RESEARCH PAPER | International Journal of Agricultural Engineering | Volume 6 | Issue 2 | October, 2013 | 423–426

Mechanical properties of sisal (*A. sisalana*) relevant to harvesting and fibre extraction

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Received : 05.07.2013; **Revised :** 05.10.2013; **Accepted :** 04.11.2013

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ABSTRACT : The mechanical properties of sisal leaf (*A.sisalana)* relevant to leaf harvesting and fibre extraction were determined. Measurements of leaf bending resistance, friction coefficients and mass distribution were made to get information for designing of leaf handling equipment. The leaf cross- sectional area at 7 cm from butt-end was 11.65 cm^2. Fibre content of leave varied from 3.0 – 4.0 % of fresh green leaf weight. The mean fibre bundle strength was 32.31 g/tex and fibre fineness was 4.92. The coefficient of friction of sisal leaf was lowest on mild steel surface for tilting panel test (0.054) as well as for horizontal test surface (0.464).

KEY WORDS : Extraction, Fibre, Harvest, Physical properties, Sisal

HOW TO CITE THIS PAPER : Naik, R.K., Dash, R.C. and Goel, A.K. (2013). Mechanical properties of sisal (*A. sisalana*) relevant to harvesting and fibre extraction. *Internat. J. Agric. Engg.*, **6**(2) : 423-426.

In the last few decades there has been a trend for synthetic fibres to replace natural fibres. But, more recently there has been a resurgence of demand for natural fibres because of their biodegradability, unique appearance and texture. In India, sisal was introduced by Portugese around 1825 and is mainly grown or found in the arid and semi-arid regions of Odisha, Andhra Pradesh, Tamil Nadu, Maharashtra, Madhya Pradesh, Karnataka, Jharkhand and West Bengal (Singh *et al.*, 1999). Despite the availability of sisal plants throughout the country, their commercial fibre production could not be augmented. Domestic demand of sisal fibre in India is fulfilled through import of fibre from foreign countries like Brazil, Kenya, and Tanzania. The major constraints are the labour-intensiveness of traditional sisal harvest methods, the high cost involvement in fibre extraction and non-availability of suitable fibre extraction machines (Borkar, 2000; Chatterji, 1962 and Sircar, 1948). The non-availability of information about sisal leaf behaviour, attempts have been made in the present study to investigate the mechanical properties of sisal leaves relevant to leaf handling and fibre extraction.

The sisal crop :

The major sisal species available in India are *Agave sisalana, Agave cantala, Agave vera-cruz, Agave amaniensis, Agave angustifolia and Agave fourcrryodes*. However, *A. sisalana* contributes major fibre production and having highest plantation area with a high yield of fibre.

The average *Agave sisalana* plant (Fig.A) has a height of 1.2 m to 1.6 m and a hard bole diameter of 0.50 m to 0.85 m. Leaves are typically arranged around the meristem or bole with length varies from 0.55 m to 1.6 m and width of 4.5 cm to 12 cm and mass of approximately 0.27 kg to 0.75 kg.

Fig. A : Photograph of Agave sisalana plants in a typical plantation

Over its life of 11 to 12 years a typical sisal plant produces about 200 to 250 leaves, each with dry fibre content of 3 to 4% of the green weight of the leaf (Lock, 1969).

Traditional sisal production procedure :

Typically 4,000 to 6,000 sisal plants are established per hectare (1600 to 2400 plants per acre) and plant density depends on nature and fertility status of soil. Both single-row and double-row plantings are followed. Double-row planting arrangement typically has 3.0 m between pair of rows, each row in a pair separated by 1.0 m and plants spaced about 0.8- 1.0 m in the row. Single-row planting arrangement has fewer plants per unit area despite a distance between rows of approximately 2.5 m. Generally yield of single-row planting is lower than the double-row planting system.

Harvesting of sisal leaves is usually conducted once in a year during the months of November to March. A leaf is considered to be matured, when it attains a length about 0.6-1.0 m and forms an angle of 45^0 with the main spike or the colour of the terminal spine changes to ashy brown. Harvesting of leaf starts from the lower most whorls to upper ones leaving about 20-25 leaves after first cut and about 10-15 leaves at subsequent cuts. This facilitates better growth of sisal plant and good fibre yield. A worker uses a sickle or special curved knife to cut leaf at the base and then to trim the spine from the outer end of the leaf. The leaf is then thrown into the 3.0 m space between the row pairs. A typical cutting time per plant (15 leaves) is about 42 s. Once, plants on both sides of row space have been cut, the worker collects the leaves into bundles of 50 with orienting butt-ends in the same direction and ties the bundle with sisal leaf fibres. The bundling operation consumes about 46 s per bundle. The bundles are then carried manually (2 to 4 bundles at a time) to the end of the row and stacked. Stacked leaf bundles are later loaded manually on to a tractor trolley and transported to the decorticator site.

METHODOLOGY

Cutting of sisal leaves :

Leaves of *Agave sisalana* were harvested from sisal plantation area of Central Research Institute for Jute and Allied Fibres (ICAR), Barrackpore, Kolkata and subjected to measurements of general morphological and mechanical properties and of cutting resistance characteristics.

Force-deflection characteristics of leaves attached to plant :

Eight leaves (inclination below vertical greater than 45^0) on each of two plants (four from each plant) were subjected to down-bending forces by spring balance perpendicular to the leaf axis at two points on the leaf *i.e.* 30.5 cm and 45.7 cm from the point of leaf bole attachment. The externally applied force and displacement per degree of leaf downward rotation were measured.

Leaf shape, size, mass distribution and stiffness :

All the selected leaves were cut from the plant with spine and mean leaf length (with spine and without spine), width (base, middle and tip), thickness (base, middle and tip), leaf weight, centre of mass of leaf and cross-sectional area (7 cm from butt-end) of leaves were recorded using measuring scale, vernier calliper and electronics balance.

Fibre extraction :

After measuring the morphological parameters of the leaves, fibre was extracted from all leaves by sisal fibre extractor and fibres were washed with water and sun dried. The fresh fibre weight, dry fibre weight and fibre length were recorded. Fibre recovery from leaf and leaf moisture content were calculated (Fig. B).

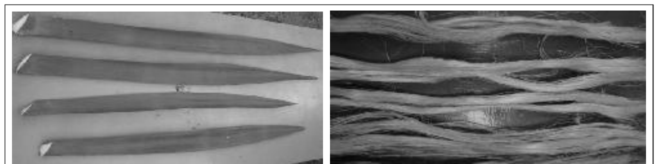

Fig. B : Semi cylindrical greenhouse

The fibre bundle strength and fibre fineness were determined. The fibre recovery and moisture content of leaf was calculated by the following formula :

$$\text{Fibre recovery, } F_r (\%) = F_w / F_p \times 100 \qquad (1)$$

where,

F_w = Weight of decorticated fibre

F_p = Weight of the green leaf

$$\text{Moisture content (\%) wet basis} = (W_i - W_f)/ W_i \times 100 \qquad (2)$$

where,

W_i = Fresh weight of sample, g

W_f = Dry weight of sample, g

Frictional characteristics :

The co-efficients of friction of sisal leaves were measured in two methods on four surfaces namely mild steel, galvanized steel, aluminium sheet and sisal leaf surface. One method involved placing the sisal leaf on a tilting panel test surface and tilting the panel until the leaf began to slide. The other method involved measuring the force to pull a leaf across a horizontal test surface with different levels of added normal load on the leaf. The leaves were pulled both manually and mechanically. The observations were recorded for each test surface and mean value was calculated.

$$\text{For tilting panel, } \mu = \tan^{-} \qquad (3)$$

where,
μ = Coefficient of friction, and
θ = Angle of static friction, degree.

For horizontal test surface, $\mu = F_f / N$ (4)
where,
F_f = Frictional force, N
N = Normal force, N

Normal force, $N = m \times g$ (5)
where,
m = Mass of the object, kg
g = Acceleration due to gravity, m/s^2

Leaf cutting parameters :

Leaf cutting force and energy values were measured in both horizontal and vertical leaf cross-sections with a typical knife blade falling vertically through the cross-sections. The blade edge was oriented horizontally at 15, 30, and 45^0 from horizontal.

RESULTS AND DISCUSSION

The results of the present study as well as relevant discussions have been presented under following sub heads:

Force deflection characteristics of leaves attached to plant:

The externally applied force and displacement per degree of leaf downward rotation were 0.245 N-m/^{0} for leaves of one plant and 0.283 N-m/^{0} for other plant, respectively. The leaves were then harvested with spine weighed and the centre of mass was determined (49.6 cm from the point of leaf-bole attachment). The leaves were mechanically decorticated for fibre, washed and dried.

Table 1 : Morphological and mechanical parameters of leaves

Sr. No.	Particulars	Mean specifications
1.	Leaf mass, g	770
2.	Leaf length (with spine), cm	158
3.	Leaf length (without spine), cm	153
4.	Leaf width (at base), cm	5.93
5.	Leaf width (maximum), cm	12.0
6.	Leaf thickness (maximum), cm	3.1
7.	Cross-sectional area (7 cm from butt-end), cm^2	11.65
8.	Fresh fibre weight, g	66
9.	Dry fibre weight, g	31
10.	Fibre length, cm	148.7
11.	Fibre content of leaves, %	4.02
12.	Moisture content, % (wb)	55
13.	Fibre bundle strength, g/tex	32.31
14.	Fibre fineness	4.92

Leaf shape, size, mass distribution :

The mean morphological parameters of all the selected leaves used in the experiment work are presented in Table 1.

It was found that the average centre of mass was 31.5% of the with-spine leaf length from the butt-end. The average moisture content of all leaves tested was 87% (wb). The moisture content increased more or less linearly from about 80% at the tip-end to about 88% at the butt-end. The average dry fibre content was 4.02% of green leaf weight. The mean cross-sectional area of leaf at 7 cm from butt-end was 11.65 cm^2. The fibre bundle strength was measured using jute bundle strength tester and average fibre strength was 32.31 g/tex and average fibre fineness was 4.92.

Frictional characteristics :

The mean values of co-efficient of friction for sisal leaf at different horizontal test surfaces of mild steel, galvanized steel, aluminium sheet and sisal leaf surface for manually pulled, mechanically pulled and tilting panel are presented in Table 2.

Table 2 : Co-efficients of static and sliding friction for sisal leaves on four different surfaces

Method	Mild steel	Galvanized steel	Aluminium sheet	Leaf surface
Tilting panel	0.054	0.388	0.420	0.414
Static coefficient (Manual)	0.567	0.511	0.511	
Static coefficient (Mechanical)	0.464	0.494	0.508	0.499

The maximum co-efficient of friction of sisal leaf for tilting panel was found in aluminium sheet (0.420) followed by galvanized steel (0.388) and mild steel surface (0.054), respectively. In case of horizontal test surface with manual pulling and mechanical pulling, maximum coefficient of

Table 3 : Cut energy at butt-end with blade angle orientation

Leaf cross-section orientation	Blade edge angle from horizontal (^{0})	Average cutting force (kg)	Average cutting force/ width (kg/cm)	Specific cutting energy (J/ cm^2)
Horizontal	0	18.5	3.11	1.86
	15	15.5	2.59	1.56
	30	10.5	1.74	1.06
	45	15.0	2.61	1.51
Vertical	0	10.75	1.71	1.08
	15	11.0	1.83	1.11
	30	12.0	1.95	1.21
	45	11.5	1.87	1.16

friction was observed for mild steel (0.567) and aluminium sheet surface (0.508), respectively.

Leaf cutting parameters :

The experiment work on mean cut energy at butt-end with blade orientation was presented in Table 3.

Cutting forces per unit cut width were within a confined range indicating that the width of cut was a major factor affecting cutting forces. Specific cutting energy values were also within a range from 1.06 to 1.86 J/ cm^2. The cutting energy was low (1.06 J/ cm^2) at 30^0 knife blade angle with horizontal leaf cross-section orientation. Calculating with data from Table 3 the average cutting energy at butt-end section was found to be 1.31 J/ cm^2. The value is comparable with the results obtained by Majaja and Chancellor (1997) for cutting of sisal leaves.

Conclusion:

The minimum coefficient of friction of sisal leaf for tilting panel was 0.0.054 on mild steel surface. For horizontal test surface coefficient of friction were 0.511 and 0.464 for manual and mechanical pulling on galvanized steel surface and mild steel surface, respectively. The average centre of mass leaf was 31.5% from the butt-end of the leaf with-spine. The dry fibre content was 4.02% of weight green leaf weight. The mean cross-sectional area of leaf at 0.07 m from butt-end was 11.65 m^2. The fibre extracted by sisal fibre extractor was more strength, lustrous and finer than retting method. The fibre bundle strength was 32.31 g/tex and fibre fineness was 4.92. The average cutting energy at butt-end section was found out 1.31 J/ cm^2.

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