Int.J.Curr.Microbiol.App.Sci (2020) *9*(8): 2365-2375

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 9 Number 8 (2020)**
Journal homepage: http://www.ijcmas.com

Original Research Article https://doi.org/10.20546/ijcmas.2020.908.271

Moisture Dependent Physical and Engineering Properties of Sorghum Grains

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A B S T R A C T

An experimental study on engineering, frictional, and aerodynamic 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).It was observed that the linear dimensions such as length, width, and thickness increased with an increase in moisture content in the said range. With an increase in moisture content, the geometrical mean diameter, arithmetic mean diameter, square mean diameter, and equivalent mean diameter increased from 3.20 to 3.53 mm, 3.38 to 3.70mm, 5.74 to 6.30 mm and 4.11 to 4.51 mm, respectively. The coefficient friction for glass, mild steel surface, GI sheet, and plywood increased linearly from 0.25 to 0.31, 0.26 to 0.43, 0.27 to 0.42, and 0.30 to 0.45, respectively with an increase in moisture content. It was observed that glass has the lowest coefficient friction whereas plywood has the highest coefficient of friction as compared to other 3 surfaces. Angle of repose, terminal velocity, aspect ratio, sphericity, surface area, volume, and 1000 grain weight were increased from 39.84^0 to 43.19^0, 7.06 to 7.99 m^{-s}, 0.705 to 0.735%, 32.27 to 39.25 mm^2, 17.25 to 23.13 mm^3 and 20.67 to 22.01 g, whereas bulk density, true density and porosity decreased from 755.75 to 723.50 kg m^{-3}, 1671.50 to 1161.00 kg m^{-3} and 0.53 to 0.37% within the said moisture content range.

Keywords

Sorghum, Engineering properties, Terminal velocity, Aspect ratio, Coefficient of friction

Article Info

Accepted:
20 July 2020
Available Online:
10 August 2020

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 waterlogging 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 (1, 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. Mechanization of different post-harvest operations like threshing, cleaning, grading, etc. of sorghum can reduce the cost of operation, labor requirement and thus increase the net benefit of the small and marginal farmers. It is quite imperative to have a scientific study of the physical and engineering properties of sorghum at different moisture contents for design and development of suitable gadgets for these operations (Gely *et al.,* 2017, Kachru *et al.,* 1994, Sologubik *et al.,* 2013, Kenghe *et al.,* 2015). The physical and aerodynamic properties of sorghum grain in terms of size, shape, weight, diameter, surface area, and bulk density are essentially required for designing the threshing cylinder, threshing element, concave clearance of a thresher, hopper, sieves, etc., concerning size, and slope (Asoegwu *et al.,* 2006, Hurburgh, 1995, Simonyan, 2005, Vilche *et al.,* 2003, Tettamanti *et al.,* 2015). The various machine parameters such as threshing cylinder length, cylinder speed, sieve size, velocity and quantity of airflow, angle of inclination of sieve, etc are designed for the physical properties namely, equivalent diameter, sphericity and aerodynamic properties like terminal velocity and frictional properties such as the angle of repose, and angle of internal friction, etc, (Brooker *et al.,* 1992, Singh *et al.,* , 2004 and Wilhelm *et al.,* 2004, Chang, 1988; Nelson and You, 1989; Nelson, 1980; Mohsenin, 1980, Obi *et al.,* 2014 and Vaughan *et al.,* 1980). A study on the physical properties of Nigerian varieties of sorghum and their behaviour with the moisture content was conducted by Oke (1984) and Mwithiga and Sifuna (2004) where it was reported that the biological nature of the material influences its properties; therefore, the evaluated properties are not universal but rather represent the behaviour of the material under the studied conditions. The present experiment was conducted to study the effect of moisture content on the physical and engineering properties of one popular variety of sorghum grain, grown in the state of Odisha by the majority of small and marginal farmers.

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 different physical and engineering 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, I. K. *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 design of the experiment for the study of different physical properties was Randomized Block Design (RBD) with five treatments (levels of moisture contents) and four replications (values of properties). 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).

Linear dimensions

Linear dimensions of the sorghum grains, selected randomly from the samples (Var: Pusachariand five levels of moisture contents) were determined by measuring the dimensions along the three principal axes, namely, major (L), medium (W) and minor (T) using an electron microscope with an accuracy of ±0.01 mm (Mohsenin, 1970, Shashikumar *et al.*, 2018).

Grain size (Dm)

The average diameter of the grain was calculated by using arithmetic mean and the geometric mean of the three axial dimensions. The arithmetic mean diameter (*AMD*), geometric mean diameter (*GMD*), square mean diameter (SMD), and equivalent diameter (EQD) of the grains were calculated by using the following relationships (Mohsenin, 1986).

$$AMD = (L+B+T)/3 \quad (1)$$
$$GMD = (LBT)^{1/3} \quad (2)$$
$$SMD = \sqrt{(LB + BT + TL)} \quad (3)$$
$$EQD = (AMD+GMD+SMD)/3 \quad (4)$$

Surface area

Surface area (S) was calculated by using the expression given by (Singh *et al.*, 2010).

$$S = \pi * (GMD)^2 \quad (5)$$

Aspect ratio (Ra) is the ratio of longer diameter to shorter diameter, was calculated by using the relationship given by Maduako and Faborode (1990):

$$Ra = \frac{B}{L} \times 100 \quad (6)$$

Sphericity (Φ)

Sphericity (**Φ**) is defined as the ratio of the surface area of the sphere having the same volume as that of the grain to the surface area of the grain and was determined using the following formula (Mohsenin, 1986, Abalone *et al.*, 2004).

$$\Phi = \{(LBT)^{1/3}\}/L \ \ldots \quad (7)$$

where,
L= length of grain, mm
B= width of grain, mm
T= thickness of grain, mm

Volume (V)

The volume of the grain was determined by taking the dimensions of the two varieties of the grains in three axes of length, width, and thickness in 10 replications, and then the volume was estimated using the relationship as described by Mohsenin (1986).

Angle of Repose (θ)

The angle of repose is the angle with the horizontal at which the material will stand when piled. This was determined by using the apparatus consisting of a plywood box of 140 x 160 x 35 mm and plates fixed and adjustable. The box was filled with the sample from constant height (15 cm), and then the adjustable plate was inclined gradually allowing the grains to fall freely and assume a natural slope, this was measured as angle of repose.

Thousand-grain weight (M1000)

One thousand randomly selected grains of test samples at various moisture levels were collected and weighed on electronic top pan balance (Contech, India) having a least count of 0.01 g. This magnitude was termed as the thousand-grain weight specific to the grain. The procedure described in IS: 4333 (Part IV) -1968 was adopted. Average of ten replications have been considered and reported as a thousand grains weight of the sample.

Bulk Density (BD)

The bulk density of the grain is the ratio of its mass to bulk volume. Bulk density was measured using the IS:4333 (Part III)-1967 method, in which a 500 mL cylinder was filled with grains from a height of 15 cm. The excess grains were removed by sweeping the surface of the cylinder and the grains were not compressed. Bulk density was then calculated as the ratio between the kernels weight and the volume of the cylinder (Gikuru Mwithiga, *et al.,* 2005).

True Density (TD)

True density (ρ_t) was determined using the toluene displacement method (Mohsenin, 1986; Singh *et al.,* 1996). Toluene (40 ml) was filled in 100ml graduated measuring cylinder and 50g of grains were poured in it. The amount of toluene displaced was recorded. The true density was estimated as the ratio of sample mass to the volume of displaced toluene.

Density ratio

It is the ratio of bulk density to true density**.** Calculated by the formula

$$\text{Density ratio} = BD/TD \qquad (8)$$

Porosity (∈)

It is the percentage of the volume of voids in the test sample at given moisture content and calculated as the ratio of the difference in the true and bulk density to true density value which is expressed in percentage with the following equation. The average of ten replications was considered as a percent porosity value of the sample.

$$\epsilon = 1 - (BD/TD) \qquad (9)$$

Static coefficient of friction (μ)

The coefficient of static friction of samples of sorghum grain was determined concerning four surface materials including plywood, glass, galvanized iron and mild steel to study the flowability of the samples through the hopper with reduced friction as reported by Shashikumar *et al.,* (2018), and Obi *et al.,* (2014). The coefficient of friction was calculated using the equation.

$$\mu = \tan\theta \qquad (10)$$

where,

μ = coefficient of friction; and
θ = angle of inclination of the material surface.

Terminal velocity

The terminal velocity of sorghum grain was measured by using an air column Singh & Goswami (1995), Sial *et al.,* (2019). It is the velocity of air at which the grain is neither blown upward nor fallen downward; rather remains in the suspended state.

Results and Discussion

The results on the physical properties of sorghum grain (Variety: Pusa chari) such as linear dimensions and average diameters within the moisture range of 8.7 percent to 21.8 percent have been placed in Table 1.

Effect of moisture content on linear dimensions and average diameters

The linear dimensions i.e. length, width & thickness of sorghum grain were found to increase significantly within the moisture content range from 4.54 to 4.80 mm, 3.55 to 3.87 mm, and 2.24 to 2.43 mm respectively which may be due to absorption of moisture by sorghum grain. The increase of length, width, and thickness were found linearly related to the corresponding increase in moisture content (Fig. 1). Similarly, the average diameters i.e., AMD, GMD, SMD, and EQD were observed to increase linearly with an increase in moisture content within the same range (Fig. 1). It was observed that the AMD, GMD, SMD, and EQD increased significantly from 3.38 to 3.53 mm, 3.20 to 3.53 mm, 5.74 to 6.30 mm, and 4.11 to 4.51 mm respectively with the corresponding moisture content from 8.7% to 21.8% (Table 1). The observations of an increase in linear dimensions and average diameters of sorghum grain with regard to an increase in moisture content agree with the findings reported by Simonyan *et al*., (2005) and Kenghe *et al*.,(2015).

Effect of moisture content on physical properties of Sorghum

The physical properties i.e. aspect ratio, 1000 grain weight, sphericity, surface area, volume of sorghum grain have been placed in Table 2 which were found to increase significantly within the test moisture content from 73.78 to 80.54 mm, 20.67 to 22.01 g, 0.705 to 0.735 %, 32.27 to 39.25 mm^2, 17.25 to 23.13 mm^3, 0.464 to 0.624, respectively, which may be due to absorption of moisture by the sorghum grain. It was observed that physical properties were increased linearly with increase in moisture content from 8.7 to 21.8% (w.b.). The increased value of physical properties within the corresponding moisture content were in agreement with the findings of Kenghe *et al.*, (2015) for sorghum, Simonyan *et al.*, (2005) and Gely *et al.*, (2017) (Fig. 2).

The physical properties such as bulk density, true density and porosity of sorghum grain decreased with an increase in moisture content whereas density ratio increased within moisture content. It was observed that the bulk density, true density, and porosity decreased from 775.7 to 723.50 kg m^{-3}, 1671.50 to 1161 kg m^{-3},0.536 to 0.376%, respectively with the corresponding moisture content range 8.7 to 21.8% (wb. The density ratio increased significantly within the test moisture content range from 0.464 to 0.624. The decreased values of bulk density, true density, and porosity of sorghum grain coincides with the findings of Kenghe *et al.*, (2015), Jambamma *et al.,* (2011), Simonyan *et al.*, (2005) (Fig. 3).

Effect of moisture content on frictional and aerodynamic properties

The result of the effect of moisture content on frictional and aero-dynamic properties of sorghum grain within the moisture content range of 8.7 to 21.8% (w.b) was presented in Table 3. The effect of moisture content on the angle of repose and terminal velocity was found to be statistically significant (Table 2). The lowest and highest value of the angle of repose was 39.84^0 and 43.19^{0}at 8.7 % and 21.8% moisture contents respectively. These findings are in agreement with Mitthiga and Mark (2006), Gely *et al.*, (2017). The result showed that the terminal velocity increased linearly with an increase in test moisture content range from 7.06 to 7.99 ms^{-1}. These results are in coincidence with the findings of Sial *et al.,* (2019) (Fig. 4).

Table.1 Effect of moisture content on the physical properties of Sorghum grain (Linear dimensions and Average diameters)

Moisture content %	**Linear Dimensions,mm**			**Average Diameter,mm**			
	Length (L)	Width (W)	Thickness (T)	Arithmetic mean diameter (AMD)	Geometric mean diameter (GMD)	Square mean diameter (SMD)	Equivalent mean diameter (EQD)
8.7	4.54	3.55	2.24	3.38	3.20	5.74	4.11
11.6	4.60	3.48	2.30	3.46	3.29	5.88	4.21
14.8	4.67	3.65	2.34	3.55	3.38	6.05	4.33
17.7	4.73	3.76	2.39	3.63	3.46	6.17	4.42
21.8	4.80	3.87	2.43	3.70	3.53	6.30	4.51
$CD_{0.05}$	0.02	0.02	0.02	0.01	0.01	0.02	0.01
SE(m)±	0.02	0.01	0.01	0.01	0.01	0.01	0.01

Table.2 Physical properties of sorghum grain

Moisture content, %	**Aspect ratio**	**Sphericity (%)**	**1000 grain weight (g)**	**Surface area (mm^2)**	**Volume (mm^3)**	**Bulk density (kg m^{-3})**	**True density (kg m^{-3})**	**Density ratio**	**Porosity**
8.7	73.78	0.705	20.67	32.27	17.25	775.75	1671.50	0.464	0.536
11.6	75.65	0.718	21.03	33.99	18.64	766.50	1565.75	0.490	0.510
14.8	78.07	0.725	21.52	35.95	20.28	758.75	1362.75	0.558	0.442
17.7	79.45	0.730	21.84	37.68	21.76	744.00	1272.75	0.586	0.414
21.8	80.54	0.735	22.01	39.25	23.13	723.50	1161.00	0.624	0.376
$CD_{0.05}$	0.58	0.006	0.15	0.20	0.16	6.40	45.67	0.022	0.022
SE(m)±	0.19	0.002	0.05	0.06	.05	2.05	14.66	0.007	0.007

Table.3 Frictional and Aerodynamic properties of Sorghum

Moisture content (%)	**Angle of Repose (^{0})**	**Coefficient of friction at different surfaces**				**Terminal velocity ($msec^{-1}$)**
		Glass	Mild steel sheet	GI sheet	Plywood	
8.7	39.84	0.25	0.26	0.27	0.30	7.06
11.6	40.80	0.26	0.28	0.28	0.32	7.18
14.8	41.84	0.28	0.31	0.31	0.41	7.46
17.7	42.41	0.30	0.34	0.35	0.42	7.74
21.8	43.19	0.31	0.43	0.42	0.45	7.99
$CD_{0.05}$	0.51	0.01	0.01	0.01	0.01	0.07
SE(m)±	0.16	0.01	0.01	0.01	0.01	0.02

Fig.1 Effect of moisture content on linear dimensions and average diameters of sorghum grain

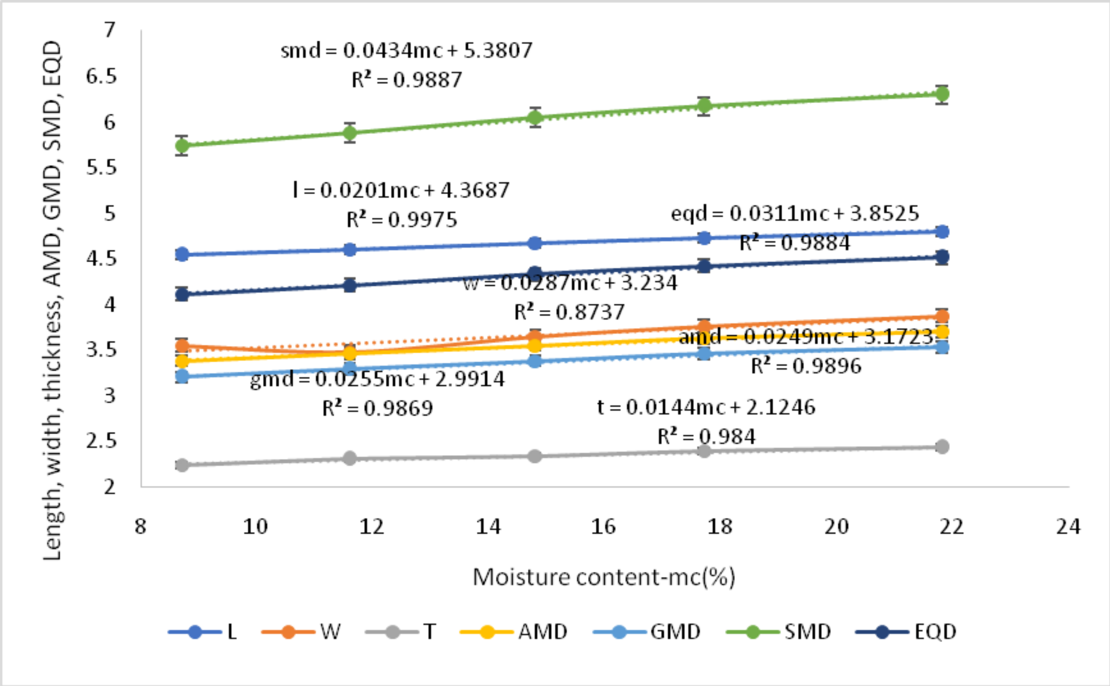


Fig.2 Effect of moisture content on aspect ratio, 1000 grain weight, surface area, volume, and sphericity of sorghum grain

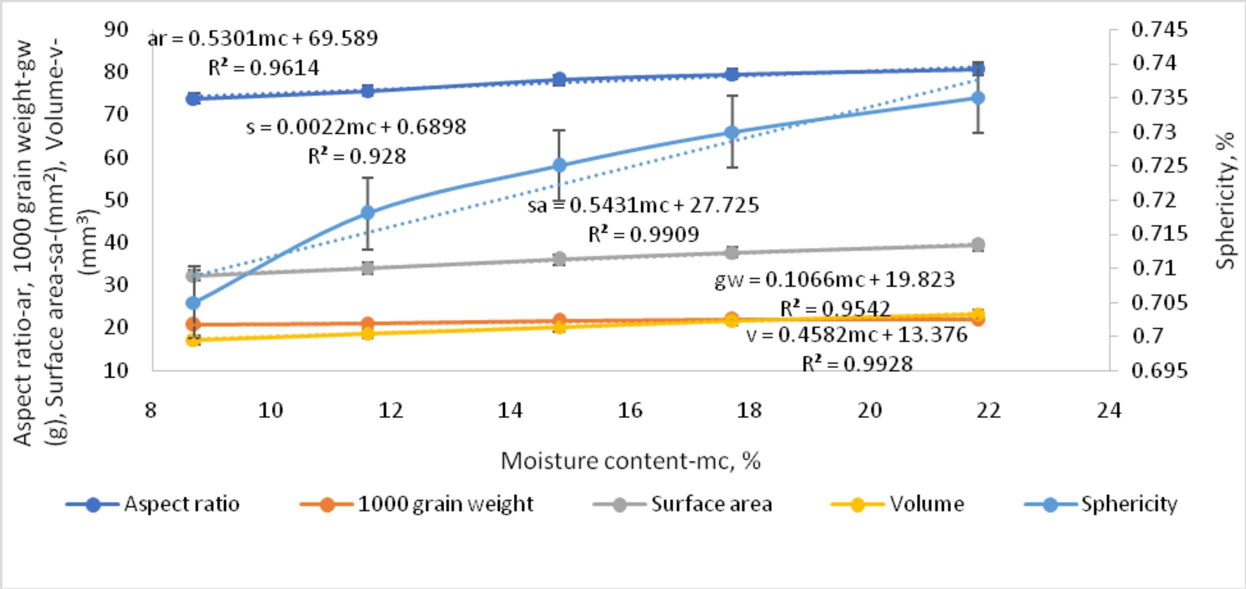


Fig.3 Effect of moisture content on bulk density, true density, density ratio and porosity of sorghum grain

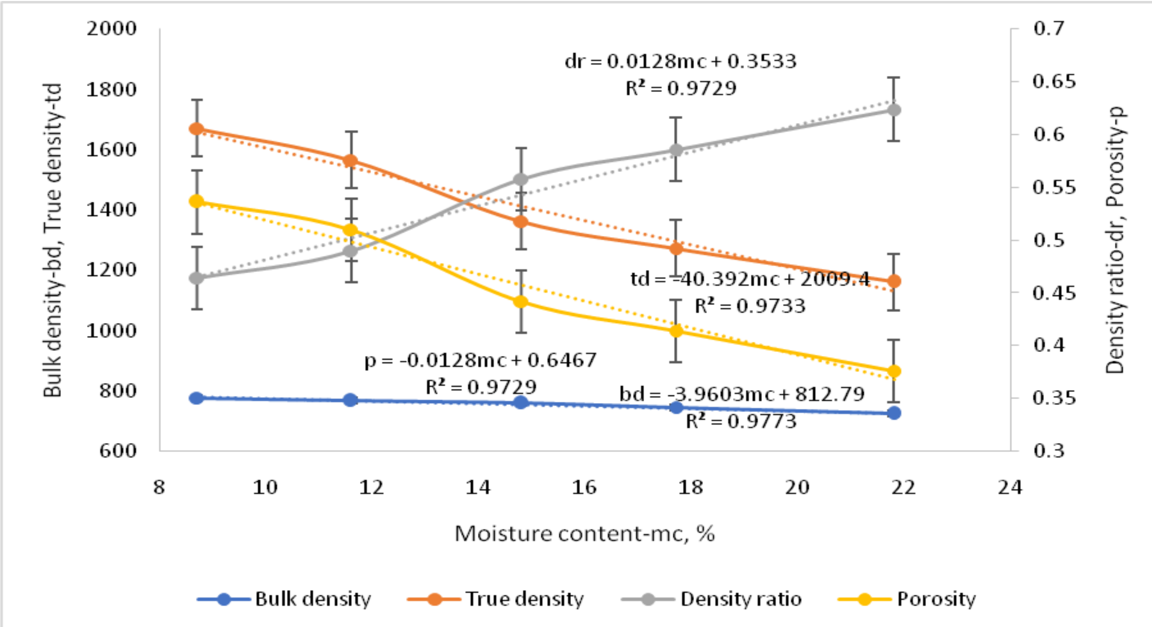
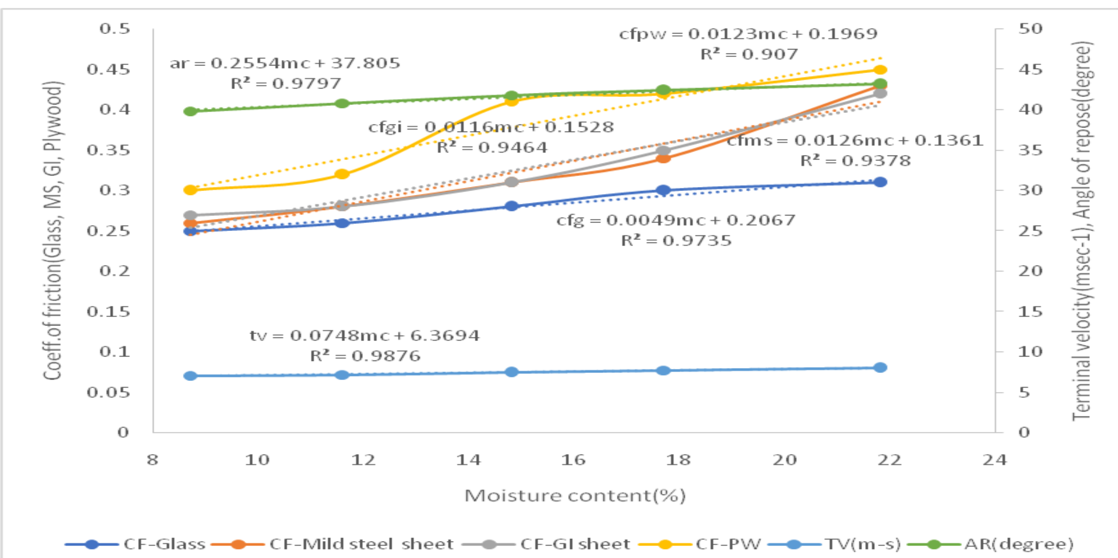


Fig.4 Effect of moisture content on the coefficient of friction, terminal velocity and angle of repose of sorghum grain



The coefficient of friction of sorghum grain was determined concerning four different surfaces within the test moisture range from 8.7 to 21.8 % (wb). It was observed that the coefficient of friction for all the contact surfaces was increased linearly with an increase in moisture content. The data revealed that the lowest value of glass, mild steel sheet, GI sheet and plywood were found to be 0.25, 0.26, 0.27 and 0.30 at 8.7% (wb) moisture content and the highest value of 0.31, 0.43, 0.42 and 0.45 respectively at

21.8% (wb) moisture content. The coefficient of friction for glass was lowest as compared to other surfaces whereas the value of the coefficient of friction for plywood was highest as compared to other surfaces. These findings are in agreement with the earlier findings of Kenghe *et al.,* (2015), Gely *et al.,* (2017) and Jambamma *et al., (*2011).

In conclusion, the present study provides a comprehensive basic information about the engineering, frictional and aerodynamic properties of sorghum grain for designing small scale post-harvest machinery especially a sorghum thresher for small and marginal farmers which include the coefficient of friction for designing of sieve slope, angle of repose for designing of hopper and feeding chute, terminal velocity for designing of blower and aspirator and grain size (GMD, SMD, AMD & EQD) for designing of sieve openings, size of holes and concave clearance.

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How to cite this article:

Sabar, S. S., S. K. Swain, D. Behera, K. Rayaguru, A. K. Mohapatra and Dash, A. K. 2020. Moisture Dependent Physical and Engineering Properties of Sorghum Grains. *Int.J.Curr.Microbiol.App.Sci*. 9(08): 2365-2375. doi: https://doi.org/10.20546/ijcmas.2020.908.271