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# Development of studies on the mechanical properties of winter rape stems

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A b s t r a c t. In the study the author used a mechanical and an X-ray method for the determination of the strength properties of the stems of winter rape varieties. In a bending process, rigidity and maximum bending stress were determined. Also, were determined the static shearing energy and the dynamic shearing energy, and the shearing energy per unit of a stem cross section area, naturally as well as after the removal of the parenchyma, and density and the ΔOD parameter in order to define the amount of X-ray radiation energy absorbed by the stem. It was found that the character of the changes in the mechanical properties on the length of the stem is described by a square polynomial. The studies showed that the shearing energy from the static and dynamic tests are identical to the determination of the shearing energy of rape stems. High values of correlation coefficients between the shearing energy from the two test were obtained. It was found, on the basis of an analysis of results concerning the variability of the work required the shearing of a unit of the cross section area of rape stems, that is, a characteristic spot located close to the first branching of the plant. A significant relationship was shown to exist between the mechanical parameters of the stem and the amount of X-ray radiation energy absorbed by the stem. In this study, a close correlation was found between the mechanical properties of stems and the resistance of rape plants to lodging.

K e y w o r d s: rigidity, maximum bending stress, static shearing energy, dynamic shearing energy, shearing energy per unit of a stem cross-section area

## INTRODUCTION

Studies on the mechanical properties of winter rape stems provide the knowledge necessary for the assessment of the susceptibility of plants to lodging. Plant resistance to lodging depends on the mechanical properties of the stems of individual plants. This fact is reflected in the year-on-year studies on the mechanical properties of plant stems [3,5-7,9].

The expansion of studies on the mechanical properties of rape stems seems to be justified not only by the possibility of variety evaluation with respect to the characteristics of strength but also due to the heritability of the mechanical parameters observed by the breeders. This fact was shown by Doliński *et al*. [1] and by Jeżowski *et al*. [2].

The methods of studies on the mechanical properties of rape stems provide for a wide range of parameters, determined in static and dynamic processes. Numerous rape varieties were studied, grown under a variety of agrotechnical conditions (sowing density, plant row spacing, nitrogen fertilization). Also, conditions conducive to plant lodging were applied. The mechanical properties were correlated with the structure of the stems, as expressed by the cross section surface area, both naturally and after the removal of the parenchyma, and by the stem density. In recent years, an X-ray method has also been applied for the study of rape stems, which has permitted a more accurate assessment of the structure of rape stems.

The purpose of this paper was to show a development of studies on the mechanical parameters of rape stems.

## METHODS

The mechanical properties of rape stems were characterised by their mechanical parameters determined in the study (Fig. 1). In dynamic tests the author measured the dynamic shearing energy ($E_d$) by means of a strength Dynstat apparatus operating on the principle of a pendulum hammer moving at a speed of $v$ = 2.1 cm s$^{-1}$. Static tests were used to determine, by means of an Instron strength tester, in the shearing process, the shearing energy ($E_s$) and in the bending process, rigidity ($EI$) and the maximum bending stress ($\sigma_{bm}$). The results were recorded by a computer system, using software specially developed for the purpose. In the static tests the process of shearing was effected by means

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of special cutters causing the simultaneous cutting of the double surface of the stem. Shearing energy in the static tests was obtained through integrating the curve plotted by the static shearing force. The values of $E_d$ and $E_s$ were used to calculate the values corresponding to the work required to shear a unit of a cross section area of the stem ($w_d$ and $w_s$). The maximum bending stress, in turn, was expressed as a function of the measurable cross-section area of the stems, i.e., for a natural cross-section of rape stem $\sigma_{bm.}$ [4]. To determine the variability of the mechanical properties on the stem length, measurements were taken at five equal points, from the root to the tip.

The natural stem cross-section area $S$ and the cross-section area after the removal of the parenchyma $S$' were determined by means of a $\Delta T$ areometer. The density $\rho$ and $\rho$' (naturally and after the removal of the parenchyma) of 3 cm stem sections was determined geometrically.

Assessment of plant lodging was made using a 10-step scale, where 10 is equivalent to no lodging and 1 indicates the most advanced lodging (where the stem is just above the ground).

In the last years of the studies on the strength properties of rape stems, an X-ray method was applied [8]. The densitometric method was used to determine the value of $\Delta OD$ which indicates the degree of the darkening of the film after the passage of X-ray radiation through a stem, which corresponds to the amount of radiation energy absorbed by the stem. The values determined in the densitometric method are shown in Fig. 1 at the paper by Skubisz and Vielikanov [8]. In this paper, densitometric experiments were performed to determine a number of values (specified below) which allowed for an analysis of X-ray pictures obtained after the passage of X-rays through the stems at specific measurement spots.

## RESULTS

A considerable variability of the mechanical parameters under study was observed along the length of the stem. The character of the changes is described by an $n$-th degree polynomial. The studies permitted the determination of the variability of the mechanical properties along the length of the stem, also taking into consideration the stage of development of the plant [3,5].

It was shown that shearing energy $E_d$ and $E_s$ assesses the intervarietal differences in a comparable manner (for example Fig. 2).

A characteristic spot was identified on the stem, located close to the first branching of the plant (Fig. 3).

A strong correlation was observed between the variability of the mechanical properties of stems and their structure as expressed by the cross-section areas, by stem density, and by the amount of X-ray radiation energy absorbed by the stems [8,9].

As a result of the variance analysis performed, intervarietal differences were obtained, both on the basis of the mechanical parameter ( the work required the shearing of a unit of cross-section area of the stem $w_d$) and on the basis of the value representing the amount of X-ray energy absorbed by the stems ($\Delta OD$) (Fig. 4).

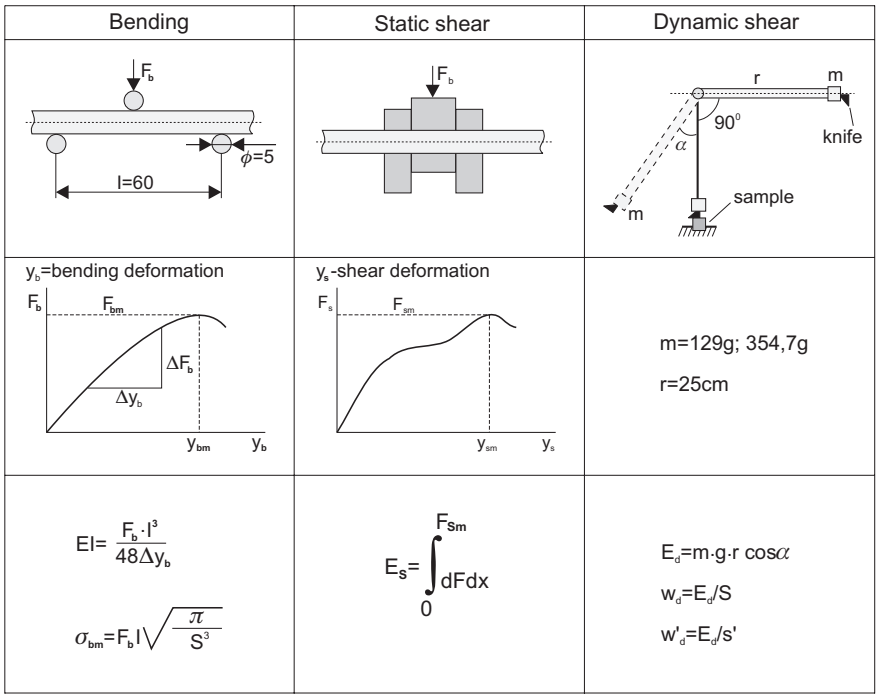


**Fig. 1.** Schematic ilustration of tests used to study mechanical properties of rape stems [8].

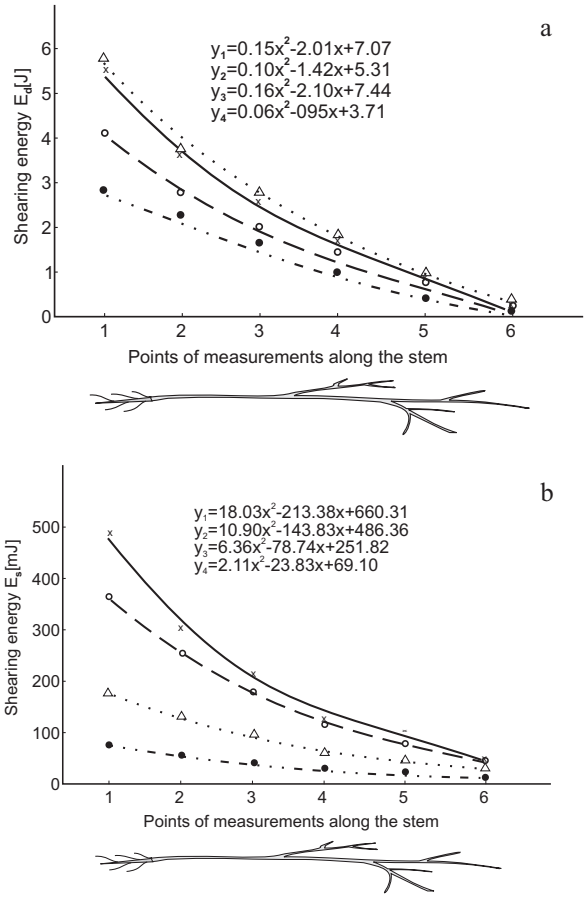


**Fig. 2.** Distribution of the values of the shearing energy in dynamics (a) and static (b) tests along the stem Jupiter rape in succesive phenophasess (x, • , o, Δ - experimental points; $y_1$, $y_2$, $y_3$, $y_4$ - regresion curve; x, $y_1$ - blooming; o, $y_2$ - complete silique filling; • , $y_3$ - technical ripeness; Δ, $y_4$ - full ripeness).

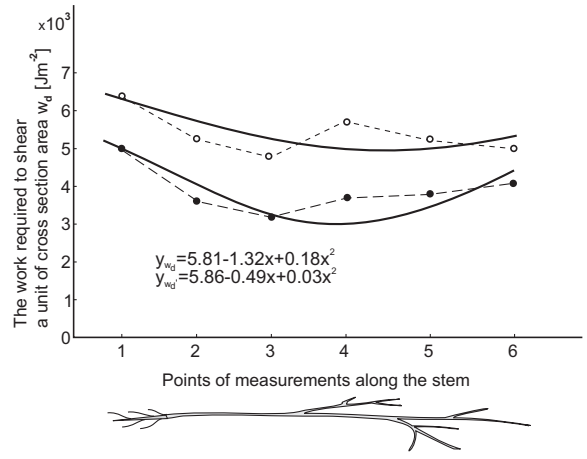


**Fig. 3.** Distribution of the values of the shearing energy per stem total cross section area unit and the partial cross-section area along the stem of the Jet Neuf.

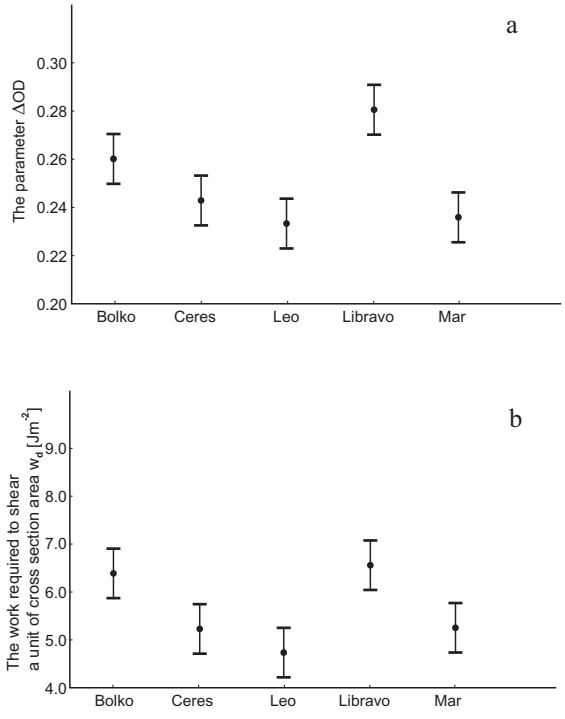


**Fig. 4.** Mean values and the 95% Tukey HSD intervals of Δ*OD* (a) and $w_d$ (b) stems for the varieties of the winter rape.

Simultaneously, the study showed that the application of the X-ray method greatly enhanced the possibility of determining the susceptibility of rape stems to shearing.

The investigation results showed an effect of the sowing density of plants per square meter on the variability of the mechanical properties of plant stems [8]. At the same time it was found that the sowing density differentiates the plants with respect to their resistance to lodging. The average values of the mechanical parameters decreased with an increasing sowing density while their rate of lodging increased, which proved beyond any doubt that the resistance of plants to lodging decreased (Figs 5-7).

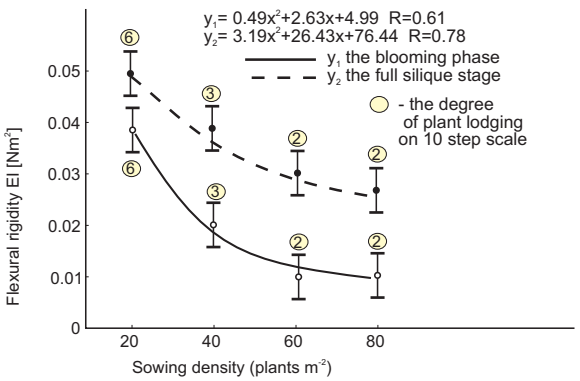


**Fig. 5.** Variation of rigidity of Jupiter winter rape stalk with sowing density.

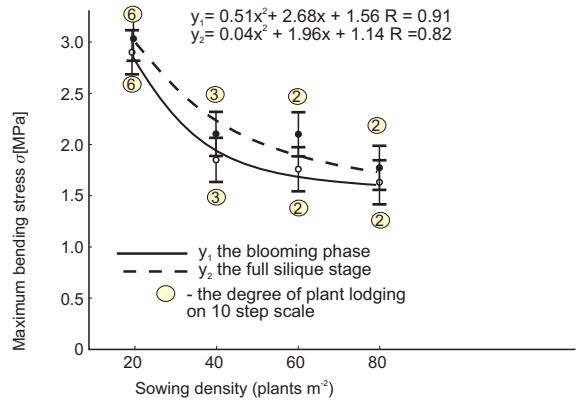


**Fig. 6.** Variation of maximum bending stress of Jupiter winter rape stalk with sowing density.

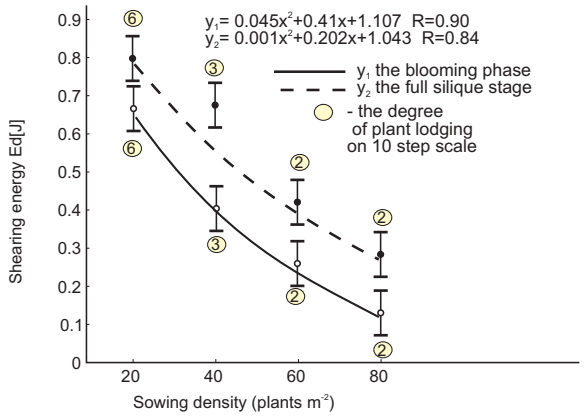


**Fig. 7.** Variation of shearing energy of Jupiter winter rape stalk with sowing density.

## CONCLUSIONS

- The studies permitted the determination of the variability of the mechanical properties on the length of the stem with the development phase of the plant being taken into consideration. It was found that the character of the changes is described by a square polynomial.

- It was found that the shearing energy $E_d$ and $E_s$ gave comparable results in the assessment of the intervarietal differences. High values of correlation coefficients between those were obtained. This conclusion indicates the identical or equivalent possibility of using the two tests, the static and the dynamic, for determining the shearing energy of rape stems.

- On the basis of the analysis of results concerning the variability of $w_d$ along the length of rape stems, it was observed as being a characteristic spot located close to the first branching of the plant.

- A strict correlation was shown to exist between the mechanical parameters of the stem and the amount of X-ray radiation energy absorbed by the stem.

- The application of the X-ray method greatly enhanced the possibility of determination of the susceptibility of rape stems to shearing.

- A close correlation was found between the mechanical properties of stems and the resistance of rape plants to lodging.

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