

## Bending and Shearing Characteristics of Canola Stem

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**Abstract:** Shearing stress, bending stress and young's modulus were determined for Canola (*Brassica napus* L.) stem. The cutting and bending forces were measured at four moisture content levels (35, 43, 50 and 57%), three varieties (Zarfam, Opera and Okapi) and three nitrogen fertilizer levels (250, 400 and 550kg/ha) so that the shearing stress, the bending stress and the young's modulus were calculated from these data. The results showed that the shearing stress, bending stress and the young's modulus were decreased with increasing moisture content. The maximum value of the shearing strength was 1.32 MPa for the Opera stems, while Zarfam with 0.92 MPa has the minimum shearing strength among these three varieties. The maximum value of the bending stress was 48.1 MPa for the Opera stems and Zarfam with 44.83 MPa has the minimum bending stress among these three varieties. The average values for the young's modulus were found to be 1.57, 1.71 and 2.04GPa for Zarfam, Okapi and Opera varieties, respectively. The shearing stress and young's modulus were decreased with increasing nitrogen fertilizer. The maximum and minimum values of the bending stress was recorded with 400 and 550 kgN/ha respectively.

**Key words:** Canola · Shear strength · Stem cutting · Bending stress · Young's modulus

### INTRODUCTION

As windrowers, haybine harvesters and combine harvesters all feature reciprocating knife cutterbars, studying the shear strength for cutting stems is very valuable for selecting design and Operational parameters of equipments. Studies on the mechanical properties of rape stems seem to be justified not only by the possibility of variety evaluation with respect to the characteristics of lodging strength but also due to the heritability of the mechanical parameters observed by the breeders [1, 2].

Studies of cutting energy requirements have been conducted on winter rape [3, 4], hemp [5], pea [6], rice [7], soybean stalks [8], alfalfa and wheat [9, 10], cotton stalks [11], maize stalks [12] and pyrethrum flowers [13]. These studies showed that cutting energy is related to the stem mechanical and physical properties. Furthermore, most cutting experiments were conducted using pendulum type apparatus or shear rig, which may not fully represent the cutting process using reciprocating knives.

Halyk and Hulburt [14] studied the shear strength of alfalfa between nodes intervals and showed that shear strength will be varying between 0.6 to 17.95 MPa. Persson (1987) reviewed several studies on the cutting speed and concluded that cutting power is only slightly affected by cutting speed. Majumdar and Dutta [15]

studied the required shear energy for two varieties of rice and a variety of wheat in cutting speeds of 2.53 and 4.5 m/s and edge angle of 20 and 40 degrees, by using a Pendulum type impact shearing device. Analysis of the data showed that the effects of crop type and edge angles on shear energy were significant. Increasing shear speed makes decreasing the cutting force and consequently the shear energy and also edge angle of 20 degree required less energy than the 45 degree angle. El Hag *et al.* [16] determined the effect of moisture content, special mass of dry material and loading speed on the ultimate shear strength of cotton stems. The ultimate shear strength was 13.75 and 19.98 MPa for 52.5 and 13.2 percent of stem moisture content wet basis respectively. Jafari [11] determined the effect of some factors such as shear angle, edge angle, stem diameter and knife type on required shear force of wheat and alfalfa by a tension-compression machine. The main effect of knife type and some of the mutual effects shear force were significant. Prince [9] had some efforts to measuring the shear force of forage crops, but exactness of their results was limited by using a cutting device which is very far from a real harvester's knives Operation states. The broad objective of this study was to determine the shear strength of the canola stems to measure the power requirement associated with combine harvesters.

Curtis and Hendrick [17] determined that the section modulus in bending varied with the third power of the diameter for cotton stalks of diameters ranging from 7 to 16 mm. The modulus of elasticity varied from 600 to 3500MPa. Prince *et al.* [18] studied on the modulus of rigidity of green lucerne and oven-dried specimens, finding mean values of 0.225 and 1.45 GPa, respectively. Chattopadhyay and Pandey [19] determined the bending stress for sorghum stalk as 40.53 and 45.65MPa at the seed stage and forage stage, respectively.

Hosseinzadeh *et al.*[20] determined effect of three varieties of wheat and knife bevel angles, four levels of moisture content and three shearing speeds of pendulum on the specific shearing energy of wheat straw. Results showed that the effects of variety, knife bevel angle, moisture content and shearing speed on specific shearing energy were significant ( $P<0.01$ ). Specific shearing energy decreased with decreasing moisture content and bevel angle and with increasing shearing speed. Esehaghbeygi *et al.* [21] reported the shearing stress of wheat stems decreased as the moisture content decreased and the shearing force of stems, decreased as the cutting height of stalk increased, because of a reduction in stalk diameter. Esehaghbeygi and Hosseinzadeh [22] considered effect of three variety, three nitrogen fertilizer levels (250, 400 and 550kg ha<sup>-1</sup>) and four moisture content levels (35, 43, 50 and 57%) on specific shearing energy using pendulum method. They reported the specific shearing energy increased as the moisture content decreased and amount of nitrogen fertilizer increased. Esehaghbeygi *et al.* [23] reported the amount of nitrogen fertilizer and variety had effect on canola shearing strength using quasi-static method. The main objective of the present study was to determine the shearing strength of sugar cane stems, which can be used to measure power requirements associated with harvesting machine [24].

## MATERIALS AND METHODS

The research was conducted in order to determine the bending stress, the young's modulus and the shearing stress of canola stem as a function of moisture content, nitrogen fertilizer and variety. To determine the average moisture contents of the canola stem on the date of the test, the specimens gathered from the field were weighed and dried at 103°C for 24 h in the oven and reweighed [25]. The experiments were conducted at moisture contents of 35%, 43%, 50% and 57% w.b.

Three varieties of winter canola, Zarfam, Opera and Okapi were cultivated in large pots under controlled conditions and due to the importance of urea fertilizer on

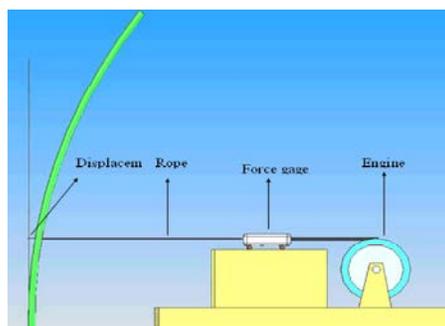


Fig. 1: The measurement method of bending force; d, stem diameter

physical and mechanical properties of crop stems, [26] three levels of urea fertilizer 250, 400 and 550 kg/ha were applied.

The diameter of the canola stem decreases towards the top of the plant. Therefore, the stems were sheared at the height of 10 cm as it was the common rate when harvesting by combine.

**Bending Test:** The stiffness of stalks encountered during harvesting depends on the rigidity of materials. The modulus of rigidity of stalk is expressed by the product EI, where E is the modulus of elasticity in bending in MPa and I is the moment of inertia of cross-sectional area in mm<sup>4</sup> [27]. The deflection and rigidity in bending under load can be determined by the cantilever test or calculated by the following theoretical equation [15, 28]:

$$D = \frac{F_b L^3}{3EI} \quad (1).$$

Where: D is the deflection under load in mm; F<sub>b</sub> is the bending force in N; L is the length of the beam between the load and support in mm; and C is the constant (1/3 for cantilever beam). In order to obtain the bending strength, a bending test was undertaken in the field under quasi-static conditions at four different moisture contents [20, 29]. The experimental arrangement shown in Fig. 1 was used to determine the bending strength. Selected stems in the field were tied from 400mm height with inelastic rope connected horizontally with a digital force gauge. Then the stem was bent by pulling the rope. On reaching 50 mm deflection at the tying point, the bending strength from the gauge indicator was recorded. The test was repeated three times for each stem. Stem diameter was measured at the embedded point at which maximum bending moment occurs. However, there is no significant difference in terms of stalk diameter between the measurement point and the tying point.

The bending stress  $s_b$  in MPa was calculated by using Eqns (2) and (3) [29, 30].

$$M_b = F_b L \quad (2)$$

$$\sigma_b = \frac{M_b y}{I} \quad (3)$$

Where:  $M_b$  is the bending moment in N mm and  $y$  is the distance of outermost fibre from the neutral axis in mm. The modulus of elasticity in bending was calculated by using Eq(1) at different moisture contents, nitrogen fertilizer and variety.

**Shearing Test:** To measure the shear strength of the stem, an apparatus was constructed to hold the counter shear and canola specimen, so that it would possible to cut the stem under constant speed. To record the measured force continues an electric engine (Simens, 5.5 kW), an inverter (Hyundai 5.5 kW, 400 Volts), a digital force meter (A&D, load cell 1 kN) was connected to a computer (P4, 2.4 GHz) equipped data acquisition system at 10 Hz. The device basis could convert the rotating movement into linear movement at a constant velocity Fig. 2.

The knife section was attached onto the moveable crosshead and the specimen was positioned on the specimen support so that it was cut at the location of approximately 20 mm from the base of the canola stem to approximate the typical cutting height used in field harvesting Operations with constant cutting velocity 200 mm/min. To determine the cross sectional area of the stem, the mesh-grid method is used. Shear strength of the stem was determined by dividing the shear force by section area of the stem. Analysis of variance was performed to examine the effect of canola variety, the amount of urea fertilizer and moisture content level on shear strength of canola stems. A complete randomized block design was used in a factorial experiment with five repetitions by statistical software, SAS10 and MINITAB15. Means were compared using Duncan's multiple range tests  $p < 0.05$ .

$$\tau = \frac{F_{S \max}}{2A} \quad (4)$$

## RESULTS AND DISCUSSION

The analysis of variance shows that the effect of canola variety, Fertilizer, moisture content, the mutual effect of variety and fertilizer are significant on stem shear strength in %% level.

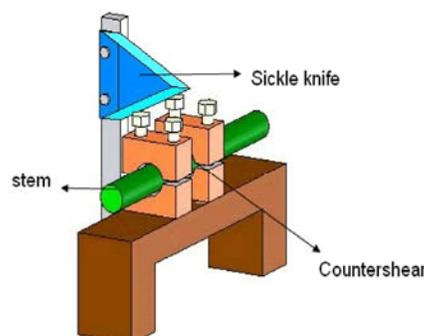


Fig. 2: Shear strength measuring device

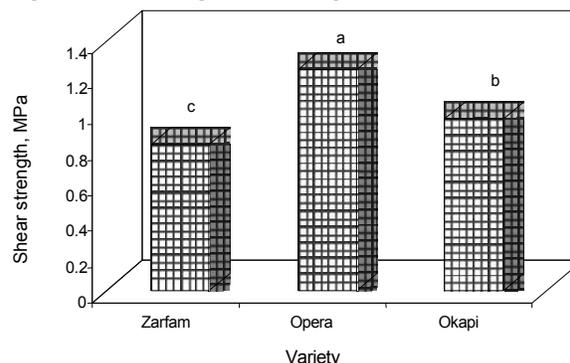


Fig. 3: Effect of variety on stem shear strength

**Effects of Variety on Shear Strength:** The maximum value of the shear strength was 1.32 MPa for the Opera stems and Zarfam with 0.92 MPa has the minimum shear strength among these three varieties. Duncan test results in Fig. 3 shows that the shear strength between Zarfam, Opera and Okapi in 1% level has significant difference. This difference is due to different physical and physiological properties of stem varieties [3]. For example, Zarfam stems are thicker, while for Okapi is less thick but more solid. The values of the shear strength for the canola stems are lower than that of maize stalks (2-7 MPa) [12] and hemp (3.1-3.8 MPa) [5]. The values for  $F_{\max}$  ranged from 74 to 190N with an average of 93N which is much lower than that of hemp (67-555N) (5) and higher than that of maize (23-80N) [12], grasses (26N) [31] and pyrethrum flowers (6N) [13]. In a study on rape stems a 50% lower content of lignin and 50% higher content of cellulose were found in non-lodging cultivars, while reverse proportions were characteristic of lodging cultivars. At the same time those groups of cultivars differed significantly in their content of hemi cellulose [4].

**Effects of Nitrogen Fertilizer on Shearing Strength:** Generally the amount of urea fertilizer was determined by crop efficiency but in this study its effects on shear strength of stem while combine harvesting discussed.

Using 550 kg/ha urea fertilizer had the lowest and using 250 kg/ha urea fertilizer had the highest canola stem shear strength (Fig. 4). Increasing urea fertilizer in Opera and Okapi, decreased shear strength force by 20 and 31%, respectively, while in Zarfam increased stem shear strength by 8%. In Zarfam and Opera no significant difference was observed between fertilizer levels while, in Okapi between 250 and 550 kg/ha urea fertilizer there is a significant difference at 5% level (Fig. 5). Application of urea fertilizer increased plant growth and produced taller plant with low stem diameter due to low supportive tissues as low development of collenchymas and peculiarities of stem architectonics [25].

**Effect of Moisture Content on Shear Stress:** The value of shearing stress at low moisture content was approximately 35% higher than at high moisture content. The average shearing stresses were found to be 82.9, 84.95, 95.97 and 101.53MPa for moisture contents of 57, 50, 43 and 35%, respectively (Fig.6). Moisture content has a significant effect on the shearing stress at 1% probability level. Moreover, according to Duncan's multiple range test results the bending stress values are statistically different from each other. The presents an exponentially increasing relationship between the shearing stress and moisture content reported by Chancellor [32] and McRandal and McNulty [31].

**Effect of Variety on Bending Stress:** The analysis of variance showed that the effect of canola variety, moisture content, fertilizer, the mutual effect of variety and fertilizer, the mutual effect of variety and moisture content are significant on stem bending stress at 1% probability level.

The maximum value of the bending stress was 48.1 MPa for the Opera stems and Zarfam with 44.83 MPa has the minimum bending stress among these three varieties. The results are shown in Fig 7 indicated that there is significant difference between Zarfam with Opera and Okapi in terms of the bending stress at the probability level of 5%. This Difference is due to different physical and physiological properties of stem varieties [19]. For example, Zarfam stems are thicker, while for Okapi is less thick but more solid. The values of the bending stress for the canola stems are lower than that of sunflower stalks (67.09 MPa) [13].

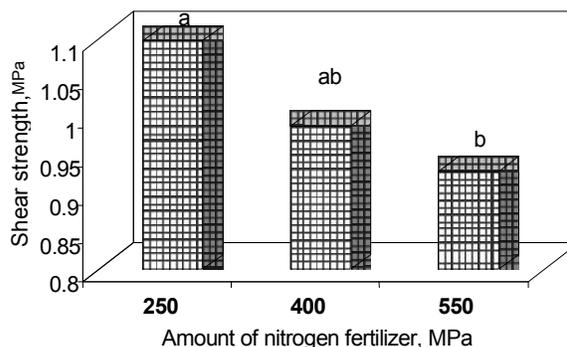


Fig. 4: Effect of amount of nitrogen fertilizer on stem shear strength

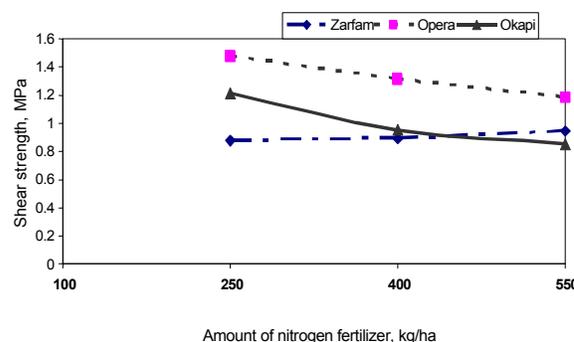


Fig. 5: Relation between shear strength and amount of nitrogen fertilizer

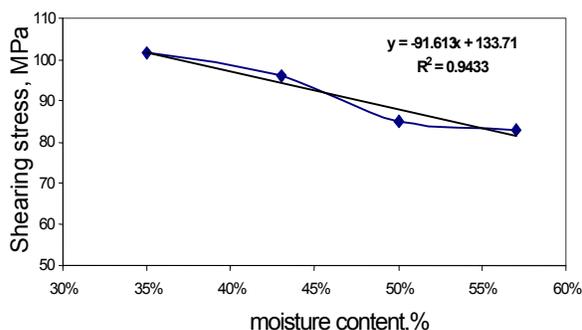


Fig. 6: Correlation of shear force and stem moisture content

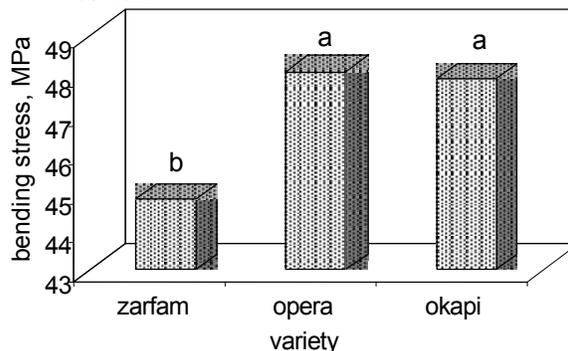


Fig. 7: Effect of variety on stem bending stress

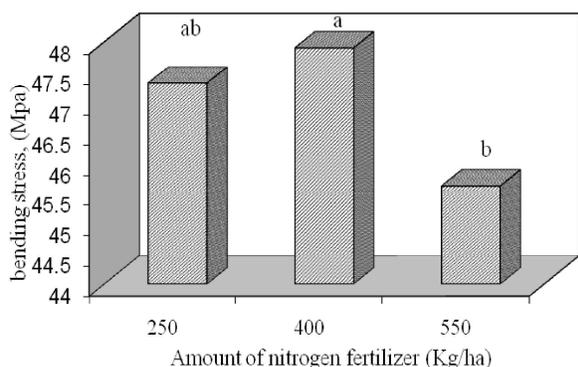


Fig. 8: Effect of nitrogen fertilizer on stem bending stress

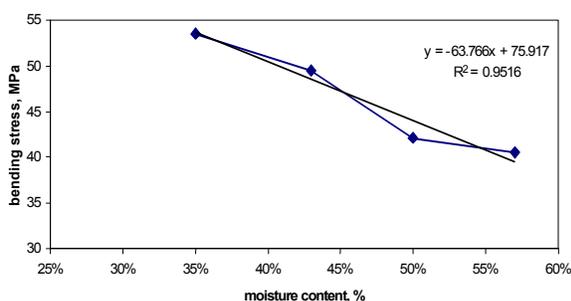


Fig. 9: Effect of moisture content on bending stress

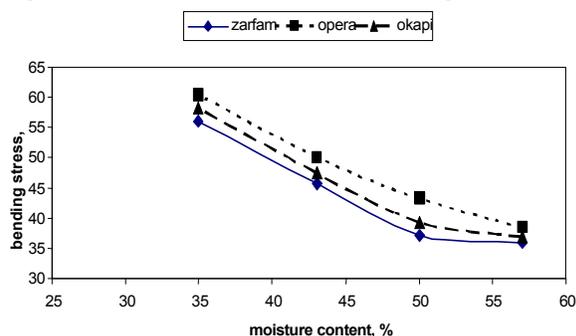


Fig. 10: Relation between bending stress and moisture content in three variety

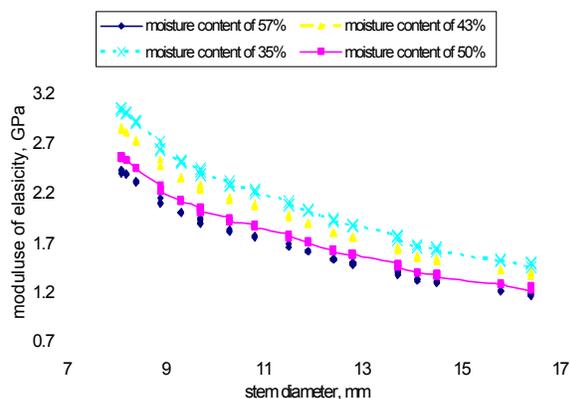


Fig. 11: Relation between modulus of elasticity and stem diameter in vary moisture content

**Effects of Nitrogen Fertilizer on Bending Stress:**

The maximum and minimum of the bending stress were obtained with 400 and 550kgN/ha, respectively. The results presented in Fig. 8 showed no significant difference between 250kg/ha, 400kg/ha and 550kg/ha. While, there is significant difference between 400 and 550kg/ha at the probability level of 5%. Application of urea fertilizer increased plant growth resulted in taller plant and low stem diameter because of low supportive tissues as low development of collenchymas and peculiarities of stem architectonics [33]. So low stem diameter led to increase of bending stress.

**Effects of Moisture Content on Bending Stress:**

Fig.9 showed that the examples of the force recorded during bending tests with the distance covered by the movable support. The bending stress was evaluated as a function of moisture content. As the moisture content of the stem increased, the bending stress decreased. Fig. 10 indicated that a reduction in the brittleness of the stem. This effect of moisture content was also reported by İnce *et al.* [33].

Moisture content has a significant effect on the bending stress at 0.05 probability level. Moreover, the bending stress values are statistically different from each other.

**Young's Modulus:**

The young's modulus in bending was evaluated according to the moisture content, nitrogen fertilizer and variety. O'Dogherty *et al.* [34] showed that the young' modulus for wheat straw had a magnitude of 4.76 to 6.58 GPa. They also showed that the young's modulus is reduced when internodes' moisture increased. The average values for the young's modulus were found to be 1.43, 1.52, 1.70 and 1.81 GPa for moisture contents of 57, 50, 43 and 35%, respectively. The effects of moisture content and variety on the young's modulus were significant at 0.05 probability level. The average values for the young's modulus were found to be 1.57, 1.71 and 2.04GPa for variety of Zarfam, Okapi and Opera, respectively. The maximum value of the modulus of elasticity was for 250 kg/ha and 550 kg/ha has the minimum modulus of elasticity these three nitrogen fertilizer. Using urea fertilizer causes the plants to grow rapidly and so the taller stems have lower stem diameter [26] which led to reduce the elasticity modulus (Fig. 11).

## CONCLUSIONS

- The canola variety is an important factor on shearing strength, bending stress and young's modulus of the stem.
- Application of urea fertilizer decreased the impact on shearing strength and young's modulus of the canola stems.
- Application of urea fertilizer increased the impact on bending stress after changing the fertilizer content from 250 kg/ha to 400 kg/ha while decreased the effect after altering 400k to 550kg/ha.
- With increasing stem diameter, the bending stress and young's modulus reduced, while it increased the shearing stress.
- The shearing stress, the bending stress and young's modulus are evaluated as functions of moisture content. As the moisture content of the stem increased, the shearing stress, the bending stress and young's modulus decreased. It proves that the harvesting time is very important for the response of canola stem to the agricultural activities.

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