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Moisture Dependent Physical and Engineering Properties of Pearl Millet Grains

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ABSTRACT: An experimental study on the engineering, frictional, and aerodynamic properties of pearl millet grain was conducted which are essential to design different post-harvest gadgets such as threshers, winnowers, and storage bins. The study was conducted within the moisture content range from 9.2% to 20.9% (wb). Within the said range it is observed the with increasing moisture content the linear dimension such as length, width and thickness increased. With an increase in moisture content, the geometrical mean diameter, arithmetic mean diameter, square mean diameter, and equivalent mean diameter increased from 1.39 to 1.65 mm, 1.65 to 1.98 mm, 2.30 to 3.09 mm and 1.73 to 1.98 mm, respectively. The coefficient friction for glass, mild steel surface, GI sheet, and plywood increased linearly from 0.365 to 0.398, 0.402 to 0.414, 0.396 to 0.412, and 0.339 to 0.357, respectively with an increase in moisture content. It was observed that plywood has the lowest coefficient friction whereas mild steel has the highest coefficient of friction as compared to the other 3 surfaces. The angle of repose, terminal velocity, aspect ratio, sphericity, surface area, volume, and 1000 grain weight were increased from 23.420 to 25.600, 4.42 to 4.62 m^{-s}, 0.353 to 0.386%, 0.682 to 0.699%, 6.60 to 8.55 mm^2, 2.69 to 4.56 mm^3 and 2.91 to 3.13 g, whereas bulk density, true density and porosity decreased from 608.68 to 611.78 kg m^{-3}, 967.53 to 968.93 kg m^{-3} and 0.37 to 0.39% within the said moisture content range.

Keywords: Pearl millet, engineering properties, terminal velocity, aspect ratio, coefficient of friction

INTRODUCTION

Millet crops or Nutri-Cereals are well known as poor man's crop; of late are termed as rich man's diet; because it has numerous nutrients and vitamins and can tolerate adverse environmental conditions like tolerance to moisture stress, resistance to waterlogging. Pearl millet is cultivated globally in 27 million ha (FAO, 1972). Africa is the highest pearl millet producing and consuming country globally and it is the fourth most important cereal crop grown in India (Harinarayana, 1987). Pearl millet 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. It is used as food for human, feed for poultry birds and dry/wet fodder for cattles (Pawase *et al.,* 2021). Mechanization of different post-harvest operations like cleaning, threshing, grading, etc. of Pearl millet 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 pearl millet at different moisture contents for the design and development of suitable gadgets for these operations (Kachru *et al.,* 1994, Sologubik *et al.,* 2013). The physical and aerodynamic properties of pearl millet grain in terms of size, shape, weight, diameter, surface area, and bulk density are essentially required for designing the threshing cylinder, concave clearance of a thresher, sieves, threshing element, hopper, etc., concerning size, and slope (Simonyan, 2005). Singh *et al.,* 2004 and Wilhelm *et al.,* 2004, Chang, 1988; Nelson and You, 1989; Nelson, 1980; Mohsenin, 1980, Obi *et al.,* 2014). A study on the physical properties of Nigerian varieties of pearl millet and their behavior with the moisture content revealed that the biological nature of the material influences its properties; therefore, the properties represents the behavior 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 Pearl millet grain, grown in the state of Odisha by the majority of small and marginal farmers. The physical and engineering properties of any grain such as pearl millet is commonly influenced by a change in its moisture content which are again critically vital for designing the different components of post-harvest gadgets for the same crop. No research work has been reported in this regard particularly for the pearl millet varieties locally available in this part of the country. The experiment was thus conducted to study the moisture-related physical and engineering properties of pearl millet.

MATERIALS AND METHODS

The pearl millet grains of one popular indigenous(Gajapati local) variety were collected in adequate quantity from the Centre for Pulse Research (OUAT), Ratanpur, Ganjam, Odisha, India. The grain samples were prepared by removing foreign materials such as dirt, stones, dust, immature grain, broken grains, and chaffs thorough cleaning and sorting them subsequently. The initial moisture contents of these samples were found following the standard hot-air oven method (AACC, 1995). Since pearl millet is harvested at around 23.5 per cent moisture content and stored at around 10 per cent in India, the moisture content range for the study of the properties of Pearl millet grain was decided accordingly. To study the effects of moisture content on different physical and engineering properties of pearl millet grains, the samples with five levels of moisture contents within the range from 9.2 to 20.9 percent were prepared by adding the desired amount of distilled water as followed by 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 pearl millet grain, selected randomly from the samples (Var: Pusachari and 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 ±0.01mm (Mohsenin, 1970).

Grain size(Dm). The average diameter of the grain was calculated by using the 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). 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).

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

where,

L= length of grain, mm

B=width of grain,mm

T=thickness of grain, mm

Volume(V). The volume was determined by taking the dimensions of the pearl millet 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 with the horizontal at which the material will stand when piled is known as angle of Repose. By using a plywood box apparatus (140 × 160 × 35)mm and plates fixed adjustable the angle of repose can be determined. The sample was filled in the box 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 the angle of repose.

Thousand-grain weight(M1000). One thousand randomly selected grains of test samples at various moisture levels were collected and weighed one 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(PartIV)-1968 was adopted. The average of ten replications has 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 500ml 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.

True Density(TD). True density(ρ_t) was determined using the toluene displacement method (Mohsenin,1986; Singh *et al.,* 1996). Toluene(40ml) 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

$$\text{Density Ratio} = BD/TD \quad (8)$$

Porosity(∈). Porosity 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.

$$\in=1-(BD/TD) \quad (9)$$

Static coefficient of friction(μ). The coefficient of static friction of samples of pearl millet 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 Obi *et. al.*,(2014). The coefficient of friction was calculated using the following equation.

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

where,

μ=coefficient of friction; and

θ=angle of inclination of the material surface.

Terminal velocity. The terminal velocity of pearl millet 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 pearl millet grain (Variety: Pusachari) such as linear dimensions and average diameters within the moisture range of 8.7 percent to21.8 percent have been placed in Table 1.

A. Effect of moisture content on linear dimensions and average diameters

The linear dimensions *i.e.* length, width & thickness of pearl millet grain were found to increase significantly within the moisture content range from 3.30 to 3.71mm, 1.17 to1.31mm, and 0.76 to 0.94 mm respectively which may be due to absorption of moisture by pearl millet grain. The increase in 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 1.65 to 1.98mm, 1.65 to 1.98mm, 2.59 to 2.98mm, and 1.73 to 1.98mm 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 pearl millet grain corresponding to an increase in moisture content agree with the findings reported by Ojediran *et al.*, (2010), Jain *et al*., (1997), Chhabra *et al.,* (2017), Badau *et al.,* (2007), Simonyan *et al.*, (2005) and Kenghe *et al.*, (2015).

Table 1: Effect of moisture content on the physical properties of Pearl millet 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)	Equivalentmean diameter (EQD)
9.2	3.03	1.17	0.76	1.65	1.39	2.59	1.73
11.1	3.28	1.21	0.81	1.76	1.47	2.65	1.76
14.9	3.34	1.23	0.85	1.80	1.51	2.72	1.80
18.3	3.62	1.29	0.89	1.93	1.60	2.91	1.93
20.9	3.71	1.31	0.94	1.98	1.65	2.98	1.98
$CD_{0.05}$	0.069	0.021	0.017	0.027	0.015	0.016	0.019
SE(m)±	0.022	0.007	0.005	0.009	0.005	0.005	0.006

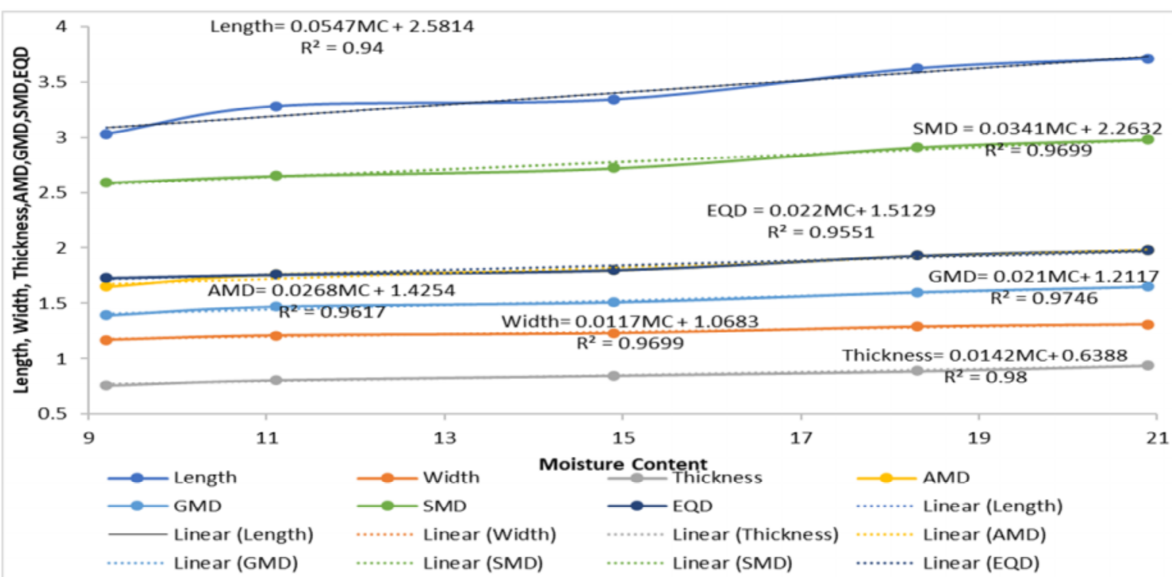

Fig. 1. Effect of moisture content on linear dimensions and average diameters of Pearl Millet grain.

B. Effect of moisture content on physical properties of Pearl Millet

The physical properties i.e., aspect ratio, 1000 grain weight, sphericity, surface area, the volume of pearl millet grain have been placed in Table 2 which were found to increase significantly within the test moisture content from 0.353 to 0.386%, 2.91 to 3.13 g, 0.682 to 0.699%, 6.60 to 8.55mm^2, and 2.69 to 4.56mm^3 respectively, which may be due to absorption of moisture by the pearl millet grain. It was observed that physical properties were increased linearly with an increase in moisture content from 9.2 to 20.9% (w.b.). The increased value of physical properties within the corresponding moisture content was in agreement with the findings of Ojediran *et al.,* (2010), Jain *et al.,* (1997), Chhabra *et al*., (2017), Badau *et al.,* (2007), Simonyan *et al.,* (2005).

The physical properties such as bulk density, true density, and porosity of pearl millet grain decreased with an increase in moisture content whereas density ratio increased within the test moisture content range. It was observed that the bulk density, true density, and porosity decreased from 608.68 to 611.78 kg m^{-3}, 967.53 to 968.93 kg m^{-3} and 0.398 to 0.354% respectively with the corresponding moisture content range 9.2 to 20.9% (wb. The density ratio increased significantly within the test moisture content range from 0.37 to 0.39. The decreased values of bulk density, true density, and porosity of pearl millet grain coincide with the findings of Simonyan *et al.*, (2005), Ojediran *et al.*, (2010), Jain *et al.,* (1997), Chhabra *et al* (2017), Badau *et al.,* (2007).

C. Effect of moisture content on frictional and aerodynamic properties

The result of the effect of moisture content on frictional and aerodynamic properties of pearl millet grain within the moisture content range of 9.2 to 20.9% (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 23.420 to 25.600 at 9.2 % and 20.9% moisture contents respectively. These findings are in agreement with Mitthiga and Mark (2006). The result showed that the terminal velocity increased linearly with an increase in test moisture content range from 4.42 to 4.62 ms^{-1}. These results are in coincidence with the findings of Sial *et al*., (2019), Ojediran *et al.*, (2010), Jain *et a.,l* (1997), Chhabra *et al.,* (2017), Badau *et al.,* (2007).

Table 2: Physical properties of pearl millet grain.

Moisture content (%)	Aspect ratio	Sphericity (%)	1000 Grain weight (g)	Surface area (mm^2)	Volume (mm^3)	Bulk density (kgm^{-3})	True density (kgm^{-3})	Density ratio	Porosity
9.2	35.30	0.686	2.97	6.60	2.69	611.7	968.93	0.629	0.398
11.1	35.63	0.687	3.01	6.78	3.21	610.98	968.59	0.63	0.38
14.9	36.82	0.692	3.04	7.16	3.38	610.57	968.23	0.632	0.37
18.3	36.89	0.696	3.10	8.04	4.15	609.2	967.8	0.634	0.36
20.9	38.61	0.699	3.13	8.55	4.56	608.68	967.5	0.637	0.354
$CD_{0.05}$	0.042	0.003	0.197	0.028	0.029	0.465	0.727	0.022	0.003
SE(m)±	0.013	0.001	0.063	0.009	0.009	0.128	0.233	0.007	0.001

Table 3: Frictional and Aerodynamic properties of Pearl millet.

Moisture content (%)	Angle of Repose (^{0})	Coefficient of friction at different surfaces				Terminal velocity (msec^{-1})
		Glass	Mild steel sheet	GI sheet	Plywood	
9.2	23.42	0.365	0.4022	0.3962	0.339	4.42
11.1	23.53	0.376	0.4062	0.3992	0.345	4.48
14.9	24.51	0.377	0.4082	0.4052	0.348	4.51
18.3	25.49	0.388	0.4102	0.4112	0.351	4.54
20.9	25.60	0.399	0.4142	0.4142	0.357	4.6
$CD_{0.05}$	0.038	0.003	0.005	0.001	0.004	0.027
SE(m)±	0.012	0.001	0.001	0.000	0.001	0.009

The coefficient of friction of pearl millet grain was determined concerning four different surfaces within the test moisture content range from 9.2 to 20.9% (wb). It was observed that the coefficient of friction for all the contact surfaces 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 0.365to 0.398, 0.402 to 0.414, 0.396 to 0.412, and 0.339 to 0.357 respectively at 9.2 - 20.9% (wb) moisture content. The coefficient of friction for plywood 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 Ojediran *et al.,* (2010).

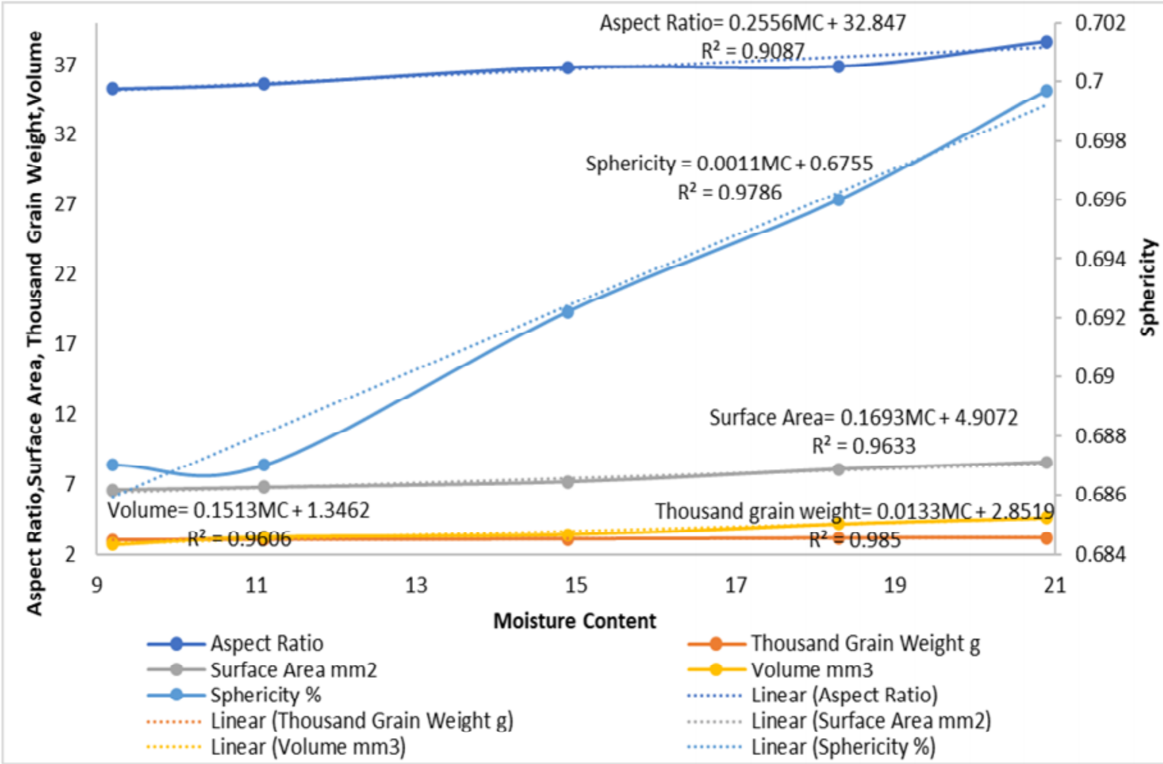

Fig. 2. Effect of moisture content on aspect ratio, 1000 grain weight, surface area, volume and sphericity of Pearl Millet grain.

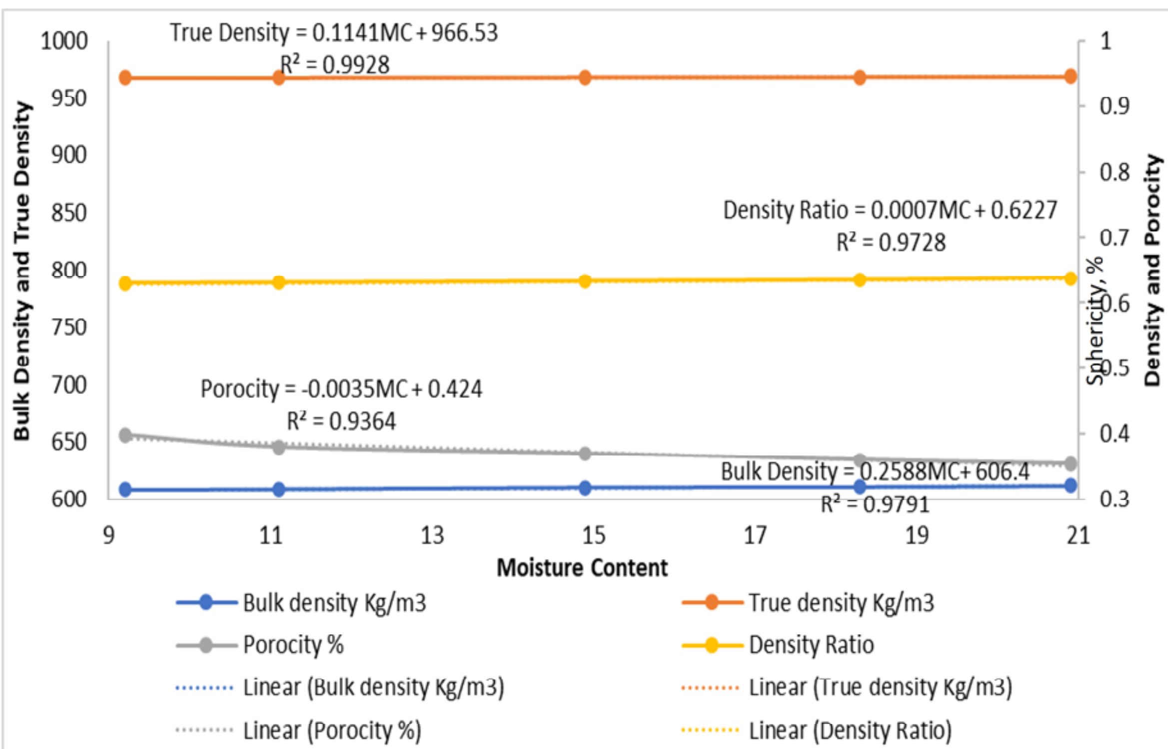

Fig. 3. Effect of moisture content on bulk density, true density, density ratio and Porocity of Pearl millet grain.

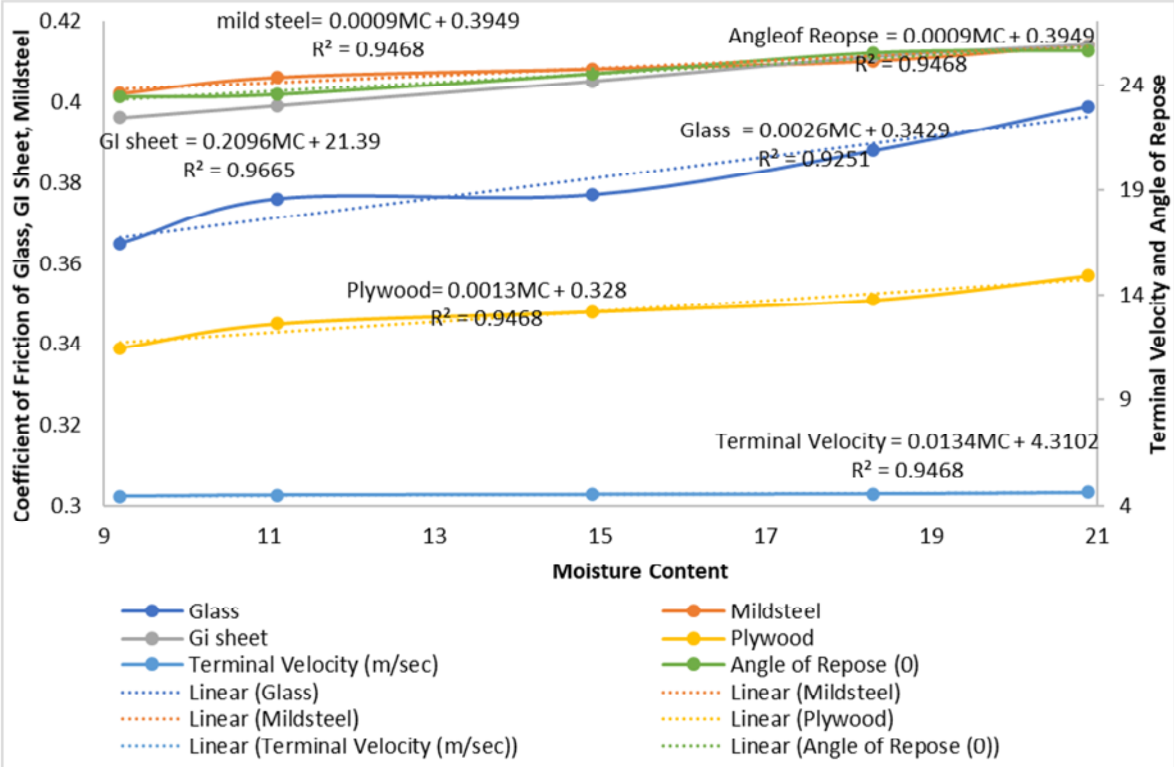

Fig. 4. Effect of moisture content on the coefficient of friction, terminal velocity and Angle of repose of pearl millet grain.

CONCLUSION

The present study provides a piece of comprehensive basic information about the engineering, frictional and aerodynamic properties of pearl millet grain for designing small scale post-harvest machinery especially a pearl millet 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.

FUTURE SCOPE

After studing physical, frictional, aero-dynamic the properties of pearl millet grain with in the moisture content of 9.2–20.9%, it will help in prototype development of Pearl Millet thresher's different parts like hopper, threshing cylinder, screen and aspirator.

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