Iranica Journal of Energy & Environment 3 (4): 333-340, 2012
ISSN 2079-2115
IJEE an Official Peer Reviewed Journal of Babol Noshirvani University of Technology
DOI: 10.5829/idosi.ijee.2012.03.04.07

BUT

Influence of Knife Bevel Angle, Rate of Loading and Stalk Section on Some Engineering Parameters of Lilium Stalk

Adel Heidari, Gholamreza Chegini, Mohammad Hossein Kianmehr,
Seyed Reza Hassan-Beygi and Javad Khazaei

Department of Agrotechnology, College of Abuoreihan, University of Tehran, Tehran, Iran

(Received: January 18, 2011; Accepted in Revised Form: August 14, 2012)

Abstract: Some physical and mechanical property testing of main stalks of Lilium was conducted to provide information for future automatic machine design. Shear, compression and bending properties of Lilium stalks were determined with using a universal testing machine. The experiments were conducted at three rate of loading levels from 30 to 50 mm/min, three knife bevel angle levels from 30 to 60 degree and at two levels the stalk; upper and lower. The results showed that all the mentioned above parameters had significant effect on the measured mechanical properties ($P<0.01$). In all three loading rate, an increasing the shear strength and specific cutting energy were observed as the knife bevel angle increased. The highest compression strength and specific compressing energy were 6.86 MPa and 21.34 mJ/mm^2 at the lower level, while the lowest compression strength and specific compressing energy were 2.90 MPa and 10.69 mJ/mm^2 at the upper level. As the loading rate of the stalk increased, the bending strength decreased, indicating a reduction in the brittleness of the stalk. The average values for modulus of elasticity were found to be 23.48 and 15.96 MPa for stalk regions of upper and lower, respectively.

Key words: Bending · Compression · Lilium · Physical properties · Shear strength · Stalk

INTRODUCTION

Flower is one of the agricultural crops considering its exporting potential, Studying on post harvesting losses of this crop has special importance. Nowadays using mechanized and auto mechanized equipments is necessary in post harvest processing of cut flower [1]. For this purpose a machine was designed which picks leafs of cut flowers (Lilium). Before designing of this machine some physical and mechanical properties of cut flower were determined.

Most of studies on the physical and mechanical properties of plants have been carried out during their growth using failure criteria (force, stress and energy) or their Young's modulus and the modulus of rigidity. Studies have focused on plant anatomy, lodging processes, harvest optimization, animal nutrition, industrial applications and the decomposition of wheat straw in soil [2, 3]. The physical properties of the cellular material are important for cutting, tension, bending, density and friction [4, 5]. Methods and procedures for determining most of mechanical and rheological properties of agricultural products have been described.

Prasad and Gupta [6] studied the mechanical properties of maize stalk in relation to cutting under quasi-static deformation. They observed that for maize stalks at a moisture content of 74% w.b. studies showed that with increasing cutting rate from 200 to 1000 mm/min the shear strength of maize stalk decreased from 3.63 to 2.10 MPa. Khazaei *et al*. [7] reported that with increasing cutting rate from 20 to 200 mm/min the shear strength of pyrethrum stalk decreased. The maximum values of shear force and energy for cutting of hemp were 243 N and 2.1 J, respectively. Ince *et al*. [8] reported that the maximum shear stress and specific cutting energy of sunflower stalk were 1.07 MPa and 10.08 mJ/mm^2, respectively. Chattopadhay and Pandeyreported [9] reported that the shear strength of sorghum stalk decreased from 3.74 to 1.94 MPa at the forage stage and decreased from 4.68 to 2.20 MPa at the seed stage when the cutting rate was

Corresponding Author: Adel Heidari, Department of Agrotechnology, College of Abuoreihan, University of Tehran, Tehran, Iran. P.O. Box: 3391653775. Tel: +989189558580, Fax: 02136040746, E-mail: adelheidari310@ut.ac.ir.

increased from 10 to 100 mm/min at 30° knife bevel angle. McRandal and McNulty [10] have reported that the average values of shear strength and shear energy of grasses were 16MPa and 12 mJ/mm^2, respectively.

Considering the above points, there is a need for information on the variation in the physic-mechanical properties of Lilium stalk to design and fabrication of a new picking leaf machine. This study was focused on determining the shearing, bending and compression strength and the specific shearing energy, specific compressing energy, specific bending energy of Lilium stalks as a function of various stalk regions, different rate of loading and different knife bevel angle. Also the effect of stalk diameter on modulus of elasticity in compression was investigated.

MATERIALS AND METHODS

The Lilium flower were harvested from Ashian-e-Sabz greenhouse in Tehran, Iran, from healthy mother stock plants by sharp knife at a height of 10 cm above the soil surface in the morning of each testing date. Harvested stalks were covered and transported in an insulated container to the biomechanical test devices, laboratory in Tehran University, Tehran, Iran. Specimens were kept in the refrigerator at temperature 4°C. The diameter of the Lilium stalk decreased towards the top of the plant. Therefore, it was divided equally into two levels as upper and lower [2] Test specimens were taken from two locations: near the growth tip (upper) and near the root internode (lower).Testing was completed as rapidly as possible in order to reduce the effects of drying. An instron Universal Test Machine (UTM) which equipped with 50 N load cell with an accuracy of ±0.001 N was used to measure the shearing, bending and compression force of Lilium stalk test (Figure 1).

Measurement of the Physical Properties of Lilium Stalk: A venire caliper with 0.005 cm divisions and 25 cm maximum reading was used in measuring the stalk diameter. The weights of the stalk specimens were recorded using weight balance with an accuracy of 0.01 g. The density of the stalk was found by displacement method using toluene instead of water to avoid water absorption by the specimen. The weight of the specimen in the air and the weight of the toluene displaced were recorded and density was calculated by the following equation (1) [11].

$$\rho = W_a/W_k \times S_k \quad (1)$$

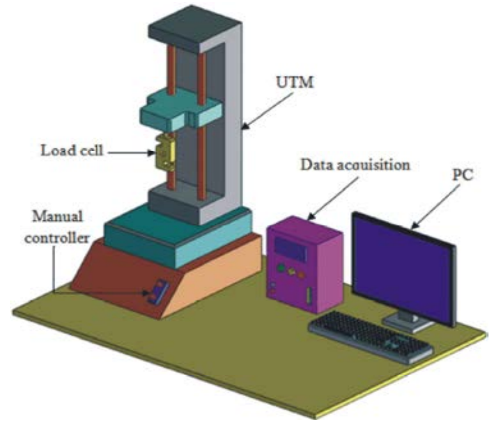
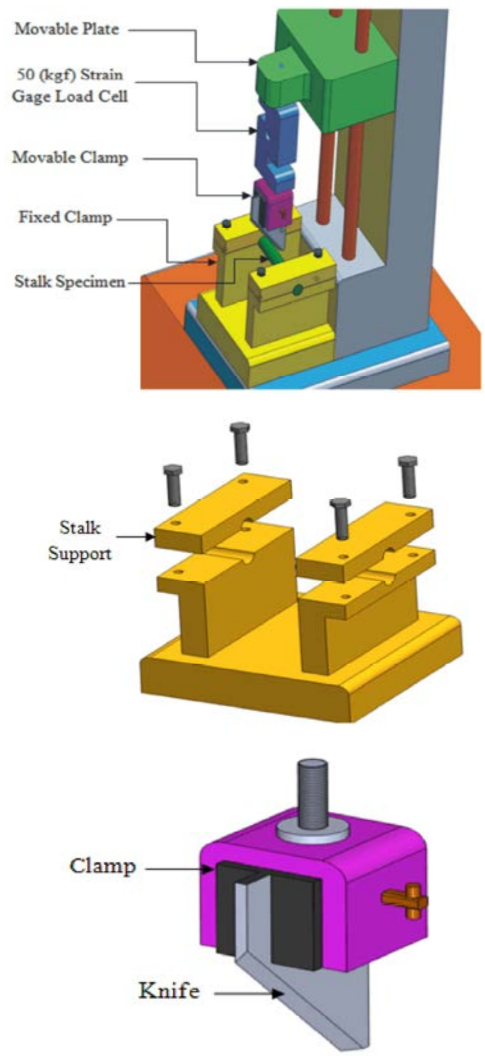


Fig. 1: Instron Universal Testing Machine.



(a) (b) (c)

Fig. 2: Apparatus for the measurement of Shear strength: a - schematic of apparatus, b - fixed clamp, c - movable clamp

The moisture content and mass per unit length of the specimen were determined by the use of oven method. The oven temperature was set at 105±3°C for 24 h. The moisture content and mass per unit length can be expressed by the following equation [11]:

$$M.C_{wb} = (\frac{W_i \times W_d}{W_i}) \times 100 \quad (2)$$

$$\mathrm{M} = \frac{\mathrm{md}}{1} \quad (3)$$

Measurement of the Mechanical Properties of Lilium Stalk Shear: The fabricated fixture (fixed clamp) was fixed rigidly on the base platform of the test machine under the crosshead (movable clamp) with the help of four bolts. A flat knife of 3 mm thickness, 50 mm width, 70 mm length and 0.05 mm edge radius was fitted on the crosshead of UTM perpendicular to the length of stalk specimen (Figure 2). The flat knives were fabricated out of high carbon steel and had 30, 45 and 60 degree bevel angle. The stalk specimen was held on the fixture with the help of two stalk supports of fixed clamp at both ends of the specimen. During the downward movement of the crosshead, the knife cut the specimen by shear and passed through the slots provided in the fixture below the specimen. The force required for shearing the stalk at the crosshead speeds of 30, 40 and 50 mm/min was recorded against time on the UTM chart recorder.

The shear strength and specific cutting energy were determined from the force-displacement curve for different loading rate and knife bevel angles using Eqs. (4) and (5). The shearing energy was calculated by integrating the curves of shear force and displacement [9].

$$\sigma_s = \frac{F}{A} \quad (4)$$

$$E_{ss} = \frac{1}{A}\int F.dx = n \times \frac{f}{A} \quad (5)$$

Compression: A parallel plate apparatus with both plate surfaces larger than the major dimension of the stalk specimen were used, Therefore stalk specimens were placed between flat steel plates in the following manner, a specimen support plate, 100 mm square, upon which the specimen is placed and a loading plate, 20 mm square, for applying the force. The specimen Lilium stalk of 60 mm length was placed on the base platform (Figure 3). This arrangement allowed for a more concentrated applied load on the center of the specimen. The compressive force on the stalk specimen was applied by a force plate (probe) at the deformation rates of 30, 40 and 50 mm/min.

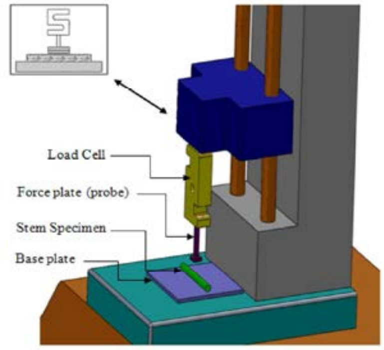


Fig. 3: Schematic of compression test of Lilium stalk

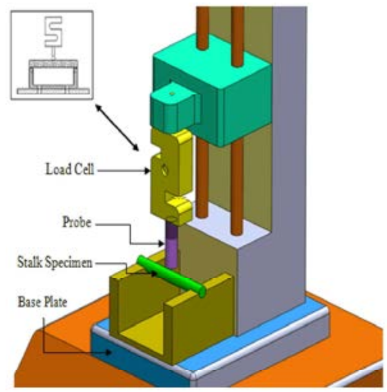


Fig. 4: Schematic of bending test of Lilium stalk

The force - displacement curve was recorded on the chart recorder. The linear portion of the force - displacement curve was used to compute the modulus of elasticity in compression using Eq. (6) [9].

$$\sigma_c = \frac{F_c d}{A \Delta L} \quad (6)$$

The compressive energy is found by determining the area under the linear portion of the compressive force vs. displacement curve. Here, the compressive energy E_c was found by Eq. (7) [9].

$$E_c = \frac{1}{A}\int F_c.dx = n \times \frac{f}{A} \quad (7)$$

Bending: Specimens were placed in the three-point loading apparatus under the Instron probe and the force was applied to the center of the stalk (Figure 4). The movable plate was moved at the speeds of 30, 40 and 50 mm/min and the force - displacement curve recorded.

The bending energy was determined from the force - displacement curve using Eq. (8) [9].

$$E_b = \frac{1}{A}\int F_b.dx = \frac{nf}{A} \quad (8)$$

Table 1: Dependent and independent variables studied in the research

Dependent variables	Independent variables	Values
Shearing strength and Specific cutting energy	Loading rate, mm/min	30,40 and 50
	Knife bevel angle, deg	30, 45 and 60
	Stalk region	Upper and Lower
Compression strength and Specific compressing energy	Loading rate, mm/min	30,40 and 50
	Stalk region	Upper and Lower
Bending strength and Specific bending energy	Loading rate, mm/min	30,40 and 50
	Stalk region	Upper and Lower
Modulus of elasticity	Stalk region	Upper and Lower

Experimental Design and Statistical Analysis: The research was conducted in order to determine shearing strength and the specific shearing energy, compression strength and the specific compression energy, bending strength and the specific bending energy as a function of various stalk regions, different rate of loading and different knife bevel angle.

A complete randomized block design was used in a factorial experiment with five replications using the statistical packages SAS10. Experimental data were analyzed using analysis of variance (ANOVA) and the means were separated at the 1% level applying Duncan's multiple range tests in SAS software. The values of independent variables discussed in the study are detailed in Table 1.

RESULTS AND DISCUSSIONS

The mean values for the physical properties are presented in Table 2. The effects of loading rate and stalk region on shearing strength and the specific shearing energy, compression strength and the specific compression energy, bending strength and the specific bending energy were significant at the 1% probability levels. The effect of knife bevel angle on shearing strength and the specific shearing energy was significant at the 1% probability levels. The interaction of loading rate and knife bevel angle on shear strength and specific shearing energy was significant at 1% level while the effect on compression strength and the specific compression energy, bending strength and the specific bending energy was not significant. Also, the interaction of loading rate and stalk region, knife bevel angle and stalk region on the all measured mechanical properties were not significant at 1% level. The results obtained are discussed in detail below.

Physical Property: For physical properties, Specimens were taken from the lower were greater in diameter and mass per unit length also, those were smaller in moisture content and density Specimens than from the upper of the cutting (Table 2). The results of analysis of variance (ANOVA) showed that Specimens group had significant effect on the all measured physical properties ($P < 0.01$). Observations indicate differences in the woody versus succulent nature of tissue depending upon the physiological age of the stalk section [12].

Mechanical Property

Shear Strength: The shear strength and specific cutting energy decreased with increases in the loading rate for all levels (Table 3). This effect of loading rate was also reported by Hassan-Beygi *et al*. [13] for saffron stalk. The shear strength and specific cutting energy also decreased towards the upper level. The value of the shear strength and specific cutting energy at low stalk regions was approximately 2 times higher than at the upper stalk regions. Values varied from 0.58 to 1.52 MPa and 2.36 to 6.79 mJ/mm^2 for the upper level and 0.73 to 2.42 MPa and 3.78 to 11.89 mJ/ mm^2 for the lower level, respectively, at the different loading rate studied. The values of the shear strength and specific cutting energy were significantly affected by loading rate, knife bevel angle and stalk regions at the 1% probability level. According to Duncan's multiple range test results, with increasing loading rate from 30 to 50 mm/min the shear strength and specific cutting energy decreased significantly ($P < 0.01$) in the ranges of 1.15 to 0.83 MPa and 6.91 to 4.36 mJ/mm^2 respectively (Table 3). Prasad and Gupta [6] also reported that for maize, the maximum shear strength decreased with the rate of loading from 20 to 100 cm/min. Similar results were reported by Heidari and Chegini [14].

With increasing of the knife bevel angle from 30 to 60 degree the shear strength and specific cutting energy of the stalk increased in the ranges of 0.76 to 1.31 MPa and 4.02 to 7.34 mJ/mm^2, respectively (Table 4). Similar increase in shear strength with respect to knife bevel angle was reported by Chancellor [15]. He found the maximum shear strength at a moisture content of 35% w.b. McRandal and McNulty [10] suggested mean specific

Table 2: Physical properties of Lilium stalk

	Stalk region				
	Upper			Lower	
	Mean	Sd[1]		Mean	Sd
Moisture content, %	88.13**	1.23	**	80.88	1.18
Diameter, mm	6.59**	0.83	**	8.11	1.36
Mass per unit length, gr/m	3.46**	0.50	**	4.26	0.67
Density, kg/m^3	0.987**	0.44	**	0.791	0.96

** significant at 1% level

Table 3: Effect of loading rate on the shear strength and specific cutting energy

Loading rate (mm/min)	Shear strength (MPa)	Specific cutting energy (mJ/mm^2)
30	1.15^a	6.91^a
40	0.94^b	5.49^b
50	0.83^c	4.36^c

Common letter means that there was non-significant at 1% probability level by Duncan's test

Table 4: Effect of knife bevel angle on the shear strength and specific cutting energy

Knife bevel angle (deg)	Shear strength (MPa)	Specific cutting energy (mJ/mm^2)
30	0.76^c	4.02^c
45	0.85^b	5.40^b
60	1.31^a	7.34^a

Common letter means that there was non-significant at 1% probability level by Duncan's test

shear strength of 12.5MPa for field grasses and 15.7MPa for greenhouse grown grasses. Prasad and Gupta [6] found a mean value of 8.02 MPa for maize at a moisture content of 73% w.b.

The results of analysis of variance (ANOVA) also showed that the interactive effect of loading rate and knife bevel angle were significant at 1% confidence on the shear strength and specific cutting energy and, in all three loading rate, an increasing the shear strength and specific cutting energy were observed as the knife bevel angle increased (Figures 5 and 6). The reason for decreasing shear strength and shear energy with an increase in cutting rate could be contributed to this phenomenon that at low cutting rate the stalk was compressed against the blade. However, at higher loading rate elastic wall of cells was not enough time to transmit the shear forces to viscous fluid within the cells so the stalk cut with lower force. Similar results were reported by previous researchers like Prasada and Gupta [6] have reported that the shear strength of maize stalk was decreased with increasing rate of loading from 200 to 1000 mm/min. The investigations of Chattopadhyay and Pandey [9] showed that with increasing cutting rate from 10 to 100 mm/min the shear strength of sorghum stalk decreased from 3.74 to 1.94 MPa. Hassan-Beygi *et al*. [13] reported with increasing rate of loading from 200 to 1000 mm/min

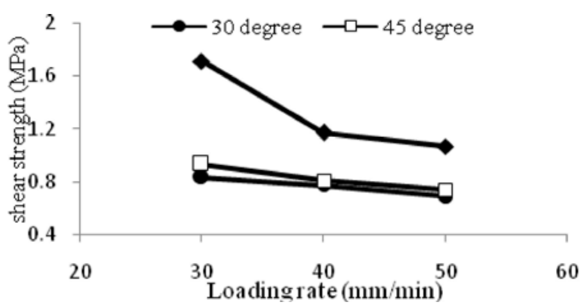


Fig. 5: Effect of loading rate on Lilium stalk shear energy for different knife bevel angle

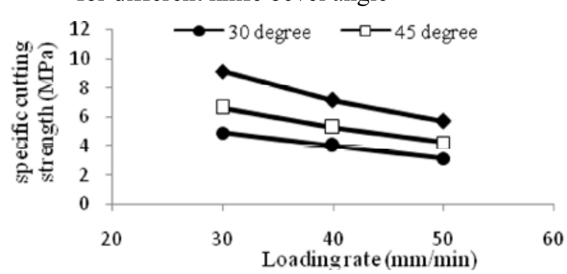


Fig. 6: Effect of loading rate on Lilium stalk specific cutting energy for different knife bevel angle

the shear strength and specific cutting energy of saffron stalk was decreased. Also, with increasing cutting rate the shear strength and specific cutting energy were decreased for all of the bevel angle levels.

[1]Standard deviation

Table 5: Effect of loading rate on the Compression strength and specific Compressing energy

Loading rate (mm/min)	Compression strength (MPa)	Specific Compressing energy (mJ/mm^2)
30	5.49[a]	10.90[a]
40	5.19[b]	9.09[b]
50	4.33[c]	7.07[c]

Common letter means that there was non-significant at 1% probability level by Duncan's test

Table 6: Effect of loading rate on the bending strength and specific bending energy

Loading rate (mm/min)	Bending strength (MPa)	Specific bending energy (mJ/mm^2)
30	1.52[a]	4.84[a]
40	1.17[b]	4.14[b]
50	0.95[c]	3.09[c]

Common letter means that there was non-significant at 1% probability level by Duncan's test

Compression Strength: The highest compression strength and specific compressing energy were 6.86 MPa and 21.34 mJ/mm^2 at the lower level, while the lowest compression strength and specific compressing energy were 2.90 MPa and 10.69 mJ/mm^2 at the upper level. The compression strength and specific compressing energy decreased towards the upper levels of the stalk. The differences in the values of the compression strength and specific compressing energy in the stalk levels reduced as the loading rate increased. The analysis of variance showed that loading rate and stalk regions had significant effect on stalk shearing stress at 1% probability level. In addition, according to Duncan's multiple range tests, with increasing loading rate from 30 to 50 mm/min the compression strength and specific compressing energy decreased significantly ($P < 0.01$) in the ranges of 5.49 to 4.33 MPa and 10.90 to 7.07 mJ/mm^2 respectively (Table 5). Similar results were reported by Simonton [16] for geranium.

The compression strength and specific compressing energy also varied towards the stalk regions. With increasing the stalk diameter the compression strength and specific compressing energy were increased significantly ($P < 0.01$). The average values of the compression and specific compression energy were 3.73 MPa and 8.14 mJ/mm^2 for upper specimen and 6.27 MPa and 9.90 mJ/mm^2 for lower specimen, respectively.

Bending: The bending strength was evaluated as a function of loading rate and stalk regions. As the loading rate of the stalk increased, the bending strength decreased, indicating a reduction in the brittleness of the stalk. A similar result was also reported by Annoussamy *et al*. [2] and Nazari Galedar *et al*. [17]. The bending strength also decreased towards the upper level. The variation range of bending strength and specific bending energy were 0.26 to 1.45 MPa and 0.76 To 3.72 mJ/mm^2 for near the growth tip specimen and 0.97 to 1.66 MPa and 4.43 To 6.28 mJ/mm^2 for near the root internode specimens, respectively. According to the Duncan's multiple range test with increasing loading rate from 30 to 50 mm/min the required bending strength and specific bending energy decreased significantly ($P < 0.01$) in the ranges of 1.52 to 0.95 MPa and 4.84 to 3.09 mJ/mm^2 respectively (Table 6). Results the bending strength and specific bending energy values are statistically different from each other.

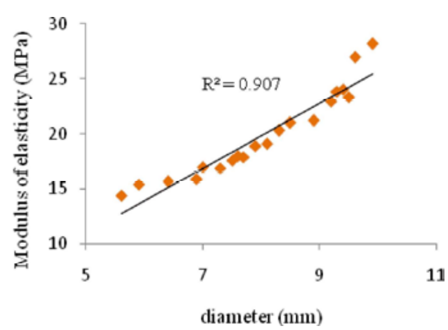


Fig. 7: Effect of stalk diameter on the modulus of elasticity

Modulus of Elasticity: Modulus of elasticity in compression was determined at various stalk regions (stalk levels). O'Dogherty *et al*. [18] showed that modulus of elasticity for wheat straw was between 4.76 GPa and 6.58 GPa. The effect of stalk region on modulus of elasticity was significant at 1% probability level. The average value for modulus of elasticity were found to be 23.48 MPa and 15.96 MPa for stalk regions of upper and lower, respectively. However, with increasing the stalk diameter (change in stalk levels) the modulus of elasticity was increased (Figure 7).

CONCLUSIONS

For physical properties, Specimens were taken from the lower were greater in diameter and mass per unit length also, those were smaller in moisture content and density Specimens than from the upper of the cutting. The average values of the shearing and required specific shearing energy were 0.81 MPa and 4.37 mJ/mm^2 for upper specimen and 1.13 MPa and 6.92 mJ/mm^2 for lower specimen, respectively. With increasing of the knife bevel angle from 30 to 60 degree the shear strength and specific cutting energy of the stalk increased in the ranges of 0.76 to 1.31 MPa and 4.02 to 7.34 mJ/mm^2, respectively. The highest compression strength and specific compressing energy were 6.86 MPa and 21.34 mJ/mm^2 at the lower level, while the lowest compression strength and specific compressing energy were 2.90 MPa and 10.69 mJ/mm^2 at the upper level. The variation range of bending strength and specific bending energy were 0.26 to 1.45 MPa and 0.76 To 3.72 mJ/mm^2 for near the growth tip specimen and 0.97 to 1.66 MPa and 4.43 To 6.28 mJ/mm^2 for near the root internode specimens, respectively. The average value for modulus of elasticity were found to be 23.48 MPa and 15.96 MPa for stalk regions of upper and lower, respectively.

ACKNOWLEDGEMENTS

The authors would like to thank the University of Tehran for full support of the project.

Abbreviations:

A	Cross-sectional area of stalk (m^2)
d	Diameter of the stalk at the point of compression (mm)
E_{ss}	Specific shearing energy (mJ/mm^2)
f	Scale factor of unit area
F_b	Bending force at which the stalk fails (N);
F_c	Compressive force(N)
F_s	Shearing force (N)
l	Length of specimen(m)
$M.C_{wb}$	Moisture content (%)
M	Mass per unit length(g/m)
m_d	Dried mass of specimen (g)
n	Number of units under force-displacement curve on the universal testing machine (UTM) chart
S_k	Mass density of kerosene (kg/m^3)
W_a	Weight of stalk in air (kg)
W_d	Dried weight of specimen (kg)
W_i	Initial weight of specimen (kg)
W_k	Weight of toluene displaced by specimen (kg)
x	Knife displacement (mm)
ΔL	Transverse deformation due to compressive force (mm)
ρ	Density of stalk (kg/m^3)
σ_c	Modulus of elasticity in compression (MPa)
σ_s	Shear strength (MPa)

REFERENCES

1. Ige, M.T. and M.F. Finner, 1975. Effects and interaction between factors affecting the shearing characteristic of forage harvesters. Transactions of the ASABE., 18(6): 1011-1016.
2. Annoussamy, M., G. Richard, S. Recous and J. Guerif, 2000 Change in mechanical properties of wheat straw due to decomposition and moisture. Applied Engineering in Agriculture, 16(6): 657-664.
3. Skubisz, G., T.I. Kravtsova and L.P. Velikanov, 2007. Analysis of the strength properties of pea stalks. Int. Agrophysics, 21: 189-197.
4. Yiljep, Y.D. and U.S. Mohammed, 2005. Effect of Knife Velocity on Cutting Energy and Efficiency during Impact Cutting of Sorghum Stalk. Agricultural Engineering International, the CIGR Journal, Manuscript PM, 05-004, Vol. VII. ecommons. cornell.edu › ... › Journals › CIGR E-Journal Volume 7.
5. Shaw, M.D. and L.G. Tabil, 2007. Compression, Relaxation and Adhesion Properties of Selected Biomass Grinds. Agricultural Engineering International, the CIGR Ejournal, Manuscript FP 07-006, Vol. IX.
6. Prasada, J. and C.B. Gupta, 1975. Mechanical properties of maize stalks as related to harvesting. J. Agric. Eng. Res., 20(1): 79-87.
7. Khazaei, J., H. Rabani, A. Ebadi and F. Golbabaei, 2002. Determining the shear strength and picking force of pyrethrum flower. Iranian J. Agric. Sci., 33(3): 433-444.
8. Ince, A., S. Ugurluay, E. Guzel and M.T. Ozcan, 2005. Bending and shearing characteristics of sunflower stalk residue. Biosystalks Eng., 92(2): 175-181.
9. Chattopadhyay, P.S. and K.P. Pandey, 1998. Mechanical properties of sorghum stalk in relation to quasi-static deformation. J. Agric. Eng. Res., 73: 199-206.
10. McNulty, P.B. and N.N. Moshenin, 1979. Compaction of bulk corn carnal to failure. Transaction of the ASAE, 22(2): 264-269.
11. Mohsenin, N.N., 1986. Physical Properties of Plant and Animal Material. Gordon and Branch. New York, USA.
12. Grossman, H.H., 1982 Anatomy and Morphology. In Geraniums Mastalerz and Holcomb, pp: 331-340.

13. Hassan-Beygi, S.R., H. Vale Ghozhdi and J. Khazaei, 2010. Picking Force of Saffron Flower and Shear Strength of Saffron Stalk. Electronic Journal of Polish Agricultural Universities. Volume 13. www.ejpau.media.pl/volume13/issue1/art-09.html.
14. Heidari, A. and G.H.R. Chegini, 2008. Determining the shear strength and picking force of rose flower. Electronic Journal of Polish Agricultural Universities, pp: 14. http:// www.ejpau.media.pl/ volume14/ issue2/ art-13.html.
15. Chancellor, W.J., 1958. Energy requirements for cutting forage. Agricultural Engineering, 39(10): 633- 640.
16. Simonton, W., 1992. Physical properties of zonal geranium cuttings. Trans of the ASAE., 35(6): 1899-1904.
17. Nazari, Galedar, M., A. Jafari, S.S. Mohtasebi, A. Tabatabaeefar, A. Sharifi, M.J. O'Dogherty, S. Rafiee and G. Richard, 2008. Effects of moisture content and level in the crop on the engineering properties of alfalfa stalks. Biosyst. Eng., 101: 199-208.
18. O'Dogherty, M.J., J.A. Hubert, J. Dyson and C.J. Marshall, 1995. A study of the physical and mechanical properties of wheat straw. J. Agric. Eng. Res., 62: 133-142.