ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 8, Issue 4 , April 2021

Physico-Mechanical Properties of Corn Stalks

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ABSTRACT: The results of one of the physical and mechanical properties of the stems of forage plants, resistance to bending in the field in terms of the choice, simplification and creation of machines and working bodies for harvesting and crushing forage stems as an object of the research and theoretical models which obtained from the results of field experiments are presented in this article.

KEY WORDS: stem, grinding, bending, resistance, stiffness, model, working body.

I. INTRODUCTION

The physical and mechanical properties of the plants are fundamental in the choice of technology and technical means of their processing [1].

The founder of agricultural mechanics' V.P. Goryachkin highlighted the need for a more complete and comprehensive research of the properties of the cultivated plant objects in order to determine the difference between varieties on the one hand and assess the leveling of individual varieties on the other hand [2].

The research of biometric (which includes a part of morphological and dimensional-mass characteristics) and physical and mechanical (which includes strength indicators, friction coefficients, etc.) properties of corn cobs is an essential condition in the development of designs and definitions of the parameters of the working bodies of devices and machines for harvesting post-harvest processing [2, 3, 4, 5, 6, 7, 8, 9].

Data on the research of the physical and mechanical properties of corn are presented by almost all developers of the designs of the working bodies of corn harvesters and post-harvest processing means both in the Republic of Uzbekistan, Russia and abroad [10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20].

There is a large number of works devoted to certain aspects of deformations and strength characteristics of the agricultural materials, various methods and processes of cutting, crushing, pressing, etc. Their distinctive feature is that they were carried out in relation to a preselected working body and the method of material processing. The direction of modeling the processes of deformation and fracture of materials is very perspective. For example, in the works of N.E. Reznik. the method of modeling the process of material compression by using a mechanical analogs of deformations ("Hooke's body", "Maxwell's body", "Kelvin's body", etc.) is considered in general form [1]. This approach, with various combinations of mechanical analogs, makes it possible to simulate the deformation of materials with rather complex combinations of elastic- visco-plastic properties, while the mathematical interpretation of the processes is greatly simplified. A high theoretical level is distinguished by works in the field of mathematical physics, devoted to the research of complex stress states of various solids. It should also be noted that the work on modeling the deformations of stem and grain materials is insufficient, the results of which are presented in the form of probabilistic models.

The lack of work on the research of the strength characteristics of the main types of feed, their narrow focus does not allow obtaining a complete and clear picture of the processes of deformation and destruction. This situation creates significant difficulties in improving the working organs and processes of machines for preparing feed, and the developers are forced to rely more on intuition and heuristic abilities than on accurate analytical methods.

The solution of the urgent problem is possible by conducting fundamental theoretical and experimental researches of the processes of deformation and destruction of feed materials that prevail in the existing feed rations of animals.

The purpose of this work is to obtain the theoretical models based on the results of field experiments, which can be taken as a basis for the design of machines for mowing and chopping corn stalks.

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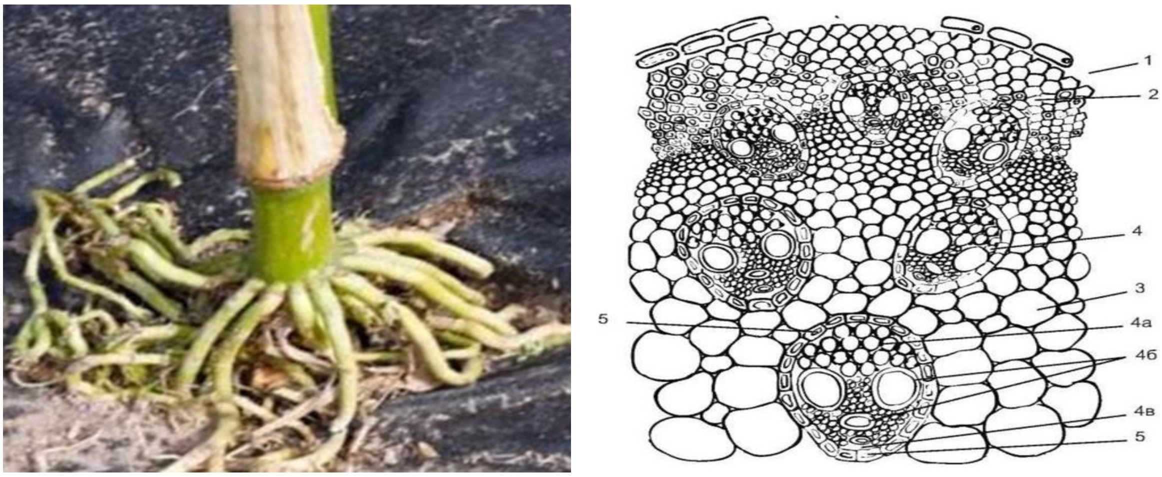
II. MATERIALS AND METHODS

For the stems of agricultural plants with their bending, the constancy of rigidity $E\mathcal{J}$ is not observed. This is due to the complexity of the internal structure of the material. The stalk of maize (Fig. 1), for example, in its cross-section has a round shell filled with parenchymal mass, in which there are bundles of thin steel comparable in strength to that of steel. Stem nodes with high strength significantly strengthen the structure.

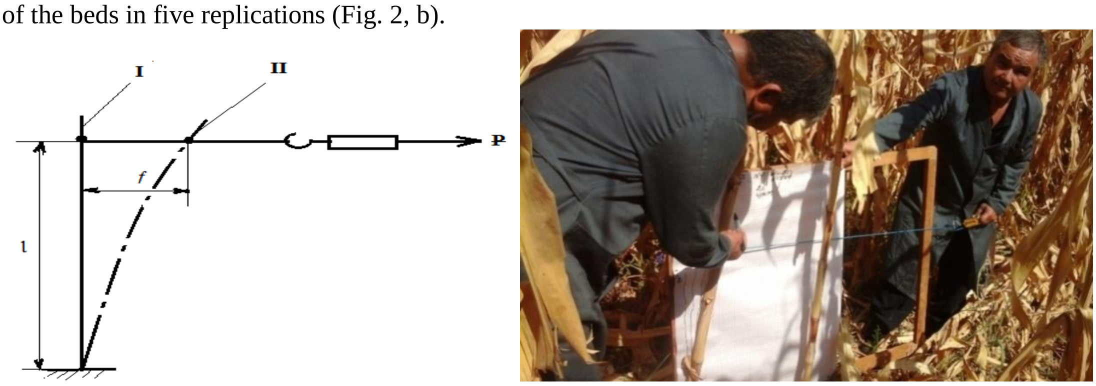


a) b)

Fig. 1. Type of the root system (a) and the cross-section of the stem (b) of corn: 1-epidermis; 2-sclerenchyma; 3-main parenchymal mass; 4-closed collateral threads; 4a- phloem; 4b - xylem vessels; 4b-airspace; 5-sclerenchymal mass of filament sheath.

However, the strength of the stem at different directions of deformation is significantly different. This applies primarily to the modules of elasticity of compression and tension both along and across the fibers of the stem in the internodes. When the stem is bent, a significant difference in the modules of elasticity leads to a displacement of the neutral axis towards the stretched fiber, a change in the moments of inertia of the section, an uneven increase in maximum stresses, in the case of which destructive values are reached, the stem breaks either due to breaking the fibers or due to their crushing.

To study the resistance to bending of plant stems, we carried out field experiments at the stage of maize ripeness (maize variety Karasuv 350 AMV). The experiments were carried out along the longitudinal and transverse axes of the beds in five replications (Fig. 2, b).



a) b)

Fig. 2. Scheme for defining the limb of stems (a) and a fragment of the type of field experiments (b): I-initial position of the stem; II-position of the bend of the stem after the application of force; *l*-height of the bend force setting; *P*-bending force; *f*-bend amount

The bending force *P* was applied to the stem in the horizontal plane at a height *l* between the ground level and the line of action of the force *P* (Fig. 2, a). The distance *l* was measured from the point between the root collar and the

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
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first node of the stem to the line of action of the force *P*. The bend from the vertical position of the stem and until the moment of loss of resistance (break of the stem) was fixed in accordance with the value of *P*.

III. RESULT AND DISCUSSION

Table 1, as an example, shows the results of testing four stalks of corn with diameters in the area of the root collar of 25, 26, 28 and 30 mm. The table shows that the stiffness of the stems depends on the diameter in the design section, takes a maximum value at the limit of elastic deformation, and then decreases until the moment of destruction. An analysis of the graphs of the stiffness dependences on *f* and P showed the possibility of obtaining analytical models in the form of second degree polynomials:

$$EJ(f) = a^2 f^2 + a_1 f + a_2,$$

$$EJ(p) = C_o P^2 + C_1 P + C_2.$$

For this, the Polyfit *(x, y, z)* file was used, where $y = EJ, x = f \; or \; x = P$ This file is used in the MatLAB system to obtain the coefficients of the models by the least squares method [21]. For example, for a stem with a diameter of $d = 2{,}5cm$ has $EJ[163691100070005000]$; $f = [4133054]$; $P = [1234]$.

Model coefficients:

$$P_a(f): a_0 = 0{,}0057 * 10^3 \qquad P_a(P): c_0 = 0{,}75 * 10^3$$

$$a_1 = -0{,}5405 * 10^3 \qquad c_1 = -7{,}45 * 10^3$$

$$a_2 = 17{,}7209 * 10^3 \qquad c_2 = 22{,}5 * 10^3$$

Table 1. Results of determining the resistance of corn stalks to bending in the field

Stem diameter 2.5 cm					
Bending force *P*, kgf	1	2	3	4	
Bend arrow *f*, cm	4	13	30	54	
Hardness *EJ*, kgf * cm^2	16 363	11 000	7 000	5 000	
Stem diameter 2,6 cm					
Bending force *P*, kgf	2	3	4	5	
Bend arrow *f*, cm	8	12,5	19,5	30,6	
Hardness *EJ*, kgf * cm^2	18 000	17 300	14 770	12 000	
Stem diameter 2,8 cm					
Bending force *P*, kgf	3	4	5	6	7
Bend arrow *f*, cm	10,8	16,5	32	44	56
Hardness *EJ*, kgf * cm^2	21 000	17 400	11 000	981	892
Stem diameter 3,0 cm					
Bending force *P*, kgf	4	6,5	7,5	8,5	10
Bend arrow *f*, cm	7	18	26,5	37,5	46,5
Hardness *EJ*, kgf * cm^2	41 142	27 500	20 370	16 300	15 483

The bending arm in the given data is $l = 60 \; cm,$ the bending force *P* was applied in a plane parallel to the surface of the field the stiffness was determined by the $EJ = \frac{Pl^3}{3f}$ formula.

As a result, we get the required models:

$$EJ(f)_m = (0{,}0057 * f^2 - 0{,}5405 * f + 17{,}7209) * 10^3;$$

$$EJ(P)_m = (0{,}75 * P^2 - 7{,}45 * P + 22{,}75) * 10^3;$$

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The error between the experimental data EJ_{on} and EJ_m calculated by the equations was estimated for each cross section in percentage and the maximum value was chosen in modulus

$$\Delta EJ = \max\{\frac{EJ_{on} EJ_m}{EJ_{on}}\} * 100.$$

In particular, for the considered example

$$\Delta EJ(f)_{\max} = 2{,}14\% \ and \ \Delta EJ(P)_{\max} = 6{,}1\%.$$

Similar equations were obtained for stems with different diameters:

$a)\quad d = 2{,}6 \ cm:$

$$EJ(f)_m = (0{,}0068 * f^2 - 0{,}6872 * f + 23{,}2641) * 10^3$$
$$EJ(P)_m = (0{,}7351 * P^2 - 8{,}8750 * P + 39{,}9805) * 10^3$$

b) $d = 2{,}8 \ cm:$

$$EJ(f)_m = (0{,}0072 * f^2 - 0{,}7276 * f + 27{,}1859) * 10^3$$
$$EJ(P)_m = (0{,}7857 * P^2 - 10{,}9571 * P + 47{,}1714) * 10^3$$

$v)\quad d = 3{,}0 \ cm:$

$$EJ(f)_m = (0{,}0206 * f^2 - 1{,}7499 * f + 52{,}257) * 10^3$$
$$EJ(P)_m = (0{,}5550 * P^2 - 12{,}2902 * P + 81{,}6603) * 10^3$$

In this case, the maximum error for all equations does not exceed 6.3%, which indicates a good approximation of theoretical models to experimental data. Based on the results of theoretical models, graphs of dependences of stiffness EJ on the value of the bend force $P(a)$ and the size of the bend $f(b)$ were constructed for different diameters of corn stalks (Fig. 3).

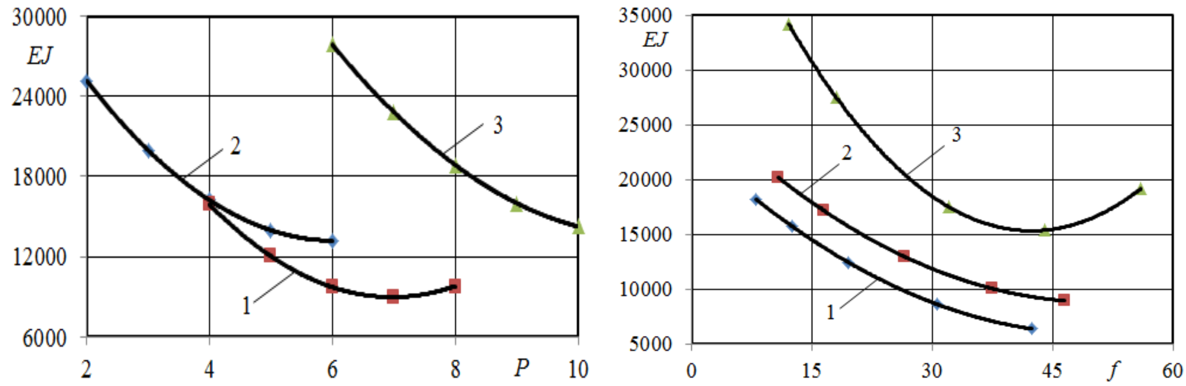

Fig. 3. Dependences of stiffness EJ on the value of the bend force $P(a)$ and the value of the bend f (b) for different diameters of corn stalks:

1 - with a stem diameter of 2.6 cm; 2 - with a stem diameter of 2.8 cm; 3- with a stem diameter of 3.0 cm

Analysis of the graphs shows that at the beginning of the bend, at relatively small values of f and P, the value of EJ increases to a maximum, i.e. to the limit of elastic state, kink. In the course of field experiments, the influence of humidity, the number of internodes, and the diameter along the length of the stem were noted.

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IV. CONCLUSION

The obtained theoretical models of the strength of corn stalks obtained from the results of field experiments can be taken as the basis for calculating the geometric parameters in the design of machines and working bodies for mowing and crushing rough-stemmed crops.

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