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Physical properties of safflower stalk

F. Shahbazi*[1], M. Nazari Galedar[2], A.Taheri-Garavand[2], and S.S. Mohtasebi[2]

[1]Department of Farm Machinery, University of Lorestan, Iran
[2]Department of Agricultural Machinery Engineering, University of Tehran, Karaj, Iran

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A b s t r a c t. The objective of this research was to determine the effects of moisture content and stalk region on some physical and mechanical properties of safflower stalks. The experiments were conducted at four moisture contents of 9.98, 17.85, 26.37 and 38.75% w.b. and at the bottom, middle and top regions of stalk. The values of the stalk physical properties increased with increasing moisture content. Their values also increased towards the bottom region. The bending stress and Young modulus in bending decreased with increase in the moisture content and increased towards the top regions. The average bending stress values and Young modulus in bending varied between 47.71 and 25.9 MPa and between 2.52 and 1.28 GPa, respectively. The shearing stress and the specific shearing energy increased with increasing moisture content. Their values also increased towards the bottom region of the stalk. The maximum shear stress and specific shearing energy were found to be 7.66 MPa and 33.05 mJ mm^{-2}, respectively, and both occurred at the bottom region with the moisture content of 38.75% w.b.

K e y w o r d s: safflower stalk, bending stress, Young modulus, shearing stress, specific shearing energy

INTRODUCTION

Safflower (*Carthamus tinctorius* L.), which belongs to the *Compositae* 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 has a high linoleic acid content (75-86%). The safflower oil is used for a variety of purposes, and especially as biodiesel for the production of fuel for internal combustion engines. Safflower production increased recently due to increasing research on alternative energy sources. In 2005 the estimated area of safflower production in the world was about 814 000 ha (FAO, 2006).

In Iran, in the last few years the safflower cultivation area has increased and was 15 000 ha in 2005-2006. The average seed yield was about 900 kg ha^{-1} (Pourdad *et al*., 2008). Safflower is a highly branched annual plant, usually with many long sharp spines on the leaves, and 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 the design and operational parameters of equipment relating to harvesting, threshing, handling and other processing of the stalks. The properties of the cellular material that are important in cutting are: compression, tension, bending, shearing, 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 (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 such as the bending and shearing stress and energy requirements for suitable knife design and operational parameters (Ince *et al*, 2005). Many studies have been conducted to determine the physical and mechanical properties of plant stems, such as: Skubisz (2001) on rape stem, Skubisz (2002) on pea stem, Chen *et al*. (2004) on hemp stem, Ince *et al*. (2005) on sunflower stalk, Nazari Galedar *et al*. (2008a) on alfalfa stem and Tavakoli *et al*. (2009) on barley straw.

The aim of this study was to investigate the effects of moisture content and stalk region on some physical properties, namely: average diameter, cross-section area, second moment of area and mass per unit length, and mechanical properties, namely: bending stress, Young modulus, shearing stress and specific shearing energy of safflower stalks.

*Corresponding author's e-mail: feizollah.shahbazi@gmail.com

MATERIALS AND METHODS

The safflower (cv. Dincer) used for the present study is one of the prevalent varieties of safflower in Iran and was obtained from the farms in the Lorestan province, Iran, during the summer season in 2008. After attaining optimum maturity, the safflower stalk samples were collected and then the flowers and the leaves were removed from the stalk. The diameter of the safflower stalks decreased towards the top of the plant. That means it shows different physical and mechanical properties at different heights due to cross sectional area. Therefore, the stalk was divided equally into three height regions as top (A), middle (B) and bottom (C) (Fig. 1). Sections from the growth and root region of the stems were cut off in approximately 40 mm lengths and were not investigated because this region (D) is usually left on the field (Fig. 1). For each region, its length (to the nearest 0.01 mm), its diameter (average diameter at the midpoint) and its mass (to the nearest 0.001 g) were measured, and then the cross-section area, second moment of area and mass per unit length were calculated.

To determine the average moisture contents of the safflower stalks, the specimens were weighed and oven-dried at 102°C for 24 h and reweighed (Ince *et al*., 2005). The initial moisture content of the specimens was determined to be 9.98% (wet basis). Specimen samples with higher moisture contents were prepared by adding calculated amounts of distilled water to wet the specimens which were sealed in separate polyethylene bags and stored in a cold store at 5ºC for 10 days (Shaw and Tabil, 2006; Tavakoli *et al*., 2009). Before starting each test, the required amounts of stalks were allowed to warm up to room temperature. The experiments were conducted at moisture levels of 9.98, 17.85, 26.37 and 38.75% w.b. The safflower stalk moisture content is about 20 to 30%, when the seeds are mature in Iran (Pourdad *et al*., 2008).

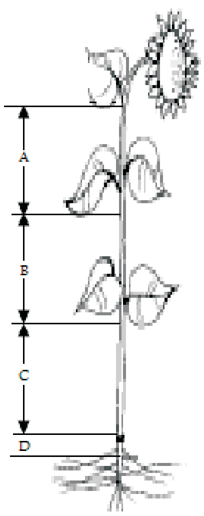

Fig. 1. Diagram of safflower stalk identifying regions: A – top, B – middle, C – bottom, D – woody regions.

The mechanical properties of safflower stalk were assessed using a shearing test and a three-point bending test machines similar to those described by Nazari Galedar *et al*. (2008a) and Tavakoli *et al*. (2009). To determine the bending stress and Young modulus in bending the specimens were placed on two rounded metallic supports 50 mm apart and the force was applied to the centre of the stem with a blade driven by the movable supports. The loading rate was 10 mm min^{-1}. Force versus deformation data were recorded by the computer until fracture of the specimen, then force-deformation curves were obtained from the test data by software. The bending force and deformation at the bio yield peak and at the inflection point were obtained from all curves. Most specimens were circular in cross-section, therefore, the second moment of inertia of the cross sectional area, I (mm^4), was calculated as:

$$I = \frac{\pi d_s^4}{64}, \qquad (1)$$

where d_s is the stalk diameter (mm).

The bending stress, σ_b (MPa), was calculated as (Nazari Galedar *et al*., 2008a; Tavakoli *et al*., 2009):

$$\sigma_b = \frac{F_b y_l}{4I}, \qquad (2)$$

where: F_b – the bending force (N), y – distance of outermost fibre from the neutral axis ($y = d_s/2$) (mm); l – distance between the two metal supports (50 mm).

The Young modulus, E (GPa), of safflower stalk was calculated from the following expression for a simply supported beam located at its centre (Tavakoli *et al*., 2009):

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

where δ is the deflection at the specimen centre (mm).

Shear force was applied to the stalk specimens by mounting a shear box in the tension/compression testing machine (Nazari Galedar *et al*., 2008a; Tavakoli *et al*., 2009). The sliding plate was loaded at a rate of 10 mm min^{-1} and, as for the shear test, the applied force was measured by a strain-gauge load cell and a force-time record was obtained up to the specimen failure. The shear failure stress (or ultimate shear strength), τ_s (MPa), of the specimens was calculated as:

$$\tau_s = \frac{F_s}{2A}, \qquad (4)$$

where: 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 shearing energy was calculated by integrating the area under the shear force and displacement curves (Chen *et al*., 2004; Nazari Galedar *et al*., 2008a). The specific shearing energy, E_{sc} (mJ mm^{-2}), was found as:

$$E_{sc} = \frac{E_s}{A}, \qquad (5)$$

where E_s is the shearing energy (mJ).

In this study, the effects of stalk moisture content (at 9.98, 17.85, 26.37 and 38.75% w.b.) and stalk region (at the top, middle and bottom regions) on the physical and mechanical properties of safflower stalks were studied. The factorial experiment was conducted as a randomised design with 12 replicates. Experimental data were analysed using analysis of variance (ANOVA) and the means were separated at the 5% probability level applying Duncan multiple range tests in SPSS 15 software.

RESULTS AND DISCUSSION

The mean values for the geometric properties of safflower stalk are presented in Table 1. The moisture content had little effect on the physical properties of safflower stalk. With increase in the moisture content, the physical properties generally increased. The effect of moisture content on the stalk average diameter, stalk cross-sectional area, second moment of area and mass per unit length was not significant at 5% probability level. The physical properties also increased towards the bottom region of the stalk. The values of all physical properties studied at the bottom, middle and top stalk regions had significant differences ($p<0.05$). Similar increasing trends for stem diameter, wall cross-sectional area and second moment of area towards the lower level of crop were reported by O'Dogherty *et al.* (1995) for wheat straw, Nazari Galedar *et al.* (2008a) for alfalfa stem, and Tavakoli *et al.* (2009) for wheat straw.

The results of Duncan multiple range tests for comparing the mean values of the mechanical properties of safflower stalks at different moisture contents and stalk regions are presented in Table 2. It is evident from Table 2 that as the moisture content of the stalk increased, the bending stress decreased, indicating a reduction in the brittleness of the stalk. 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 9.98 to 38.75% the mean value of the bending stress decreased by 1.8 times. The average values for the bending stress were found to be 25.9, 29.46, 37.01 and 47.71 MPa for moisture contents of 38.75, 26.37, 17.85 and 9.98% w.b., respectively. The bending stress increased towards the top region of the stalk (Table 2). 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 47.37% lower value of bending stress than the top region. The moisture content and the stalk region had significant effects on the bending stress at 1% probability level. Moreover, according to Duncan multiple range test results, the bending stress mean values at different moisture contents and different regions were statistically different from each other ($p<0.05$). In Fig. 2 the bending stress is plotted against the moisture content, for each stalk region. The figure reveals that, at all the stalk regions considered, the bending stress decreases as the moisture content increases. Its mean values decreased from 56.69 to 32.92, 46.67 to 23.63 and 39.76 to 21.17 MPa for the top, middle and bottom regions, respectively, as the moisture contents increased from 9.98 to 38.75%. Regression analysis was used to find and fit the best general models to the data. The results showed that as the moisture content of the stalk increased, the bending stress decreased as a polynomial, so the dependence of bending stress (σ_b, MPa) on the stalk moisture content (M, %) was expressed by the following best-fit equations for each stalk regions:

– top

$$\sigma_b = 0.0378 M^2 - 2.6523M + 79.161 \quad R^2=0.9979, \qquad (6)$$

T a b l e 1. Geometric properties of safflower stalk regions (bottom, middle, top) as a function of moisture content (12 observations)

Physical properties	Moisture content (% w.b.)											
	9.98			17.85			26.37			38.75		
	Stalk region											
	Bottom	Middle	Top	Bottom	Middle	Top	Bottom	Middle	Top	Bottom	Middle	Top
d_s (mm)	5.26 a (0.83)	4.68 a (0.77)	3.64 a (0.66)	4.94 a (1.25)	4.42 a (1.14)	3.61 a (0.49)	5.12 a (1.02)	4.66 a (0.87)	3.58 a (0.73)	5.16 a (1.21)	4.64 a (0.73)	3.62 a (0.70)
A (mm^2)	22.23 a (6.68)	17.68 a (5.89)	10.75 b (3.97)	20.31 a (7.58)	16.31 b (5.92)	10.42 b (2.87)	21.35 a (9.15)	17.64 a (7.33)	10.47 b (4.81)	21.97 a (9.33)	17.32 a (5.64)	10.69 b (4.09)
I (mm^4)	42.90 a (25.80)	27.43 ab (18.49)	10.36 b (8.08)	37.17 a (20.03)	23.75 ab (12.21)	9.26 b (5.20)	42.44 a (32.13)	28.72 ab (18.84)	10.41 b (8.66)	44.80 a (26.69)	26.21 ab (12.00)	10.33 b (6.87)
ML (g m^{-1})	5.37 ab (1.87)	3.94 cd (1.15)	2.73 d (0.82)	5.36 ab (1.17)	4.00 bcd (0.83)	2.95 cd (0.89)	5.32 ab (2.05)	4.03 bcd (1.56)	3.19 cd (1.63)	6.34 a (4.04)	4.31 bc (1.51)	3.42 cd (1.27)

*Dates in parentheses are standard deviation: a-d – means followed by different letters are significantly different from others in the same row ($p < 0.05$), d_s – average stalk diameter, A – cross-section area of stalk, I – second moment of area and, ML – mass per unit length.

T a b l e 2. Effects of moisture content and stalk region on the mechanical properties of safflower stalk

Independent variable	Mechanical properties			
Moisture content (%)	σ_b (MPa)	E (GPa)	τ_s (MPa)	E_{sc} (mJ mm^{-2})
9.98	47.71 a	2.524 a	3.23 c	13.93 c
17.85	37.01 b	1.989 b	3.51 c	16.85 c
26.37	29.46 c	1.506 c	4.59 b	20.86 b
38.75	25.90 d	1.283 c	6.04 a	26.92 a
Stalk region				
Bottom	28.76 a	1.346 c	5.61 a	23.83 a
Middle	34.08 b	1.753 b	4.42 b	19.01 b
Top	42.30 c	2.377 a	2.98 c	16.08 c

σ_b – bending stress, E – Young modulus, τ_s – shearing stress, and E_{sc} – specific shearing energy. Other explanations as in Table 1.

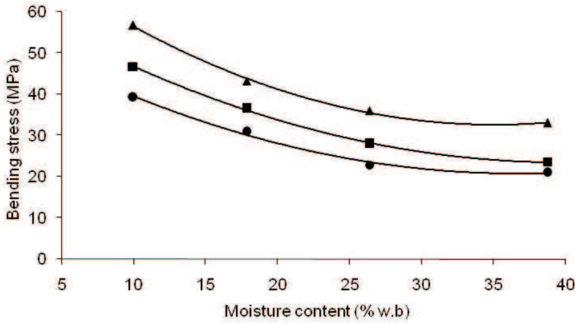

Fig. 2. Changes of bending stress with moisture content according to the stalk regions: ●bottom, ■ middle, ▲top.

– middle

$$\sigma_b = 0.0259\,M^2 - 2.0719M + 64.891 \quad R^2=0.9992, \tag{7}$$

– bottom

$$\sigma_b = 0.0244\,M^2 - 1.9388M + 56.250 \quad R^2=0.9939. \tag{8}$$

All the indexes are significant at the level of 99.99%. As follows from the above relations, the effect of moisture content is stronger for the top region than in the case of the lower ones (higher values at variable M^2).

The Young modulus in bending was evaluated according to the moisture content and stalk region. The Young modulus also decreased with increasing moisture content and increased towards the top region of the stalk (Table 2). Similar results were also reported by O'Dogherty *et al*. (1995), Ince *et al*. (2005), Nazari Galedar *et al*. (2008b) and Tavakoli *et al*. (2009).The average values of the Young modulus varied from 2.524 to 1.283 GPa, between the lowest and the highest moisture content (Table 2). The difference between the values for the Young modulus at the lowest and highest moisture contents was about 100%. The changes of Young modulus decreased as moisture content increased. The average values for the Young modulus were found to be 1.346, 1.753 and 2.377 GPa for the bottom, middle and top region, respectively. The higher values of Young modulus were found at the top region due to the smaller stalk diameter in this region. Both the moisture content and the region of the stalk significantly affected the Young modulus ($p<0.01$). According to the Duncan multiple range tests, the Young modulus was found to be significantly higher ($p<0.05$) for the three lowest moisture contents (9.98, 17.37 and 26.37% w.b.), with a mean value of 2.002 GPa. This is compared with a mean value of 1.283 GPa for the other moisture content (38.75% w.b.). The Young modulus mean values at different regions are statistically different from each other ($p<0.05$). The interaction effect of moisture content × stalk region on the Young modulus was not significant ($p>0.05$). Fig. 4 shows the variation of the safflower stalk Young modulus with the moisture content at each stalk region. As follows from the relations presented in the figure, for all the stalk regions considered, the Young modulus of stalks decreased with increase in their moisture content. The highest Young modulus value was obtained as 3.18 GPa in the top region at a moisture content of 9.98%, while the lowest value was found to be 0.98 GPa in the bottom region at a moisture content of 38.75%. Regression analysis showed that the Young modulus decreased as a polynomial with increasing moisture content at all regions. The relationship between the stalk Young modulus (E, GPa) and moisture contents (M, %) at each stalk region can be expressed by the following best-fit regression equations for regions:

– top

$$E = 0.001\,M^2 - 0.144M + 4.489 \quad R^2=0.996 \tag{9}$$

– middle

$$E = 0.001\,M^2 - 0.086M + 2.638 \quad R^2=0.989 \tag{10}$$

– bottom

$$E = 0.001M^2 - 0.1111M + 3.462 \quad R^2=0.999 \tag{11}$$

All the indexes are significant at the level of 99.99%.

The shearing stress was evaluated as a function of moisture content and stalk region. The shearing stress of stalks increased with increase in the moisture content (Table 2). Similar results were reported by most previous researchers (Annoussamy *et al*., 2000; Nazari Galedar *et al*., 2008a; Tavakoli *et al*., 2009). The average values for the shearing stress varied from 3.23 to 6.04 MPa at the moisture content from 9.98 to 38.75%. The difference between the values for the shearing stress at the lowest and highest moisture contents was about 85%. Shearing stress decreased towards the top region (Table 2). This result was also reported by others (Ince *et al*. 2005; Nazari Galedar *et al*., 2008a). The average values for the shearing stress were found to be 5.61, 4.42 and 2.98 MPa for the bottom, middle and top regions, respectively. The safflower stalk has a hard structure because of the high cellulose content. Therefore, the shearing stress of the bottom region is higher than that of the middle and top regions of the stalk. In the bottom region the shearing stress increased from 4.25 to 7.66 MPa with increasing moisture content from 9.98 to 38.75%. The moisture content and the stalk region had a significant effect on the shear stress ($p<0.01$). In addition, according to the Duncan multiple range tests, the values for the shearing stress were completely different for the distinct stalk regions, but only at moisture contents above 17.85%; there were no statistically significant differences at moisture contents of less than 17.85% (Table 2). Figure 3 presents the relationship between the shearing stress and moisture content for all the stalk regions. As moisture content of the stalk increased, the shearing stress increased in all the regions (Fig. 4). The greatest shearing stress was obtained as 7.66 MPa in the bottom region at the moisture content of 38.75% of stalk, while the lowest shearing stress was found to be 2.22 MPa in the top region at a moisture content of 9.98%. The shearing stress decreased towards the top region of the stalk. The differences in the values for the shearing stress in the intermediate stalk regions also diminished as the moisture content decreased. It was found that the shearing stress of stalks increased as a polynomial function of their moisture content for all the regions. The following relationships were found between the shearing stress (τ_s, MPa) and moisture content (M, %), for each stalk region:

– top

$$\tau_s = 0.001M^2 + 0.019M + 2.204 \quad R^2=0.998, \tag{12}$$

– middle

$$\tau_s = 0.001M^2 + 0.052M + 2.473 \quad R^2=0.990, \tag{13}$$

– bottom

$$\tau_s = 0.002M^2 + 0.024M + 3.727 \quad R^2=0.989. \tag{14}$$

All the indexes are significant at the level of 99.99%.

The specific shearing 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 values of specific shearing energy varied from 13.93 to 26.92 mJ mm^{-2} between the lowest and highest moisture contents. The reason for this difference may be attributed to the viscous damping effect of moisture. The specific shearing energy decreased towards the top region of the stalk. Its values varied between 11.98 to 21.45, 13.14 to 26.26, and 16.66 to 33.05 mJ mm^{-2} for the top, middle and bottom regions, respectively, at the different moisture contents that were studied. It was greater in the bottom regions because of the accumulation of more mature fibres in the stem (Ince *et al*., 2005). The values of the specific shearing energy were significantly affected by moisture content and stalk region ($p<0.01$). According to the Duncan multiple range test results, these values are different from each other for the distinct stalk regions, but the effect of moisture content is only significant at above 17.85% (Table 2).

Figure 5 shows the variation of specific shearing energy with moisture content for all the stalk regions. The values of this interaction varied from 11.98 to 33.05 mJ mm^{-2} that occurred in the top region at the lowest moisture content and

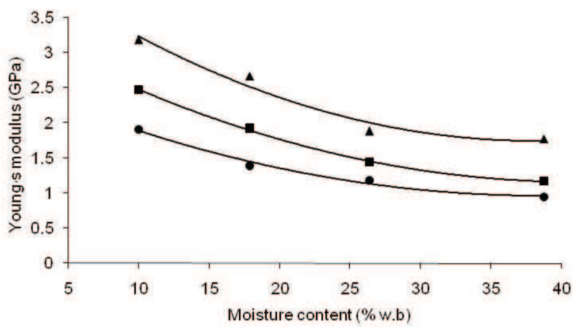

Fig. 3. Changes of Young modulus with moisture content according to the stalk regions. Explanations as on Fig. 2.

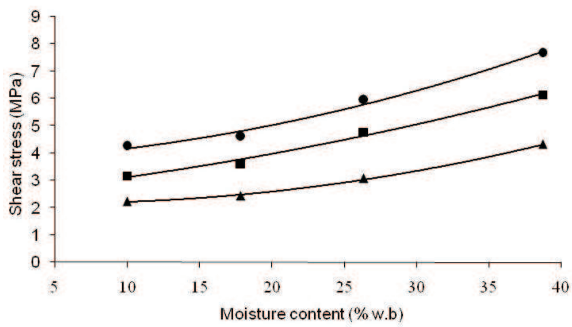

Fig. 4. Changes of shear stress with moisture content according to the stalk regions. Explanations as on Fig. 2.

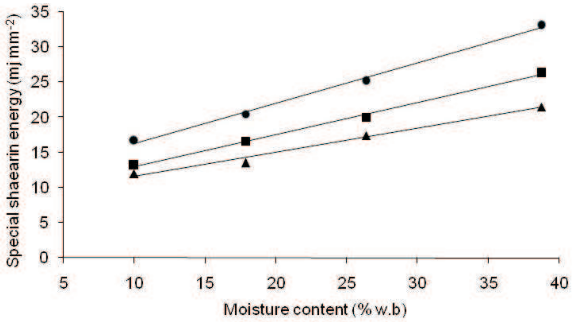

Fig. 5. Variation of specific shearing energy with moisture content according to the stalk regions. Explanations as on Fig. 2.

in the bottom region at the highest moisture content, respectively. The models fitted to the data using the regression technique showed that the specific shearing energy increased linearly with increases in the moisture content for all stalk regions. So the following equations were found for the relationship between specific shearing energy (E_{sc}, mJ mm^{-2}) and moisture content (M, %), at each stalk region:

– top:

$$E_{sc} = 0.342\,M + 8.124 \quad R^2=0.994, \qquad (15)$$

– middle:

$$E_{sc} = 0.452\,M + 8.486 \quad R^2=0.997, \qquad (16)$$

– bottom:

$$E_{sc} = 0.572\,M + 10.511 \quad R^2=0.995. \qquad (17)$$

All the indexes are significant at the level of 99.99%.

CONCLUSIONS

1. The values of the physical properties of safflower stalk increased with increasing moisture content. The physical properties also increased towards the bottom region.

2. An increase in moisture content of safflower stalk led to a decrease in the bending stress and Young modulus and an increase in the shear stress and specific shearing energy.

3. The average values of the bending stress, Young modulus, shearing stress and shearing energy varied from 47.71 to 25.90 MPa, 2.25 to 1.28 GPa, 3.23 to 6.04 MPa and 13.93 to 26.92 mJ mm^{-2}, respectively, as the moisture content increased from 9.98 to 38.75%.

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

5. There was a big difference between the highest and the lowest moisture contents in terms of shearing stress and specific shearing energy. This result indicates that harvesting safflower stalk at lower moisture contents can be recommended to minimize the shearing force and shearing energy requirements; also the effect of cutting height is very important for reducing shearing force and energy.

REFERENCES

Annoussamy M., Richard G., Recous S., and Guerif J., 2000. Change in mechanical properties of wheat straw due to decomposition and moisture. Appl. Eng. Agric., 16(6), 657-664.

Baumler E., Cuniberti, A., Nolasco S.M., and Riccobene I.C., 2006. Moisture dependent physical and compression properties of safflower seed. J. Food Eng., 72(2), 134-140.

Chen Y., Gratton J.L., and Liu J., 2004. Power requirements of hemp cutting and conditioning. Biosys. Eng., 87(4), 417-424.

FAO, **2006.** Available from <http://faostat.fao.org/faostat/>.

Ince A., UOurluay S., Guzel E., and Ozcan M.T., 2005. Bending and shearing characteristics of sunflower stalk residue. Biosys. Eng., 92(2), 175-181.

Nazari Galedar M., Tabatabaeefar A., Jafari A., Sharifi A., O'Dogherty M.J., Rafee S., and Richard G., 2008a. Effects of moisture content and level in the crop on the engineering properties of alfalfa stems. Biosys. Eng., 101(2), 199-208.

Nazari Galedar M., Tabatabaeefar A., Jafari A., Sharifi A., and Rafee S., 2008b. Bending and shearing characteristics of alfalfa stems. Agric. Eng. Int. CIGR Ejournal, FP 08 001, X.

O'Dogherty M.J., Hubert J.A., Dyson J., and Marshall C.J., 1995. A study of the physical and mechanical properties of wheat straw. J. Agric. Eng. Res., 62, 133-142.

Pourdad S.S., Moghadami M.J., Hatamzadeh H., and Alipour S., 2008. The first released safflower variety for dry-lands of Iran. Proc. 6th Int. Conf. Safflower, November 3-6, Wagga, Australia.

Sacilik K., Tarimci C., and Colak A., 2007. Moisture content and bulk density dependence of dielectric properties of safflower seed in the radio frequency range. J. Food Eng., 78, 1111-1116.

Shaw M. and Tabil L., 2006. Mechanical properties of selected biomass grinds. Proc. ASABE Annual Int. Meeting, July 9-12, Portland, OR, USA.

Skubisz G., 2001. Development of studies on the mechanical properties of winter rape stems. Int. Agrophysics, 15, 197-200.

Skubisz G., 2002. Method for the determination of the mechanical properties of pea stems. Int. Agrophysics, 16, 73-77.

Tavakoli H., Mohtasebi S.S., and Jafari A., 2009. Physical and mechanical properties of wheat straw as influenced by moisture content. Int. Agrophysics, 23, 175-181.

Yiljep Y.D., and Mohammed U.S., 2005. Effect of knife velocity on cutting energy and efficiency during impact cutting of sorghum stalk. Agric. Eng. Int. CIGR Ejournal, PM 05 004, VII.