamped simultaneously across the entire width of the pulling belt, i.e. perpendicular to the plane of the pulling apparatus. The more inclined the pulling apparatus to the surface of the field, the smaller the angle of the stalks that are led to the pulling streams should be.

The main adjustments of the dividers are to set the height of the dividers' noses h and the width of the gap b_o between the side bars of neighbouring dividers. Having studied the effect of these factors for different plant densities i on the angle of inclination of θ_{xy} central stalks, the position of the dividers can be adjusted to improve the quality of the stalk tape - to reduce stretching and skewing of the stalks in it.

Materials and methods

To study in laboratory conditions the effect of dividers on the flax stalk, a special device was made (Fig. 3), consisting of two risers 1 and a crossbar 2, on which two dividers 3 are fixed with screw connections.

Auxiliary equipment is used to bring the flax stalks to the flax dividers. This construction consists of two wooden plates 4 with a size of 35×30 cm on each side supported by wheels 5 and fixed with an offset from each other on different sides on a bar 6. The bar 6 fits into the groove of the fixed guide 7, which is placed in line with the central bar of the divider. Holes ∅3 mm are drilled in the wooden plate 4 at intervals of 2.5×2.5 cm, in which the flax stalks 8 are fixed. A rectangular parallelepiped 9 is installed so that its face is in the plane of the hinge attachment of the side bars of the dividers 3. A rectangular rod 10 was attached to the plate 4 along the line of installation of the outermost flax stalks 8. A ruler with a measurement accuracy of 1 mm was used to determine the distance k between the inner faces 9 and 10.

The distance b between the noses of the dividers 3 was 0.35 m, respectively, according to the working width of one pickling section of the pickling apparatus or the width of the slab 4. The side bars of the dividers 3 were characterised by the following: length l = 0.5 m, the angle between the side bars of the dividers 2β = 30°, the angle of inclination to the horizon α = 10° (see Fig. 2). The height h of the dividers was set by changing the position of the crossbar 3 in the holes of the risers 1. The width b_o was changed by moving the side bars of the dividers 3. Different stalk densities i were provided by the corresponding number of stalks 9 installed in the holes of the plates 4.

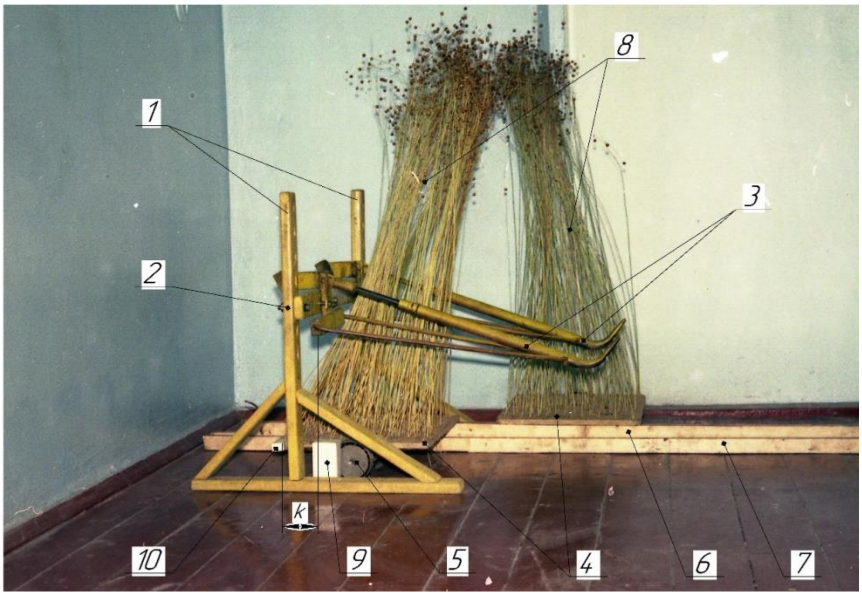

Fig. 3. **Photo of the experimental setup**: 1 – rack; 2 – crossbar; 3 – divider; 4 – plate; 5 – wheel; 6 – bar; 7 – guide; 8 – flax stalks; 9 – rectangular parallelepiped; 10 – rectangular rod

The experiments were carried out as follows. The guide of the setup 2 was located in the same plane as the centre of symmetry of the right divider 3. The racks 1 with the dividers 3 were stationary, and a bar 6 with a plate 4 in which flax stalks 8 were installed was moved along the guide 7 towards the dividers. The stalks, deflected by the side rods of the dividers, acted on the central stalks, which were also tilted by a certain angle θ_{xz} (see Fig. 2). To determine this angle, a ruler with an accuracy of 1 mm was used to measure the projection k onto the horizontal of the segment of the tilted central stalk formed between the point of fixing the stalk in the opening of the plant plate 2 and the point at the level of the hinge attachment of the side rods of the dividers, i.e. the point beyond which the influence of the side rods on the flax stalks ceases (see Figs. 2 and 3). Then formula (3) was used to determine the angle θ_{xz}, recording this value in the journal:

$$\theta_{xz} = arctg(\frac{h + l\cos\beta\sin\alpha}{k}), \quad (3)$$

To find the dependencies of θ_{xz} on h, b_o and i, taking into account the nonlinear nature of these dependencies, a second-order polynomial was chosen as the mathematical model. Experiments to determine the parameters of the models were conducted according to the Box-Benkin plan for three factors [9]. The range of variation of the studied factors at three levels was determined based on the analysis of literature data and previous experiments. The following values of the factors were taken: i – 1000 stalks per m^2, 1600 stalks per m^2 and 2200 stalks per m^2; b_o – 35 mm, 55 mm and 75 mm; h – 6 cm, 16 cm and 26 cm.

Twelve variants of experiments and three experiments at the zero level were conducted in triplicate. The reproducibility of the experiments was checked by the Cochrane criterion.

The significance of the regression coefficients was evaluated using the Student's t-test, while the model conformity with the experimental results was assessed by the Fisher's F-test for a 95% probability.

Results and discussion

The experiments were carried out on stalks of Miandr flax of the following characteristics: stalk height – 74...83 cm, average stalk diameter (1/3 of the height) – 1.5 mm; ripeness stage – yellow; stalk moisture content – 50.7%, number of bolls per stalk – 3...9 pieces.

The processing of statistical data of the results of the three-factor experiment according to the three-level plan of the second order Box-Benkin was carried out using a specially developed program in the Mathcad environment. The condition of reproducibility of the experiments is fulfilled, since the calculated value of the Cochrane criterion $G^{calc} = 0.131$ is less than the tabulated value $G^{tab}(0.05;\ 15;\ 2) = 0.335$ [10]. The coefficients of the regression equation were calculated, their confidence intervals and significance were determined. After removing the insignificant coefficients, the hypothesis of the adequacy of the equation was tested by the Fisher's criterion. The calculated value of this criterion with the variance of inadequacy $S_n^2 = 4.252$ and the variance of reproducibility of the experiment $S_y^2 = 1.398$ was $F^{calc} = 2.24$. The tabular value of the Fisher's criterion at the accepted 5% significance, according to [10], was $F^{tab}(0.05; f_2; f_1) = 19.35$, where $f_2 = 7$ – the number of degrees of freedom of the inadequacy variance; $f_1 = 2$ – the number of degrees of freedom of variance of the reproducibility of the experiment. As $F^{calc} = 2.24 < F^{tab}(0.05;\ f_2;\ f_1) = 19.35$, the adequacy of the regression equation by the experimental data is confirmed.

The following regression equation was obtained to determine the stalk angle in the coded factors:

$$\theta_{xz} = 76.5 + 3.908X_1 + 6.013X_2 - 5.846X_3 - 2.138X_1^2 - 0.496X_2^2 + 2.121X_3^2 + 1.6X_1X_3, \quad (4)$$

where X_1, X_2, X_3 – coded values of the plant density i (-1; 0; + 1, corresponding to 1000, 1600, 2200 stems per m^2), the gap between the side bars of the dividers b_o (-1; 0; + 1, corresponding to 35, 55, 75 mm) and the height of the divider h (-1; 0; + 1, corresponding to 6, 16, 26 cm).

Moving from the coded values of the factors to the natural values, the regression equation was obtained:

$$\theta_{xz} = 54.14889 + 0.021251i + 0.43795b_0 - 1.68999h - 0.59389 \cdot 10^{-5} i^2 -$$
$$-0.00124b_0^2 + 0.02121h^2 + 0.26667 \cdot 10^{-3} i \cdot h. \quad (5)$$

Fig. 4 shows the graphical dependences of the nuchal angle θ_{xz} of the central stalks on the height of the divider h at different intervals between the side bars of neighbouring dividers b_o and the plant density i, calculated by equations (4) and (5) using a specially developed computer program.

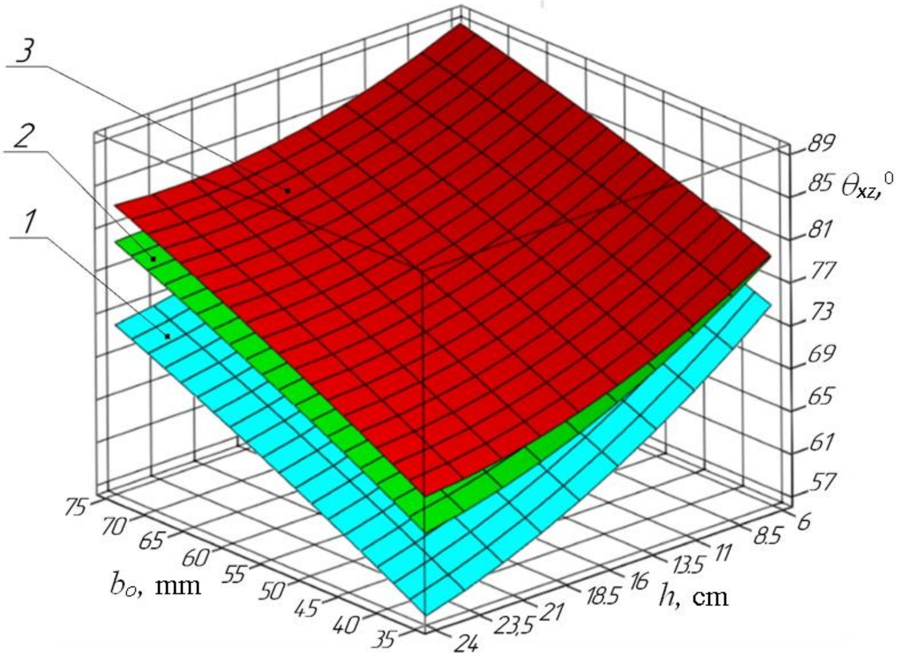

Fig. 4. **Response surface is built by formula (5):** 1 – i = 1000 stalks per m^2; 2 – i = 1600 stalks per m^2; 3 – i = 2200 stalks per m^2

Analysing the regression equation (4) and these graphs (Fig. 4), it is clear that the angle θ_{xz} decreases with a decrease in i and b_o and an increase in h. This is explained by the fact that with a decrease in the plant density i, the resistance to the tilt of the central stalks from the stalks following them decreases.

And with a decrease in the gap b_o, the number of stalks that are directly tilted by the side bars of the dividers and act on the central stalks increases. The last change θ_{xz} from h is associated with a decrease in the height of the stiffness and elasticity of flax stalks.

Conclusions

Reducing the angle of inclination of the central stalks, which do not interact with the dividers, is a positive phenomenon, as it reduces the stretch and skew of the stalks in the belt. The more inclined the pulling apparatus to the field surface, the smaller the angle of the stalks that are led to the pulling streams. Using the obtained dependence of the angle of inclination of the central stalk (5), it is possible to adjust the gap between the the side bars of dividers from 35 to 75 mm and installation height of the dividers from 6 to 26 cm for the appropriate plant density of 1000 to 2200 stalks per m^2. Thus, for a plant density of 1000...2200 stalks per m^2, it is possible to reduce the angle of inclination of the central stalks to 57°...68°.

Author contributions

Conceptualization, S.Y.; methodology, S.Y. and Sv.Y.; software, S.Y. and M.T.; validation, M.T. and L.D.; investigation, S.Y., Sv.Y., M.T. and T.D.; data curation, S.Y. and Sv.Y.; writing – original draft preparation, S.Y.; writing – review and editing, Sv.Y. and L.D.; visualization, S.Y., L.D. and T.D. All authors have read and agreed to the published version of the manuscript.

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