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Mechanical Properties of Sugarcane Stalk

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The study was undertaken to assess the mechanical properties including compressive and shearing strength of sugarcane (*Saccharum officinarum L.*) stalks for four varieties *viz.,* Co-99004,CoC-671,Co-85004 and Co-86032. The highest value of compressive strength (47.75 kN) at lower section was recorded for the variety Co-86032, whereas the lowest value (34 kN) was obtained with Co-85004. The maximum value of compressive strength for top section (49.25 kN) was recorded with CoC-671 and the minimum (39.75 kN) for the variety Co-99004. The cutting force required for shearing sugarcane stalk, ultimate cutting stress and specific shearing energy were determined at two sections for all the four varieties. It was observed that the maximum value of shearing force (1333.89 N) would be observed for the variety Co-85004 at lower section and it was (815.29 N) recorded for the variety CoC-671.The maximum value of ultimate cutting stress was (1.98 MPa) with Co-85004 at the lower section, while it was minimum (1.05 MPa) for the variety Co-99004. Similarly, the maximum value of specific shearing energy (39.68 mJ/mm^2) was recorded for the variety Co-85004 for the lower section, while it was minimum (13.06 mJ/mm^2) with CoC-671.

Key words: Sugarcane, Cutting force, Ultimate cutting stress, Specific shearing energy.

The properties of cellular materials that are important in cutting are compression, tension, bending, shearing, density and friction. These properties depend on the species, variety, stalk diameter, maturity, moisture content and cellular structure (Person, 1987; Kronbergs, 2000 and Morntree *et al*., 2012). Such physical properties also different at different heights of the plant stalk (Ince *et.al.,* 2005). The methods and procedures for determining most of the mechanical and rheological properties of agricultural products have been described by Mohsenin (1986); Sing *et al*., (2012); Patil and Patil (2013). Study of mechanical properties of sugarcane stalk are essential for the design of equipment and the analysis of the behaviour of the product during harvesting, handling, threshing and processing. Mechanical properties comprises shearing characteristics and compressive strength of sugarcane stalks. The present research work was carried out to determine cutting force, ultimate cutting stress and specific shearing energy.

Material and Methods

The experimental material selected for the study was four different varieties of sugarcane *viz.*Co-99004, CoC-671, Co-85004 and Co-86032 planted during 2013 in the experimental field at Sugarcane Research Unit, Central Research Station, Dr. P. D. K.V, Akola. Physiologically matured stalks of sugarcane having different diameter were selected and the experiment was conducted for assessing three shearing characteristics namely, cutting force, ultimate cutting stress and specific shearing energy at top and lower position of the stalk.

Moisture content and stem diameter were also considered during experimentation. Selection of varieties was done on the basis of thickness and hardness of stalk. The moisture content of the sugarcane stalk was determined according to ASAE standard S.352 (ASAE, 1979). It was determined for upper and lower section of the stalk. Stalk diameter was determined with the help of a vernier caliper having least count of 0.1 mm. Three repeated measurements were taken for upper and lower sections of the stalk to get the average value.

Mechanical properties

Compressive strength

The compressive strength was determined by using compression testing machine. The machine (Fig. 1) consists of a platform for sample, which is mounted on a centrally moving shaft and the upper steady platform. The shaft is attached with a hydraulic ram. Which operates with the pressure of hydraulic oil (4T SAE20W 40). The samples of stalk were kept on the platform and by operating the handle, the shaft was moved upward towards the steady platform. The pressure was applied until the stalk was completely compressed between two platform plates. The reading for the compressive strength was noted from the dial gauge. Three repetitions were made for upper and lower sections

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of the four test varieties. Moisture content was also determined for each variety.

Shear strength

The shearing tests were conducted using food texture analyzer at Indian Agricultural Research Institute, New Delhi (Fig. 2) to determine shearing force of the sugarcane stalk. The machine consists of a shearing blade, rigid fixture and the base platform to keep the stalk specimen and a load cell of capacity 250 kg. The machine also has a facility of computerized data chart recorder, where the live graph of each test can be observed separately and the tabular data can be recorded in the format of excel sheet.

Loading rate of 2 mm/min was selected for the study. The stalk samples were kept on the fixture. During the downward movement of the crosshead, the knife cut the specimen by shear and passed it through the slots provided in the fixture below the specimen. The force required for shearing stalk at the crosshead speed of 2 mm/min was recorded against time on the chart recorder. The indices which determine the shearing behaviour of the plant material are ultimate shear strength and specific shearing energy. The shear failure stress (or ultimate shear strength) of the specimen was calculated from the following equation (Tavakoli *et al*., 2009)

$$\tau_s = \frac{F_s}{A}$$

where,

t_s = Shear strength (MPa)

F_S = Shear force at failure (N)

A = Wall area of the specimen at the failure cross-section (mm^2)

The specific shearing energy, Es, was calculated by integrating the area under curves of shear force and displacement (Nazari Galedar *et. al.*, 2008).

The curves were used to evaluate a) the shear strength, obtained by using the maximum recorded force and b) the shearing energy, given by the area

$$_{ss} = \frac{1}{A} f F_x \, dx$$

where,

E_{ss} = Specific shearing energy mJ/mm^2

F = Shearing force N

A = Cross section of sample at the place of cutting mm^2

x = Travel of knife (displacement) mm

Variables for the study

The independent variables were sugarcane varieties (Co-99004, CoC-671, Co-85004 and Co-86032) and one rate of loading (2 mm/min). The dependent variables were cutting force, ultimate cutting stress and specific shearing energy. The experiments were replicated thrice using completely randomized design and the date were statistically analysed.

Results and Discussion

Compresssive strength

The compressive strength was determined for sugarcane stalks of varieties Co-99004, CoC-671, Co-85004 and Co-86032 at top and lower sections at the harvesting stage. The samples of stalks from

Plate 1. Compression testing machine

two sections were kept separately in an oven for 24 hours at 105° C. The loss in weight of the sample was recorded and the moisture content in percent was determined.

Table 1 shows that the average values of compressive strength of varieties Co-99004, CoC-671, Co-85004 and Co-86032 for lower section of stalk were 41.25, 38.0, 34.0 and 47.75 kN, respectively; whereas, for top section the compression strength was recorded as 39.75, 49.25, 49.0 and 43.0 kN, respectively. The maximum value of compressive strength (47.75 kN) at lower section was recorded for the variety Co-86032, while the minimum value (34 kN) was obtained with Co-85004 as compressive strength for lower section. The maximum value of top section was 49.25 kN in

Table.1 Compressive strength of stalks of different sugarcane varieties

Section	Co-99004		CoC-671		Co-85004		Co-86032	
	Dia. (cm)	Compressive strength, (kN)	Dia. (cm)	Compressive strength, (kN)	Dia. (cm)	Compressive strength, (kN)	Dia. (cm)	Compressive strength, (kN)
Lower	2.43	44	3.10	36	2.60	50	2.20	50
	2.44	40	3.00	38	2.66	24	2.14	48
	2.40	41	3.10	38	2.50	34	2.20	44
	2.41	40	3.20	40	2.54	28	2.16	49
Avg.	2.42	41.25	3.10	38	2.57	34	2.17	47.75
Top	2.46	40	3.41	50	2.40	50	2.02	38
	2.70	38	3.10	48	2.42	48	2.20	40
	2.70	39	3.04	49	2.40	50	2.20	42
	2.50	42	3.13	50	2.50	48	2.00	52
Avg.	2.59	39.75	3.17	49.25	2.43	49	2.10	43

variety CoC-671 and minimum value was 39.75 kN in variety Co-99004. The maximum value (49.25 kN) compressive strength for top section was recorded for the variety CoC-671, whereas minimum value (39.75 kN) was obtained for the variety Co-99004.

When compressive strength was considered for four selected varieties, in variety Co-99004 the values of compressive strength were at par for lower and top sections (Fig.1). When variety CoC-671 was considered then increasing trend was observed and

Table 2. Shearing characteristics of sugarcane stalks of different varieties

Section	Variety											
	Co-99004			CoC-671			Co-85004			Co-86032		
	Cutting force (N)	Ultimate cutting stress (MPa)	Specific shearing energy (mJ/mm²)	Cutting force (N)	Ultimate cutting stress (MPa)	Specific shearing energy (mJ/mm²)	Cutting force (N)	Ultimate cutting stress (MPa)	Specific shearing energy (mJ/mm²)	Cutting force (N)	Ultimate cutting stress (MPa)	Specific shearing energy (mJ/mm²)
Lower	979.99	1.26	16.06	748.98	1.12	6.31	1163.91	1.64	30.47	872.99	1.31	12.05
	865.68	1.07	9.81	731.26	1.03	5.64	1611.14	2.10	48.08	1078.72	1.74	23.49
	1129.23	1.46	26.41	1071.31	2.33	37.30	1386.16	2.63	52.91	1026.55	1.66	22.04
	963.85	1.44	17.97	740.65	1.27	7.07	1460.55	2.15	44.99	892.91	1.36	13.68
	1079.69	1.71	29.19	784.29	1.37	8.98	1047.72	1.37	21.93	962.19	1.56	18.76
Avg.	1003.58	1.05	19.89	815.29	1.43	13.06	1333.89	1.98	39.68	966.67	1.53	18.01
Top	1052.66	1.48	22.81	804.83	1.64	13.10	3235.30	4.05	102.1	1098.04	1.68	23.41
	1072.18	1.62	26.14	877.82	1.94	18.36	626.03	1.05	3.40	1009.39	1.66	22.36
	1110.03	1.99	35.27	818.87	1.59	12.49	617.88	1.16	3.72	941.03	1.47	17.12
	992.62	1.55	29.08	767.84	1.91	11.30	1303.43	2.45	46.95	865.52	1.47	13.48
	657.38	1.18	4.97	844.38	2.24	18.39	466.61	0.94	2.40	873.30	1.43	13.23
Avg.	976.97	1.57	23.66	822.75	1.86	14.74	1237.85	1.94	31.73	957.46	1.54	17.99

same trend was observed for the variety Co-85004, where as, in case of variety Co-86032 decreasing trend was observed.

Shear strength

The shearing strength of stalk for four varieties Co-99004, CoC-671, Co-85004 and Co-86032 at top and lower sections were determined with 2 mm/ min rate of loading. The average values of cutting force, ultimate cutting stress and specific shearing energy obtained for lower section of variety Co-99004 were 1003.58 N, 1.05 MPa and 19.89 mJ/mm^2 and for top section 976.97 N, 1.57 MPa and 23.66 mJ/ mm^2, respectively (Table 2). For the variety CoC-671, the values of force, Ultimate cutting stress and specific shearing energy obtained were 815.29 N, 1.43 MPa, 13.06 mJ/mm^2 for lower section and 822.75 N, 1.86 MPa and 14.74 mJ/mm^2 for top section, whereas for the varieties Co-85004 and Co-86032 the values obtained for cutting force, ultimate cutting stress and specific shearing energy for lower section were 133.89 N , 1.98 MPa, 39.68 mJ/mm^2, and 966.67 N, 1.53 MPa,18.01 mJ/mm^2.

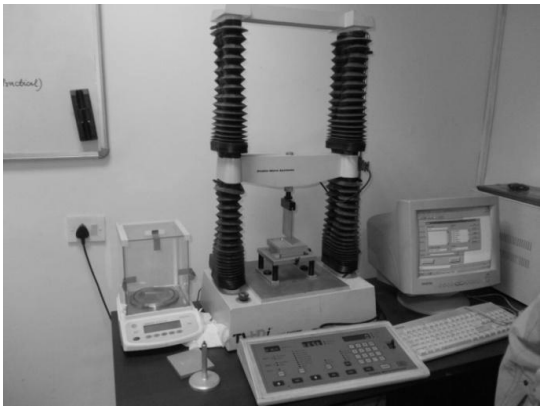

Plate 2. Food texture analyser

For top section the values were 1237.85 N,1.94 MPa, 31.73 mJ/mm^2, and 957.46 N,1.54 MPa,17.99 mJ/ mm^2, respectively. From the table it is observed that the maximum value of force (1333.89 N) was observed for the variety Co-85004 at lower section, and minimum value (815.29 N) recorded for the

variety CoC-671 The maximum value of ultimate cutting stress was 1.98 MPa in variety Co-85004 at lower section, and minimum value 1.05 MPa for the variety Co-99004. The maximum value of specific shearing energy (39.68 mJ/mm^2) was recorded for the variety Co-85004 for lower section, whereas minimum (13.06 mJ/mm^2) was obtained for the variety CoC-671 for the same lower section of stalk. Person (1987) also reported that the species related material features, which would be expected to influence the maximum cutting force ultimate tensile strength, stiffness of the fiber, thickness of the strong fiber and structure of the stem. From Fig.2, specific shearing energy could be observed in variety Co-99004 in an increasing trend. Similar trend was observed for variety CoC-671 also. In case of variety Co-85004, decreasing trend was observed; and for variety Co-86032 value of ultimate cutting stress was found to be at par.

The maximum value of compressive strength (47.75 kN) at lower section was recorded for the variety Co-86032 while, the minimum value (34 kN) was obtained for the variety Co-85004 of compressive strength for lower section. The maximum value (49.25 kN) compressive strength for top section was recorded for the variety CoC-671 and the minimum value (39.75 kN) was obtained for the variety Co-99004. The highest value of compressive strength was recorded for top section of stalk for the variety CoC-671. The shearing force was found to be minimum for lower section of stalk for the variety CoC-671. The maximum value of force (1333.89 N) was observed for the variety Co-85004 at lower section, and the minimum value (815.29 N) recorded with CoC-671 for lower section. The maximum value of ultimate cutting stress was 1.98 MPa in variety Co-85004 at lower section, and the minimum value 1.05 MPa for the variety Co-99004. The maximum value of specific shearing energy was (39.68 mJ/mm^2) recorded for the variety Co-85004 for lower section and the minimum value of specific shearing energy was (13.06 mJ/mm^2) observed for the variety CoC-671 for lower section of stalk.

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