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Bending and Shearing Properties of Safflower Stalk

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ABSTRACT

The research was conducted in order to determine the bending stress, Young's modulus, shearing stress, and shearing energy of safflower stalk as a function of moisture content and stalk region. The bending forces were measured at different moisture contents and the bending stress and the Young's modulus were calculated from these data. For measuring the shear forces, the stalk specimens were severed by using a computer aided cutting apparatus. The shear energy was calculated by using the area under the shear force versus displacement curve. The experiments were conducted at four moisture contents (8.61, 16.37, 25.26, and 37.16% wb) and at three stalk regions (bottom, middle, and top). Based on the results obtained, the bending stress decreased as the moisture content increased. The value of the bending stress obtained at the lowest moisture content was approximately 2 times higher than that of the highest moisture content. Bending stress values also decreased from top to the bottom of stalks. The average bending stress value varied from 21.98 to 59.19 MPa. The Young's modulus in bending also decreased as the moisture content and diameter of stalks increased. The average Young's modulus varied between 0.86 and 3.33 GPa. The shear stress and the shear energy increased with increasing moisture content. Values of the shear stress and energy also increased from top to the bottom of stalks due to the structural heterogeneity. The maximum shear stress and shear energy were found to be 11.04 MPa and 938.33 mJ, respectively, both occurring at the bottom region with the moisture content of 37.16%.

Keywords: Bending stress, Safflower stalk, Shear energy, Shear stress, Young's modulus.

INTRODUCTION

Safflower (*Carthamus tinctorius* L.), which belongs to the Composite family, is cultivated in several parts of the world due to its adaptability to different environmental conditions (Baumler *et al*., 2006; Sacilik *et al*., 2007). It is a rich source of oil (35-40%) and linoleic acid content (75-86%). The safflower oil is multi-purpose used especially as bio-diesel for the production of fuel for internal combustion engines. The safflower production has recently increased due to increasing research on alternative energy sources. The estimated planting area of safflower in the world was about 814,000 ha in 2005 (FAO, 2006). Safflower cultivated area has increased in the last few years in Iran in a way that its cultivated area reached 15,000 ha in 2005-06 (Pourdad *et al*., 2008). The average seed yield of safflower is around 900 kg ha^{-1} in Iran (Pourdad *et al*., 2008). Safflower is highly branched, usually with many long sharp spines on the leaves, but is sometimes spineless. Plants are 600 to 1,200 mm tall with globular flower heads and commonly brilliant yellow, orange, or red flowers.

The physical and mechanical properties of safflower stalks, like those of other plants, are essential for selecting design and operational parameters of equipment relating

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to harvesting, threshing, handling, and other processing operations of the stalks. The properties of the cellular material that are important in cutting are: compression, tension, bending, shear, density, and friction (Shaw and Tabil, 2007; Yiljep and Mohammed, 2005). These properties are affected by numerous factors such as the species variety, stalk diameter, maturity, moisture content, and cellular structure (Bright and Kleis, 1964; Persson, 1987; Nazari Galedar *et al*., 2008a; Tavakoli *et al*., 2009). These properties are also different at different heights of the plant stalk. Hence, it is necessary to determine the mechanical properties of stalks such as the bending and shear stresses and energy requirements for suitable knife design and operational parameters (Ince *et al*., 2005). Methods and procedures for determining most of mechanical and rheological properties of agricultural products have been described by Mohsenin (1986). Many studies have been conducted to determine the physical and mechanical properties of plants. Curtis and Hendrick (1969) determined that the section modulus in bending varied with the third power of the diameter for the cotton stalks with the diameter ranging from 7 to 16 mm. They also found that Young's modulus of cotton stalks varied from 600 to 3,500 MPa. Prince *et al*. (1969) reported mean values of 0.225 and 1.45 GPa for the modulus of rigidity of green lucerne and oven dried specimens, respectively. Sakharov *et al*. (1984) reported that the required force to cut stretched (bent) stalks was 50% less than that for straight stalks. Chattopadhyay and Pandey (1999) found that the bending stress for sorghum stalks at the seed stage and forage stage were 40.53 and 45.65 MPa, respectively. Prasad and Gupta (1975) showed that the cross-sectional area and moisture content of the maize stalks had a significant effect on the cutting energy and the maximum cutting force. Similar results were also reported by Choi and Erbach (1986). Skubisz (2001) used a mechanical and an *X*-ray method to determine the mechanical properties of the stems of winter rape varieties, and found that the character of the changes in the rigidity, bending stress, static shear energy, and the dynamic shear energy properties over the length of the stem was best expressed by a quadratic polynomial equation. Similar results were also reported by Grundas and Skubisz (2008) on rape stem and Skubisz (2002) on pea stem. Chen *et al.* (2004) found that the average values of the maximum force and the total cutting energy for hemp were 243 N and 2.1 J, respectively. Nazari *et al*. (2008a) reported that the maximum shear strength and shear energy for alfalfa stem were 28.16 MPa and 345.80 mJ, respectively. Tavakoli *et al*. (2009) found that the values of the physical properties (major and minor diameter, thickness of stem, cross-section area of wall, second moment of area and mass per unit length) of barley straw increased with increasing moisture content. The physical properties also increased towards the stem third internode position. Esehaghbeygi *et al*. (2009) reported that the bending stress and Young's modulus of canola stems decreased as the moisture content increased while, the specific shear energy increased with increasing the stem moisture content.

Information relating to the physical and mechanical properties of safflower stalk is limited. Therefore, the objective of this study was to investigate the effects of moisture content and stalk region on some physical properties including average diameter, cross-section area, second moment of area, and mass per unit length, and mechanical properties namely bending stress, Young's modulus, shear stress, and shear energy of the safflower stalks.

MATERIALS AND METHODS

Sample Preparation

The safflower stalk (IL-111 Variety) used for the present study was one of the prevalent varieties of safflower in Iran and was obtained from the farms in Lorestan province, Iran, during the summer season in 2008. After attaining optimum seed maturity, the safflower stalk samples were collected and then the flowers and leaves were removed. The diameter of the safflower stalk decreases from the bottom of the plant to the top; therefore, stalk shows different physical and mechanical properties at different heights due to the variable cross sectional area. For this reason, the stalks were equally divided into three regions as top (A), middle (B), and bottom (C) (Figure 1) after removing 40 mm (region D in Figure 1) from the bottom end (this part is usually left on the field at the harvesting time). Diameter of each sample (average diameter at the midpoint) was measured using an electronic digital caliper (GUANGLU, China) having a resolution of 0.01 mm before starting the tests.

ASAE standard (358.2DEC 98) was used to determine the average moisture content of the safflower stalks (ASAE standards, 2008). The initial moisture content of the specimens was determined to be 8.61% (wb). The samples with higher moisture contents were prepared by adding calculated amounts of distilled water to the samples which were sealed in separate polyethylene bags and stored in a climate controlled storage at 5ºC for 10 days (Tavakoli *et al*., 2009). Before starting each test, the required amounts of stalks were allowed to warm up to the room temperature. The experiments were conducted at moisture levels of 8.61, 16.37, 25.26, and 37.16% (wb). The field measurements showed that safflower stalk moisture content was in the range of 20 to 30% (wb), at the harvesting time.

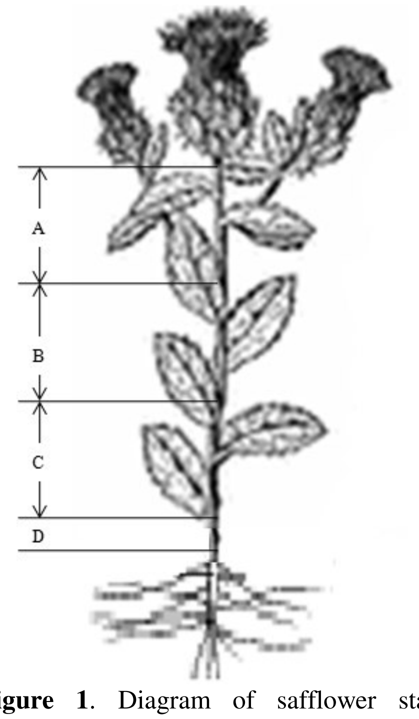

Figure 1. Diagram of safflower stalk identifying regions: (A) Top region; (B) Middle region; (C) Bottom region, and (D) Woody region.

Test Apparatus

The measurements were made using a proprietary tension/compression testing machine (a Santam universal tester).

Shear Test

The shear stress was measured in double shear using a shear box (Figure 2-a) consisting of two fixed parallel hardened steel plates spaced 6 mm apart, between which a third plate can slide freely in a close sliding fit. A series of holes with diameters ranging from 1.5 to 15 mm were drilled through the plates to accommodate the stalks of differing diameter. Shear force was applied to the stalk specimens by mounting the shear box on the tension/compression testing machine. A few idle runs without stalks were also performed before running the main testes to account for and eliminate the influence of the frictional resistance between the sliding plate and fixed plates of shear apparatus on the experimental values. The sliding plate was loaded at a rate of 10 mm min^{-1} and the applied force was measured by a load cell and a force-time record was obtained up to the specimen failure. The shear stress (or ultimate shear strength) was calculated using the following equation:

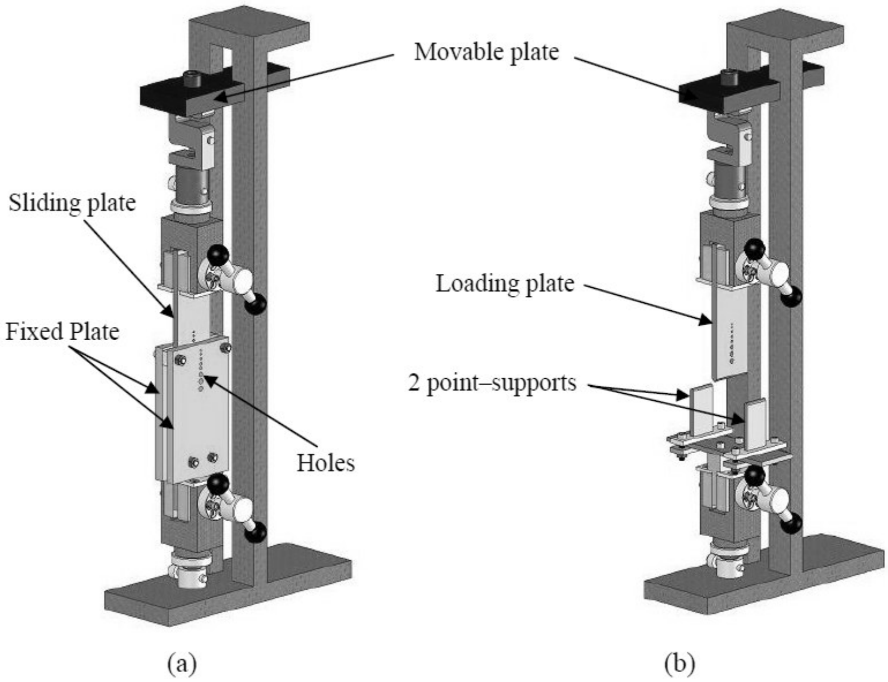

Figure 2. Apparatus (Instron universal testing machine) for the measurement of: (a) Shear stress, and (b) Bending stress of stalks (Nazari *et al.,* 2008a).

$$\tau_s = \frac{F_s}{2A} \tag{1}$$

Where: τ_s is shear stress (MPa), F_s is the shear force at failure (N), and *A* is the cross-sectional area of the stalk at shearing plane (mm^2).

The shear energy was calculated by using the area under curves of shear force and displacement (Chattopadhyay and Pandey, 1999; Chen *et al*., 2004). For this case, the area under the curve was divided into the basic geometrical shapes and the area was calculated using the force and displacement data and a standard computer program (version 5, SMT Machine Linker, software, SANTAM Company, Tehran, Iran).

Bending Test

To determine the bending stress and Young's modulus in bending, a three point loading apparatus was used (Figure 2-b). The specimens were placed on the two round metallic supports 50 mm apart, and the force was applied to the center of the stem at the loading rate of 10 mm min^{-1} (same as shear test) using a loading plate driven by the movable support of the instron universal testing machine (Figure 2-b). Force versus deformation data were recorded by the computer until sample fracture, then force-deformation curves were obtained from the test data using the software. The bending force and deformation at the bio yield peak and at the inflection point as defined by ASAE Standard S368.1 (ASAE Standards, 1985) were obtained from all curves. Most specimens had circular cross-section; therefore, the second moment of inertia of the cross sectional area was calculated as follows (Mohsenin, 1986):

$$I = \frac{\pi d_s^{\,4}}{64} \tag{2}$$

Where, *I* is second moment of inertia (mm^4), and d_s is the stalk diameter (mm).

The bending stress was calculated by the following equation (Gere and Timoshenko, 1997; Crook and Ennos, 1994):

$$\sigma_b = \frac{F_b y l}{4I} \quad (3)$$

Where: σ_b is bending stress (MPa), F_b is the bending force (N), y is the distance of outermost fiber from the neutral axis (y= d_s/2) (mm), and l is the distance between the two metal supports (50 mm).

The modulus of elasticity or Young's modulus in bending of safflower stalk was calculated from the following equation (Gere and Timoshenko, 1997):

$$E = \frac{F_b l^3}{48\delta I} \quad (4)$$

Where: E is Young's modulus in bending (GPa), and δ is the deflection at the specimen centre (mm).

Experimental Design and Statistical Analysis

In this study, the effects of stalk moisture content (at: 8.61, 16.37, 25.26, and 37.16% wet basis) and stalk region (at: top, middle and bottom regions) on the mechanical properties of safflower stalks were studied. A factorial test with two factors and twelve replications based on completely randomized experimental design was used in this study. Experimental data were analyzed using analysis of variance (ANOVA) and the means were compared applying Duncan's multiple range tests in SPSS 15 software.

RESULTS AND DISCUSSION

The average diameter of the sample stalks used in this study, in the top, middle, and bottom regions, and at different moisture contents, varied between 3.62 and 5.01, 4.64 and 5.777, and 5.28 and 6.87 mm, respectively.

Shear Stress

The variance analysis of the data (Table 1) indicated that the moisture content and stalk region had significant effects on the shear stress at 0.01 probability level (P< 0.01). The effect of interaction between moisture content and stalk region on the shear stress was significant at 0.05 probability level of (P< 0.05). The results of Duncan's multiple range tests for comparing the mean values of the mechanical properties of safflower stalk

Table 1. Results of analyses of variance (Mean Square Error) for the shear and bending properties of safflower stalk.

Source	Dependent Variable	*df*	Mean Square	*F* value
Moisture content (M)	Shear stress	3	134.24	63.79**
	Shear energy	3	1652228.14	61.12**
	Bending stress	3	3925.35	28.91**
	Young's modulus	3	10.88	23.64**
Stalk region (R)	Shear stress	2	151.32	71.91**
	Shear energy	2	704486.06	26.06**
	Bending stress	2	2580.45	19.00**
	Young's modulus	2	15.16	32.94**
$M \times R$	Shear stress	6	5.46	2.59*
	Shear energy	6	302436.99	11.189**
	Bending stress	6	43.55	0.32ns
	Young's modulus	6	0.72	1.52ns
Error	Shear stress	132	2.10	
	Shear energy	132	27029.31	
	Bending stress	132	135.76	
	Young's modulus	132	460442.20	

** Significant at 1% level; * Significant at 5%l evel, ns: Not Significant.

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at different moisture contents are presented in Tables 2. Results showed that the shear stress of stalks increased with increasing moisture content (Table 2). Similar results were reported by most previous researchers (McRandal and McNulty, 1980; Annoussamy *et al*., 2000; Nazari Galedar *et al*., 2008a; Tavakoli *et al*., 2009). The average values for the shear stress varied from 4.00 to 8.46 MPa, by increasing the moisture content from 8.61 to 37.16% showing that the shear stress at the highest moisture content was approximately 2 times higher than that at the lowest moisture content. Table 3 shows the results of Duncan's multiple range tests on the effect of stalk region on the mechanical properties of safflower stalk. From Table 3 it is seen that shear stress decreased when moving from the bottom of the stalks to the top (Table 3). This result had a good correlation with the results reported by Cakir (1995), Ince *et al*. (2005), and Nazari Galedar *et al*. (2008a). The average values for the shear stress were found to be 7.90, 5.73, and 4.38 MPa for the bottom, middle, and top regions, respectively (Table 3). The safflower stalk has a hard structure because of high cellulose content. The top regions of plant stalk have the lowest amount of cellulose (Annoussamy *et al*., 2000); therefore, the shear stress of the bottom region is higher than that of the middle and top regions of the stalk. In the bottom region the shear stress increased from 5.48 to 11.04 MPa by increasing moisture content from 8.61 to 37.16%. In addition, according to the Duncan's multiple range tests, the values for the shear stress were completely different for distinct moisture contents and stalk regions (Tables 2 and 3). Table 4 shows the means comparison of the interaction between moisture content and stalk region on the shear stress and shear energy. In Table 4 the greatest shear stress was obtained as 11.04 MPa, occurring in the bottom region and at the moisture content of 37.16%, while the lowest shear stress was found to be 2.92 MPa in the top region at a moisture content of 8.61%. Figure 3-a presents the relationship between the shear stress and moisture content for all stalk regions. Regression analysis was used to find and fit the best general models to the

Table 2. Effect of moisture content on the mechanical properties of the safflower stalk.

Independent variable	Dependent variables (Mechanical properties)			
	σ_b [a](MPa)	E [b](GPa)	τ_s [c] (MPa)	E_s [d](mJ)
Moisture content (%)				
8.61	50.59 a*	2.60 a	4.00 d	231.45 d
16.37	40.93 b	2.17b	5.05 c	458.95 c
25.26	31.85 c	1.58 c	6.51 b	605.56 b
37.16	26.91 c	1.41 d	8.46 a	730.02 a

* Means followed by different letters are significantly different from others in the same column (Alpha= 0.05).
[a] Bending stress; [b] Young's modulus; [c] Shear stress, [d] Shear energy.

Table 3. Effect of stalk region on the mechanical properties of the safflower stalk.

Independent variable	Dependent variables (Mechanical properties)			
	σ_b [a](MPa)	E [b](GPa)	τ_s [c] (MPa)	E_s [d] (mJ)
Stalk region				
Bottom	30.71 c	1.54 b	7.90 a	600.58 a
Middle	36.70 b	1.71 b	5.73 b	549.10 b
Top	45.30 a	2.59 a	4.38 c	369.80 c

* Means followed by different letters are significantly different from others in the same column (Alpha= 0.05).
[a] Bending stress; [b] Young's modulus; [c] Shear stress, [d] Shear energy.

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Table 4. The means comparison of the interaction between moisture content and stalk region on the shear stress and shear energy of the safflower stalk.

Moisture content (%)	Stalk region					
	Shear stress (MPa)			Shear energy (mJ)		
	Bottom	Middle	Top	Bottom	Middle	Top
8.61	5.48 cd	3.61 e	2.92 e	338.52 e	230.89 ef	124.95 f
16.37	6.47 c	4.99 d	3.70 e	628.73 c	462.69 cd	279.24 e
25.26	8.62 b	5.81 cd	4.81d	826.87 ab	616.46 c	373.33 de
37.16	11.04 a	8.52 b	6.54 cd	938.33 a	754.19 b	497.55 cd

For each property, mean values with common index are not significantly different (*P*> *0.05*) according to Duncan's multiple ranges test.

experimental data. Results showed that the safflower stalk shear stress was a quadratic function of the stalk moisture content for all regions as follows:

$$\tau_s = 0.001M^2 + 0.134M + 4.128 \quad R^2= \ 0.994$$

For: Top region (5)

$$\tau_s = 0.002M^2 + 0.068M + 2.986 \quad R^2= \ 0.985$$

For: Top region (6)

$$\tau_s = 0.001M^2 + 0.073M + 2.194 \quad R^2= \ 0.999$$

For: Top region (7)

Where, τ_s is the shear stress (MPa), and M is the stalk moisture content (%).

Shear Energy

The values of the shear energy were significantly affected by moisture content, stalk region, and the interaction effect of moisture content and stalk region at 0.01 probability level (P< 0.01) (Table 1). The shear energy requirement increased with increasing moisture content (Table 2). This effect of moisture content was also reported by Annoussamy *et al*. (2000) for wheat straw, Chen *et al*. (2004) for hemp stalk, Ince *et al*. (2005) for sunflower stalk, and Nazari Galedar *et al*. (2008a) for alfalfa stem. The mean values of shear energy varied from 231.45 to 730.02 mJ when moisture content changed from 8.61 to 37.16% wb (Table 2). The reason for this difference may be expressed due to the viscous damping effect of moisture as reported by Persson (1987). The shearing energy decreased from the bottom of the stalk to the top (Table 3). The shearing energy values varied from 338.52 to 938.33, 230.89 to 754.19, and 124.97 to 497.55 mJ for the bottom, middle, and top regions, respectively, at the moisture contents studied in this research. This energy was greater in the bottom region compared to the top region because of the accumulation of more mature fibers in the stem (Ince *et al*., 2005). According to the Duncan's multiple range test results, the values of shear energy were

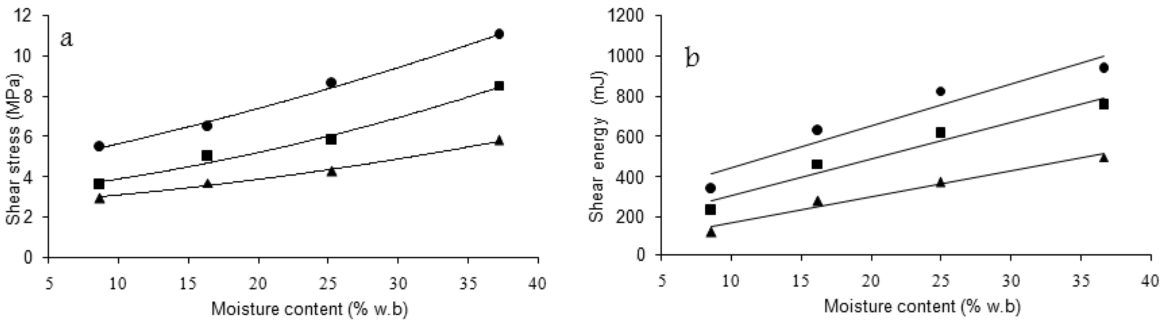

Figure 3. Variations of: (a) Shear stress and; (b) Shear energy, with moisture content according to the stalk regions: ● Bottom region; ■ Biddle region, and ▲ Top region.

different from each other for the distinct moisture contents and stalk regions (Tables 2 and 3). The values of the interaction between moisture content and stalk region on the shear energy (Table 4), varied from 124.95 to 938.33 mJ. The minimum shear energy (124.95 mJ) was obtained for the top region with the lowest moisture content (8.61%), whereas the maximum shear energy (938.33 mJ) was obtained for the bottom region with the highest moisture content (37.16%).

Figure 3-b shows the variation of shear energy with moisture content for all stalk regions. The models fitted to the data using the regression techniques showed that the shear energy increased linearly with increasing the moisture content for all stalk regions. Therefore, the following best-fit regression equations were found for the relationship between shear energy and moisture content at each stalk region:

$E_s = 20.51M + 234.90$ R^2= 0.985 At: Top region (8)

$E_s = 17.84M + 126.00$ R^2= 0.997 At: Middle region (9)

$E_s = 12.64M + 42.54$ R^2= 0.975 At: Bottom region (10)

Where, E_s is the shearing energy (mJ), and M is the stalk moisture content (%).

Bending Stress

Moisture content and stalk region had significant effects on the bending stress at 0.01 probability level (Table 1). The interaction effect of moisture content and stalk region on the bending stress was not statistically significant (P> 0.05). It is evident from Table 2 that as the moisture content of the stalks increased, the bending stress decreased indicating a reduction in the brittleness of the stalks. Similar results were also reported by Annoussamy *et al*. (2000) for wheat straw, Ince *et al*. (2005) for sunflower stalk and Nazari Galedar *et al*. (2008 b) for alfalfa stem. With increasing moisture content from 8.61 to 37.16% the mean value of the bending stress decreased by 1.87 times (47%). The bending stress increased towards the top region of stalk (Table 3). Similar results have been reported by other researchers (Ince *et al*., 2005; Nazari Galedar *et al*., 2008b; Tavakoli *et al*., 2009). The bottom region had about 48% lower value for the bending stress than that of the top region. From Table 2 it is seen that the stalk bending stresses were significantly different at all moisture contents at 0.05 probability level except for the moisture contents of 25.26 and 37.16%. This shows that the effect of 37.16% moisture on the bending stress is not significantly different from that of the 25.26% moisture content. The mean values of bending stress at different stalk regions were statistically different from each other at 0.05 levels (Table 3).

Table 5 shows the means comparison of the interaction between moisture content and stalk region on the bending stress and Young's modulus. Results shown in this table revealed that the bending stress decreased as the moisture content increased for all stalk regions in such a way that bending stress decreased from 43.22 to

Table 5. The means comparison of the interaction between moisture content and stalk region on the bending stress and Young's modulus of the safflower stalk.

Moisture content (%)	Stalk region					
	Bending stress (MPa)			Young's modulus (GPa)		
	Bottom	Middle	Top	Bottom	Middle	Top
8.61	43.22 bc	49.59 ab	59.19 a	2.18 bc	2.54 b	3.33 a
16.37	31.31 def	41.66 bc	49.84 ab	1.54 bcd	1.89 bcd	2.91 a
25.26	26.35 ef	30.13 def	39.07 cd	1.18def	1.53cde	1.83 bcd
37.16	21.98 f	25.65 ef	33.01 cdf	0.86 f	1.08 ef	1.77bcd

For each property, mean values with common index are not significantly different (P> 0.05) according to Duncan's multiple ranges test.

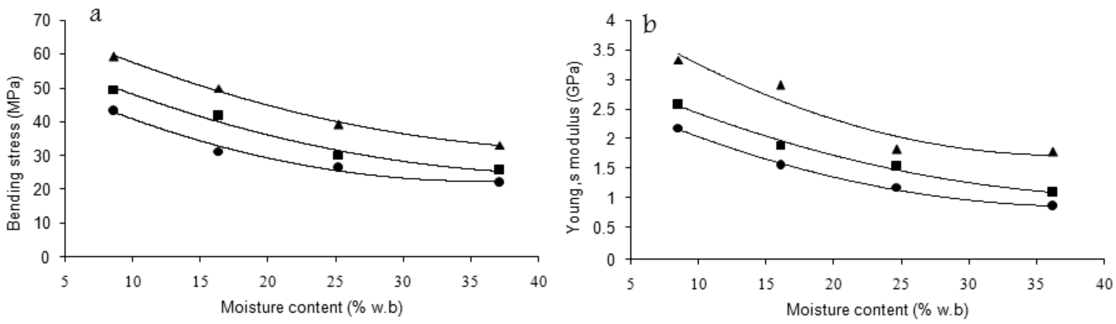

Figure 4. The changes of: (a) Bending stress and; (b) Young's modulus, with moisture content according to the stalk regions: ● Bottom region; ■ Middle region, and ▲ Top region.

21.98, from 49.59 to 25.65, and from 59.19 to 33.10 MPa for the bottom, middle, and top regions as the moisture contents increased from 8.61 to 37.16%, respectively. In Figure 4-a the bending stress is plotted against the moisture content, for each stalk region. Regression analysis was used to find and fit the best general models to the data of bending stress. Results showed that the bending stress can be best expressed as a quadratic function of moisture content for the different stalk regions as follows:

$\sigma_b = 0.021M^2 - 1.899M + 74.34 \quad R^2 = 0.996$

For: Top region (11)

$\sigma_b = 0.021M^2 - 1.849M + 64.57 \quad R^2 = 0.989$

For: Middle region (12)

$\sigma_b = 0.027M^2 - 1.990M + 57.77 \quad R^2 = 0.998$

For: Botom region (13)

where: σ_b is the bending stress (MPa), and M is the stalk moisture content (%).

Young's modulus

Effects of moisture content and stalk region on the Young's modulus in bending were also evaluated in this study. Both the moisture content and region of stalk significantly affected Young's modulus at the 0.01 level of probability (P< 0.01). The interaction effect of moisture content and stalk region on the Young's modulus was not significant (P> 0.05) (Table 1). Results revealed that the Young's modulus was also decreased with increasing moisture content, and increased from the bottom of the stalk to the top (Tables 2 and 3). Similar results were also reported by El Hag *et al.* (1971), Mohsenin (1980), O'Dogherty *et al.* (1995), Ince *et al.* (2005), Nazari Galedar *et al.* (2008b), and Tavakoli *et al.* (2009). The average values for the Young's modulus varied from 2.69 to 1.22 GPa when the moisture content changed from its lowest value to its highest amount in this study (Table 2). The difference between the values of the Young's modulus at the lowest and the highest moisture contents was about 120%. The average values for the Young's modulus were found to be 1.44, 1.71, and 2.45 GPa for the bottom, middle, and top region, respectively. Higher values of Young's modulus were found at the top region because of smaller stalk diameter in this region. Similar results were also reported by Simonton (1992). The Young's modulus mean values at different moisture contents were statistically different from each other (Tables 2). The difference between the mean values of Young's modulus of middle and top regions were significant at 0.05 level, but the observed difference between middle and bottom regions was not significant (Table 3). Based on the results of the means comparison of the interaction between moisture content and stalk region on the Young's modulus (Table 5), for all the stalk regions considered, the Young's modulus decreased with increasing moisture content. The highest Young's modulus value (3.33 GPa) was obtained in the top region at the moisture content of 8.61 %, while the lowest value (0.86 GPa) was

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found in the bottom region at the moisture content of 37.16%.

Figure 4-b shows the variation of the safflower stalk Young's modulus with the moisture content at each stalk region. Regression analysis showed that the Young's modulus was a quadratic function of moisture content for all regions as follows:

$E = 0.002M^2 - 0.151M + 4.589 \quad R^2 = 0.996$

At: Top region (14)

$E = 0.001M^2 - 0.107M + 2.984 \quad R^2 = 0.985$

At: Middle region (15)

$E = 0.001M^2 - 0.103M + 3.345 \quad R^2 = 0.991$

At: Bottom region (16)

Where, E is the Young's modulus (GPa), and M is the stalk moisture content (%).

CONCLUSIONS

From the results of this study, the following conclusions can be drawn:

An increase in the moisture content of the safflower stalk led to a decrease in the bending stress and Young's modulus, and an increase in the shear stress and shear energy.

The average values of the bending stress, Young's modulus, shear stress, and shear energy varied from 50.59 to 26.91 MPa, 2.52 to 1.22 GPa, 4.00 to 4.00 MPa, and 231.45 to 730.02 mJ, respectively, as the moisture content increased from 8.61 to 37.16%.

For all moisture contents that were studied, the bending stress and Young's modulus increased from the bottom towards the top region of stalk, while the shear stress and shear energy decreased.

There was a significant difference between the highest and the lowest moisture contents in terms of shear stress and shear energy. This result indicated that harvesting safflower stalk at lower moisture contents can be recommended to minimize the shear force and shear energy requirements. Meanwhile, the effect of cutting height can also play an important role in reducing shear force and energy.

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خصوصیات خمشی و برشی ساقه گلرنگ

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چکیده

هدف از این تحقیق تعیین تأثیر مقدار رطوبت و ارتفاع ساقه بر خواص مکانیکی ساقه گلرنگ بود. کلیه آزمایش‌ها در چهار سطح رطوبت ساقه شامل: ۸/۶۱، ۱۶/۳۷، ۲۵/۲۶ و ۳۷/۱۶ درصد بر مبنای وزن تر، انجام گرفت. هر کدام از ساقه‌ها به سه ناحیه ارتفاعی مساوی فوقانی، میانی و تحتانی تقسیم شدند و خواص مکانیکی ساقه مانند: تنش خمشی، مدول یانگ در خمش، تنش برشی و انرژی برشی ساقه اندازه‌گیری و اثر رطوبت و نواحی ارتفاعی بر روی آنها بررسی شد. نتایج آنالیز داده‌ها نشان داد که با افزایش درصد رطوبت ساقه و همچنین حرکت از ناحیه فوقانی ساقه به سمت ناحیه تحتانی، تنش خمشی کاهش یافت. مقدار تنش خمشی در پایین ترین رطوبت تقریبا دو برابر آن در بالاترین رطوبت بود. مقدار متوسط تنش خمشی بین ۵۹/۱۹ تا ۲۱/۹۸ مگاپاسکال به‌دست آمد. همچنین مدول یانگ ساقه با افزایش رطوبت و حرکت از ناحیه فوقانی ساقه به سمت ناحیه تحتانی کاهش یافت و مقدار آن بین ۳/۳۳ تا ۰/۸۶ گیگاپاسکال متغیر بود. بر خلاف دو فاکتور فوق، تنش برشی و انرژی برشی با افزایش رطوبت و حرکت از ناحیه فوقانی ساقه به سمت ناحیه تحتانی افزایش یافتند. بیشترین مقدار تنش برشی و انرژی برشی به ترتیب برابر با ۱۱/۰۴ مگاپاسکال و ۹۳۸/۳۳ میلی ژول بود که هر دو در ناحیه تحتانی و در رطوبت ۳۷/۱۶ درصد به‌دست آمدند.