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Physio-mechanical Properties of Cotton Stalk for Development of Cotton Stalk Shredder cum uprooter

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ABSTRACT: Physio mechanical properties of cotton stalk is important for design of cotton stalk shredder cum uprooter. The current investigation about the physical and mechanical properties of cotton stalk. The average height of plant, stem diameter (bottom, middle and top portion), weight of one stalk, number of branches and moisture content, were 1007.40 mm, 10.42, 8.45 and 4.39 mm, 33 g, 14 and 28.7 per cent (wb), respectively. To find the mechanical properties cotton stalk divided into three portions. The average value of cutting force (top, middle and bottom) and cutting force (top, middle and bottom) portion of cotton stalk for cutting were found as 360.64, 1201.38, 1785.66 and 83.02, 163.01, 379.77 N, respectively. The minimum cutting force and fracturability360.64 N and 83.02 N was found at top portion and maximum cutting force and fracturability1785.66 N and 379.77 N was found at bottom portion, respectively. The hardness (top, middle and bottom) portion of cotton stalk for bending were found as 14.34, 60.62, 135.93 N, respectively. The minimum bending force 14.59 N was found at top portion and maximum bending force 135.93 N was found at bottom portion.

Keywords: Bending, cutting force, fracturability, hardness, and physio mechanical properties.

INTRODUCTION

Cotton stalk is used as an agricultural waste in large quantities in the cotton growing areas (Hiloidhari *et al.*, 2014). Crop stubble retention in soil promotes a more biologically active soil system that is conducive to more efficient use of nitrogen fertilizer and maintains higher cotton yields. After final picking of cotton stalk, the cotton stalk in the field is removed by either uprooting manually or cutting them using sickle above the ground level. The uprooted or cut stalks from the field are transported for use as fuel. One of the difficulties in cotton production is the need to clear the ground from old cotton plants after harvesting (Anonymous, 2018). Only manual uprooting or cutting the stalks are followed which is highly labour intensive. Some farmers uses cross blade, rotovator, repeated heavy disking to cut the cotton stalk and cover it with soil.

Incorporation of cotton stalks into the soil ensures rapid decomposition. The most rapid decomposition occurs when residue is placed 10 to 15 cm deep and shredding stalks as finely as possible also allows for rapid decomposition. The present migration of labour from rural sector to scholastic jobs in urban areas necessitates the need for mechanizing the farming operation of cotton stalk shredding cum uprooter in the field (Tang *et al.*, 2010). The objective of this paper is to study about the physical and mechanical properties of cotton stalk for development of cotton stalk shredder cum uprooter.

MATERIAL AND METHODS

A. Physio-mechanical properties of cotton stalk

Crop parameters are useful and necessary in the design and operation of various equipments employed in agricultural operations (Sahay and Singh 1994). Knowledge of engineering properties of cotton stalk includes both physical and mechanical properties which forms important and essential engineering data in the design of machines. Basic information on these properties is of great importance and helps towards the refinement of equipment (Amer Eissa *et al.*, 2008).

B. Physical properties of cotton stalk

The physical properties of the cotton stalk play an important role in the development of cotton stalk shredder cum uprooter. It is important to determine the following parameters (Sudheendar, 2019).

(a) Height of plant, mm
(b) Stem diameter, mm
(c) Weight of one stalk, g
(d) Number of branches

(e) Moisture content, % wb

(a) Height of plant. Height of plant is an important parameter in feeding of the cotton stalk to the shredding unit of the machine. The height of plant was measured using a steel tape (Fig. 1). The readings of height of plants were taken for ten different randomly selected plants and the average values were reported.

(b) Stem diameter. The diameter of stalk is a cardinal parameter for determining mechanical properties of crops. A digital vernier caliper with 0.005 cm least count was used to measure stalk diameter (Fig. 2). The diameter of the stalk was measured at three different portions, *i.e.*, at the top, in the middle and at the bottom and the average value was determined.

(c) Weight of one stalk. The weight of the stalk was measured by using an electronic weighing balance**.** The measurement was taken for ten different randomly selected plants and the average values was recorded.

Fig. 1. Measurement of height of cotton stalk.

Fig. 2. Measurement of diameter of cotton stalk

(d) Number of branches. The number of branches was counted manually**.** The measurement was taken for ten different randomly selected plants and the average values was reported.

(e) Moisture content (M.C.). The moisture content of cotton stalks was determined using the oven method. The initial weights of samples were recorded using the electronic balance. The samples were dried in air convection oven set at temperature of 105°C ± 2 (ASAE, 1995) and monitored over a period of 24 hours at 6 hour intervals until the weights of the samples were found to be constant. The moisture content was calculated by using following relationship.

$$\text{Moisture content (\% wb)} = \frac{W_1 - W_2}{W_1} \times 100$$

Where,

W_1 = Weight of the wet sample, g

W_2 = Weight of the dry sample, g

C. Mechanical properties of cotton stalk

Mechanical properties of cotton stalks *viz.*, cutting and bending force were measured using texture analyzer (Amer Eissa *et al.*, 2008). Different tests, probes, fixtures and measuring parameters used for analysis of texture are given in Table 1. During the testing, the samples were held manually against the base plate and the different tests were applied according to TA setting mentioned in Table 2.

Cutting force. The cutting force required to cut the cotton stalk is an essential parameter in the design of the blade. Cutting force was measured with cutting blade attached with test unit. Pre test speed, test speed, post test speed and distance were set in the unit (Fig. 3). Texture analyzer produced results in the form of graph with force v/s displacement or time on Y and X-axis, respectively (Amer Eissa *et al.*, 2008).

Fig. 3. Measurement of cutting force of cotton stalk.

Table 1: Different tests and probe/fixtures used in texture analysis of cotton stalk.

Tests	Probe/Fixtures	Measuring Parameters
Cutting Test	Blade set with knife	Mean first peak force (Hardness) Mean distance at break (Fracturability)
Bending Test	Three point bend rig	Mean maximum force (Hardness)

Table 2: TA settings used for texture analyzer for performing different test.

TA Settings	Cutting test	Bending test (Bottom)	Bending test (Middle and Top)
Modes	Compression	Compression	Compression
Options	Return to start	Return to start	Return to start
Pre test speed, mm s^{-1}	2	1	1
Test speed, mm s^{-1}	2	3	3
Post test speed, mm s^{-1}	10	10	10
Distance, mm	40	50	30
Trigger force, kg	0.02	0.05	0.05
Tare mode	Auto	Auto	Auto

Bending force. The bending behavior of the cotton stalk is an important parameter in the design of shredder. Bending force was determined using texture analyzer. Pre test speed, post test speed and distance were set in the unit (Fig. 4). Texture analyzer produced results in the form of graph with force v/s displacement or time on Y and X-axis respectively (Amer Eissa *et al.*, 2008)

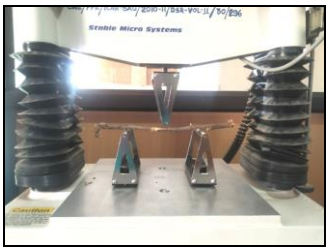

Fig. 4. Measurement of bending force of cotton stalk

RESULTS AND DISCUSSION

Physico-mechanical properties of cotton stalk. The physico-mechanical properties of cotton stalk are necessary in the design and operation of cotton stalk shredder cum uprooter. The results of physical and mechanical properties of cotton stalk are presented and discussed below:

Physical properties of cotton stalk. The physical properties of cotton stalk, which are essential for the design of machine were determined as per the procedure explained in methodology, and are results presented in Table 3.

Table 3: Physical properties of cotton stalk.

Sr. No.	Particulars	Average	Standard Deviation
1.	Height of cotton stalk before operation (mm)	1007.40	16.25 ± 5.14
2.	Diameter (mm)		
	a. Bottom	10.42	1.85 ± 0.58
	b. Middle	8.45	1.56 ± 0.49
	c. Top	4.39	0.79 ± 0.25
3.	No of branches	14.00	2.57 ± 0.81
4.	Weight (g)	33.00	16.19 ± 5.12
5.	Moisture content (%)	28.70	1.32 ± 0.42

Height of plant (mm). The height of plant before cutting was measured. The average height of plant was 1007.40 mm.

Stem diameter (mm). The diameter of stem was measured. The average diameter of cotton stalk was found at bottom, middle and top portion were 10.42, 8.45 and 4.39 mm, respectively.

Weight of one stalk (g). The weight of stalk was recorded. The average value of weight of stalk was 33 g.

Number of branches. The number of branches was counted. The average value of number of branches was 14.

Moisture content (%)

The moisture content of cotton stalk was determined. The average value of moisture content of cotton stalk was 28.7 per cent (wb).

Mechanical properties of cotton stalk. Mechanical properties of cotton stalk play an important role while designing the blade. The procedures followed for determination of various mechanical properties of cotton stalk, and results are presented in Table 4 and 5.

Table 4. Cutting force and Fracturability of cotton stalk for cutting test.

Sr. No.	Particulars	Average	Standard Deviation
1.	Cutting force (N)		
	a. Top	360.64	1.18 ± 0.37
	b. Middle	1201.38	1.21 ± 0.38
	c. Bottom	1785.66	0.64 ± 0.20
2.	Fracturability (N)		
	a. Top	83.02	0.21 ± 0.06
	b. Middle	163.01	0.13 ± 0.04
	c. Bottom	379.77	0.68 ± 0.21

Table 5: Bending force of cotton stalk for bending test.

Sr. No.	Particulars	Average	Standard Deviation
1.	Bending force (N)		
	a. Top	14.34	0.20 ± 0.06
	b. Middle	60.62	0.49 ± 0.15
	c. Bottom	135.93	0.27 ± 0.08

Cutting Force. The cutting force required to cut the cotton stalk was determined. The average value of cutting force (top, middle and bottom) and fracturability (top, middle and bottom) portion of cotton stalk for cutting were found as 360.64, 1201.38, 1785.66 and 83.02, 163.01, 379.77 N, respectively and graph of

texture profile were presented in Fig. 5, 6 and 7. It was observed that maximum peak force and its respective distance obtained in the curve is the force required to cut the stalks into two pieces *i.e.*, cutting force. The minimum cutting force 360.64 N was found at top portion and maximum cutting force of 1785.66 N was found at bottom portion due to increase in the diameter from bottom to top portion more force is required to cut the cotton stalk into two pieces. The minimum force required to cut the stalk is fracturability. The minimum fracturability 83.02 N was found at top portion and maximum 379.77 N was found at bottom portion due to increase in the diameter from bottom to top portion of cotton stalk more force is required to initiate to cut the stalk (Zhao *et al.*, 2022).

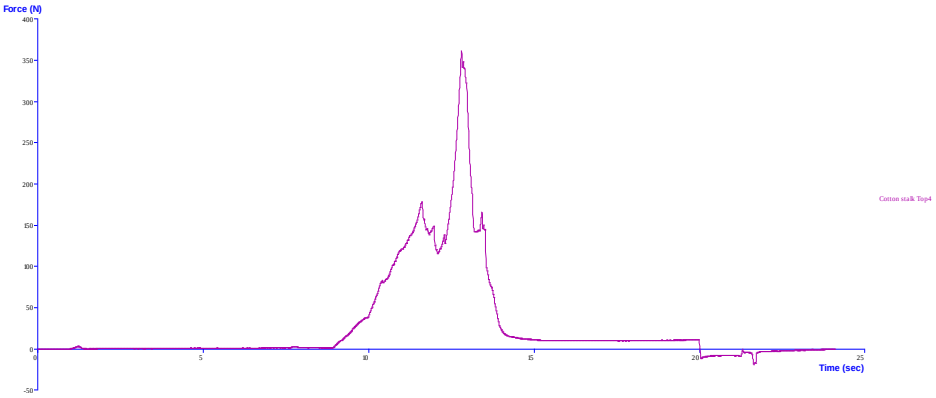

Fig. 5. Texture profile curve for cotton stalk at top portion by cutting test.

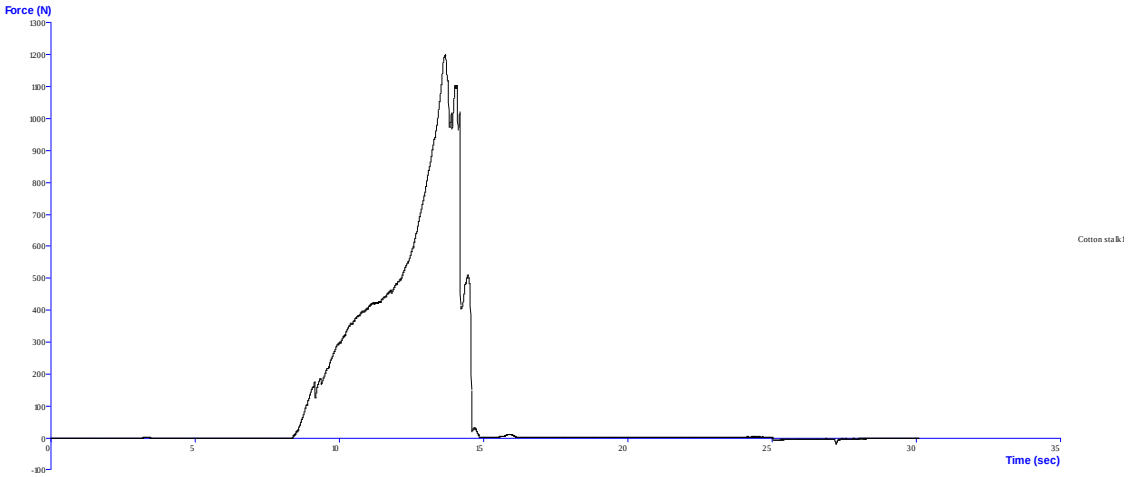

Fig. 6. Texture profile curve for cotton stalk at middle portion by cutting test.

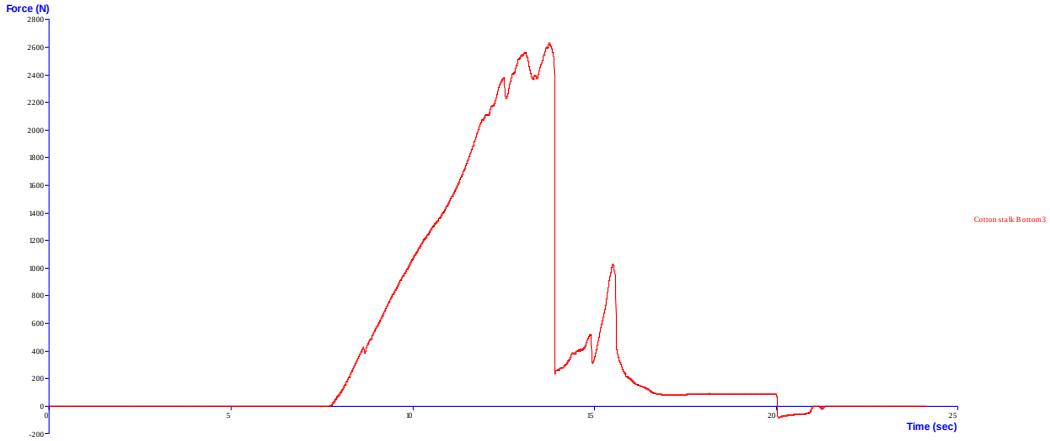

Fig. 7. Texture profile curve for cotton stalk at bottom portion by cutting test

Bending force. The bending force required to bend the cotton stalk was determined. The hardness (top, middle and bottom) portion of cotton stalk for bending were found as 14.34, 60.62, 135.93 N, respectively and graph are presented in Fig 8, 9 and 10. It was observed that maximum peak force obtained in the curve is the force required to bend the cotton stalk. The minimum bending force 14.59 N was found at top portion and maximum bending force 135.93 N was found at bottom portion due to increase in the diameter from bottom to top portion more force is required to bend the cotton stalk (Zhao *et al.*, 2022).

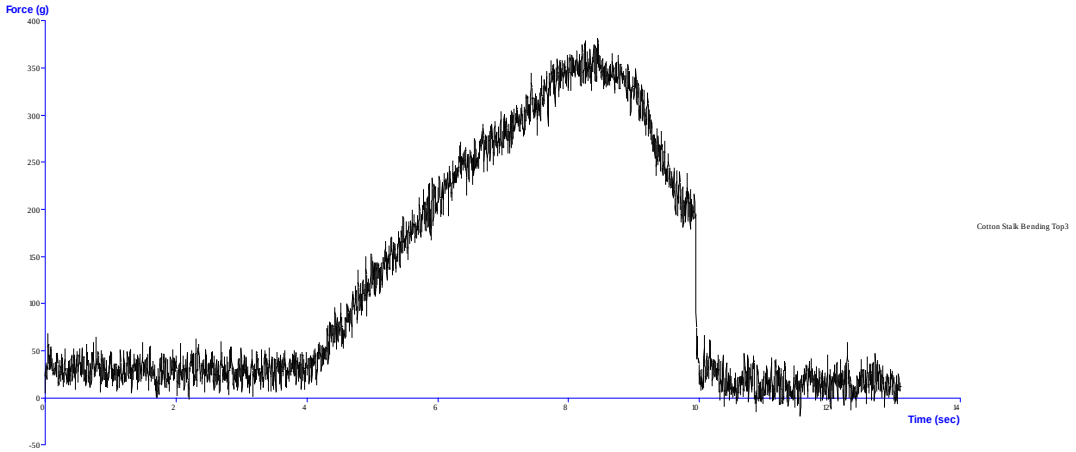

Fig. 8. Texture profile curve for cotton stalk at top portion by bending test.

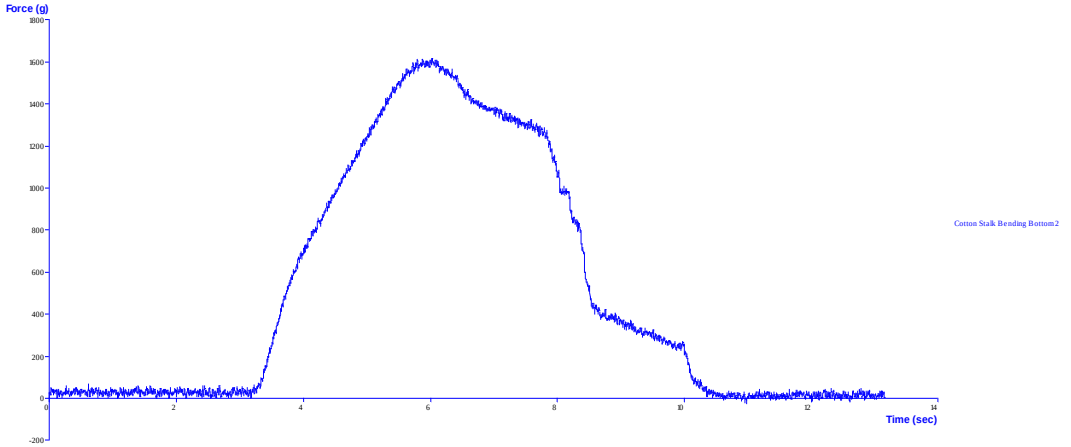

Fig. 9. Texture profile curve for cotton stalk at middle portion by bending test

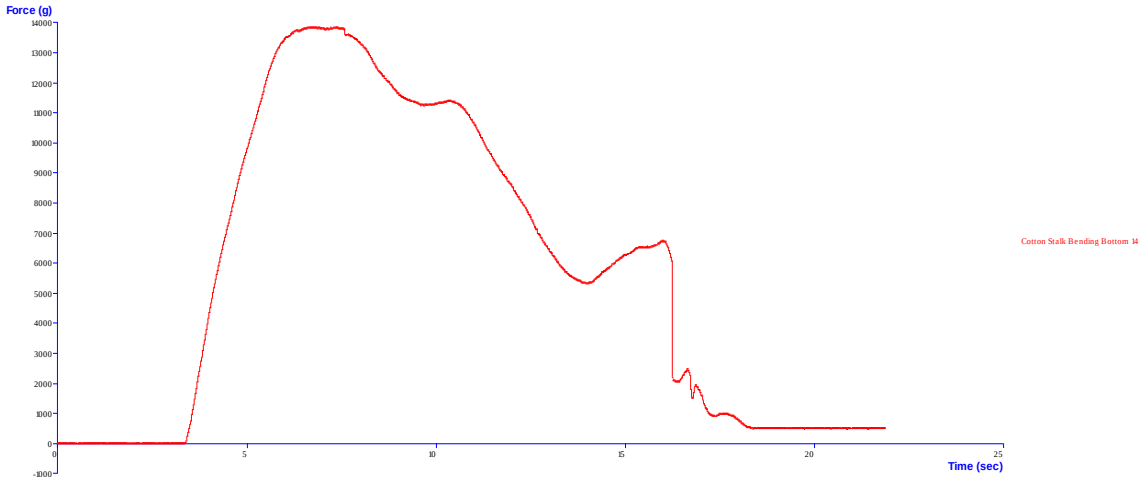

Fig. 10. Texture profile curve for cotton stalk at bottom portion by bending test.

CONCLUSIONS

—The physical properties *viz.*, height, diameter (bottom, middle, top portion), no of branches, weight and moisture content of cotton stalk were 1007.40, 10.42, 8.45, 4.39 mm, 14, 33 g and 28.7 per cent (wb), respectively.

—The mechanical properties *viz.*, cutting force (bottom, middle, top), fracturability (bottom, middle, top) for cutting test and bending force (bottom, middle, top) portion for bending test of cotton stalk were obtained as 1785.66, 1201.38, 360.64 N, 379.77, 163.01, 83.02 N and 135.93, 60.62, 14.34 N, respectively.

FUTURE SCOPE

To study mechanical properties for cotton stalk in universal testing machine to determine the cutting and strength parameters

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Conflict of Interest. None.

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