World Applied Sciences Journal 7 (4): 515-521, 2009
ISSN 1818-4952

Shear Strength and Area Density of the Leaves of Five Tree Species in Esfahan City

[1]A.R. Shirneshan, [2]M.A. Ghazavi, [3]M. Poursina and [2]B. Hoseinzadeh

[1]Mechanical Engineering Group, Faculty of Engineering,
Islamic Azad University, Najafabad Branch, 517, Iran
[2]Farm Machinery Group, Faculty of Agriculture, University of Shahrekord, Shahrekord, 115, Iran
[3]Mechanical Engineering Group, Faculty of Engineering, University of Shahrekord, Shahrekord, 115, Iran

Abstract: The shear strength of the leaves of *Platanus orientalis*, *Ulmus carpinifolia*, *Fraxinus excelsior*, *Salix alba* and *Morus alba* in Esfahan was measured and compared. Shear strength is calculated as the maximum force required for shearing a leaf, divided by the cross sectional area of the cut at the widest part of the leaf material and measured by using a shearing device consisting of 2 blades. In shearing test, the effect of rake angle of upper blade for five angles (15°, 30°, 45°, 60° and 75°) and the effect of three moisture content level (15, 25 and 35%, w.b) were investigated. The leaf area density of each species as morphological property was also measured. The maximum mean value of shear strength was 4.5 Mpa for *Morus Alba,* while *Salix alba* had the minimum mean value of shear strength of 1.6 Mpa among the five species. The results of data analysis showed that the shear strength decreased as the blade angle increased, but except for *Platanus orientalis* as the moisture content decreased the shear strength decreased. *Salix alba* had the maximum mean value of leaf area density, while the minimum mean value of leaf area density belonged to *Ulmus carpinifolia* species.

Key words: Leaf · Shearing force · Area density · Moisture content

INTRODUCTION

Some mechanical and morphological properties of leaves are applicable in engineering. *Platanus orientalis*, *Ulmus carpinifolia*, *Fraxinus excelsior*, *Salix alba* and *Morus alba* are the common tree species in Esfahan [1]. A leaf vacuum shredder machine is used to collect and recover leaves from parks and gardens. To design and select suitable shredder blades of the machine, shear strength as a mechanical property of leaves can be applicable. Also the leaf area density as a morphological property of leaves can be used to design the vacuum system of the machine. Because leaf vacuum shredder machines are not manufactured in Iran, design and fabrication of this machine are therefore required. The strength of leaves has been measured in two ways. The energy or force required to grind or shear a mass of plant material has been measured to represent the strength of the material [2]. Alternatively, the strength of individual leaves or stems can be measured by fracturing them in shear [3-5]. Many workers have used a Warner-Bratzler shearing apparatus [3-7] that was originally designed for measuring the shear strength of meat as a measure of meat tenderness. Lucas and Pereira [8] and Choong *et al.* [9] used instrument scissors to shear individual leaves. Their measure of shear strength was calculated as the energy required to shear the specimen, divided by the product of length of the cut and specimen thickness and was termed fracture toughness. Henry *et al.* [2] measured the shear and tensile fracture properties of the leaves of pasture grasses by using a shearing device consisting of two blades at the fixed angles. In this study, the mechanics of the shearing process were examined with both paper and leaves of *Festuca arundinacea.* Intrinsic shear strength of leaves of pasture grasses and legumes was measured by Henry *et al*. [10]. This study showed that a significant variation in intrinsic shear strength exists between both species of grasses and species of grasses and legumes. Aranwela *et al.* [11] studied the methods of assessing leaf-fracture properties and for shearing tests the effects of blade proximity and sharpness were investigated. Edwards *et al.* [12] measured some mechanical properties of leaves from heath and forest of Australia. Two of the most appropriate and practically applicable mechanical properties of sclerophyllous leaves are strength and toughness which were applied by using punching, tearing

Correspoding Author: A.R. Shirneshan, Mechanical Engineering Group, Faculty of Engineering,
Islamic Azad University, Najafabad Branch, 517, Iran Tel: +98 0331229111

and shearing tests to 19 species of tree and shrub. In this study, the results of these tests were compared with leaf specific mass (LSM). Results showed that there were positive correlations between leaf mechanical properties and LSM. Leaves of 12 accessions of *Brachiaria* sp. were subjected to tests of shearing strength using a Warner Bratzler meat shear by Hughes *et al.* [7]. Morphological measurements such as leaf area density and leaf weight were also taken in an attempt to standardize shearing strength measurements per unit of leaf tissue. Henry *et al.* [13] measured the intrinsic shear strength of leaves of 6 temperate pasture grasses by using a guillotine. In this study, shear strength increased when leaves were allowed to dehydrate. Leaf biomechanical properties were measured in studies of herbivory by Sanson *et al.* [14]. In this investigation, shearing test involved shearing the specimen between two blades mounted on a force tester that could record force and displacement of the blades simultaneously and calculate work to shear. Read and Sanson [15] measured a wide range of mechanical properties across a diverse range of species and leaf forms, including highly scleromorphic leaves and compared these with sclerophylly indices to determine the mechanical properties of sclerophylls. Relationships between leaf strength and cattle (Bos Taurus) preference for eight cultivars of tall fescue (*Festuca arundinacea* Schreb.) were studied by Macadam and Mayland [16]. In this study, shear strength of tall fescue was measured with a QTRS-25 guillotine equipped with a square blade and shear strength calculated as the breaking force per leaf cross sectional. The present study was conducted in order to determine the shear strength and area density of leaves of *Platanus orientalis*, *Ulmus carpinifolia*, *Fraxinus excelsior*, *Salix alba* and *Morus alba.* Also shear strength as a function of leaf thickness, moisture content of leaf and leaf area density was determined. In shearing test, the effect of rake angle of upper blade for five angles was investigated.

MATERIALS AND METHODS

For each experiment, fully expanded Leaves of five species were collected in August-September 2008 from Boustan Sadi Garden, Esfahan, Iran (32.7° N, 51. 5° E). The climate of Esfahan is relatively dry-mild, with a mean daily maximum and minimum temperature of-7.4°C and 39.8°C, respectively. Its annual rainfall is *c.*171.66 mm. Each leaf was picked from a different tree and always cutting a portion of leaf sheath so as to avoid damage to the leaf lamina. For each experiment, at least twice as many leaves as required were collected and a subset of these were selected randomly for testing. It is important to note that as moisture content proved to vary with weather, so as soon as the material was brought in from the field, the first morphological measurement taken was the weight. Once in the laboratory, the ends of the collected leaves were cut, sprayed with water and sealed in a plastic bag with moist tissue in an isolated container. To determine the average moisture content of the leaves on the date of the test, the specimens were weighed and dried at 103°C for 24 h in the oven and then reweighed [17, 18]. For determining the effect of rake angle of upper blade on shearing force, three blades with different rake angle was used. From each collection, leaves were randomly taken for measurement of shear strength and area density. Complete randomized block design was used in a factorial experiment with five replications using the SAS10 and MINITAB15 statistical packages. Means were compared using Duncan's multiple range tests ($p<0.05$). The values of independent variables discussed for shearing test in the study are detailed in Table 1.

Measurement of Shear Strength: Shear strength was calculated as the maximum force exerted during the cut dividing by cross-sectional area of the widest part of the leaf. The force measured is the resistance to the blades that are being driven through the test specimen.

Table 1: Dependent and independent variables studied for shearing test in the research

Dependent variable	Independent variables	Values
Shear strength	Moisture content, % w.b.	15, 25 and 35
	species of leaf	Platanus orientalis, Ulmus carpinifolia, Fraxinus excelsior, Salix alba and Morus alba
Shearing force	rake angle of upper cutting blade, deg	15, 30 and 45

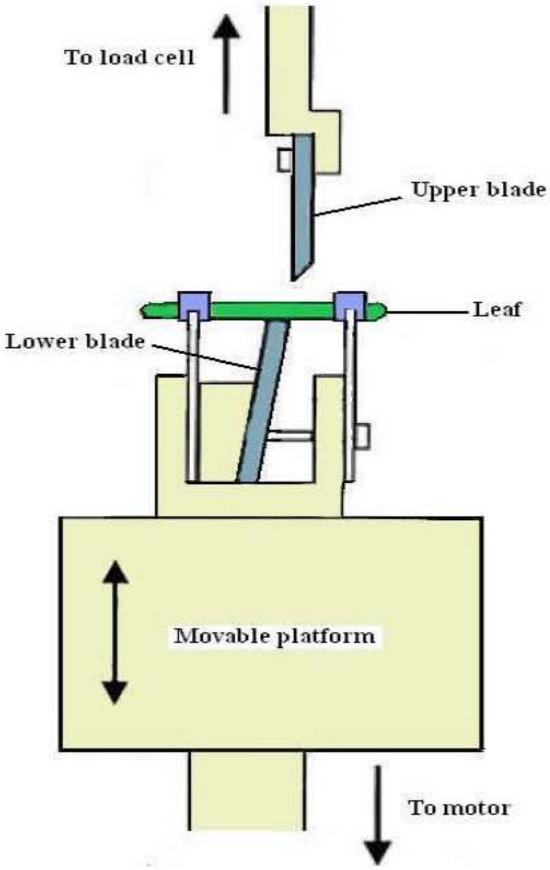

Fig. 1: The set up of the blade arrangement and support structures necessary for shearing leaves

The test involved shearing the specimen between two blades mounted on a force tester that can record force. We used a sliding carriage fixed to the movable platform of the test machine (Fig.1). Two high-carbon steel blades, one at a lower level with horizontal cutting angle mounted on the carriage and another was upper blade with a constant approach angle of 45° to the horizontal was attached above it. For this experiment, the clearance between the upper blade and the lower blade was 0.1 mm [11]. The lower blade was inclined at 4° towards the upper one as the optimized relief angle [11, 19]. The upper blade was raked at 45° as the standard in this work, but the lower blade was not raked [2]. A digital force meter (AandD, load cell 1 KN) was used to perform the shearing test. An electrical motor (Simens, 5.5 kW) was connected to a movable platform and the digital force meter was mounted over it. A shaft transmitted force to the digital force meter. The digital force meter with an inverter (Hyundai 5.5 kW, 400 Volts) was connected to a computer (P4, 2.4 GHz), equipped with a data acquisition system at 10 Hz. The widest part of each leaf was placed under the upper blade and the lower blade moved at a displacement speed set at 0.84 mm s^{-1} [11], shearing the specimen into two parts. The cross-sectional area of the leaf was calculated as the width of the leaf at the point of the shear multiplies by the thickness of the leaf. The width and thickness of each specimen was measured in laboratory, using a ruler graduated in millimeters and 0-25 mm micrometer (Mitutoyo, Japan) respectively. An attempt was made to keep the pressure of the micrometer similar during all thickness measurements by tightening it to three steps of its ratchet tightening device.

Measurement of Area Density: Area density is represented as leaf mass per unit area, was measured on the leaves (petiole removed) chosen randomly per five replicates of each species and the mean was calculated. Leaf area was measured by image analysis (Bioscan Image Analyzers) and leaves were weighed separately. Leaf ligules and sheaths were removed. Therefore weights only included leaf lamina tissues.

RESULTS AND DISCUSSION

Shear Strength: There were significant differences among species for each of shearing tests (Table 2, Fig. 2). These differences are due to different chemical and structural components of leaf species [7]. Relatively large variation in the shear strength was also reported for grass

Table 2: The shear properties of each species

Species	Width (mm)	Thickness(mm)	Cross-sectional area(mm^2)	Shearing force(N)	Shear strength (MPa)
Morus alba	70±3.2	0.76±0.02	53.5±.3.9	238.8±12.0	4.50±0.16
Platanus orientalis	88.8±5.7	0.86±0.04	76.1±5.8	255.8±13.8	3.39±0.15
Ulmus carpinifolia	44.4±2.7	0.74±0.02	32.5±1.6	119.8±8.3	3.68±0.11
Salix alba	16.2±0.4	0.50±0.20	8.2±0.2	13.2±0.7	1.60±0.06
Fraxinus excelsior	28.2±0.6	0.54±0.01	15.2±0.4	42.2±1.3	2.67±0.05

Values given are means±SE (Rake angle of upper blade and moisture content of the leaves are 45° and 35% w.b. respectively)

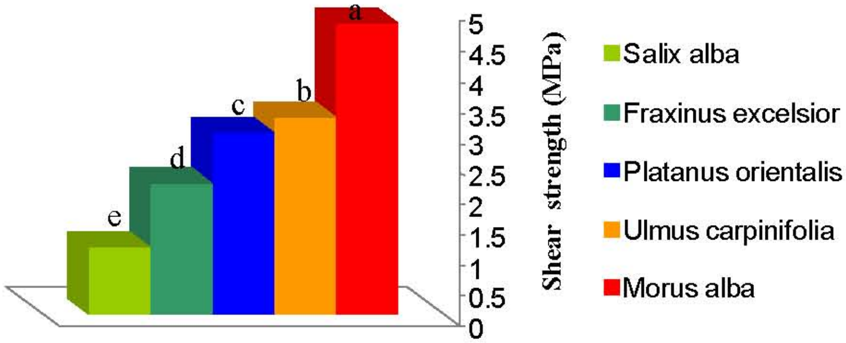

Fig. 2: Shear strength of each species (Different letters in each column, shows significant difference, Duncan 5%)

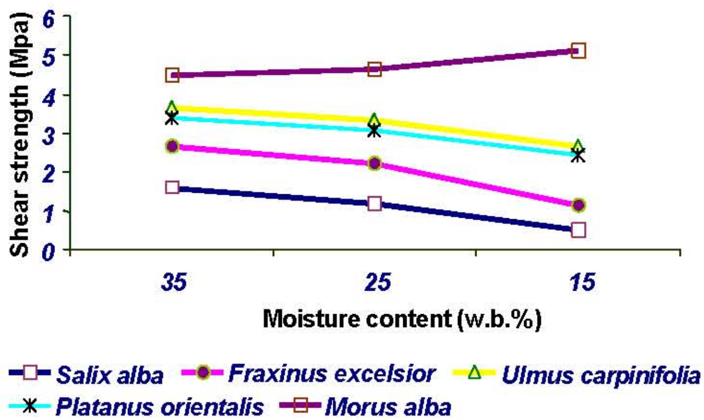

Fig. 3: Effect of moisture content on shear strength

leaves and legumes leaves [10]. The highest values for shear strength (4.5±0.16 MPa) were recorded in *Morus alba* followed by *Ulmus carpinifolia* and *Platanus orientalis.* Also *Salix alba* had the lowest value of shear strength with 1.6±0.06 MPa. Mean values of the shearing force for the 5 species ranged widely, with a 20-fold difference between the highest (255.8±13.8 N; *Platanus orientalis*) and lowest (13.2±0.7 N; *Salix alba*). The cross-sectional area of *Platanus orientalis* was higher than other five species. Leaves of *Platanus orientalis* were the widest leaves and the minimum width was for leaf of *Salix alba* leaf. The results detailed in table2 show that *Salix alba* and *Platanus orientalis* had the lowest and the highest thickness, respectively. Eq. (1), (2), (3), (4) and (5) show the relation between the shearing force in N and thickness for leaves of *Morus alba, Platanus orientalis, Ulmus carpinifolia, Salix alba* and *Fraxinus excelsior* species, respectively.

$$F_{max} = -164.4 + 530t \qquad (R^2 = 95\%) \qquad (1)$$

$$F_{max} = 244.6 + 38.36\cos(71.57t - 3.57) \qquad (R^2 = 96\%) \qquad (2)$$

$$F_{max} = 157764.59 - 632224.85t + 844013.9t^2 - 375083.85t^2 \qquad (R^2 = 96\%) \qquad (3)$$

$$F_{max} = 12.85 + 2.22\cos(986t + 9.2) \qquad (R^2 = 98\%) \qquad (4)$$

$$F_{max} = -59200 + 331374t - 617478.2t^2 + 383319.8t^2 \qquad (R^2 = 98\%) \qquad (5)$$

Where

t = Thickness (mm)

Area Density: The results of morphological measurement showed that area density of five species varied from a mean of 0.011 gr/ cm^2 for *Ulmus carpinifolia* leaves to 0.018 gr/ cm^2 for *Salix alba* leaves (Table3). The highest value of the leaf area (120.3±8.8 cm^2) was recorded for *Morus alba,* while the lowest was recorded for Salix *alba* (14.46±0.62 cm^2). The leaves of *Morus alba* had the highest mean weight and the lowest mean weight was for *Salix alba* leaf. Eq. (6), (7), (8), (9) and (10) show the relation between the shearing force in N and area density for leaves of *Morus alba, Platanus orientalis, Ulmus carpinifolia, Salix alba and Fraxinus excelsior* species, respectively.

Table 3: The area density properties of each species

species	Weight(gr)	Area(cm^2)	Area density (gr/ cm^2)
Morus alba	1.92±0.14	120.3±8.8	0.016±0.001
Platanus orientalis	1.55±0.16	113.8±8.7	0.014±0.001
Ulmus carpinifolia	0.42±0.03	39±2.0	0.011±0.000
Salix alba	0.26±0.01	14.46±0.62	0.018±0.002
Fraxinus excelsior	0.41±0.03	26.16±1.54	0.016±0.001

Values given are means±SE

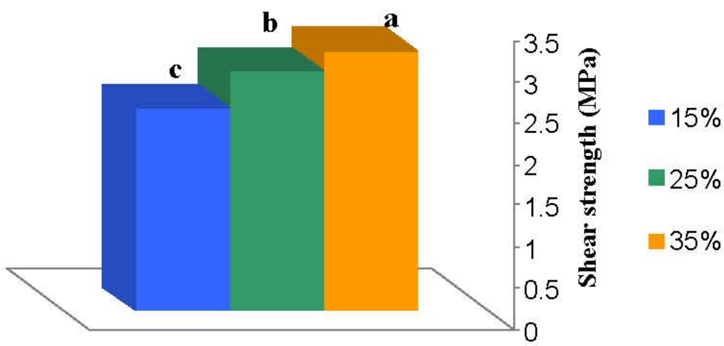

Fig. 4: The average values of the shear strength for moisture contents of 15%, 25% and 35% w.b. (Different letters in each column, shows significant difference, Duncan 5%)

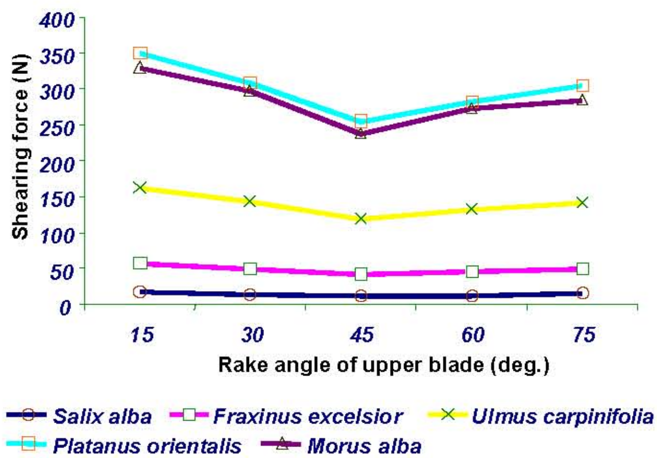

Fig. 5: Effect of rake angle on shearing force (moisture content of leaves is 35% w.b)

$$F_{max} = 808.6 + 135.6 \ln a \qquad (R^2 = 96\%) \tag{6}$$

$$F_{max} = -71727 + 1.60056\times10^7 a - 1.1833\times10^9 a^2 + 2.908\times10^{10} a^3 \qquad (R^2 = 90\%) \tag{7}$$

$$F_{max} = -20 + 14833.3a \qquad (R^2 = 93\%) \tag{8}$$

$$F_{max} = -27.5 + 4886.6a - 142510.1a^2 \qquad (R^2 = 98\%) \tag{9}$$

$$F_{max} = 92.33 - 9750a + 416666.69a^2 \qquad (R^2 = 96\%) \tag{10}$$

Where

a = Area density (gr/ cm^2)

Effect of Moisture Content on Shear Strength: Moisture content had a significant effect on shear strength at 1% probability level. The shear strength decreased with decreasing moisture content for leaves of *Ulmus carpinifolia, Fraxinus excelsior, Salix alba* and *Morus alba.* But, because of more and bigger nervures than other species, shear strength of leaves of *Platanus orientalis* increased when moisture content decreased (Fig.3). This result was also reported for leaves of 6 temperate pasture grasses by other workers [13]. Results showed that the average value of shearing strength at low moisture content was approximately 28% lower than at high moisture contents. The average values of the shear strength were found to be 2.47, 2.91and 3.16 MPa for moisture contents of 15%, 25% and 35% w.b., respectively (Fig.4). Eq. (11), (12), (13), (14) and (15) show the relation between the shear strength in MPa and moisture content for leaves of *Morus alba, Platanus orientalis, Ulmus carpinifolia, Salix alba and Fraxinus excelsior* species, respectively.

$$\tau_{max} = 0.94 - 0.12m - 0.001m^2 \qquad (R^2 = 98\%) \qquad (11)$$

$$\tau_{max} = 6.55 - 0.12m + 0.001m^2 \qquad (R^2 = 98\%) \qquad (12)$$

$$\tau_{max} = 1.01 + 0.139m - 0.0019m^2 \qquad (R^2 = 97\%) \qquad (13)$$

$$\tau_{max} = -0.97 + 0.11m - 0.001m^2 \qquad (R^2 = 98\%) \qquad (14)$$

$$\tau_{max} = -1.79 + 0.249m - 0.0034m^2 \qquad (R^2 = 97\%) \qquad (15)$$

Where
m = Moisture content (w.b. %)

Effect of Rake Angle on Shearing Force: The analysis of variation in rake angle indicated that the shearing force varied over rake angles with the minimum value of shearing force occurring for all species at rake angle of 45° (Fig.5). Shearing force decreased from rake angles of 15° to 45° and increased form rake angles of 45° to 75°. The same results were also reported for shearing of Burnie cartridge paper [2]. Fig 5 shows that effect of rake angle on shearing force of *Morus alba* and *Platanus orientalis* leaves was more than other species. For these species, the value of shearing force at rake angles of 75° and 15 ° was approximately 19% and 38% higher than that at rake angle of 45°, respectively.

CONCLUSIONS

- Because of the highest value of the Shear strength for *Morus alba* leaves, the shear strength of this species must be considered for designing shredder blades of the leaf vacuum shredder machine.
- Because of the highest value of the area density for *Salix alba* leaves, the area density of this species must be considered for designing vacuum section of the leaf vacuum shredder machine.
- According to the results, shredder blades of the leaf vacuum shredder machine must be raked at 45°, because of the lowest value of shear strength at this angle.
- Results showed that the shearing force was highly correlated with moisture content and thickness of the leaves.
- Results showed that shear strength of leaves was highly correlated with leaf area density.

ACKNOWLEDGMENTS

The authors would like to thank the University of Shahrekord vice chancellor in research affairs for his financial support.

REFERENCES

1. Matinkhah, H., 2006. Phenological study of thirty five tree and shrub species in Esfahan city. Journal of Sciences and Technology of Agriculture and Natural Resources, Isfahan University of Technol., 4: 503-516.
2. Henry, D.A., R.H. Macmillan and R.J. Simpson, 1996. Measurement of the shear and tensile fracture properties of leaves of pasture grasses. Aust. J. Agric. Res., 47: 587-603.
3. Mackinnon, B.W., H.S. Easton, T.N. Barry and J.R. Sedcole, 1988. The effects of reduced leaf shear strength on the nutritive value of perennial ryegrass. J. Agricultural Sci. Cambridge, 111: 469-474.
4. Easton, H.S., 1989. Variability of leaf shear strength in perennial ryegrass. New Zealand Journal of Agricultural Res., 32: 1-6.
5. Inoue, T., I.M. Brookes, T.N. Barry and A. John, 1989. Effects of selection for shear strength on the voluntary intake and digestion of perennial ryegrass fed to sheep. Proceedings of the New Zealand Society of Animal Production, 49: 221-224.
6. John, A., T. Inoue, I.M. Brookes, W.F. Hunt and H.S. Easton, 1989. Effects of selection for shear strength on structure and rumen digestion of perennial ryegrass. Proceedings of the New Zealand Society of Animal Production, 49: 225-228.
7. Hughes, N.R.G., C. HES, C. Borges, V. Sabatel, J. Book, N.S. Jessop and M. Herreo, 2000. Shearing strength as an additional selection criterion for quality in Brachiaria pasture ecotypes. Journal of Agricultural Science, Cambridge, 135: 123-130.
8. Lucas, P.W. and B. Pereira, 1990. Estimation of the fracture toughness of leaves. Functional Ecol., 4: 819-22.

9. Choong, M.F., P.W. Lucas, J.S.Y. Ong, B. Pereira, H.T.W. Tan and I.M. Turner, 1992. Leaf fracture toughness and sclerophylly: their correlations and ecological implications. New Phytologist, 121: 597-610.
10. Henry, D.A., R.J. Simpson and R.H. Macmillan, 1997. Intrinsic shear strength of leaves of pasture grasses and legumes. Aust. J. Agric. Res., 48: 667-74.
11. Aranwela, N., G. Sanson and J. Read, 1999. Methods of assessing leaf-fracture properties. New Phytol, 144: 369-393.
12. Edwards, C., J. Read and G. Sanson, 2000. Characterising sclerophylly: some mechanical properties of leaves from heath and forest. Oecologia, 123: 158-167.
13. Henry, D.A., R.J. Simpson and R.H. Macmillan. 2000. Seasonal changes and the effect of temperature and leaf moisture content on intrinsic shear strength of leaves of pasture grasses. Aust. J. Agric. Res., 41: 823-831.
14. Sanson, G., J. Read, N. Aranwela, F. Clissold and P. Peeters, 2001. Measurement of leaf biomechanical properties in studies of herbivory: Opportunities, problems and procedures. Austral Ecology, 26: 535-546.
15. Read, J. and G.D. Sanson, 2003. Characterizing sclerophylly: the mechanical properties of a diverse range of leaf types. New Phytologist, 160: 81-99.
16. MacAdam, J.W. and H.F. Mayland, 2003. The Relationship of Leaf Strength to Cattle Preference in Tall Fescue Cultivars. Agron. J., 95: 414-419.
17. Anonymous, 2006. ASABE Standards, 52nd Edn. S358.2, 1:1 Measurement-Forages. St. Joseph, MI.
18. Esehaghbeygi, A., B. Hoseinzadeh, M. Khazaei and A. Masoumi, 2009. Bending and shearing properties of wheat stem of alvand variety. World Applied Sci. J., 6(8): 1028-1032.
19. Atkins, A. and J. Vincent, 1984. An instrumented microtome for improved histological sections and the measurement of fracture toughness. Journal of Materials Sci. Letters, 3: 310-312.