__Original Research Article__

A Study on Moisture Dependent Properties of Barnyard Millet (*Echinochloa frumentacea*) Grains

---

.

ABSTRACT

A vital component in the design of threshers, dehuskers, shellers, and winnowers is the combination of geometrical, frictional, gravimetric, and aerodynamic characteristics. Consequently, in order to assess these qualities of barnyard millet grain, experiments were conducted. samples within a suitable moisture content range of 6.21 to 22.57% (db) were used in the experiments. Based on the moisture content appropriate for majority of post-harvest operations, a range of 6 to 24% was selected. The geometrical mean diameter, equivalent mean diameter, arithmetic mean diameter, and square mean diameter increased from 2.05 to 2.24 mm, 2.63 to 2.87 mm, 2.18 to 2.38 mm, and 3.67 to 4.00 mm, respectively, with an increase in moisture content.Similarly, the coefficient of static friction with mild steel, GI sheets, plywood, and glass increased linearly from 0.369 to 0.533, 0.342 to 0.492, 0.288 to 0.301, and 0.314 to 0.363, respectively. Comparing the other three surfaces, it was found that mild steel had the highest coefficient of static friction while plywood had the lowest. Porosity, bulk density, and true density decreased from 0.572 to 0.429, 682.92 to 563.72 kgm^{-3}, and 1318.95 to 1196.81 kgm^{-3} within the moisture content range, while angle of repose, aspect ratio, sphericity, surface area, volume, 1000 grain weight, coefficient of internal friction, and terminal velocity increased from 23.62° to 40.82°, 65.53 to 66.77, 0.6492 to 0.6569, 13.20 to 15.76 mm^2, 4.35 to 6.22 mm^3, 3.97 to 5.07 g, 0.556 to 0.863, and 4.42 to 5.23 ms^{-1}.

Keywords: Barnyard millet; engineering properties; millet processing.

1. INTRODUCTION

Barnyard millet (*Echinochloa frumentacea*) is an oldest millet crop grown in warm regions of the globe, notably in India, Japan,China, and Korea. Globally, it is the world's fourth most produced minor millet. In terms of area (0.146 Mha) and production (0.147 MT), India is the world's top producer of barnyard millet, with an average productivity of 1034 kg/ha during the previous three years [1]. It is mainly cultivatedin Indian states of Odisha, Gujarat, Madhya Pradesh, Maharashtra, Bihar, Tamil Nadu, Punjab, and hills of Uttarakhand [2]. It contains 10.1% protein, 3.9% fat, 8.7% moisture, 2.0% total fat, 68.8% carbohydrate,6.7% crude fibre, and 398 kcal/100 g. High dietary fibre content (12.5%) including insoluble (8.4%) and soluble (4.2%) fractions was reportedfor barnyard millet [3]. Mechanization of post-harvest activities of barnyard millet, such as threshing, grading, and cleaning can minimize operating costs and labor requirements.This helps in increasing the net benefit to small and marginal farmers. Subramanium and Viswanathan (2007) [4]evaluated some physical properties like friction coefficient and bulk density of barnyard millet grain. Similarly, Singh et al., 2010 [5] studied the physical, mechanical and engineering properties of barnyard millet grains and kernels. However, the local varieties of barnyard millet grown in Odisha is not studied. The threshing cylinder, threshing element, hopper, sieve size, sieve slope, and concave clearance of a thresher are all designed with consideration to engineering characteristics of barnyard millet grain, including size, weight, shape, surface area, diameter, and bulk density[6–10]. Additional machine parameters, like the threshing cylinder's length, sieve size, speed, air flow velocity and discharge capacity, angle of inclination, etc., are decided as perengineering properties. This includes, physical characteristics like sphericity and equivalent diameter, frictional characteristics like the angle of repose and internal friction [11–18] and aerodynamic properties like terminal velocity. The present experiment was conducted to study the effect of moisture content on engineering properties of barnyard millet grain of variety barnyard millet (*Echinochloa frumentacea*) grown in the state of Odisha by the majority of small and marginal farmers.

2. MATERIAL AND METHODS

The barnyard millet grains were collected in adequate quantity from the Centre for Pulse Research (OUAT), Ratanpur, Ganjam, Odisha, India (20.264512°N 85.81202°E). After precisely cleaning the grain samples to get rid of any extraneous materials such dust, dirt, stones, broken grains, immature grain, and chaffs, they were sorted. The standard hot-air oven procedure was utilised to ascertain the initial moisture levels of these samples [19]. The moisture content range was chosen in accordance with the fact that the crop is harvested in October and November at a dry basis (db) moisture content of 24–26% and is thereafter maintained in the sun to dry until the moisture content falls to 12–14% (db). Samples with five levels of moisture content within the range of 6.21 to 22.57% (db) were prepared by adding the appropriate quantity of distilled water, following the procedure by Coşkun et al., (2006) [20] and Jambamma et al., (2011) [21]. The sample's moisture content was calculated and presented as the average of the four replications.Figure 1 shows the oven drying of samples to determine moisture content. The design of the experiment for the study was Randomized Block Design (RBD) with five treatments (levels of moisture contents) and four replications (values of properties). There were five treatments (levels of moisture content) and four replications (values of properties).Statistical analysis of the results was conducted using Microsoft excel. The association between moisture content and different parameters were modelled using linear, logarithmic, polynomial, and exponential models. The models with best coefficient of determination (R^2) were resulted as most suitable model to predict.

Figure 1. Measurement of moisture content through oven drying

2.1 Geometrical properties

Using an electron microscope with an accuracy of ±0.01 mm, barnyard millet grains were randomly selected and measured along the three principal axis (major (L), medium (W), and minor (T). For every moisture content level, all engineering parameters were measured [16,22].

The geometric mean of the three axial dimensions and the arithmetic mean were used to determine the grain's average diameter. The following relationships were used to compute the grains' arithmetic mean diameter (AMD), geometric mean diameter (GMD), square mean diameter (SMD), and equivalent diameter (EMD) [23].

$$AMD = ((L+W+T))/3 \qquad \text{Equation 1}$$

$$GMD = \sqrt[3]{((LWT))} \qquad \text{Equation 2}$$

$$SMD = \sqrt{((LW + WT + TL))} \qquad \text{Equation 3}$$

$$EMD = ((AMD+GMD+SMD))/3 \qquad \text{Equation 4}$$

By using the expression given by Singh et al., 2010, surface area (S) was calculated [5].

$$S=\pi\times GMD^2 \qquad \text{Equation 5}$$

The aspect ratio (R_a), which is the ratio of longer diameter to shorter diameter, was determined using the relationship provided by Maduako and Faborode. (1990) [24]:

$$R_a = W/L\times100 \qquad \text{Equation 6}$$

Sphericity (ϕ) is defined as the ratio of the surface area of a sphere with the same volume as the grain to the surface area of the grain, and was found using the following formula.[23,25].

$$\phi=\sqrt[3]{LWT}/L \qquad \text{Equation 7}$$

Where,

L= length of grain, mm

W= width of grain, mm

T= thickness of grain, mm

The volume of the grain was determined by taking the dimensions of the grains in three axes of length, width, and thickness in 4 replications at different moisture contents and then the volume was estimated using the relationship as described by Mohsenin (1986) [23].

2.2 Angle of Repose (θ)

The angle at which a material will stand when poured and the horizontal is known as the angle of repose. This was ascertained with the apparatus, which was as shown in Figure 2 and comprised a 140 x 160 x 35 mm wooden box with fixed and adjustable plates. The sample was placed within the box at a fixed height of 15 cm, and the plate was adjusted to tilt the sample at a progressive inclination. This allowed the grains to fall freely and develop a natural slope, or angle of repose.

Figure 2. Measurement of Angle of Repose

2.3 Gravimetric Properties

Using an electronic top pan balance (Contech, India) with a minimum count of 0.01 g, one thousand randomly chosen test sample grains at different moisture levels were gathered and weighed (Figure 3). This magnitude obtained is called as thousand-grain weight. The procedure mentioned in IS: 4333 (Part IV)-1968[26]was followed. The weight of one thousand grains for the sample was recorded based on the average data of ten replications.

Figure 3. Measurement of 1000 grain weight

The bulk density of grains is the ratio of its mass to bulk volume. It was measured using the IS: 4333 (Part III)-1967 [27]. A 500 ml cylinder was filled with grains from a height of 15 cm. Without crushing the grains, the excess grains were taken out by scraping the cylinder's surface. The ratio of the kernel weight to the cylinder's volume was then used to calculate the bulk density.True density (ρ_t) was determined using the toluene displacement method [23, 28]. Toluene (40 ml) was filled in 100ml graduated measuring cylinder and 50g of grains were poured in it. The volume of displaced toluene was measured, and the ratio of sample mass to toluene displacement volume was used to determine the true density.

Density ratio is the ratio of bulk density to true density, which was calculated by the formula

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

The percentage of void volume in the test sample at a given moisture content is called porosity ($\in$). It is computed as the following formula, which expresses the true density value in percentage terms, divided by the difference between the true and bulk densities. The average of ten replications was considered as a percent porosity value of the sample.

$$\in = 1 - BD/TD \qquad \text{Equation 9}$$

2.4Frictional Properties

The coefficient of static friction (μ_s) of the prepared samples of barnyard millet grain were determined in a set up that consists of a hollow wooden box connected to a weighing pan through a thread passing on a pulley. The coefficient of static friction was measured with respect to four surface materials like plywood, glass, galvanized iron and mild steel (Figure 4). As stated by Shashikumar et al., (2018) [22], and Obi et al., (2014)[17], this work investigates the flowability of grains by the hopper. The coefficient of friction was calculated using the equation presented below.

$$\mu_s = \tan\theta \qquad \text{Equation 10}$$

Where,

μ_s = coefficient of friction; and

θ = angle of inclination of the material surface

Figure 4. Measurement of coefficient of friction w.r.t. different materials

The coefficient of internal friction of samples of barnyard millet grains was determined with two hollow wooden boxes of different dimensions, placed one over the other and filled with barnyard millet grains. Then the smaller wooden box was hooked with the weighing pan through a thread. The coefficient of internal friction was calculated using the equation given below.

$\mu_i = (F_1 - F_2)/N$ Equation 11

F_1 = Force required to displace filled wooden box

F_2 = Force required to displace empty wooden box

N = Weight of the barnyard millet grains

2.5 Aerodynamic Properties

The terminal velocity is the air velocity which cancels the effect of gravity; generating suspended state for the grains. It was measured by using an air column apparatus [28]. The measuring process is shown in Figure 5.

Figure 5. Measurement of terminal velocity

3. RESULTS AND DISCUSSION

3.1 Effect of moisture content on linear dimensions and average diameters

The linear dimensions i.e. length, width and thickness of barnyard millet grain was reported increasing from 3.13 to 3.41, 2.09 to 2.27 and 1.33 to 1.46 mm respectively with increased moisture content. Thisis due to absorption of moisture by barnyard millet grain, increasing it's size. A strong relation between moisture content and grain dimensions was found. Similarly, the average diameters i.e., AMD, GMD, SMD, and EMD were observed to increase linearly with an increase in moisture content(Figure 6). It was observed that the AMD, GMD, SMD, and EMD increased significantly from 2.18 to 2.38, 2.05 to 2.24, 3.67 to 4.00 and 2.63 to 2.87 mm respectively with the corresponding moisture content from 6.21 to 22.57%.

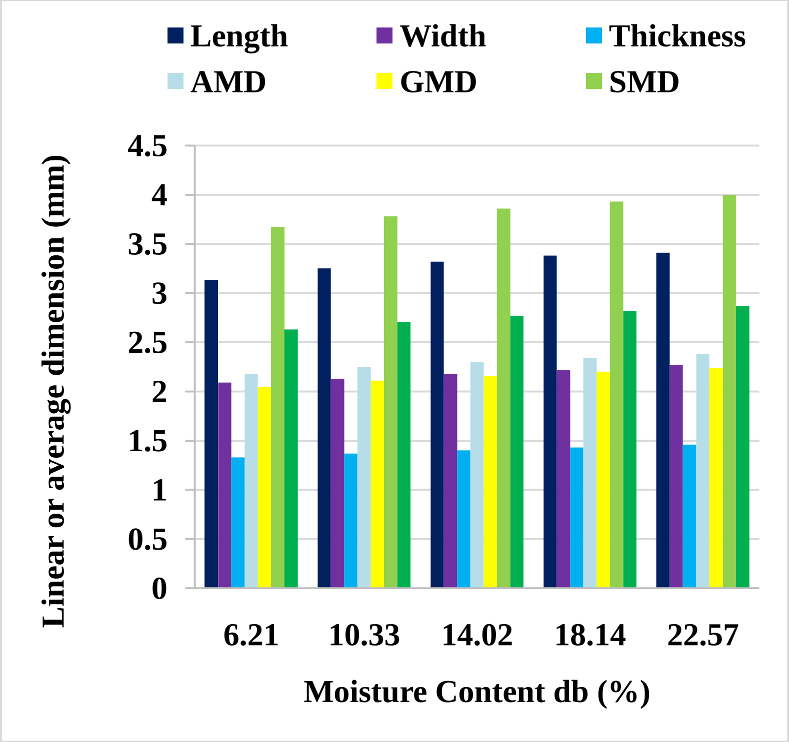


Figure 6. Effect of moisture content on linear dimensions and average diameters of Barnyard Millet grain

The following relations were established between moisture content and linear as well as average diameters.

Length = 0.2216ln(x) + 2.7301 ($R^2 = 0.99$)

Width= 0.0111x + 2.0199 ($R^2 = 0.99$)

Thickness= 0.0079x + 1.2856 ($R^2 = 0.99$)

AMD= $-0.0003x^2 + 0.0221x + 2.0575$ ($R^2 = 0.99$)

GMD= $-0.0003x^2 + 0.0191x + 1.9415$ ($R^2 = 0.99$)

SMD= $-0.0005x^2 + 0.0334x + 3.4823$ ($R^2 = 0.99$)

EMD= $-0.0004x^2 + 0.0248x + 2.4904$ ($R^2 = 0.99$)

3.2 Effect of moisture content on shape

The physical properties i.e. aspect ratio, sphericity, surface area, volume of barnyard millet grain are shown in Figure 7 which were found to increase significantly within the test moisture content from 65.53 to 66.77, 64.92 to 65.69%, 13.20 to 15.76 mm^2, 4.35 to 6.22 mm^3, respectively, which may be due to absorption of moisture by the barnyard millet grain. It was observed that physical properties were increased linearly with increase in moisture content from 6.21 to 22.57% (db).

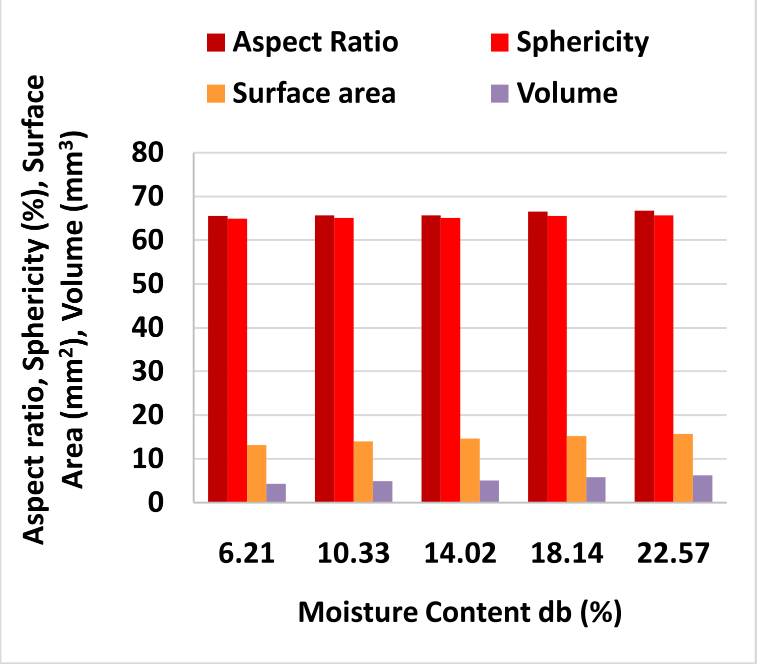


Figure 7. Effect of moisture content on aspect ratio, 1000 grain weight, surface area, volume, and sphericity of Barnyard Millet grain

The following relations were established between moisture content and shape parameters.

Aspect ratio= $0.0037x^2 - 0.0243x + 65.502$ (R^2= 0.90)

Sphericity= $2E\text{-}05x^2 - 1E\text{-}05x + 0.6486$ (R^2= 0.96)

Surface Area= $0.1561x + 12.333$ ($R^2 = 0.99$)

Volume= $0.1157x + 3.6088$ ($R^2 = 0.97$)

3.3 Effect of moisture content on gravimetric properties

While density ratio increased, the physical characteristics of barnyard millet grain, such as bulk density, true density, and porosity, decreased as moisture content increased. With moisture content varying from 6.21 to 22.57% (db), the bulk density, true density, and porosity dropped from 682.92 to 563.72 kgm^{-3}, 1318.95 to 1196.81 kg m^{-3}, and 0.572 to 0.429, respectively. Between the test moisture content range, the density ratio dramatically increased from 0.43 to 0.57. The result is presented in Figure 8.

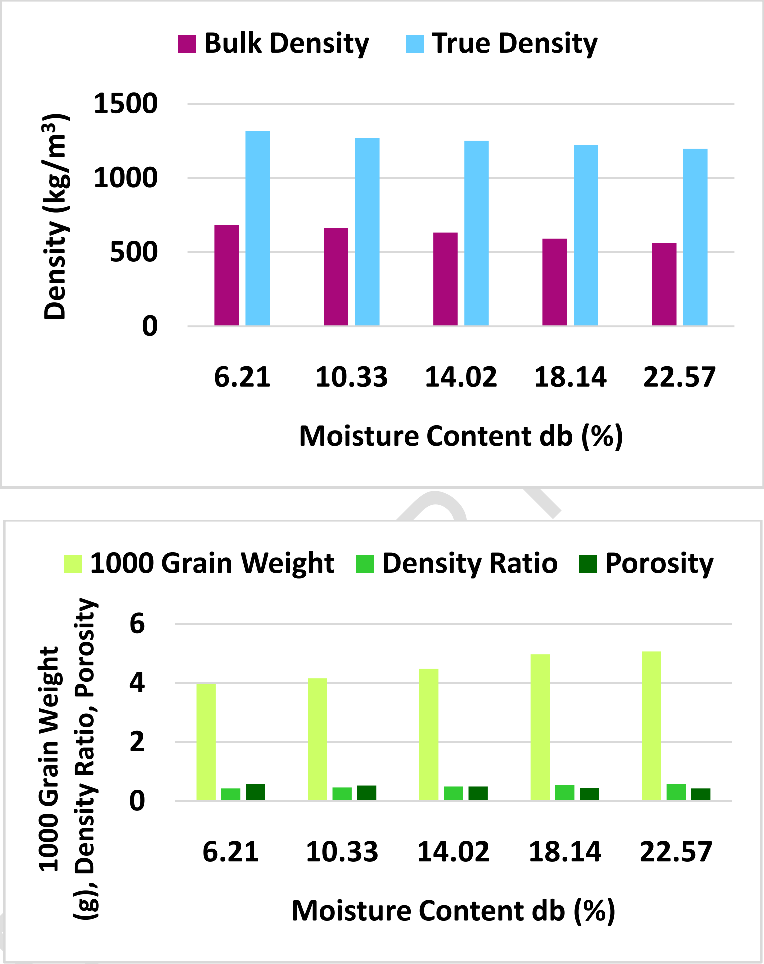


Figure 8. Effect of moisture content on bulk density, true density, density ratio and porosity of Barnyard millet grain

The following relations were established between moisture content and gravimetric properties.

1000 Grain Weight= $0.074x + 3.475$ ($R^2 = 0.96$)

Bulk Density= $-7.7039x + 736.92$ ($R^2 = 0.98$)

True Density= $0.1688x^2 - 12.026x + 1384.1$ ($R^2 = 0.99$)

Porosity= $-0.009x + 0.6249$ ($R^2 = 0.99$)

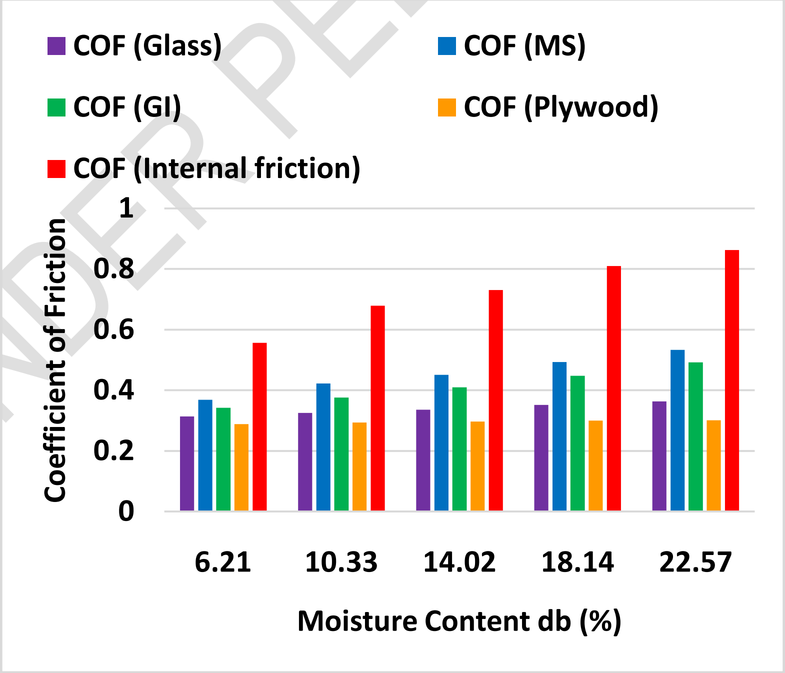
3.4 Effect of moisture content on frictional and aerodynamic properties

The result of the effect of moisture content on frictional and aerodynamic properties of barnyard millet grain within the moisture content range of 6.21 to 22.57% (db) is presented in Figure9. Moisture content has a statistically significant effect on both the angle of repose and terminal velocity. The angle of repose obtained was 23.62° and 40.82° at moisture content of 6.21 and 22.57%, respectively.These findings are in agreement with Singh et al., 2010 [5]. The result showed that the terminal velocity increased linearly with an increase in test moisture content range from 4.42 to 5.23 ms^{-1}.

The coefficient of static friction of barnyard millet grain was calculated for four distinct surfaces within the test moisture rangefrom 6.21 to 22.57% (db). The coefficient of static friction for all contact surfaces increased linearly with moisture content.The data revealed that the lowest value to highest value of glass, mild steel sheet, GI sheet and plywood were found to be 0.314 to 0.363, 0.369 to 0.533, 0.342 to 0.492, and 0.288 to 0.301 respectively at 6.21 to 22.57% (db) moisture content.

When compared with different surfaces, plywood had the lowest coefficient of static friction, while mild steel had the greatest coefficient of static friction.These findings are in agreement with the earlier findings of Subramanium and Viswanathan (2007) [4]; and Singh et al., (2010) [5].

The coefficient of internal friction of barnyard millet grain was determined at moisture range from 6.21 to 22.57% (db). Higher value for coefficient of internal friction was obtained with higher moisture levels. The data revealed that the lowest value to highest value was 0.556 to 0.863 respectively at 6.21 to 22.57% (db) moisture content. The obtained result is presented through Figure 9.



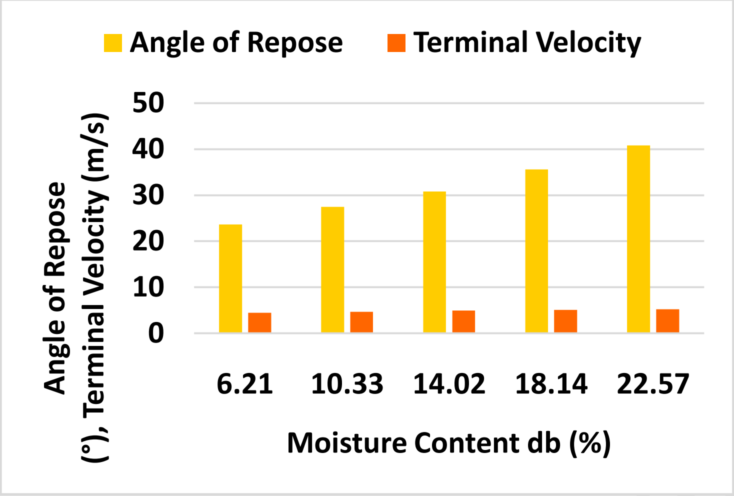


Figure 9 Effect of moisture content on the coefficient of static friction, coefficient of internal friction, terminal velocity and angle of repose of barnyard millet grain

The following relations were established between frictional and aerodynamic properties.

Angle of repose (°)= $1.051x + 16.692$ (R^2=0.99)

Coefficient of static friction (Glass)= $0.0031x + 0.2941$ (R^2=0.99)

Coefficient of static friction (MS)= $0.0098x + 0.3133$ ($R^2 = 0.99$)

Coefficient of static friction (GI)= $0.0092x + 0.2827$ ($R^2 = 0.99$)

Coefficient of static friction (Plywood)= $0.0092x + 0.2827$ ($R^2 = 0.99$)

Coefficient of static friction (Internal)= $0.3025x^{0.3381}$($R^2 = 0.99$)

Terminal velocity (ms^{-1})= $-0.0014x^2 + 0.091x + 3.8939$ ($R^2 = 0.99$)

The trend of increase or decrease of the magnitudes of these engineering properties were found to be similar to the results of Singh et al., (2010) [5]; Panda et al., (2021) [29]; Sabar et al., (2020) [30]; Simonyan et al., (2009) [8]; and Kenghe et al., (2015) [31].

4. CONCLUSION

In order to design small-scale post-harvest machinery, particularly a barnyard millet thresher for small and marginal farmers, the current study offers a thorough understanding of the geometrical, gravimetric, frictional, and aerodynamic properties of barnyard millet grain. This includes information on the angle of repose for designing hopper and feeding chutes, grain size (GMD, SMD, AMD, and EMD) for designing sieve openings, size of holes and concave clearance, coefficient of friction for designing sieve slopes, and terminal velocity for designing blower and aspirator. Post-harvest machineriesand processing equipment can also be designed applying the evaluated properties and their relation to moisture content.

REFERENCES

1. IIMR, Annual Report 2017-18. Hyderabad: Indian Institute of Millets Research 2018.

2. Kumar, P., Lakshmi, N. J., Dube, S. D., & Mani, V. P. (2000). Genotypic differences in photosynthesis and its associated parameters in relation to yield among barnyard millet (Echinochloa frumentacea), genotypes under rainfed condition in hills. *The Indian Journal of Agricultural Sciences*, *70*(4).

3. Ugare, R., Chimmad, B., Naik, R., Bharati, P., &Itagi, S. (2014). Glycemic index and significance of barnyard millet (Echinochloafrumentacae) in type II diabetics. *Journal of food science and technology*, *51*, 392-395. https://doi.org/10.1007%2Fs13197-011-0516-8

4. Subramanium, S., Viswanathan, R., 2007. Bulk density and friction coefficient of selected minor millet grain and flour. *Journal of Food Engineering* 81, 118–126. https://doi.org/10.1016/j.jfoodeng.2006.09.026

5. Singh, K. P., Mishra, H. N., & Saha, S. (2010). Moisture-dependent properties of barnyard millet grain and kernel. Journal of Food Engineering, 96(4), 598-606. https://doi.org/10.1016/j.jfoodeng.2009.09.007

6. Asoegwu, S. N., Ohanyere, S. O., Kanu, O. P., & Iwueke, C. N. (2006). Physical properties of African oil bean seed (Pentaclethra macrophylla). Agricultural Engineering International: CIGR Journal.

7. Hurburgh, Jr. C. R. 1995. An economic model of corn cleaning. Applied Engg., In Agri. 11 (4) 539-547.

8. Simonyan, K.J., Yiljep, Y.D., Oyatoyan, O.B., & Bawa, G.S. (2009). Effects of moisture content on some physical properties of Lablab purpureus (L.) sweet seeds. Agricultural Engineering International: The CIGR Journal, 11.

9. Vilche, C., Gely, M., & Santalla, E. (2003). Physical properties of quinoa seeds. *Biosystems engineering*, *86*(1), 59-65. https://doi.org/10.1016/S1537-5110(03)00114-4

10. Tettamanti, A., A. M. Pagano, and M. C. Gely. 2015. Efecto del contenido de humedadSobrepropiedadesfísicas de unavariedad Argentina de sorgo granífero. In Proc. XV Congreso Argentino de Ciencia y Tecnología de Alimentos.

11. Brooker, D. B., F. Bakker-Arkema, and C. W. Hall. 1992. Drying and Storage of Grains and Oilseeds. New York: Van Nostrand Reinold.

12. Luther, R., Suter, D. A., & Brusewitz, G. H. (2004). Physical properties of food materials. Food & Process Engineering Technology, 23.

13. Chang, C. S. (1988) Measuring density and porosity of seed kernels using a gas pycnometer. Cereal Chemistry. 65 (1):13 – 15.

14. Nelson, S. O., & You, T. S. (1989). Microwave dielectric properties of corn and wheat kernels and soybeans. Transactions of the ASAE, 32(1), 242-0249.

15. Nelson, S. O. (1980). Moisture-dependent kernel-and bulk-density relationships for wheat and corn. Transactions of the ASAE, 23(1), 139-0143.

16. Mohsenin, N. N. (1970). Physical properties of plant and animial materials. Vol. 1. Structure, physical characterisitics and mechanical properties. *Physical properties of plant and animial materials. Vol. 1. Structure, physical characterisitics and mechanical properties.*, *1*. https://doi.org/10.4324/9781003062325

17. Obi, O. F., Anyadike, C. C., &Onyeke, C. O. (2014). Moisture-dependent physical properties of pigeon pea grown in Nigeria. World Applied Sciences Journal, 31(8), 1396-1405.

18. Vaughan, C. E., B. R. Gregg. and J. C. Delouche.1980. Seed Processing and Handling. Seed Tech. Lab. handbook 1. Mississipi State University. Mississipi America.

19. American Association for Clinical Chemistry's (AACC). 1995. Approved methods of the AACC (9th ed). Method 08-01, revised October 1981; Method 44–15A, revised October 1994; Method 46–18, revised October 1994; Method 76-13, approved November 1995. The Association: St. Paul, MN.

20. Coskun, M.B., I. Yalçin and C. Özarslan, (2006) Physical properties of sweet corn seed (Zea mays saccharata Sturt.). J. Food Engg., 74(4): 523-528. https://doi.org/10.1016/j.jfoodeng.2005.03.039

21. Jambamma, Imaya Kumari, and A. Kailappan. 2011. "Study of physicochemical properties of food grain sorghum and product ready-to-cook mix food from sorghum.' International Journal of Recent Scientific Research 1.3: 96-99.

22. Shashikumar, G. S., Pandey, K. M., &Rathinakumari, A. C. (2018). Physical and Engineering Properties of Sorghum Grain Towards Development of Spawn Spreading Machine for Oyster Mushroom (Pleurotus Florida) Cultivation. *The Andhra Agricultural Journal*, *65*, 175-178.

23. Mohsenin, N. N. (1986). Physical characteristics: physical properties of plant and animal materials.

24. Maduako, J. N., &Faborode, M. O. (1990). Some physical properties of cocoa pods in relation to primary processing. *Ife Journal of Technology*, *2*(1), 1-7.

25. Abalone, R., Cassinera, A., Gaston, A., & Lara, M. A. (2004). Some physical properties of amaranth seeds. *Biosystems Engineering*, *89*(1), 109-117. https://doi.org/10.1016/j.biosystemseng.2004.06.012

26. ISI. 1968. IS: (4333 Part-IV) Methods of analysis for food grains. Weight of 1000 grains, Indian Std. Inst., New Delhi ISI. 1967.

27. IS: (4333 Part-III) Methods of analysis for food grains. Determination of hectoliter weight. Indian Standard Institution, New Delhi.

28. Singh, K.K., Goswami, T.K., 1996. Physical properties of cumin seed. Journal of Agricultural Engineering Research 64 (2), 93–98. https://doi.org/10.1006/jaer.1996.0049

29. Panda. S, Swain, S.K., Behera, D., Mohanty, D.K., Mohapatra, A.K., Rayaguru, K., Dash, A.K., (2021) Moisture dependent physical and engineering properties of Pearl millet grains. Biological Forum – An International Journal 13(2): 345-351.

30. Sabar, S.S., Swain, S.K., Behera, D., Mohapatra, A.K., Rayaguru, K., Dash, A.K., (2020). Moisture Dependent Physical and Engineering Properties of Sorghum Grains Int. J. Curr. Microbiol. App. Sci (2020) 9(8): 2365-2375. https://doi.org/10.20546/ijcmas.2020.908.271

31. Kenghe, R. N., Jadhav, M. S., & Nimbalkar, C. A. (2015). Physical properties of sorghum (Sorghum bicolor) grains as a function of moisture content. *IJESRT Int. J. Eng. Sci. Res. Technol*, *4*, 496-504.