ZESZYTY PROBLEMOWE POSTĘPÓW NAUK ROLNICZYCH 1978 z. 203

THE DETERMINATION OF THE YOUNG'S MODULUS OF A STALK OF WINTER WHEAT ON THE BASIS OF FIELD AND LABORATORY MEASUREMENTS

Grażyna Skubisz

The resistance of cereals to lodging depends on many factors, particularly on the properties of the plants, on agrotechnology and the soil-climatic conditions. In order to investigate this range of problems many research works were undertaken and many various methods were presented [6]. Apart from the anatomical and chemical composition analyses of stalk, also biometrical measurements of the inflexibility coefficient of straw [5] and its resistance to lodging [2, 3] or measurements of the force bending a stalk [1] and its particular internods [4, 7] were made.

The mechanical parameters of stalk, although difficult to determine exactly because of the heterogeneity of the investigated material, can serve to build a picture of lodged cereal.

METHODOLOGY OF INVESTIGATIONS

The purpose of the present research was to work out a method of measuring the force bending particular sections of stalk and a whole stalk, leading to the determination of the Young's modulus for the stalk of winter wheat. The measurements were made with the help of prototype apparatus of the Institute of Agrophysics of Polish Academy of Sciences in Lublin. The apparatus consisted of

1) a field electrodynamometer, with the help of which the values of force bending whole stalk are measured in field conditions,

2) an electromagnetic micro-picker, with the help of which the values of force bending sections of stalk are measured in laboratory conditions,

3) a device for measuring the intersection of stalk, on which the outer and inner diameters of stalk are measured.

The field measurements were restricted to measuring the values of force bending whole stalk to the angle of 20, 30, 40, 50, 60 and 70 degrees. At the same time the arrow of bending and the angle of the force action — parameters necessary for the determination of the Young's modulus — were measured. The measurements were made for three varieties of winter wheat (Aurora, Grana, Helenka) with the application of the principle of thirty repetitions for each variety in the successive phenological periods, from earing, through milk and wax maturity, to full maturity. At the same time field measurements were made on the Aurora variety with the application of the root system blockade in order to eliminate the root lodging in the process of artificially caused bending of stalk.

In laboratory conditions the value of force bending a 6 cm long section of stalk by a fixed value — 5 mm (the arrow of bending) and the geometrical features were measured. In order to determine the Young's modulus also the inertia momentum was calculated according to the formula

$$\mathcal{J} = \frac{\pi}{2}\left(\Phi_z^4 - \Phi_w^4\right), \tag{1}$$

where:

φ_z — outer diameter,

φ_w — inner diameter.

The Young's modulus was calculated according to the formula

$$E = \frac{Pl^3}{48y\mathcal{J}}, \tag{2}$$

where:

P — force bending a sample of stalk,

l — length of the bent rod,

y — arrow of bending,

J — inertia momentum.

In this way the Young's modulus was calculated for particular sections, and in further considerations it was related to the whole stalk (from the distribution of this parameter on the whole length of stalk statistical mean value was calculated for the whole stalk).

For the calculation of the Young's modulus of stalk in field conditions the mean value of the inertia momentum obtained through laboratory measurements made for a section of stalk was applied.

On the basis of data from foeld measurements the Young's modulus was determined with the application of the theory from the resistance of rods subjected to bending to small angles

$$E = \frac{P' l^3}{3y\mathcal{J}}, \tag{3}$$

where:

$P = P'\cos\beta$,

P — force deforming the stalk,

l — length of stalk,

y — arrow of bending,

J — inertia momentum calculated statistically from results obtained from laboratory investigations.

RESULTS OF INVESTIGATIONS

The Young's modulus obtained on the basis of laboratory investigations takes various values on the length of stalk (from ear to nodium) in different stages of maturity. The variability of the values of this parameter is presented by the curves shown in the Figures.

The values of the Young's modulus for winter wheat of the Aurora variety in full earing form the range from 368 to 1045N/mm², in milk maturity they form the range from 818 to 1762 N/mm², and in full maturity the range from 562 to 1114 N/mm² (Fig. 1).

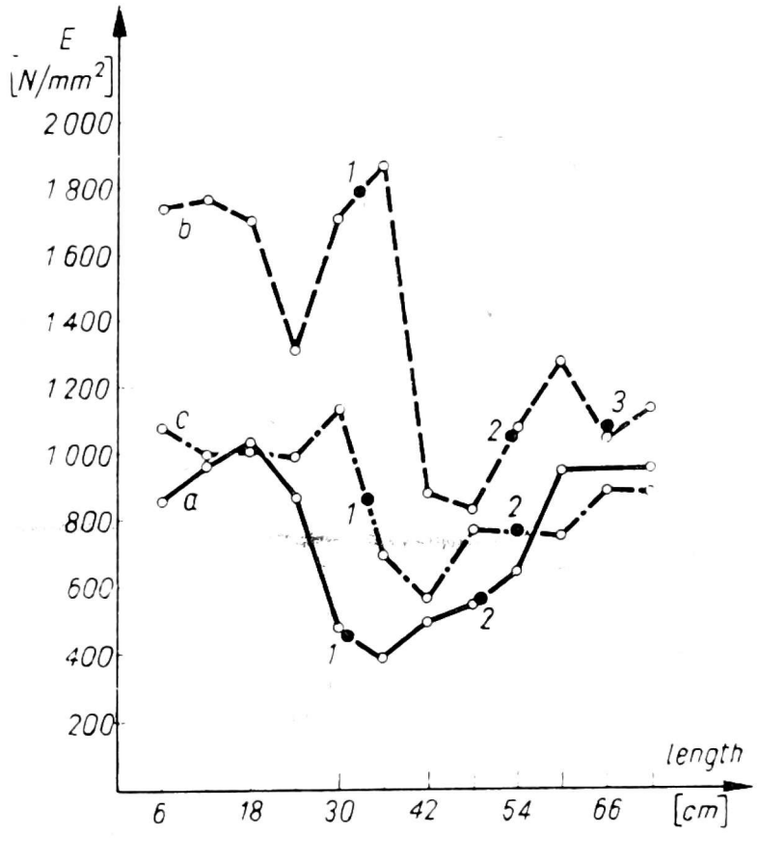

Fig. 1. Distribution of the values of elasticity coefficients on the length of stalk of winter wheat (Aurora variety) in the successive phenological periods (o — point of measurement, o¹ — nodium, *a* — after earing, *b* — milk maturity, *d* — full maturity)

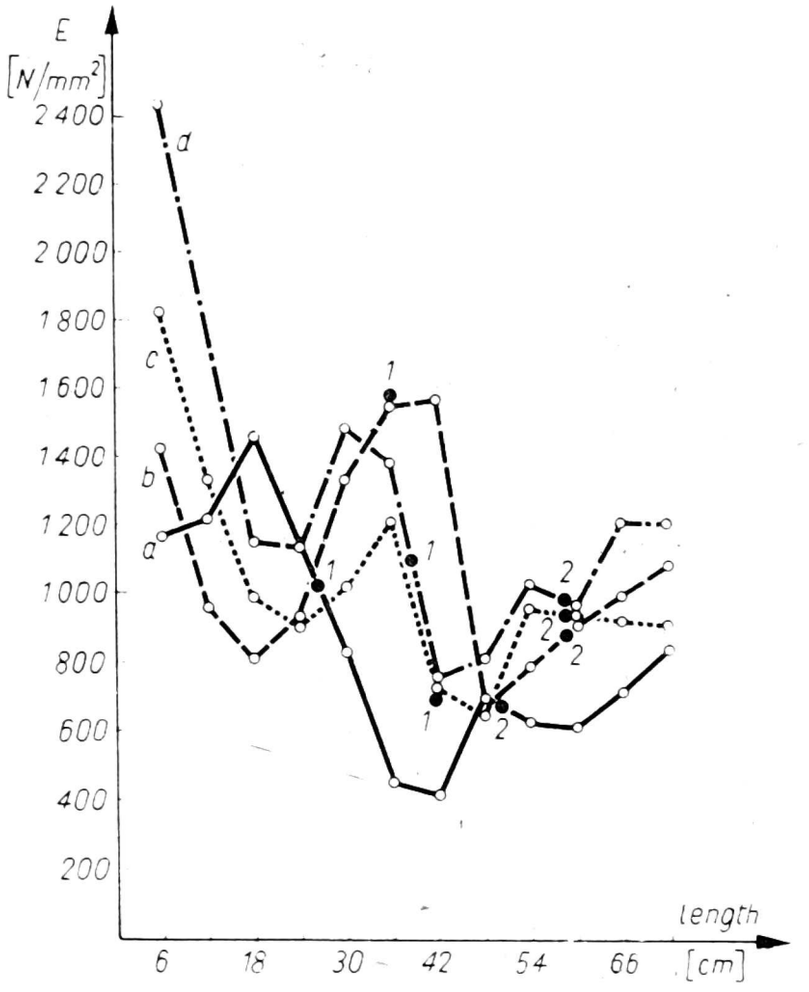

Fig. 2. Distribution of the values of elasticity coefficients on the length of stalk of winter wheat (Grana variety) in the successive phenological periods (o — point of measurement, o¹ — nodium, *a* — after earing, *b* — milk maturity, *c* — wax maturity, *d* — full maturity)

In the same periods the values for the Grana variety form the ranges: 431—1460 N/mm², 699—1559 N/mm² and 659—1813 N/mm² in wax maturity (Fig. 2), and for the Helenka variety 431—1033 N/mm², 759—2293 N/mm², and 691—2067 N/mm², 796—2381 N/mm² in wax maturity (Fig. 3).

On the basis of these results it was established that stalk as a heterogeneous material shows a very high variability of the Young's modulus on its whole length.

The mean values of the Young's modulus characterizing the varieties on the basis of field and laboratory investigations are presented in Tables 1 and 2, and the results of statistical calculations are presented in Tables 3—6 (variation analysis, Duncan's halfranges of credibility). Concluding was done with the significance level $\alpha = 0.05$.

The mean values of the Young's modulus for the three varieties of winter wheat obtained from field investigations are presented in Table 1 and their statistical analysis in Tables 3 and 4. The obtained values

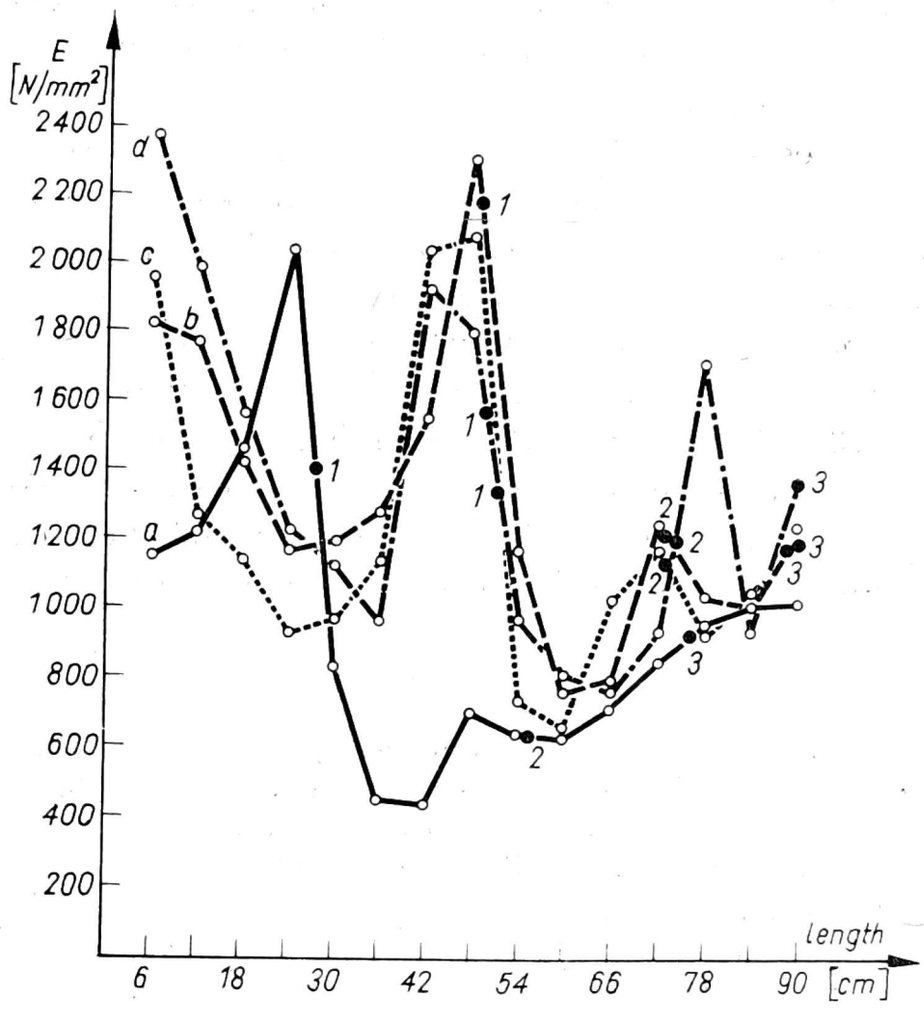

Fig. 3. Distribution of the values of elasticity coefficients on the length of stalk of winter wheat (Helenka variety) in the successive phenological periods (o — point of measurement, o^1 — nodium, *a* — after earing, *b* — milk maturity, *c* — wax maturity, *d* — full maturity)

indicate a certain differentiation of the values of the Young's modulus. The maximum value of the Young's modulus occurs for the Aurora variety (1680 N/mm²) in the period of milk maturity, while for the Grana (2681 N/mm²) and Helenka (2905 N/mm²) varieties in full maturity.

The occurence of significant differences between the investigated varieties and stages of maturity was established for the majority of the compared values. Only in the case of the Aurora variety in full earing, and between the Grana and Helenka varieties in this period and in full maturity no significant differences were noted.

Additional investigations were carried out for the Aurora variety with the application of artifficial blockade, so as to create a possibility of eliminating the unsettling of the root system that usually accompanies the bending of stalk. Generally higher values of the Young's modulus were obtained for stalks with roots blocked in the ground than for stalks investigated in natural conditions.

Significant differences were established for the Aurora variety (Table 3) in the periods of milk and full maturity, while in the period of full earing there were no significant differences.

The mean values of the Young's modulus for the three varieties of winter wheat obtained from laboratory investigations are presented in Table 2, and their statistical interpretation in Tables 5 and 6. In the case of the Grana variety an increase of the value of the Young's modulus with the increase of maturity is noted, while in the case of the Aurora and Helenka varieties the maximum values occur in the milk maturity: 1356 N/mm² and 1351 N/mm² respectively.

The laboratory investigations, apart from creating a possibility of determining the variability of the Young's modulus on the length of stalk, allowed to obtain information about the value of this parameter

Table 1

Mean values of the Young's modulus (N/m²) at various angles of bending of a stalk of winter wheat in field conditions

Varieties	Angle of bending in degrees	Periods of maturity			Mean value
		after earing	milk maturity	full maturity	
Aurora	20	1292	1773	1496	
	30	1192	1809	1439	
	40	1115	1750	1334	
	50	1099	1625	1259	
	60	1094	1596	1178	
	70	1213	1663	1140	
Mean value		1167	1680	1328	1393
Grana	20	2008	1070	2861	
	30	1826	1067	2851	
	40	1667	990	2625	
	50	1473	897	2529	
	60	1437	788	2659	
	70	1643	737	2178	
Mean value		1677	1169	2681	1837
Helenka	20	1587	1506	2196	
	30	1587	1797	2459	
	40	1578	2100	2813	
	50	1613	2065	3214	
	60	1729	2571	3612	
	70	2293	3506	3213	
Mean value		1729	2233	2905	2259
Mean value		1524	1161	1871	

Table 2

Mean values of the Young's modulus (N/m^2) of a stalk of winter wheat on the basis of laboratory measurements

Varieties	Periods of maturity			Mean value
	after earing	milk maturity	full maturity	
Aurora	704	1356	872	977
Grana	859	1005	1270	1045
Helenka	898	1351	1279	1176
Mean value	820	1237	1140	

Table 3

Significance of differences between the mean values of the Young's modulus of a stalk of winter wheat for the successive periods of maturity (on the basis of data from field measurements)

Varieties	Periods of maturity		
	after earing	milk maturity	full maturity
Aurora — Aurora B*	0	—	—
Aurora — Grana	—	+	—
Aurora — Helenka	—	—	—
Grana — Helenka	0	—	0

+ Significant difference to the advantage of the first period (or variety).

— Significant difference to the advantage of the second period (or variety).

O No differences statistically confirmed.

x Aurora — measurements made with the application of a blockade of the root system.

Table 4

Significance of differences between the mean values of Young's modulus of a stalk of winter wheat for the successive periods of maturity (on the basis of data from field measurements)

Periods of maturity	Varieties			
	Aurora B*	Aurora	Grana	Helenka
After earing — milk maturity	—	—	+	—
After earing — full maturity	—	0	—	—
Milk maturity — full maturity	0	+	—	—

Markings as in Table 3.

Table 5

Significance of differences between the mean values of Young's modulus of a stalk of winter wheat for the successive periods of maturity (on the basis of laboratory data)

Varieties	Periods of maturity		
	after earing	milk maturity	full maturity
Aurora — Grana	—	+	—
Aurora — Helenka	—	0	—
Grana — Helenka	0	—	0

Markings as in Table 3.

Table 6

Significance of differences between the mean values of Young's modulus of a stalk of winter wheat for the successive periods of maturity (on the basis of laboratory data)

Periods of maturity	Varieties		
	Aurora	Grana	Helenka
After earing — milk maturity	—	—	—
After earing — full maturity	—	—	—
Milk maturity — full maturity	+	—	0

Markings as in Table 3.

characterizing the whole stalk. The occurence of significant differences between the investigated varieties and maturity periods was established for the majority of investigated varieties. Only between the Aurora and Helenka varieties in the milk maturity and between the Grana and Helenka varieties in the other periods no significant differences were noted.

CONCLUSIONS

1. The results obtained from the field and laboratory investigations allow for making comparisons between the varieties and for the characterization of the variability course of the Young's modulus in the successive maturity periods.

2. On the basis of analyzing the obtained results it is possible to state that the accepted methodology of investigations allows to grasp the

significance of differences between the investigated varieties, considering also the stages of maturity.

3. The accepted methodology allowed to determine the ranges of the values of Young's modulus for the particular varieties and stages of maturity.

Considering the heterogeneity of the investigated material it seems necessary to repeat the above measurements in the following years in order to confirm the obtained information.

REFERENCES

1. Grafius J. E., Brown M. E.: Lodging resistance in oats. J. Agr., 1954, 46.
2. Hamilton D. G.: Certain oat culm characters and their relationship to loading. Sci. Agric., 1941, 21.
3. Kuźniecow W. S.: Rozrabotka mietoda objektiwnoj ocenki ustojczіwosti k poleganiu polewych kultur spłosznowo siewa. Dokłady TSCHA, 1961, t. 62.
4. Pickett L. K., Liljedahl J. B., Haugh C. G., Ullstrup A. J.: Reological properties of cornstalks subjected to transverse loading. The Translations of the ASAE, 1969, vol. 12, 3.
5. Ruebenbauer T., Riegerowa H.: Próba określenia sztywności słomy pszenic ozimych na podstawie pomiarów nielicznych roślin. Acta Agrobotanica, 1955, vol. 3.
6. Szot B., Kolemba G.: Metody oceny wylegania zbóż. Problemy Agrofizyki, 1973, z. 8.
7. Zuber M. S., Grogan G. O.: A new technigue for measuring stalk strength in corn. Crop Science, 1961, vol. 1, 378—380.

G. Skubisz

WYZNACZENIE MODUŁU YOUNGA ŹDŹBŁA PSZENICY OZIMEJ NA PODSTAWIE POMIARÓW POLOWYCH I LABORATORYJNYCH

Streszczenie

Przedstawiono metodę wyznaczania modułu Younga źdźbła pszenicy ozimej na podstawie pomiarów cech mechanicznych w warunkach polowych i laboratoryjnych.

W warunkach polowych określano wartości siły zginającej całe źdźbło dla trzech odmian pszenicy ozimej, począwszy od pełni kłoszenia poprzez dojrzałość mleczną i woskową do pełnej.

Następnie na tym samym materiale badawczym przeprowadzano pomiary laboratoryjne, które obejmowały określenie wartości siły zginającej odcinek źdźbła o stałą wielkość oraz cechy geometryczne.

Średnie wartości modułu Younga obliczone na podstawie badań polowych wykazały istnienie znacznych zmienności determinowanych zarówno cechami odmianowymi, jak i fazami fenologicznymi.

Na podstawie badań laboratoryjnych stwierdzono, że źdźbło jako materiał niejednorodny wykazuje dużą zmienność współczynnika sprężystości na całej długości łodygi. Ponadto podjęto próbę zastosowania różnych teorii z wytrzymałości materiałów dla scharakteryzowania cech fizycznych źdźbła.

Г. Скубиш

ОПРЕДЕЛЕНИЕ МОДУЛЯ ЮНГА СТЕБЛЯ ОЗИМОЙ ПШЕНИЦЫ НА ОСНОВАНИИ ПОЛЕВЫХ И ЛАБОРАТОРНЫХ ИЗМЕРЕНИЙ

Резюме

В работе представлен метод определения модуля Юнга стебля озимой пшеницы на основании измерений механических свойств в полевых и лабораторных условиях при помощи прототипной аппаратуры из Агрофизического института ПАН в Люблине. В полевых условиях определялись значения силы, сгибающей весь стебель в пределах от 20° до 70°, на трех сортах озимой пшеницы, начиная с полного колошения по молочную, восковую и полную спелость. Одновременно измерялись стрелка прогиба и угол действия силы. Затем на том же исследуемом материале были проведены лабораторные измерения, включающие в себя определение значения силы, сгибающей 6-сантиметровый участок стебля на постоянную величину 5 мм (стрелка прогиба), и геометрических свойств: внешнего и внутреннего диаметров. Таким образом был получен модуль Юнга для отдельных участков, отнесенный затем ко всему стеблю.

Средние значения модуля Юнга, подсчитанные на основании полевых опытов, показали наличие значительной изменчивости, детерминированной как качествами сорта, так и фенологическими фазами (1167,15 Н/мм²-1905,19 Н/мм²).

На основании лабораторных исследований обнаружилось, что стебель, как неоднородный материал, отличается большой изменчивостью коэффициента упругости по всей длине стебля. Значения модуля Юнга для отдельных сортов располагаются в пределах 368-2439 Н/мм².

Кроме того были подсчитаны коэффициенты корреляции между исследуемыми механическими и геометрическими свойствами стебля и была предпринята попытка применения различных теорий по прочности материалов для характеристики свойств стебля, важных с точки зрения практики и для познавательных целей.

Address of the author
Mgr Grażyna Skubisz,
Institute of Agrophisics, Polish Academy of Sciences,
ul. Krakowskie Przedmieście 39, 20-076 Lublin, Poland