ATTEMPT AT APPLYING THE ULTRASONIC METHOD FOR DETERMINING THE YOUNG MODULUS OF CEREAL STALK

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INTRODUCTION

In Poland cereals are the most important of cultivated plants. Breeders try to breed short stalk varieties (70—80 cm), mechanically enduring stalk and grain — straw weight relation like 2:1, resistant to lodging [1]. The constructors of harvesting machines are demanded to devise, with the increasing degree of mechanization, more and more perfect cutting mechanisms enabling the increase of productivity, functionality and quality of work of the machines. Both the breeders and the constructors do not have sufficient data about the physico-mechanical properties of cereal plants [2].

The main reason for this lack of information is the heterogeneity and complexity of the structure of biological materials. Plant, in the course of its development, changes the properties of the material it is built of, the chemical composition, moisture, and is subjected to stochastic dynamic loadings caused by wind and rain.

PRESENT STATE OF THE PROBLEM

One of the mechanical properties of considerable influence on the stability of stalk and the value of shearing resistance is the coefficient of longitudinal elasticity called the Young modulus E. According to Timoszenko [3] the value of force P at the action of which stalk is able to keep vertical position can be expressed by the formula

$$P = \frac{mEI}{l^2}$$

where

m — coefficient dependent on the distribution of loadings on the length of stalk,

I — moment of inertia,

l — length of stalk.

In organic bodies, which are anisotropic bodies, the value of the Young modulus depends on the direction of strains in relation to the fibres of material.

In investigations carried out so far the evaluation of the resistance of stalk is made by subjecting sections of stalk or whole stalks to experiments in bending, breaking, compressing or shearing. The measurement consists in determining the geometrical dimensions and the force required for the bending, breaking or shearing, with the help of special apparati [4]. Treating a live plant as a mechanical construction it is possible to calculate the basic constants of the elasticity of material:

Change of the value of the Young modulus along the stalk in different stages of development of wheat

Distance from ear	Earing (after cutting)	Earing (after drying)	Full maturity (after drying)
l (cm)	E (Nm^{-2})	E (Nm^{-2})	E (Nm^{-2})
6	$1.6\ 10^9$	$3.2\ 10^9$	$2.1\ 10^9$
12	$2.9\ 10^9$	$5.5\ 10^9$	$2.7\ 10^9$
18	$3.5\ 10^9$	$7.2\ 10^9$	$4.2\ 10^9$
24	$3.2\ 10^9$	$8.0\ 10^9$	$4.8\ 10^9$
31	$3.5\ 10^9$	$9.7\ 10^9$	$4.3\ 10^9$
37	$4.6\ 10^9$	$1.2\ 10^{10}$	$4.8\ 10^9$
43	$4.2\ 10^9$	$1.2\ 10^{10}$	$5.3\ 10^9$
56	$3.2\ 10^9$	$9.9\ 10^9$	$4.2\ 10^9$
62	$4.6\ 10^9$	$1.2\ 10^{10}$	$4.3\ 10^9$
68	$5.0\ 10^9$	$1.2\ 10^{10}$	$4.1\ 10^9$

the Young modulus and the Poisson ratio ν, on the basis of the measured values and with the help of appropriate formulae [5].

The applied investigation methods for the determination of the elasticity constants of plant material on the basis of resistance experiments are work consuming and require the destruction of the investigated sample. The highest agreement of results is achieved with the breaking experiments. The application of a modern tensile testing machine of the Instron type enables the determination of the material constants and the rheological characteristics of the investigated plant material with high precision. The carrying out of investigations requires, however, appropriate preparation of samples. In the case of straw the problem is particularly difficult, since in the point the sample is held there often occurs damage to the sample tissue and a high percentage of samples is eliminated from the investigations. The laboriousness of the preparation of samples makes mass scale of this control impossible. At this stage of investigations there is the need to introduce initial evaluation of the quality of material chosen fo investigations with destructive methods.

EVALUATION OF THE ULTRASONIC METHOD

One of very precise non-destructive methods of investigating the properties and structures of different materials is the ultrasanic method. It consists in the observation of the phenomenon of the dispersion of mechanical vibrations of ultrasonic frequency in the investigated medium. Every change in the properties of the medium causes a change in the conditions of the dispersion of acoustic wave in it, and thus a change in the velocity of wave and in the damping coefficients. Ultrasonic methods can be utilized for measuring the elasticity and viscosity coefficients of different materials, and also for recording the changes in moisture, pressure, temperature and other factors having influence on the speed or damping of ultrasonic waves [5].

The basic advantage of the ultrasonic method of investigations is the short time of measuring the investigated value (of the order of several microseconds) guaranteeing in practice the continuity of measurement which can be automated in a simple way. This method is very precise and allows for the application of waves of very low intensities (10^{-5}—10^{-2} Wcm^{-2}) which ensures that the measurements do not influence the properties of the investigated medium nor the course of the investigated process. This property has a decisive significance in the application of the ultrasonic method for investigating of properties of biological material and processes.

The propagation velocity of longitudinal waves c_l and perpendicular waves c_t in solid bodies depends on their density ϱ, Young modulus and Poisson according to the following formulae

$$c_l = \sqrt{\frac{E(1-\nu)}{\rho(1+\nu)(1-2\nu)}}\,; \qquad c_t = \sqrt{\frac{E}{\rho}\,\frac{1}{2(1+\nu)}}\,.$$

In limited media, such as rods and plates whose thicknesses d are little in comparison with the length of the dispersing wave λ and the condition $\frac{d}{\lambda} \gg 0.29$ is fulfilled, the Young modulus is expressed by the formula:

$$E = \rho c_1^2\,.$$

Starting from the assumption that the phenomenon of the dispersion of ultrasonic waves in stalk, and more precisely in mechanical tissues, can be compared to the propagation of waves in rods, attempt at determining the Young modulus for wheat stalks on the basis of the above formula was undertaken.

PRESENTATION OF THE INVESTIGATIONS

For the determination of the dispersion speed of longitudinal waves in wheat stalks the Polish ultrasonic flaw detectors of the BI-8R M66 and BI-12R types adapted to work in the 20—500 kHz frequency range were applied. The measurement of the time of passage of wave through the investigated sample was made with the exactness to 2%. The apparati were specially equipped to enable the carrying out of the investigations in both field and laboratory conditions. The ultrasonic heads made for investigating the resistance properties of concrete constructions were adapted to investigating sections of stalks (Fig. 1) and whole stalks (Fig. 2). Stalks were divided into internods and subjected to ultrasonic examination. After the determination of the mean propagation velocity in particular internods, the internods were cut into 6 cm sections and again subjected to examination. The velocity of waves was determined for fresh stalks immediately after cutting and after drying. At the same time weight measurements were carried out, which enabled the determination of the moisture and density of the investigated samples.

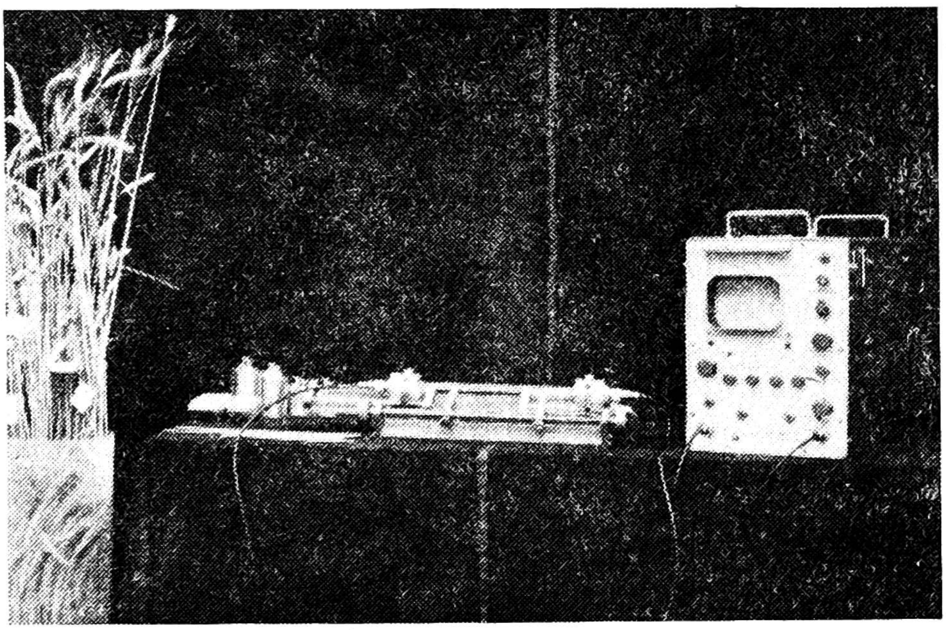


Fig. 1. Stand for the determination of weve velocity in sections of stalk

Results of the investigations obtained for wheat of the Aurora variety in the period of earing are presented in Fig. 3 and in the period of full maturity in Fig. 4. In the period of full earing, when the moisture content in stalk varies from 45% to 85% the velocities of waves vary from 1400 ms^{-1} in samples from the internod just under the ear to 2500 ms^{-1} for samples taken from the middle part of the second or third internod. After drying the investigated samples in the temperature of 105°C to a constant weight the speeds of waves changed to 2700 ms^{-1} and 4500 ms^{-1} respectively. The velocities of wave propagation in samples of stalk in a certain stage of maturity depend on their moisture content and on the part of stalk the sample comes from. In the material investigated there

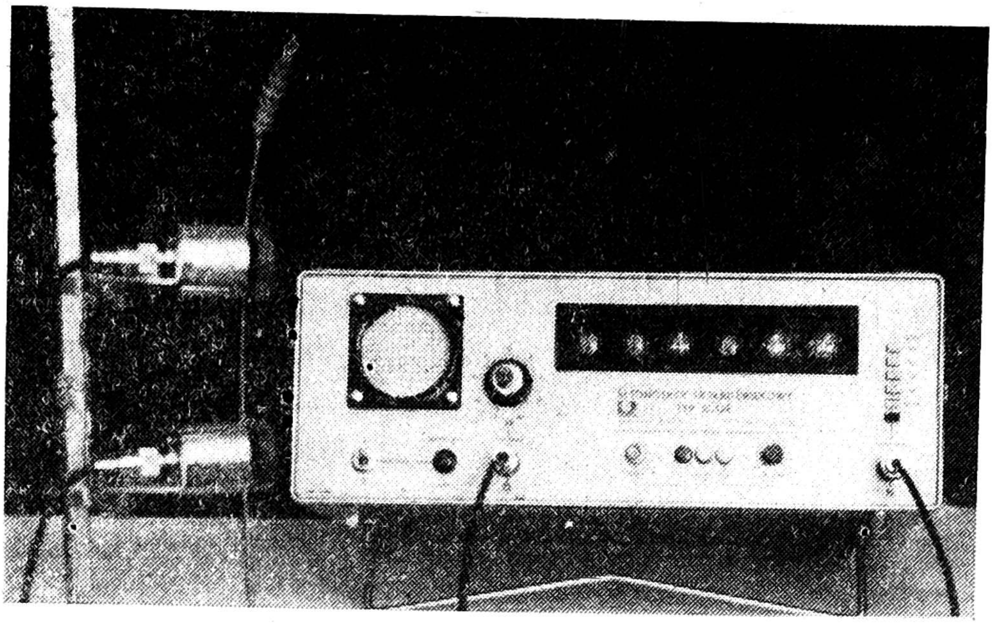
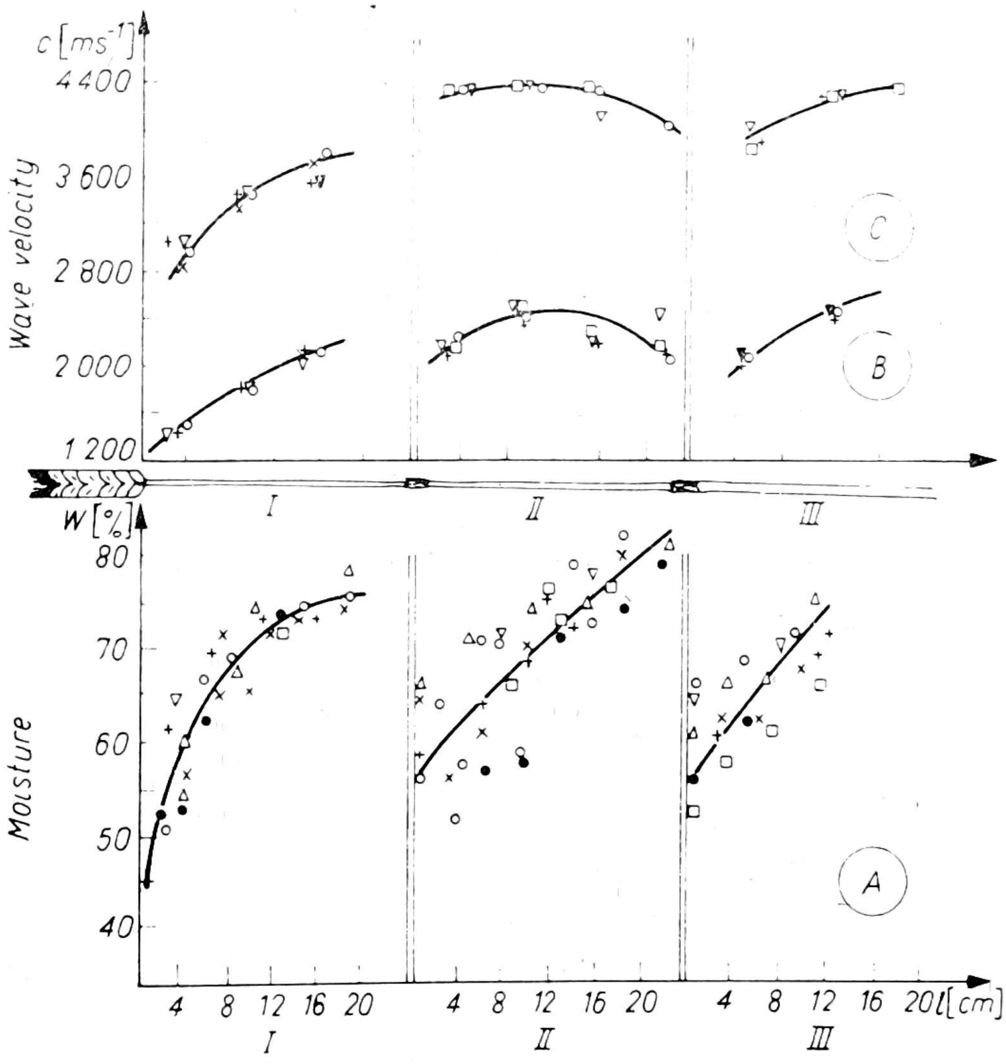


Fig. 2. Stand for the determination of wave velocity in stalk without dividing it into sections



Internodes

Fig. 3. Changes in moisture and wave velocity in wheat stalk (Aurora) in the period of earing *A* — moisture, *B* — velocity in wet stall, *C* — velocity in dry stall

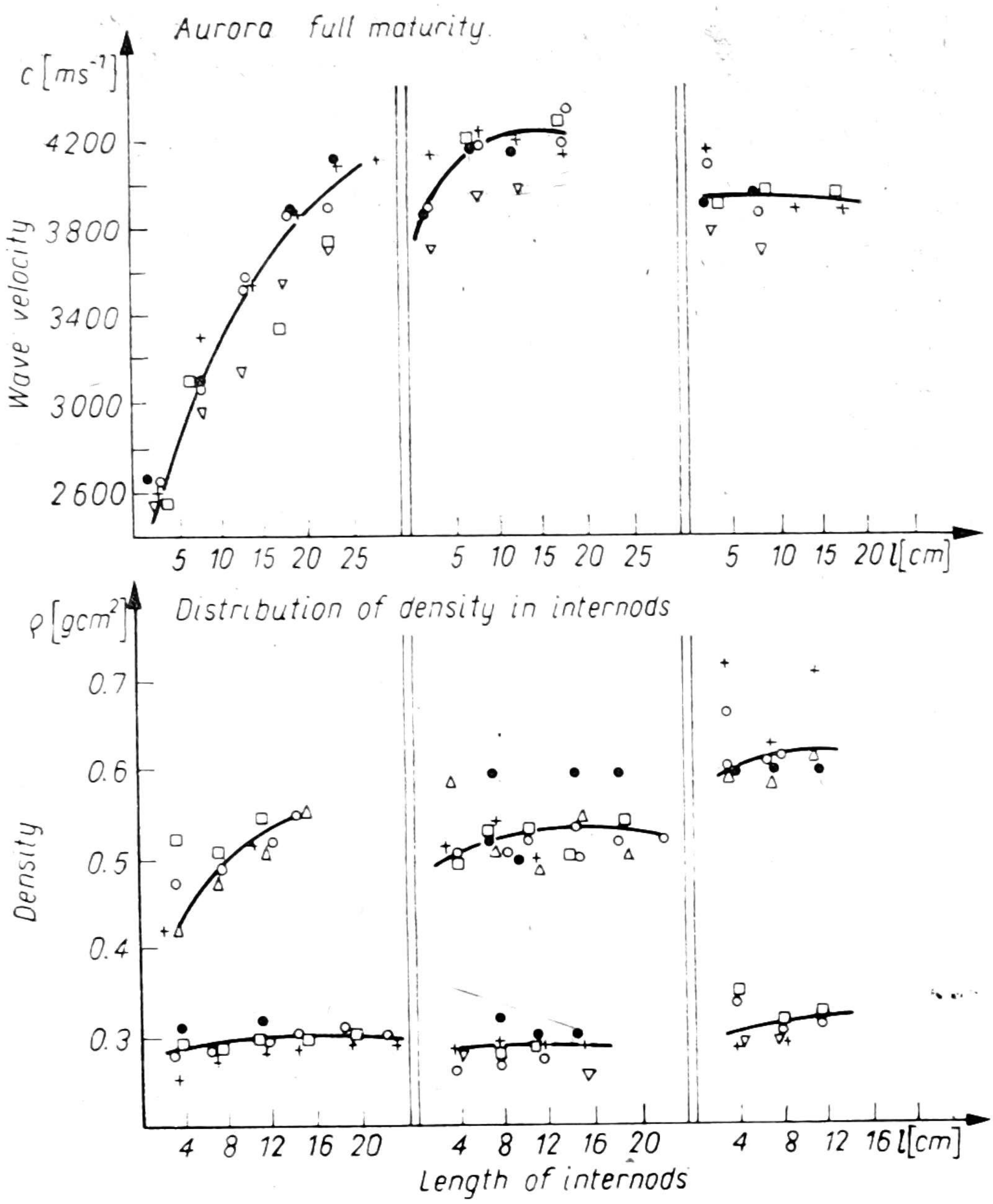


Fig. 4. Changes in density and wave velocity in wheat stalk (Aurora) in the period of full maturity

were also stalks for which the velocities of wave propagation in the second and third internods were up to 5400 ms^{-1}.

It was proved that the density of the particular sections of stalk also changes, particularly during the periods of earing and milk maturity. The density of stalk decreases with the transport of dry mass to the ear. In the period of full maturity it is only half of the level at the period of earing (Fig. 4). The diagrams present the course of changes in the density of samples after their drying.

Basing on the determined velocities of waves and densities for a given section of stalk ($l = 6$ cm) the course of change of the Young modulus on the length of stalk was calculated for the periods of earing and full maturity for wheat of the Aurora variety (disregarding the nodia).

The obtained data show a high differentiation of the value of the Young modulus in stalk, and the character of the variability is an index of the conditions of the growth of plant. At proper conditions of growth a clear differentiation in the resistance properties of the particular sections of stalk was observed. In the middle parts of stalks grown on an unlodged field higher values of the Young modulus were found in comparison with stalks grown on lodged field, for the same varieties.

Before drawing final conclusions, however, it is necessary to explain many factors that can have considerable importance for obtaining true values of the Young modulus. It follows from the measurement technique that the greatest velocity of wave propagation is measured, thus the modulus is determined for those anatomical elements of stalk that are characterized by the greatest modulus of longitudinal elasticity, while the classical mechanical methods lead to the determination of mean values which can be greatly different from the maximum values. Another source of errors can be the way of determining the mean density instead of the densities of the particular anatomical elements of stalk. Hence it is necessary to carry out additional resistance and anatomical investigations of stalks investigated with the ultrasonic method, before formulating final quantitative conclusions.

However, the carried out attempt at applying the ultrasonic method for the determination of the Young modulus of cereals points to a possibility of applying this method in investigations of the influence of natural and cultivational factors on the resistance properties of separated elements of stalk.

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PRÓBY ZASTOSOWANIA METODY ULTRADŹWIĘKOWEJ DO WYZNACZANIA MODUŁU YOUNGA ŹDŹBŁA ZBÓŻ

Streszczenie

Dokonano przeglądu prac dotyczących metod badania właściwości mechanicznych łodyg roślin zbożowych. Zaproponowano nową metodę badania takich właściwości, jak: moduł Younga i wilgotność łodyg zbóż, poprzez pomiar prędkości rozchodzenia się w nich fal ultradźwiękowych oraz ich współczynników tłumienia. Przedstawiono prototypowe stanowisko badawcze do pracy w laboratorium oraz do prowadzenia pomiarów na materiale żywym w trakcie jego wegetacji. Wykazano, że prędkość rozchodzenia się fal w łodygach zbóż, wysuszonych do stałego ciężaru, zmienia się wzdłuż źdźbła.

Badania przeprowadzono dla pszenicy z okresu kłoszenia, dojrzałości mlecznej, woskowej i pełnej. Przeanalizowano zależność występującą między wilgotnością łodyg w określonym stanie dojrzałości a prędkością rozchodzenia się fal. Wyniki przedstawiono w postaci wykresów.

Dokonano pomiarów rozkładu gęstości w łodygach pszenicy w różnych fazach wegetacji. W końcowej części przedstawiono w postaci tabel uzyskane rozkłady wartości modułu Younga dla łodyg pszenicy z poszczególnych faz wegetacji, dla materiału wilgotnego oraz po jego wysuszeniu.

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ПОПЫТКИ ПРИМЕНЕНИЯ УЛЬТРАЗВУКОВОГО МЕТОДА ДЛЯ ОПРЕДЕЛЕНИЯ МОДУЛЯ ЮНГА СТЕБЛЯ ЗЕРНОВЫХ

Резюме

В статье проведен обзор литературы, касающейся методов исследования механических свойств стеблей зерновых растений. Предложен новый метод исследования таких свойств, как: модуль Юнга и влажность стеблей зерновых, путем измерения скорости распространения в них ультразвуковых волн и их коэффициентов поглощения. Представлен испытательный стенд для работы в лаборатории и стенд для проведения измерений на живом материале во время его роста. Доказано, что скорость распространения волн в стеблях зерновых, высушенных до устойчивого веса, изменяется вдоль стебля.

Исследования велись с пшеницей в фазе колошения и молочной, восковой и полной спелости. Анализировалась зависимость между влажностью стеблей в определенной фазе спелости и скоростью распространения волн. Результаты представлены в виде графиков.

Были проведены измерения распределения плотности в стеблях пшеницы в различных фазах вегетации. В заключительной части представлены в виде таблиц полученные распределения величин модуля Юнга для стеблей пшеницы из отдельных фаз вегетации, для влажного материала, а также высушенного. Представлена программа дальнейших исследований.

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