The variability of mechanical properties of winter rape stems during plant vegetation period

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INTRODUCTION

Studies aiming at the determination of mechanical parameters of winter rape stems help to estimate stem resistance that, in turn, enables the estimation of plant resistance to lodging. Plant lodging makes harvest difficult lowering yield at the same time. Plant resistance to lodging obviously depends on the mechanical properties stems. This fact has been in the focus of attention of researchers for many years, hence numerous studies on plant stems mechanical properties (Blahovec et al. 1990; Skubisz 1982; Skubisz and Tys 1987; Skubisz et al. in press).

As rape stem as a study material is not homogenous, it is difficult to choose the best method of determining its mechanical parameters (Skubisz 1982). The present work deals with establishing the energy of shearing in dynamic studies, together with the bending stress, shear stress and the energy of cutting in static studies. Stalk mechanical properties are characterized by means of the above listed parameters. Moreover, the estimation of the influence of the cross-section area of the stalk and its density on the variability of mechanical parameters of the analyzed winter rape varieties was conducted during plant vegetation period.

MATERIALS AND METHODS

The present studies were conducted on the stems of three winter rape varieties: Jupiter, Jantar, and Jet Neuf during the period of complete silique filling, technical maturity, and full maturity. The experiment was carried out on 30 representative stems for each variety. After off-shoots had been taken off, the stems were divided into 6 equal sections, but studies were conducted on the 5 consecutive stem sections from the root to the top. The characteristics of rape stems resistance properties was obtained by the determination of the energy of shearing (Ed) in the dynamic test using a Dynstat type apparatus acting as an impact testing machine with a speed of V = 2.1 m/sec. In the series of static test the maximum bending stress (σ max) and the energy of shearing (Ed), and the shearing stress (τ max) were studied by means of an Instron testing machine. The shearing was conducted by means of special knives that cut the double stem surface simultaneously. The energy of shearing (Es) was determined by the planimetring of the surface under the curve of the static shearing force. From the value of Ed and Es was used to calculate values corresponding to the work required to shear a unitary area of stem cross section (wd and ws). The shearing stress was expressed as:

$$\tau_{max} = \frac{P_{max}}{2S} \qquad (1)$$

where: P max - the maximum shearing force
S - the area of stem cross-section

And the maximum bending stress was calculated from the equation:

$$\sigma_{max} = P_{max} \cdot l \cdot \sqrt{\frac{\pi}{S^3}} \qquad (2)$$

where: P max - the maximum shearing force
S - the area of stem cross-section
l - the length of the bent section - 7 cm

Whereas, the area of the stem natural cross-section S and non-arenchymatic cross-section S' was measured by means of ΔT-areometer made in England. The densities ρ and ρ' of the 3 cm-long stem sections was also determined by means of a geometric method according to the equation:

$$\rho = \frac{M}{l \cdot S} \quad , \quad \rho' = \frac{M}{l \cdot S'} \qquad (3)$$

where: M - the weight of the 3 cm-long stem section
l - the length of the studied stem section
S - the area of the natural stem cross-section
S - the non-arenchymatic stem cross-section area

RESULTS

The results obtained (for example figs 1-4) showed high variability of the studied parameters both at various stems lenghts and in various stages of plant development. The studies showed that the area of stem cross-section, non-arenchymatic area of stem cross-section and density were significantly related on the variability of rape stem mechanical properties.

It was noticed that the shearing energy per stem cross-section area

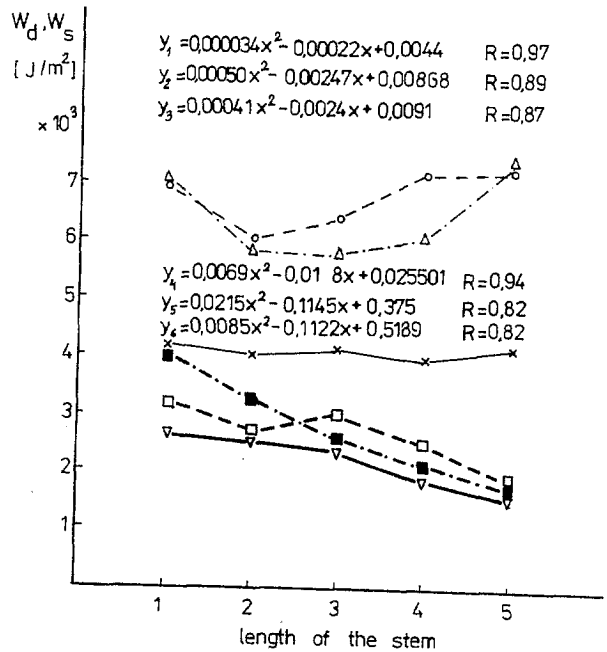

Fig. 1. Distribution of the values of the shearing energy per stem cross-section area unit in dynamic and static tests along the stem of Jupiter rape in succesive phenophases (x, o, Δ, ∇, □, ■ - experimental points, $y_1 \ldots y_6$ -regresion curve, xy_1; ∇y_4 - complete silique filling, oy_2; $\square y_5$ - technical ripeness, Δy_3; $\blacksquare y_6$ - full ripeness).

(wd) from dynamic tests had a non-linear character of variability along the stem appears, seen in the figure in the form of parabolas with minimum at the second and third measurement sections. It is known from earlier studies (Skubisz et al. 1988) and it is related to the content of arenchyma which varies along the length of the stem, as if it were to determine the parabolic character of changes of the mechanical parameters. While the shearing energy per stem cross-section area (ws) from static tests had not the parabolic character of changes of the values along the stem in this study. The studies showed considerable varietal differentiation together with changes of stem studied parameters due to the phenological period of plant development. It was confirmed that var. Jupiter had much higher values wd and ws were the following, respectively: Jupiter 3990-7511 J/m^2 and 1521-4156 J/m^2; Jantar 3903-7496 J/m^2 and 805-4033 J/m^2 ; Jet Neuf 4462-6516 J/m^2 and 874-3660 J/m^2. Analyzing the variability of the studied parameters during the period of plant development we observed that in technical maturity the shearing energy per stem cross-section area wd and ws had the highest values. It was also noticed that the polynomial of the 2nd degree described the character of changes in the energy of shearing along the stem. The result obtained-after statistical evaluation-proved that such parameters as: the area of stem cross-section (S), the area of stem non-arenchymatic cross-section (S') and density (ϱ, ϱ') experted a insignificant influence upon the variability of the amount of shearing energy per stem cross-section area of rape stem. The coefficients of correlation between wd and S, S' and ws and S, S' were insignificant (Jupiter r=0,04-0,37, Jantar r=0,01--0,25, Jet Neuf r=0,11--0,31 and Jupiter r=0,13-0,46, Jantar 0,04-0,33, Jet Neuf r=0,13-0,65). It was noticed that the stem density did not have any significant influence on the variation of the shearing energy (wd, ws) during the period of complete slique filling in later periods, however, this influence was observed. The values of the coefficients of correlation between wd and ϱ, ϱ' and ws $\times \varrho, \varrho'$ are the following (Jupiter r=0,60-0,81, Jantar r=0,70-0,79, Jet Neuf r=0,40-0,81 and Jupiter r=0,53-0,92, Jantar r=0,82-0,88, Jet Neuf r=0,30-0,80). It may be concluded that the influence of stem density on the variation in shearing energy was strongly related to the phase of plant development. It was observed that Jupiter stems had the lowest values of the cross-section area S and S (for Jupiter 13,1-91,9 mm^2 and 11,4-90,6 mm^2 : Jantar 15,0-94,7 mm^2 and 14,0-92,8 mm^2 : Jet Neuf 17,9-96,7 mm^2 and 15,4-95,9 mm^2). The Jupiter stems had also the lowest density (Jupiter 189-998 kg/m^3,). Jantar 326-864 kg/m^3 , Jet Neuf 331-878 kg/m^3). Density values in all the studied varieties reached the minimum at full maturity. The above conclusions on the morphological differentiation of varieties were also confirmed by the results obtained in the Institute of Agrophysics of the Polish Academy of Sciences in Lublin in the studies on the evaluation of the contents of skeletal substances in stems (in per cent), i.e. the contents of cellulose, hemicellulose and lignin (reports from 1990). The above mentioned report stated that var. Jupiter contained two times more lignin (Jupiter 27,9-29,2%, Jantar 14,7-17,9%, Jet Neuf 13,9-15,5%) and two times less cellulose than vars Jantar or Jet Neuf (Jupiter 13,0-16,9%, Jantar 31,9-32,2%, Jet Neuf 27,3-28,8%). The studies on the contents of skeletal substances showed differentiation of the stems of the studied rape varieties that influenced their mechanical properties.

The levels of shearing stress (τ max) appeared to be strongly and inversely proportionally related to the area of stem cross-section (S) and to the area of stem non-arenchymatic cross-section (S'). The coefficients of correlation are the following (for Jupiter r=-0.52-0.59 and r=-0.48-0.60; Jantar r=-0.59-0.73 and r=-0.54-0.73; Jet Neuf

r=-0.62-0.72 and r=-0.62-0.69). Moreover, the values of shearing stress were not significantly related to the stem densities, and the

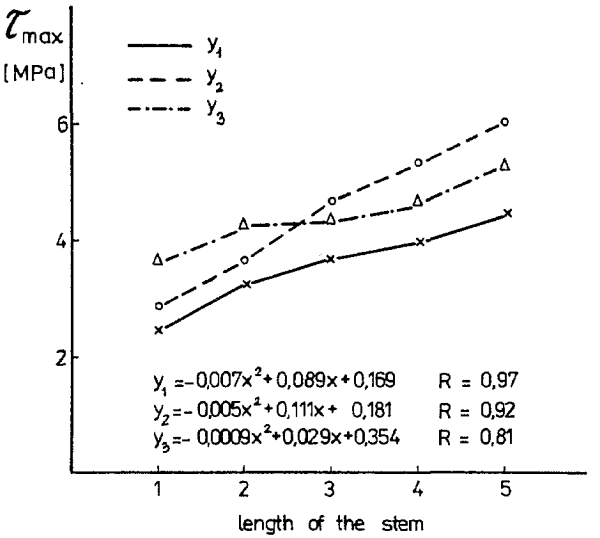

Fig. 2. Distribution of the values of shearing stress along the stem of Jupiter rape in succesive phenophases (x, o, Δ - experimental points, y_1, y_2, y_3 - regresion curve, xy - complete silique filling, oy_2 -technical ripeness, Δy_3 - full ripeness).

coefficients of correlation were rather low or non-significant. The character of changes in the shearing stress values along the stem length can be expressed by a polynomial of the 2nd degree. It was established that the Jupiter stems showed a significant inversely proportional relation between the values of shearing stress (τ max) and the values of the area of stem cross-section in all the phenological stages, whereas vars Jantar and Jet Neuf did not show any significant dependence between the studied parameters in the period of rape full maturity.

It was also observed that the changes in the bending stress (σ max) both along the stem length and during different stages of plant development were significantly correlated with the area of stem cross-section and density. The studies showed very high significant coefficients of correlation for the three studied varieties during the period of complete silique filling and full maturity, and slightly lower coefficients during technical maturity. There was also a very strong relation between the changes in the bending stress and stem density in the case of Jantar and Jet Neuf, and var. Jupiter had much lower values of the coefficients of correlation between the studied parameters σmax x ρ, ρ' (for Jupiter r=0.19-0.69 and r=0.28-0.74; Jantar r=0.33-0.79 and r=0.49-0.81; Jet Neuf r=0.62-0.77 and r=0.65-0.98). The character of the changes in the values of the bending stress along the stem length can be described by the polynomial of the 2nd degree.

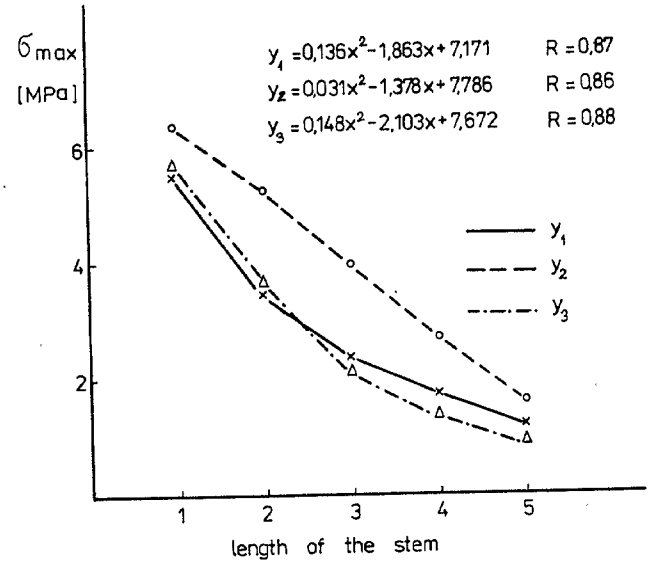

Fig. 3. Distribution of the values of the bending stress along the stem of Jupiter rape in succesive phenophases, explanations as Fig. 2.

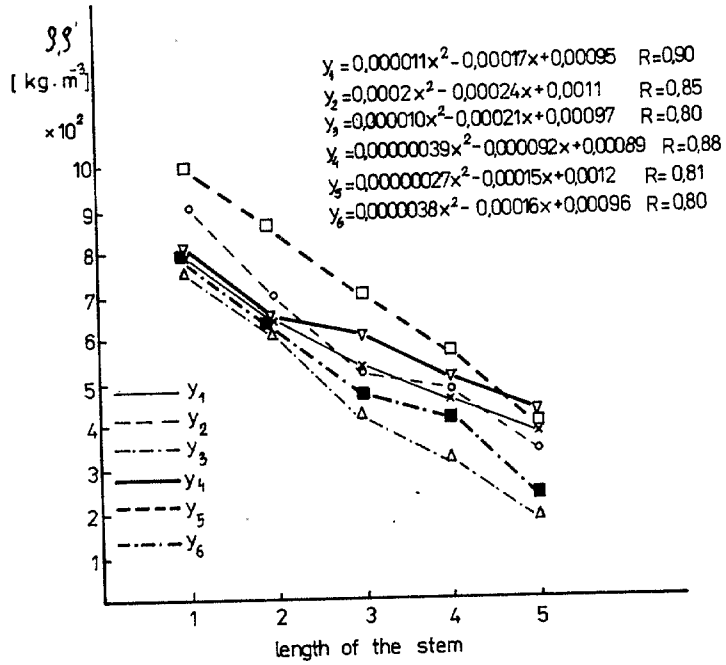

Fig. 4. Distribution of the values of the density (ρ and ρ') along the stem of Jupiter rape in succesive phenophases, explanations as Fig. 1.

On the basis of the present results a strong influence of arenchyma on the process of bending and shearing can be noticed. This phenomenon has already been discussed in numerous works (Blahovec and Skubisz 1990; Skubisz and al. in press).

CONCLUSION

1. It was found that the mechanical parameters of the winter rape stem both along the stem and during different stages of plant development were characterized by strong variability. The studies showed intervariety differentiation.
2. The character of the changes in the values of the mechanical parameters, the area of stem cross-section and density along the stem can be described by the polynomial of the 2nd degree.
3. The shearing energy per stem cross-section area from dynamic tests (wd) reached the minimum of the values at the second and third measurement sections (about 30-45 cm over the ground). It was noticed that the area of the stem cross-section did not have any significant influence on variation of the shearing energy wd and ws. It was observed that the values of shearing energy per stem cross-section area were significantly related to the stem densities (ρ and ρ') only in technical and full maturity of the plants.
4. It was confirmed that the Jupiter stems had the lowest values of the density than vars Jantar and Jet Neuf.
5. The shearing stress appeard inversely proportional related to the area of stem cross-section. It was established that the Jupiter stems showed a significant inversely proportional relation between the values of shearing stress and the values of the area of stem cross-section in all the phenological stages, whereas vars Jantar and Jet Neuf did not show any significant dependence between the studied parameters in the period of rape full maturity.
6. It was found that the values of bending stress were significantly correlated with the stem area cross-section and stem density. It was noticed that var. Jupiter had much lower values of the coefficients of correlation between the bending stress and density.

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