DETERMINATION OF AVERAGE DIAMETER AND TAPER OF FLAX STEM

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Abstract. When designing the working elements of flax-harvesting machines that interact with flax stems, it is important to know the stem diameter and taper. For example, in the pulling grooves of a flax-pulling unit, flax stems over a certain section of their length are clamped between pulling belts, or between a pulling belt and a pulling disc. The stem diameter determines the thickness of the stem ribbon clamped in the gripping groove and the pressure in the gripping groove created by the tension of the pulling belt. The stem taper affects the variation of the stem ribbon thickness and the pressure across the width of the pulling groove. A known method for determining stem diameter involves placing the stem between the jaws of a caliper and reading the result from the scale. However, due to the insufficient stiffness of the stem, it may undergo deformation under the forces exerted by the caliper jaws. Such deformation results in measurement error. To determine taper, it is necessary to measure the diameters of the stem at its lower and upper parts, first determining the distance between the measurement points, and then calculating the taper value using a formula. This procedure requires significant time expenditure. The article proposes a method for determining the average diameter and taper of a flax stem using a developed nomogram, which simplifies the procedure for reading results and increases labor productivity. Based on the obtained nomogram, which consists of four scales – diameters of the thinner, average, and thicker parts, and taper – a measuring device was manufactured. By inserting the stem simultaneously between the measuring surfaces of the scales for the thinner and thicker parts, the numerical values of the average diameter and taper of the flax stem are read from the other scales. During the processing of the obtained dimensional data using correlation analysis, it was established that there is a significant correlation between the average diameter of a flax stem and its taper.

Keywords: flax, stem, average diameter, taper, nomogram.

Introduction

Fibre flax is a valuable agricultural crop widely used for the production of fibre, food products and industrial raw materials. It is environmentally friendly to grow, improves soil condition and requires minimal use of chemicals. As a result, flax offers high economic efficiency and is of considerable practical importance [1-3].

The efficiency of technological processes involved in flax cultivation and harvesting largely depends on the design of the machines used in production [4; 5].

Flax harvesting machines play a particularly important role, as their working elements directly interact with plant stems. Therefore, the design parameters of pulling devices must take into account the geometric and physico-mechanical characteristics of flax stems. In most flax pulling devices, the stems are clamped in pulling grooves with a width of 100 mm [6].

Among the most important parameters characterizing flax stems are diameter and taper. The stem diameter determines the thickness of the stem ribbon clamped in the pulling groove. This parameter affects the magnitude of the contact pressure arising between the pulling belts and the stems.

The taper of the stem characterizes the change in its diameter along its length and affects the uniformity of stem clamping in the pulling device. Uneven pressure distribution may lead to stem damage or deterioration in harvesting quality.

Thus, accurate determination of the geometric parameters of stems is an important task in the design and improvement of flax harvesting machinery.

In practice, universal measuring instruments – micrometers and calipers – are most commonly used to determine the diameter of flax stems. These tools are widely applied in mechanical engineering and other industries to measure linear dimensions of rigid objects, i.e. those that do not deform under the force applied by the measuring surfaces. However, flax stems are not perfectly rigid bodies, which leads to a number of issues when measuring their diameter.

When measuring stem diameter with a micrometer or caliper, the stem behaves as a relatively rigid object only until the applied force exceeds a certain critical value. Beyond this point, deformation of the stem begins, resulting in distorted measurement results. In practice, it is almost impossible to control the actual force applied to the stem by the measuring surfaces. This force is generated by the operator's hand muscles as well as by friction forces between the moving and fixed parts of the measuring instrument.

Studies have shown that measurement results for the same stem, obtained by different operators, can differ significantly. Such discrepancies substantially reduce the reliability of experimental data and complicate morphological studies of plants.

In addition, further difficulties arise when reading measurement results from the scale of a micrometer or caliper, especially in models not equipped with digital indicators. To determine the diameter value, the operator must identify the vernier scale division that coincides with a division on the main scale, determine the corresponding fraction of a millimeter, and add it to the integer millimeter value of the main scale. When hundreds of measurements must be taken during a working day, such a monotonous procedure leads to significant strain on the visual system, increasing researcher fatigue and the likelihood of reading errors [7].

To determine taper, it is necessary to measure the stem diameters at two points and calculate it using the formula

$$k = \frac{d_1 - d_2}{l}, \quad (1)$$

where d_1 – diameter at the thicker part of the stem, mm;
d_2 – diameter at the thinner part, mm;
l – distance between the measurement points, mm.

The need to perform additional calculations significantly complicates the research process.

To eliminate these shortcomings, a method for determining the average diameter and taper of flax stems has been developed based on the use of a nomogram and a specialized measuring device. The proposed approach simplifies the measurement procedure, improves the accuracy of determining the geometric parameters of the stems, eliminates the need for numerical calculations, and increases the productivity of mass measurements.

Materials and methods

The aim of the study is to develop a nomographic method for determining the average diameter and taper of flax stems, which eliminates the need for numerical calculations and increases the productivity of mass measurements.

To achieve this goal, the following tasks must be addressed: 1. To develop a graphical method for determining the average diameter and taper of the stem. 2. To create a nomogram for determining these parameters. 3. To design a measuring device based on the nomogram. 4. To measure the average diameter and taper of the stem and perform statistical processing of the results.

The proposed method for determining stem parameters is based on the use of a nomographic approach. A nomogram is a graphical calculating tool that allows the value of a function to be determined by drawing a straight line between corresponding points on the scales. The developed nomogram uses four scales: a scale for the diameter of the thinner part of the stem; a scale for the diameter of the thicker part of the stem; a scale for the average diameter; and a scale for the taper.

The nomogram was constructed using the method of building a three-scale linear nomogram from selected points [8], according to the scheme shown in Fig. 1. The diagram shows four parallel scales: d_2, d_1, k and d_c, where $d_a = 0.5 \cdot (d_1 + d_2)$. The distances between scales d_2 and d_1, as well as between d_1 and k, are equal and denoted by a. Scale d_a is located between scales d_2 and $d_1$such that the distance between d_2 and d_a is $2 \cdot a/3$, and between d_a and d_1 it is $a/3$. The lengths of all scales are equal and denoted by b.

Assuming a maximum value of $d_{2\max} = 4$ mm and using the corresponding formulas and specified proportions of distances between the scales, the maximum values of the remaining parameters are determined: $d_{1\max} = 8$ mm, $d_{a\max} = 6$ mm, $k_{\max} \cdot l = 4$. Taking the length of the scales, for example, $b = 200$ mm, and dividing it into millimetres, determine the scale interval for measuring the diameter d_2: $d_{2\max}/200 = 4/200 = 0.02$ mm; for measuring the diameter d_1: $d_{1\max}/200 = 8/200 = 0.04$ mm; for measuring taper k: $k_{max} \cdot l/200 = 4/200 = 0.02$; for measuring the diameter d_a, divide the scale into 300: $d_{a max}/300 = 6/300 = 0.02$ mm. For a more accurate measurement, each division on the scales k and d_a can be further subdivided in half.

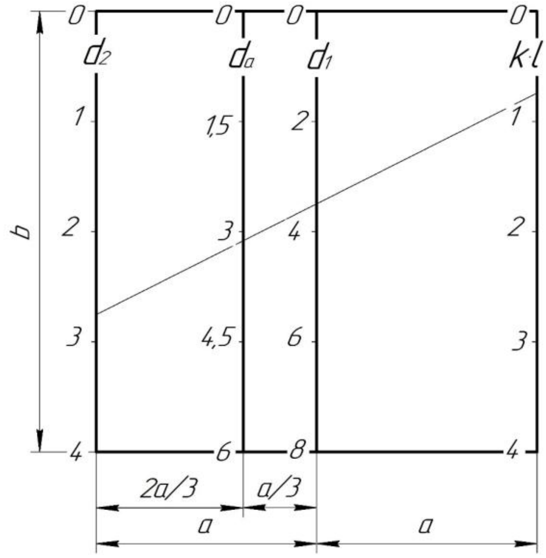

Fig. 1. **Scheme of nomogram construction**

To determine the angle of inclination of one measuring surface relative to the other (for measuring diameter d_2), from the lower end of scale d_2 (4 mm), a perpendicular segment of 4 mm is drawn, and its endpoint is connected to the upper end of this scale (0 mm). Similarly, for measuring diameter d_1, from the lower end of scale d_1 (4 mm), a perpendicular segment of 8 mm is drawn, and its endpoint is connected to the upper end of this scale (0 mm).

The device consists of a rectangular frame 1 of a certain thickness with two pairs of measuring surfaces 2 and 3. One of the measuring surfaces is parallel to the side face of the frame 1 and contains a scale, while the others are inclined at a certain angle. Scales 4 and 5, which are parallel to the side face, are applied to the surface of the frame 1. Fig. 2 also schematically shows the stem 6 and a straight line 7.

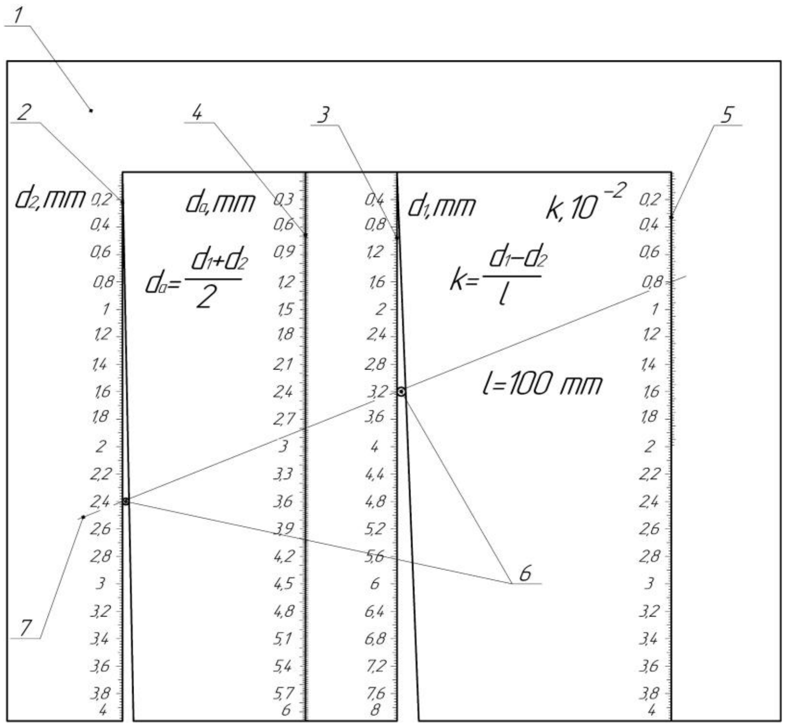

Fig. 2. **Scheme of the proposed measuring device:** 1 – frame; 2 and 3 – measuring surfaces; 4 and 5 – scales; 6 – stem; 7 – imaginary straight line

The operating procedure of the device is as follows. A stem is taken and points are marked in its upper and lower parts where measurements will be carried out at distances that are multiples of 100 mm. The stem 6 is inserted vertically, with the upper mark, into the horizontally positioned device, into the gap between the measuring surfaces 2 until it reaches a stop. The point where the stem 6 contacts the measuring surface with the scale is marked with a pencil. Similar actions are performed on the measuring surfaces 3 for the lower mark on the stem, and a corresponding mark is made on the scale.

A straight line 7 is then drawn through the marks on the scales of measuring surfaces 2 and 3. The point where this line intersects scale 4 gives the average diameter d_a of the stem segment 6, which is recorded. The point where the line intersects scale 5 gives the taper value k, which should be divided by the multiplicity factor corresponding to the distance between the measurement points on the stem (100 mm). For example, if the distance is l = 100 mm, the value is used directly; if l = 200 mm, it is divided by 2; if l = 300 mm, by 3, and so on. Instead of drawing a line 7, a ruler can be used to connect the marks on the scales of measuring surfaces 2 and 3. For example, for the case shown in Fig. 2, with l = 200 mm, d_2 = 2.4 mm and d_1 = 3.2 mm, the average diameter is d_a = 2.8 mm and the taper is $k = 0.8 \cdot 10^{-2}/2 = 0.004$.

The proposed method has several advantages compared to traditional measurement techniques: reduced time required for measurements; elimination of the need for numerical calculations; reduced errors associated with stem deformation; and increased productivity of experimental studies. The use of a nomogram significantly simplifies the procedure for determining the geometric parameters of stems, which is especially important when performing large-scale measurements.

Results and discussion

To accelerate the determination of the average diameter and taper of flax stems, a measuring setup was developed (Fig. 3, a). It consists of a base 1 on which a printed nomogram 2 is mounted so that its upper edge coincides with the end face of the base 1. A wooden bar 3 with slots is rigidly attached to the same end of the base 1 using screws, arranged so that the slots align with the d_2 and d_1 scales. Glass plates 4 with flat polished lower surfaces are inserted into these slots.

Before installing the plates 4, gauge blocks 5 from a set of flat-parallel end length measures [9] are placed on the d_2 scale: a 1 mm thick block aligned with the 1 mm mark and a 3 mm thick block aligned with the 3 mm mark. Similarly, on the d_1 scale, blocks of 2 mm and 6 mm thickness are placed opposite the corresponding marks. After that, the glass plates 4 are inserted into the slots of the bar 3 so that they rest on the edges of the corresponding gauge blocks 5. The position of the glass plates 4 is fixed using hot glue 6. After the glue hardens, the gauge blocks 5 are removed.

The determination of the average diameter and taper of flax stems using the proposed measuring setup is shown in Fig. 3, b. The flax stem, within the measurement zone, is inserted into the gaps between the glass plates and the nomogram surface until it reaches a stop. The average diameter and taper values are then read directly from the d_a and k scales, respectively. Based on a scale division of d_a, the average diameter was measured to an accuracy of 0.01 mm, whilst based on a scale division of k, the taper was measured to an accuracy of 0.0001. For example, in the case shown in Fig. 3, b d_a = 1.64 mm and k = 0.0055.

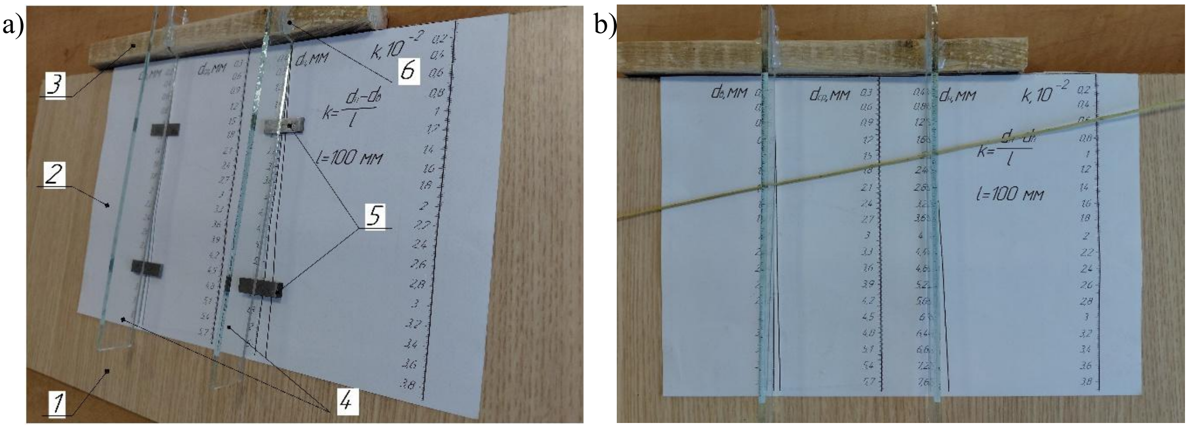

Fig. 3. **Photos of manufacturing (a) and use (b) of the measuring device**

It should be noted that, for accurate determination of these parameters, the stem must be positioned along a straight line, and the readings should be taken along the upper edge of the stem length. This compensates for the fact that, due to the inclination of the stem between the scales, the effective measurement zone for determining the average diameter and taper becomes greater than 100 mm.

Using this measuring setup, the average diameter d_a and the taper k of flax stems were determined in the zone where they are clamped in the groove of the pulling device – approximately at one-third of the stem length over a 100 mm segment. The study was conducted on fiber flax stems of the Miandr variety with the following characteristics: stem length 74-83 cm, maturity stage – yellow ripeness, and stem moisture content – 50.7%. The sample size consisted of 300 stems. During the processing of measurement results, the arithmetic mean, standard deviation, and coefficient of variation were determined. For the average diameter d_a, these values were 2.14 mm, 0.41 mm, and 19.16%, respectively, while for the taper k they were 0.00303, 0.00042, and 13.86%, respectively.

During the processing of the obtained dimensional data using correlation analysis [10], it was established that there is a significant correlation between the average diameter and the taper k of the stem ($t_r = 15.81 > t_{0.05} = 1.97$) (Fig. 4). Since the pair correlation coefficient is $r = 0.68 < 0.70$, the identified correlation can be considered of moderate strength. Analysis of the measurement data using regression methods showed that the dependence of the stem taper k on its average diameter d_a (mm) is linear (Fig. 4) and can be described by the regression equation:

$$k = (11.9 \cdot d_a + 2.4) \cdot 10^{-4}. \qquad (2)$$

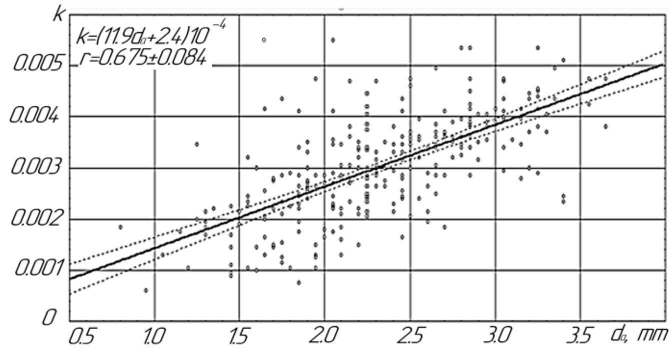

Fig. 4. **Correlation dependence between stem taper *k* and its average diameter d_a**

The obtained regression equation can be used in engineering calculations of the parameters of pulling apparatuses, in particular to determine the optimal pressure in the pulling groove depending on the geometric characteristics of the stem mass. The application of the proposed method makes it possible to improve the accuracy of adjustment of the working units of flax harvesting machines and reduce stem damage during the harvesting process.

Conclusions

1. A new method for determining the average diameter and taper of flax stems using a nomogram has been developed.
2. A measuring device has been created that allows these parameters to be determined without performing numerical calculations.
3. The use of the proposed method ensures increased productivity of mass measurements.
4. The presence of a correlation between the average diameter and taper of flax stems has been established and a linear relationship was established between these parameters.
5. The proposed method can be recommended for use in scientific research and engineering practice when designing flax harvesting machinery.

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 V.T.; data curation, S.Y. and Sv.Y.; writing – original draft preparation, S.Y. All authors have read and agreed to the published version of the manuscript.

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