

Original Research Article

<https://doi.org/10.20546/ijcmas.2020.908.447>

Studies on Moisture Dependent Strength Properties of Sorghum

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A B S T R A C T

Keywords

Tensile strength,
Rupture force,
Cutting strength,
Pedicel, Sorghum

Article Info

Accepted:
28 April 2020
Available Online:
10 August 2020

An experimental study on strength properties of sorghum grain was conducted which are essential to design different post-harvest gadgets such as threshers, winnowers, and storage bins. Since most of the post-harvest operations of sorghum are accomplished within moisture content range from around 10.0% to 25.0% (wb) in India, the study was conducted within the moisture content range from 8.7% to 21.8% (wb). The tensile strength of stalk, pedicel and grain tip was determined at five levels of moisture content and three levels of test speed i.e. 50, 100 and 150 mm/min. The rupture force of sorghum grains was measured at four levels of test speed i.e. 5, 10, 15, 20 mm/min and five levels of moisture content. The cutting strength of stalk of four different diameters was measured at a test speed of 10 mm/min at three different orientations of stalk i.e. vertical, horizontal and at 45°. This study showed that the tensile strength of stalk, pedicel and grain tip increased with increase in moisture content at all levels of moisture content and the rupture force of grain decreased with increase in grain moisture content at all levels of moisture content.

Introduction

Millet crops or Nutri-Cereals are commonly known as poor man's crop; of late are termed as rich man's diet since they contain a lot of nutrients and vitamins and can tolerate adverse environmental conditions i.e. tolerance to moisture stress, resistant to water logging and grown in various soil conditions (Taylor, 2006). Sorghum is cultivated globally in 42 m ha in 98 countries while it is the fifth most important cereal crop and is the dietary staple of more than 500 million people

in more than 30 countries (Anonymous). In India, the annual production of sorghum is 4.5 m MT being cultivated in around 9.2 m ha (2, Anonymous, 1999). Sorghum is one of the important Nutri-cereals generally grown by the small and marginal farmers in many states of the country such as Odisha, Maharashtra, Karnataka, Gujarat, Rajasthan, Madhya Pradesh, Andhra Pradesh, and Tamil Nadu etc. Traditionally, the sorghum panicles on maturity are harvested manually, dried in sun and subsequently threshed by manual hand beating method and cleaned by swinging

basket which not only accounts for higher labour, cost and drudgery; but also results in poor quality of grain because of the unhygienic environment of working. Mechanization of different harvest and post-harvest operations like threshing, cleaning, grading, etc of sorghum can reduce the cost of operation, labour requirement and thus increase the net benefit to the small and marginal farmers of the state, the nation as well while the better quality is ensured. Ribeiro *et al.*, (2019) reported that within the moisture content range of 30.7 to 9.3 percent, the reduction in moisture content caused an increase in the force required to rupture the saccharine sorghum seeds while the compressive force decreased with increasing moisture content and values of proportional modulus of deformity increased with both reduced moisture content and deformation. Gabrielly *et al.*, (2019) reported that the force required to rupture and the compression force to deform grain sorghum, dried at temperatures of 60, 80 and 100 °C with different moisture contents (0.515, 0.408, 0.315, 0.234, 0.162 and 0.099 % d.b.) decreased with increment in moisture content while the proportional deformation modulus increases with moisture content reduction. Fernandes *et al.*, (2014) reported that with the increment in moisture content the compression force required to deform wheat grain decreases because grains with higher moisture contents offer lower resistance to compression. Goneli (2008) reported that the force-deformation data of a compression test indicate the parameters which predict the response of material when subjected to a certain load which is otherwise in dispensable to reduce possible damages and maintain product quality until the processing. Henry *et al.*, (2000) conducted compression studies in soybean grains with four moisture contents on three orthogonal axes and confirmed that the compressive force, perpendicular to cotyledon division was the highest force causing rupture

while resistance and deformation decreased with increasing moisture content. Chattopadhyay *et al.*, (1999) determined the shear, compression and bending properties of sorghum stalks at the seed stage and reported the maximum shear strength and the specific cutting energy increased from 4.68 to 9.02 MPa and 34.1 to 101.1 mJ/mm² respectively when the bevel angle was increased from 30 to 70° at a 10 mm/min rate of loading. Liu *et al.*, (1990) reported that the mechanical properties of agricultural products must be analyzed to develop suitable equipment for better performance at its maximum capacity without damaging the product final quality. Mohsenin (1986) reported that the mechanical properties of grains are influenced by several factors such as drying temperature, moisture content, rigidity and region of the grain where the force is applied. Thus, studying mechanical properties becomes necessary to know the behaviour and resistance of each product under certain condition. The present experiment was conducted to study the effect of moisture content on strength properties of sorghum grain, grown in the state of Odisha by the majority of small and marginal farmers by using Universal Testing Machine (UTM).

Materials and Methods

The sorghum grains of one popular variety, namely Pusachari were collected in adequate quantity were collected from the Centre for Pulse Research (OUAT), Ratanpur, Ganjam, Odisha, India. The grain samples were prepared by thorough cleaning to remove foreign materials such as dirt, stones, dust, immature grain, broken grains, and chaffs and sorting them subsequently. The initial moisture contents of these samples were found out following the standard hot-air oven method (AACC, 1995). Since sorghum is harvested at around 25 percent moisture content and stored at around 10 percent in India, the moisture content range for the study

of the properties of sorghum grain was decided accordingly (3, Anonymous). To study the effects of moisture content on strength properties of sorghum grains, the samples with five levels of moisture contents within the range from 8.7 to 21.8 percent were prepared by adding the desired amount of distilled water as followed by Coşkun *et al.*(2005), Jambamma *et al.*, 2011). The average moisture content of three replications of the prepared samples was recorded and reported as moisture content of the sample. The strength properties of sorghum were determined by using Universal Testing Machine. Firstly, the panicles were selected randomly. The experiment was carried out to find the tensile strength of stalk, pedicel and grain tip. The tensile force required to detach the grain from the pedicel was measured. Secondly, the force required to deform or rupture the grain was found out by placing the grain on the lower fixture and allowing the upper fixture to move towards the lower fixture. Thirdly, the cutting or compressive strength of stalk was found by fixing a knife shaped structure in the upper fixture and placing the stalk of different diameters at different orientations i.e. vertical, horizontal and at 45° angle. The design of the experiment for the study of different physical properties was Randomized Block Design (RBD) and Statistical analysis of the results was conducted in One-factor Analysis using OPSTAT, a free Online Agriculture Data Analysis Tool created by O.P. Sheoran, Computer Programmer at CCS HAU, Hisar, India (4).

Results and Discussion

The results on tensile strength of stalk, pedicel and grain tip, determined at five levels of moisture content and three levels of test speed i.e. 50, 100 and 150 mm/min were found to be statistically significant. Further, the results on rupture force of sorghum grains,

measured at four levels of test speed i.e. 5, 10, 15, 20 mm/min and five levels of moisture content were also found statistically significant. The results on cutting strength of stalk of 4 different diameters, measured at a test speed of 10 mm/min at three different orientations of stalk i.e. vertical, horizontal and at 45° were also statistically significant. The results on effect of moisture content on tensile strength of stalk, pedicel and grain tip have been presented in Table 1.

Effect of moisture content and test speed on tensile strength of stalk, pedicel and grain tip

The effect of moisture content on tensile strength of stalk, pedicel and grain tip at different test speed was determined. It was found that the tensile strength of stalk increased from 38.178 to 69.688 N as the moisture content increased from 8.7 to 21.8% at test speed of 50mm/min. The tensile strength of pedicel increased from 15.865 to 27.008 N as the moisture content increased from 8.7 to 21.8% at test speed of 50mm/min. Similarly, the tensile strength of grain tip increased from 2.993 to 6.065 N as the moisture content increased from 8.7 to 21.8% at test speed of 50mm/min. Similarly, at all test speed i.e. 100 and 150 mm/min, it was observed that the tensile strength increased with increase in moisture content. The effect of test speed on tensile strength was determined at various levels of moisture content. It was observed that with increase in test speed at a particular moisture content, the tensile strength decreased. This result is in agreement with the findings of Ribeiro *et al.*, (2019). In all the three loading rates of 50mm/min, 100mm/min and 150mm/min, the tensile strengths of stalk, pedicel and grain tip of sorghum crop was found to be linearly related to the moisture content within the test range as shown in Fig. 1, 2 and 3, respectively.

Effect of moisture content and test speed on rupture force of sorghum grain

The effect of moisture content on the rupture force of sorghum grain was determined at four levels of test speed i.e. 5, 10, 15 and 20 mm/min and five levels of moisture content is

presented in Table 2. The results indicated that the rupture force increased with decrease in moisture content at all test speed. At test speed of 5 mm/min, the rupture force increased from 37.150 to 72.900 N as the moisture content decreased from 21.8 to 8.7%.

Table.1 Effect of moisture content on tensile strength of stalk, pedicel and grain tip

Parts of Sorghum	Moisture content, %	Test speed, mm/min		
		Tensile force, N		
		50	100	150
Stalk	8.7	38.178	34.955	29.440
	11.6	56.390	49.528	42.558
	14.8	60.630	57.853	49.910
	17.7	61.168	68.510	74.973
	21.8	69.688	76.933	83.795
CD		1.317	0.846	1.176
SE(m)		0.423	0.272	0.377
Pedicel	8.7	15.865	11.925	7.020
	11.6	18.945	13.715	8.673
	14.8	21.590	16.075	12.930
	17.7	23.598	17.970	16.023
	21.8	27.008	19.040	16.990
CD		0.674	0.869	1.062
SE(m)		0.216	0.279	0.341
Grain Tip	8.7	2.993	1.728	1.190
	11.6	3.910	2.830	1.835
	14.8	4.953	3.698	2.865
	17.7	5.843	4.400	3.445
	21.8	6.065	4.945	4.550
CD		0.684	0.203	0.455
SE(m)		0.219	0.065	0.146

Table.2 Effect of moisture content and test speed on rupture force of sorghum grain

Moisture content, %	Test speed, mm/min			
	Rupture force of grain, N			
	5	10	15	20
21.8	37.150	28.900	20.400	14.825
17.7	49.100	40.300	33.150	24.025
14.8	58.800	49.850	40.075	29.950
11.6	66.125	58.525	47.600	36.050
8.7	72.900	65.250	52.975	41.600
CD	0.843	0.764	0.702	0.953
SE(m)	0.271	0.245	0.225	0.306

Table.3 Effect of stalk diameter on cutting strength of stalk diameter at test speed of 10mm/min

Stalk diameter, mm	Cutting strength (N)		
	Stalk orientation		
	Vertical	Horizontal	45° angle
9.5±0.5	115.540	122.540	306.420
10.5±0.5	127.740	145.480	320.400
11.5±0.5	143.560	158.600	351.640
12.5±0.5	155.760	175.380	398.340
CD	0.821	0.819	0.656
SE(m)	0.264	0.263	0.211

Fig.1 Effect of moisture content on tensile strength of stalk of sorghum crop

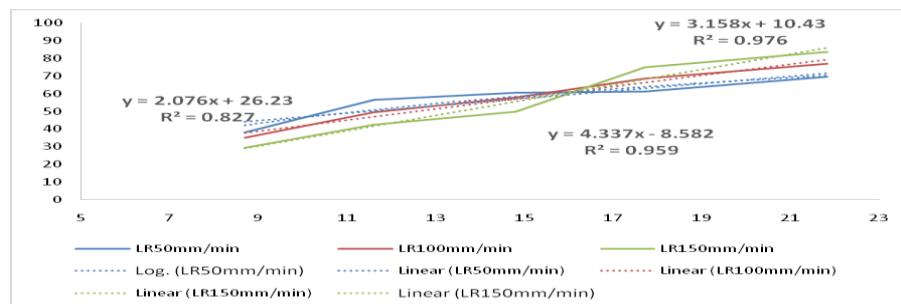


Fig.2 Effect of moisture content on tensile strength of pedicel of sorghum crop

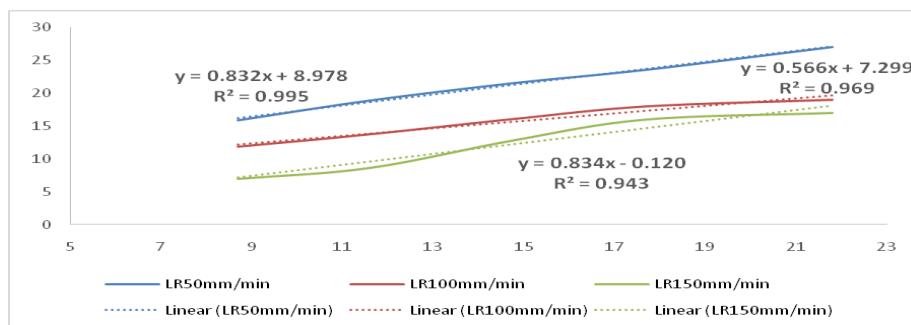


Fig.3 Effect of moisture content on tensile strength of sorghum grain tip

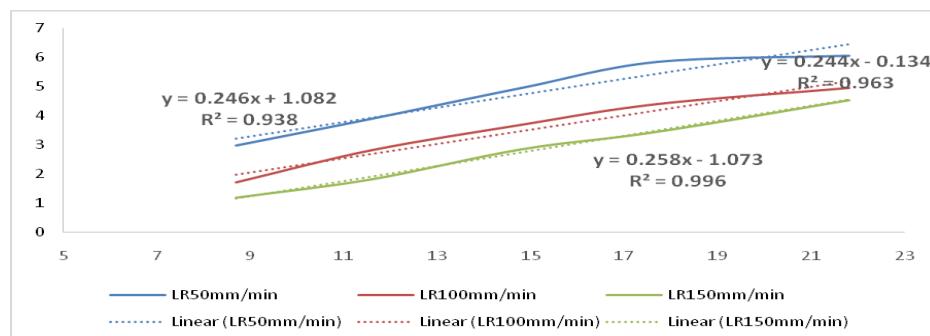


Fig.4 Effect of moisture content on rupture force of Grain at different test speeds

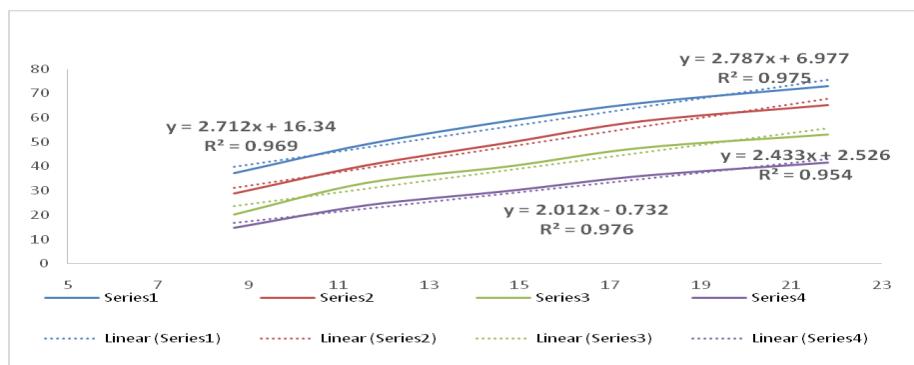
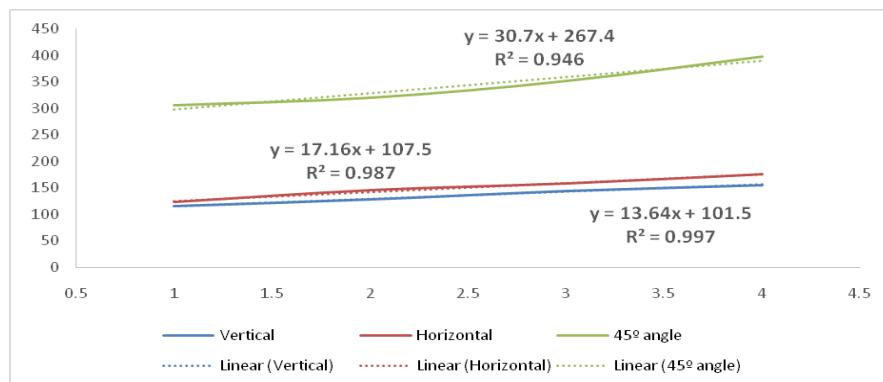


Fig.5 Effect of stalk diameter on cutting strength of stalk at different stalk orientation



Similarly, at 10 mm/min of test speed, the rupture force of sorghum grain decreased from 65.250 to 28.900 N due to the increment of moisture content. The effect of test speed on rupture force of sorghum grain was also determined. It was observed that at a particular moisture content, the rupture force decreased as the test speed increased. At moisture content of 21.8%, the rupture force decreased from 37.150 to 14.825 N as the test speed increased from 5 to 20 mm/min. These observations agree with the findings reported by Ribeiro *et al.*, (2019), Gabrielly *et al.*, (2019) and Fernandes *et al.*, (2014). Further the rupture strength was found to be linearly related with the moisture content within the test range at four different test speeds of 5mm/min, 10 mm/min, 15mm/min and 20mm/min as shown in Fig. 4.

Effect of stalk diameter on cutting strength of stalk

The effect of stalk diameter on cutting strength was studied on cutting strength of stalk at three different orientations at test speed of 10mm/min is presented in Table 3. The results indicated that the cutting strength was increased from 115.540 to 155.760 N as the stalk diameter increased from 9.5 ± 0.5 to 12.5 ± 0.5 mm when the stalk was placed in vertical orientation. The cutting strength increased from 122.540 to 175.380 N as the stalk diameter increased when placed in horizontal orientation. At 45 ° orientation of stalk, the cutting resistance increased from 306.420 to 398.340 N as stalk diameter increased from 9.5 ± 0.5 to 12.5 ± 0.5 mm. It was also observed that at a particular stalk diameter, the cutting strength increased when

orientation changed from vertical to 45° angle. In all the three orientations, the cutting strength was found linearly related to the moisture content within the stalk diameter range as shown in Fig. 5.

In conclusions the tensile strength of stalk, pedicel and grain tip was measured at three levels of test speed i.e. 50, 100 and 150 mm/min and moisture content varying from 8.7 to 21.8%. The rupture force of sorghum grains was determined at four levels of test speed i.e. 5, 10, 15 and 20 mm/min and five different moisture contents. The cutting strength of stalk was also determined with four different stalk diameter and three orientation of stalk. The following conclusions were drawn:

- The tensile strength of stalk, pedicel and grain tip increased with increase in moisture content at all levels of moisture content.
- The rupture force of grain decreased with increase in grain moisture content at all levels of moisture content.
- The cutting strength of stalk increased as stalk diameter increased. The lowest (115.540 N) cutting strength was obtained at 9.5 ± 0.5 mm diameter in vertical orientation.
- The present study provides comprehensive basic information about strength properties of sorghum grain for designing small scale post-harvest machinery especially a sorghum thresher for small and marginal farmers.

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How to cite this article:

Swain, S. K., P. P. Jena, S. S. Sabar, D. Behera, R. R. Pattanaik, A. K. Mohapatra, M. Mohapatra and Dash, A. K. 2020. Studies on Moisture Dependent Strength Properties of Sorghum. *Int.J.Curr.Microbiol.App.Sci*. 9(08): 3887-3894.
doi: <https://doi.org/10.20546/ijcmas.2020.908.447>