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# THE EFFECT OF SOWING DENSITY ON THE LODGING AND MECHANICAL PROPERTIES OF RAPE STALKS

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A b s t r a c t. In this study, the mechanical properties of rape stalks are expressed by means of stalk rigidity determined in bending, and by means of dynamic shearing energy per unit of stalk cross section area. Experiments were made using winter rape of the Jupiter variety, grown at sowing densities of 20, 40, 60 and 80 plants/m$^2$ with nitrogen fertilizer applied at 240 kg/ha. The mechanical properties of the stalks were affected by the conditions of plant growth. Sowing density was observed both to have significant effects on plant lodging and on the strength characteristics of rape stalks. It was found that sparsely sown plants had the best mechanical parameters of stalks for resistance to lodging and were characterized by tripled rigidity of the stems.

K e y w o r d s: rigidity, dynamic shearing energy, stem cross section area

## INTRODUCTION

Studies on the mechanical properties of winter rape stalks have the object of providing knowledge necessary for the assessment of the susceptibility of plants to lodging. The resistance of plants to lodging depends on their mechanical properties. A review of numerous methods and results of studies on the mechanical properties of plant stalks indicates their considerable variability, determined by the current physical status of the plant and by a variety of internal and external factors [9,12]. Depending on the object of a given study, the authors were concerned with the whole stalk [2,5,12] or with its fragments [1,3,6,10,11]. A majority of those studies dealt only with an assessment of the local variability of the mechanical properties, the growth phases of the plant being taken into consideration only sporadically. Therefore, it was difficult to formulate conclusions which would not be open to argument. The still-current problem of plant lodging enforced further research that would bring the researchers closer to in-depth understanding of the complex and involved questions related to the physical properties of plants, as well as to the range of variability of their strength parameters in the course of their growth and development [12,15]. The mechanical properties of plant stalks as characterized by the mechanical parameters showed the heritability of characteristics, and therefore provide valuable information for bree-ders of new varieties. This fact was shown by Doliński *et al.* [2] and by Jeżowski *et al.* [5].

In the present study the rigidity of winter rape stalks was determined by means of bending tests and the shearing energy and the shearing energy per unit stalk cross-sectional area in dynamic tests. These measures were used to characterize the mechanical properties of the stalks. An assessment was also made of the effect of various sowing densities on lodging and on the mechanical properties of rape stalks.

## MATERIAL AND METHODS

The study was conducted on stalks of winter rape (Jupiter variety) originating from a sowing density experiment, sampled at the end of the blooming phase and at the stage of full grain fill in the siliques.

For the measurements, an experiment was set up in which the plots had sowing densities of 20, 40, 60, and 80 plants per $m^2$, and a nitrogen fertilizer rate of 240 kg/ha was applied. The plots for the experiment were prepared in three replications. Samples of 25 plants were taken from each of the plots. This experiment was conducted on 75 stems of winter rape grown under identical agrotechnical conditions. The measurements were taken at a characteristic spot on the stalk, at the first branching of the plant. The mechanical parameters were determined in static and dynamic tests. Static tests were used to determine the stalk rigidity (*EI*) in three-point bending, using an INSTRON strength testing machine. The sample was freely supported at both ends, and the bending force was applied centrally between the supports. The rigidity of the stalk is expressed by the equation:

$$EI = \frac{Pl^3}{48y}$$

where $P$ is the load applied at the centre of the stalk, $l$ is the length of the stalk between the supports (7 cm), $y$ is the deflection at the centre of the stalk, $E$ is the Young modulus of the stalk, $I$ is the second moment of area. The results were recorded in a computer system. The dynamic tests were used to determine the shearing energy (*Ed*) and the shearing energy per unit of stalk cross-section area (*wd*). The dynamic tests were conducted with the help of a Dynstat apparatus. The apparatus operates on the principle of a pendulum hammer (to which a cutting edge is attached) moving at a rate of 2.1 mm/s. Also determined was the value of the stalk cross-section area (*S*), by means of a $\Delta T$-areometer, which uses a lens to record the cross-section area, the image being displayed on a monitor screen, and numeric calculations per unit or surface area were performed according to an adopted totally dark standard.

Assessment of plant lodging was performed under field conditions, in the plots, in visual determination of the angle of stalk deflection (close to the ground) from the vertical. A 10-step scale was used, where 10 means no lodging, and 1 corresponds to the most advanced lodging (the stalk virtually parallel to the ground).

It was found that plant lodging caused by heavy rain and wind was parabolic in character - the stalks were bent into shapes similar to the parabola, the maxima of which got closer to the ground as the degree of rape lodging increased.

## RESULTS

The study allowed for determination of the strength characteristics of the stalks of winter rape, and all the parameters under analysis showed a considerable variability in the course of plant development (Fig. 1).

It was found that the sowing density had a significant effect on the mean values of stalk rigidity *EI* (Table 1). The study showed that the stalk rigidity decreased with increasing number of plants per $m^2$. The series of values of this strength parameter obtained in the study had a direct relation to the morphological properties of stalks expressed here by means of the stalk cross-section area. This regularity was observed during the blooming phase (0.008-0.037 N $m^2$) as well as during the stage of full grain fill in the siliques (0.0227-0.0526 N $m^2$). Significant values of the coefficient of correlation between the stalk rigidity and sowing density were obtained for both the sparsely sown plots (20 and 40 plants/$m^2$) and the plots with high sowing density (60 and 80 plants/$m^2$) - r=0.43 to r=0.56.

It was also found that the other mechanical parameters, i.e., the dynamic shearing energy (*Ed*) and the shearing energy per unit of stalk cross-section area (*wa*) displayed a strong correlation with the sowing density (plants/$m^2$). The study showed that the shearing energy of rape stalks decreases systematically with increasing

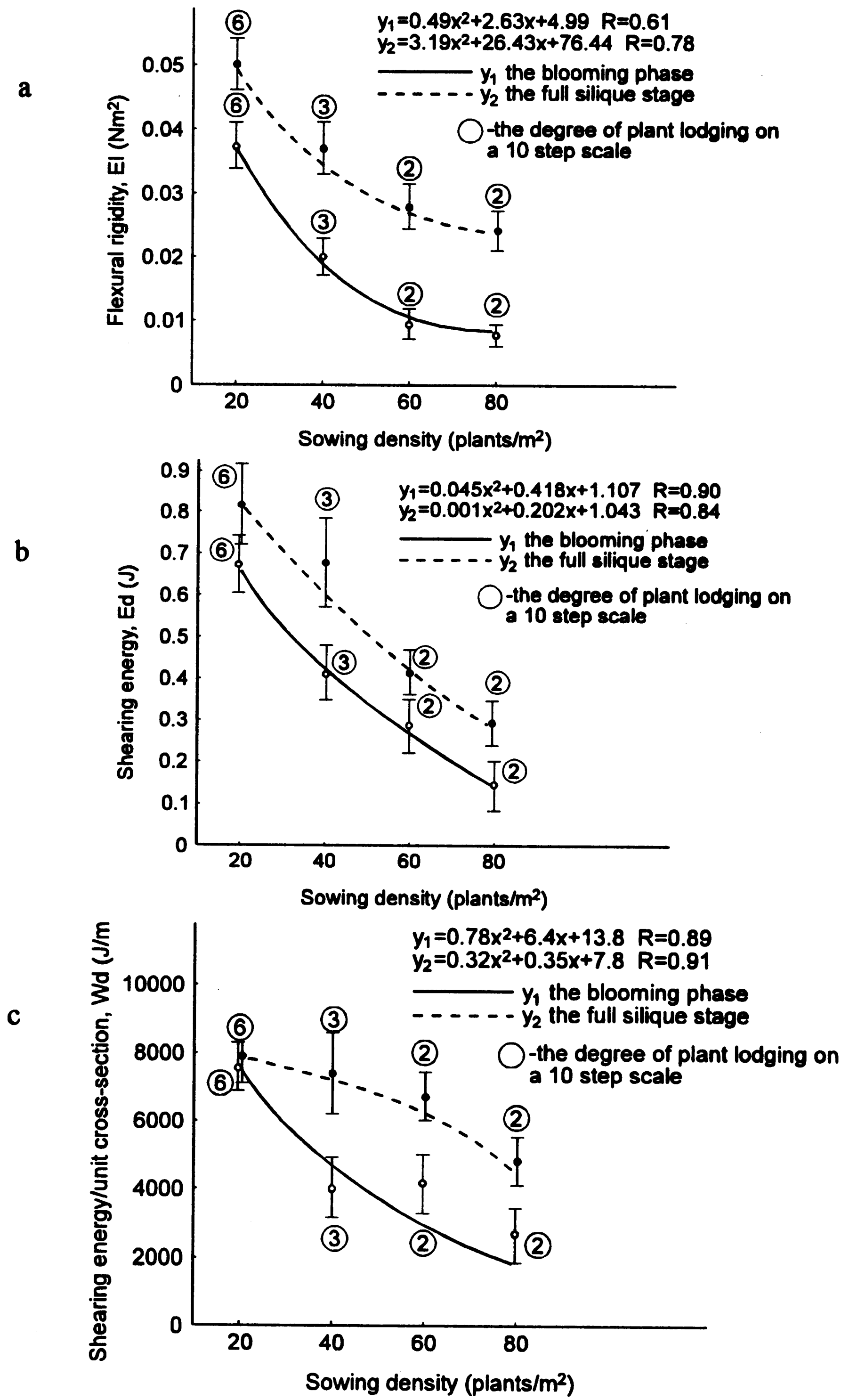


**Fig. 1.** Variation of rigidity (a), shearing energy (b) and shearing energy per cross-sectional area (c) of Jupiter winter rape stalk with sowing density.

**Table 1.** Mean values, median and coefficient of variation of parameters determining structural-mechanical properties of winter rape stems of the Jupiter variety

| Parameters | Units | Sowing density (plants/$m^2$) 20 | | | 40 | | | 60 | | | 80 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | average | median | w (%) | average | median | w (%) | average | median | w (%) | average | median | w (%) |
| | | End of the blooming phase | | | | | | | | | | | |
| $EI$ | N $m^2$ | 0.0371 | 0.0252 | 54 | 0.0200 | 0.0193 | 80 | 0.0107 | 0.0088 | 72 | 0.0078 | 0.0109 | 67 |
| $E_d$ | J | 0.6456 | 0.6312 | 32 | 0.4165 | 0.3458 | 34 | 0.2885 | 0.2704 | 48 | 0.1411 | 0.0914 | 80 |
| $w_d$ | J/$m^2$ | 7401 | 6993 | 35 | 3853 | 3261 | 49 | 4102 | 3587 | 62 | 2631 | 2074 | 82 |
| $S$ | $mm^2$ | 90.80 | 82.63 | 34 | 92.56 | 83.93 | 35 | 84.17 | 79.27 | 34 | 53.18 | 50.60 | 35 |
| | | Stage of complete filling of siliquaes | | | | | | | | | | | |
| $EI$ | N $m^2$ | 0.0526 | 0.0521 | 50 | 0.0381 | 0.0345 | 64 | 0.0254 | 0.0184 | 85 | 0.0227 | 0.0177 | 72 |
| $E_d$ | J | 0.8191 | 0.7221 | 44 | 0.7137 | 0.5534 | 73 | 0.3768 | 0.3018 | 56 | 0.2752 | 0.2319 | 67 |
| $w_d$ | J/$m^2$ | 7912 | 7331 | 35 | 7113 | 6417 | 48 | 6212 | 6307 | 48 | 4153 | 3777 | 50 |
| $S$ | $mm^2$ | 107.71 | 96.96 | 41 | 97.24 | 83.57 | 46 | 56.57 | 47.23 | 37 | 63.08 | 57.61 | 41 |

sowing density, the differences in the value of this parameter being much greater during the blooming phase (0.14-0.65 J) than during the full grain fill stage (0.28-0.82 J). The above monotonicity of the variability of the mechanical properties was obtained also on the basis of values of the shearing energy per a unit of stalk cross-section area (*wd*). A considerable differentiation of the mean values of *wd* was observed, caused by the various levels of sowing density per $m^2$ (2631-7401 J/$m^2$ in blooming and 4153-7312 J/$m^2$ in full grain fill). High values were noted for the coefficients of correlation between the average values of shearing energy per unit of stalk cross-section area, especially in the case of plants with very low sowing density of 20 plants/$m^2$, and for 40, 60 and 80 plants/$m^2$ ($r=0.64$ - $r=0.89$) at the end of the blooming phase, and a somewhat lower correlation between the mean *wd* values for plants sown at 20 and 40 plants/$m^2$ and 60 and 80 plants/$m^2$ ($r=0.41$ - $r=0.67$) in the phase of full grain fill in the siliques.

The study showed an interdependence between the variability of the mechanical parameters of the stalks and the changes in the value of the stalk cross-section area $S$, especially in the case of plants grown in plots with the lowest and the highest sowing density (Table 1), while the ranges of variability of the parameter under discussion were 53.2-90.9 $mm^2$ and 63.1-107.7 $mm^2$ in blooming and at full grain fill phases, respectively.

There can be no doubt that the mechanical properties of stalks are closely related to the stalk cross-section area, which has been suggested in earlier studies [13,14]. The study by Skubisz [14], showed a significant effect of the stalk cross-section area on the rigidity of stalks in the course of the growth and development of plants of three varieties of winter rape (r-0.42-0.81). At the same time the stalk cross-section area had a significant effect on the shearing energy per unit of stalk cross-sectional area [13]. It was found that the latter value varied along the length of the stalk identically to $S'/S$, with a minimum close to the first branching ($S'$ - stalk cross-sectional area after the removal of the ground tissue). This helped locate the characteristic point on the length of the stalk, located close to the first branching.

The assessment of the degree of plant lodging showed that the plants from plots of 20 plants/$m^2$ were the most resistant to lodging

(6 degrees), while the plants from plots with 80 plants/m$^2$ were the least resistant (2 degrees) (Fig. 1). At the same time it was found that the most resistant to lodging were those plants which were characterized by high values of the mechanical parameters under analysis. A direct proportion between the degree of lodging of cereal plants and the stalk rigidity was determined by Hess and Shands [4], Multamaki [7], and by Oda *et al.* [8].

## CONCLUSIONS

1. The study showed a significant effect of the sowing density on the variability of the mechanical properties of the stalks of rape, determined by the cross-section area of the stalks.

2. It was found that the plants that were resistant to lodging were characterized by high values of stalk rigidity $EI$, by larger stalk cross-section areas $S$ and by high values of dynamic shearing energy $Ed$.

3. Increasing the sowing density (number of plants per square metre) increased the degree of plant lodging and decreased the mean values of the mechanical parameters under analysis.

4. Plants from plots of 20 plants/m$^2$ were the most resistant to lodging, while plants from plots with 80 plants/m$^2$ were the least resistant.

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