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Kirankumar M
Department of Food Packaging & System Development, National Institute of Food Technology, Entrepreneurship, and Management-Thanjavur, Tamil Nadu, India

S Anandakumar
Department of Food Packaging & System Development, National Institute of Food Technology, Entrepreneurship, and Management-Thanjavur, Tamil Nadu, India

Atchaya PT
Department of Food Packaging & System Development, National Institute of Food Technology, Entrepreneurship, and Management-Thanjavur, Tamil Nadu, India

Corresponding Author:
S Anandakumar
Department of Food Packaging & System Development, National Institute of Food Technology, Entrepreneurship, and Management-Thanjavur, Tamil Nadu, India

Effect of moisture content on physical properties of proso millet (*Panicum miliaceum* L.)

Kirankumar M, S Anandakumar and Atchaya PT

Abstract
The physical properties of grain depend upon the moisture content, and they are essential to designing equipment for crop production, material handling, and processing equipment. A study was conducted to know the physical properties of proso millet at moisture levels ranging from 8 to 16 percent. The dimensional properties such as length range between 2.08 to 2.547 mm, width (1.1 to 1.36 mm), thickness (1.39 to 1.72 mm), arithmetic mean diameter (1.47 to 1.80 mm), geometric mean diameter (1.66 to 1.77 mm), Sphericity (1.47 to 1.73), surface area (8.661 to 9.933 mm^2), and sample volume (1.709 to 3.213 mm^3) for proso millet. Dimensional properties increased linearly as moisture content increased. Similarly, grain bulk density and hardness decreased as moisture content increased, i.e., 756.835 to 731.414 kg m^{-3} and 1.43 to 0.74 kg. The true density, porosity, and frictional properties of proso millet increased as the moisture content increased. All physical properties at different moisture levels were significantly different at a 5% significance level.

Keywords: Proso millet, dimensional properties, gravimetric properties, equipment design, frictional properties

Introduction

Proso millet (*Panicum miliaceum* L.) is a yearly millet crop grown primarily for food, feed, and forage in Asian countries such as China and India (Bangar *et al.*, 2021) [5]. The other common names include hog millet, broomcorn millet, and red millet. The smooth, spherical grains are typically white or creamy-white, yellow, or red but can also be grey, brown, or black. They are around 3 mm long and 2 mm wide and are contained within the hull. Proso millet contains proteins (9.4–9.9 g/100 g), fat (1.2–3.8 g/100 g), ash (0.6–3.3 g/100 g) and carbohydrates (70.0–74.0 g/100 g) with various other essential minerals and its nutritive parameters are comparable or better than common cereals (Kumar *et al.*, 2020) [17]. In addition, it contains high lecithin, which supports the neural health system. It is rich in vitamin B, minerals such as P, Ca, Zn, Fe, and essential amino acids (methionine and cysteine). It has a low glycaemic index and lowers the risk of developing type 2 diabetes (Das *et al.*, 2019) [9].

Information on the grain's physical, mechanical, chemical, thermal, and aerodynamic properties is necessary for design considerations for machinery handling and processing food grains. For the selection of the sieve size and inclination of the sieve, as well as the power necessary for size reduction, linear dimensions such as length, width, thickness, geometric mean diameter, and Sphericity are needed; however, surface area and volume are needed for the design of the grain dryer, aerator, heater, and cooler (Igbozulike & Amamgbo, 2019) [12].

Porosity determines the resistance to airflow during the aeration and drying of seed, whereas true density is utilized to construct separation equipment. A bulk density value is necessary to calculate the storage and transport system's capacity. Designing machinery for processing agricultural products requires consideration of friction coefficient (Chakraborty *et al.*, 2018) [8]. The frictional properties, such as the Angle of repose and coefficient of friction are important properties for the design of seed containers and other storage structures (Sologubik *et al.*, 2013) [27].

Millet's physical properties, like those of other grains and seeds, are essential to the design of machinery for handling, harvesting, processing, and storing the grain. The impact the qualities of solid items conveyed by air or water, as well as the cooling and heating loads of food materials (Sahay & Singh, 2004) [22].

In recent years, physical properties of various products like soybean (Deshpande *et al.*, 1993) [10], cumin seeds (K. K. Singh & Goswami, 1996), millets (Baryeh, 2002) [24, 6], lentils (Amin *et al.*, 2004) [2], quinoa seeds (Vilche *et al.*, 2003) [29], minor millets

(Balasubramanian & Viswanathan, 2010) [4], pearl millet (Ojediran *et al*., 2010) [20], proso millet (K. P. Singh *et al*., 2018) [26], pumpkin seeds (Igbozulike & Amamgbo, 2019) [12, 20], have been studied.

This study explored the effect of different moisture levels (8%, 12%, and 16%) on the physical properties of proso millet.

Materials and Methods

Raw material

Proso millet was procured from the South Indian Grains Corporation, Tamil Nadu, and India. The initial moisture content was found to be 12±0.5% w.b. The moisture content of Proso millet was estimated using the (AOAC, 2019) [3] method. The procured grains were sealed in an airtight HDPE container for further studies and to avoid external environmental influence. All of the reagents used in the experiments were analytical grade.

Conditioning of Proso millet

At the time of harvest of proso millet, the moisture content of the grain is around 22.0-26.5%, and it reduces up to 6.5% during storage. Threshing of proso millet is done at a moisture content of 11.2 - 16.3 percent (K. P. Singh *et al*., 2018) [26]. Hence moisture levels of 8%, 12%, and 16%, w.b were selected. The moisture levels of the proso millet were adjusted to 12, 14, and 16% w.b by adding distilled water and then mixing thoroughly for uniform moisture distribution. The conditioned proso millets were then packed in polyethylene bags and stored at 4°C for 24 hrs to attain equilibrium moisture (Balasubramanian & Viswanathan, 2010; K. P. Singh *et al*., 2018) [4, 26]. The amount of water to be added was calculated using the following equation,

$$\boldsymbol{Q_w}=\frac{\boldsymbol{G\ (m_f-m_i)}}{\boldsymbol{100-m_f}} \quad (1)$$

Where Q_w is the weight of water to be added (g); m_i is the initial moisture content of grain sample (% w.b); G is the initial weight of grain sample (g); and m_f is the final moisture content of grain sample (% w.b)

Similarly, to reduce the moisture content in proso millet, a hot air oven drying method was employed. 500 grams of a sample were taken and dried at a temperature of 130 °C (Obi *et al*., 2016) until the desired moisture content was obtained. The moisture was monitored at every 30 mins interval. The conditioned proso millet was packed in air-tight polyethylene bags and stored in a desiccator for physical property studies.

Dimensional Properties

Length, width, and thickness of the proso millet were determined by selecting 10 grains randomly and measured using a digital vernier caliper (Model: mLabs-FC31) having an accuracy of ±0.01 mm, resolution of 0.01 mm, and repeatability of 0.01 mm. The Geometric mean diameter (GMD), Arithmetic mean diameter (AMD), Sphericity, Surface area, and Sample volume were found by using the formula given by (Balasubramanian & Viswanathan, 2010; Baryeh, 2002; Ojediran *et al*., 2010; K. P. Singh *et al*., 2018) [6, 4, 20, 26].

Geometric mean diameter

$$\mathrm{GMD} = (\mathbf{L} * \mathbf{W} * \mathbf{T})^{\mathbf{1/3}} \quad (2)$$

Arithmetic mean diameter

$$\mathrm{AMD} = (\mathrm{L} + \mathrm{W} + \mathrm{T})^{1/3} \quad (3)$$

$$\text{Sphericity } (S_P) = \frac{\mathrm{GMD}}{\mathrm{L}} \quad (4)$$

$$\text{Surface Area} = \pi(\mathrm{GMD})^2 \quad (5)$$

$$\text{The volume of grain (V)} = 0.25\ [\left(\frac{\pi}{6}\right) \mathrm{L}(\mathrm{W} * \mathrm{T})^2] \quad (6)$$

Where L= longest intercept (Length), W= longest intercept normal to L (Width), and T= longest intercept normal to L and B (Thickness).

Gravimetric properties

To obtain the mass of 1000 grains (W_{1000}) randomly selected 1000 grains of proso millet and weighed on a precision electronic balance (reading to 0·001 g). Triplicate values were taken and then extrapolated this weight of 1000 grains at each moisture content (K. P. Singh *et al*., 2018) [26].

True density is defined as the ratio of sample mass to solid volume occupied by the sample. The displacement method of toluene (C_7H_8) was used to determine it. The actual volume was taken as the volume displaced by the toluene (Kakade *et al*., 2019; Thilagavathi *et al*., 2015) [14].

$$\mathrm{T.D} = \frac{\textbf{weight of grains (kg)}}{\textbf{volume of grains excluding void spaces } (\mathbf{m^3})} \quad (7)$$

A cylinder of known volume was used to calculate bulk density. The proso millet was placed in a known volume container and weighed. The bulk density was calculated using the formula (Deshpande *et al*., 1993; Koocheki *et al*., 2007) [10, 16].

$$\mathrm{B.D} = \frac{\textbf{weight of grains (kg)}}{\textbf{volume of grains including void spaces } (\mathbf{m^3})} \quad (8)$$

The porosity of the proso millet was determined from the B.D and T.D values (that were taken earlier) by using the following formula (Mohsenin, 2020) [18].

$$\text{Porosity} = 1 - \frac{\textbf{Bulk density}}{\textbf{True density}} \quad (9)$$

Frictional properties

Coefficient of static friction

A frictionless pulley mounted on a frame, a cylindrical weightless container with both ends open, a loading pan, and test surfaces were used to measure the coefficient of static friction. The container was filled with a known amount of material, and weights were added to the loading pan until the container began to slide on the various test surfaces. The experiment was carried out using proso millet with varying moisture percentages. The coefficient of static friction was determined as the ratio of weights added (frictional force) and material mass (normal force) as given below (Mohsenin, 2020; Monirul Islam Chowdhury *et al*., 2001) [18, 19].

$$u_s = \frac{F}{N} \quad (10)$$

Angle of repose

The Angle of repose is the Angle formed by proso millet when piled from a known height using an empty cylindrical cone of a specific height and diameter. A sample of Proso millet was put on a flat surface. The circumference of the pile was used to compute the radius, and the height of the pile was determined. (Dutta *et al*., 1988; Sologubik *et al*., 2013) [11, 27].

$$\theta = \tan^{-1} \frac{h}{r} \quad (11)$$

Mechanical properties

Hardness measured by using a manually operated Kiya grain hardness tester (Kiya Seisakusho Ltd., Tokyo, Japan) and crushing 10 individual proso millet grains, the hardness of the proso millet were determined, the best three readings were obtained for each hardness value presented. (Jagtap *et al*., 2008) [13].

Statistical analysis

One-way ANOVA and Tuckey test were used to analyze the difference among the means at a 5% significance level, and best-fit regression equations for physical properties were developed by using origin pro (2021).

Results and Discussion

Dimensional properties

It was observed from (Fig.1 a, b, c) that the length, width, and thickness of the proso millet linearly increased with an increase in moisture content from 8 to 16 percent (w. b). Length of proso millet increased from 2.08 to 2.54 mm, width increased from 1.1 to 1.36 mm and thickness increased from 1.39 to 1.72 mm. The increase in size could be attributed to the swelling of the grain due to moisture absorption in the intracellular regions of a grain (Sologubik *et al*., 2013) [27]. The regression equations for length, width, and thickness with moisture content were expressed by a linear relationship with the coefficient of determination ranging 0.862 to 0.993 as presented in table 4.

The AMD (Arithmetic mean diameter), GMD (Geometric mean diameter), and the Sphericity of proso millet have a linear relationship with moisture content. These properties are directly proportional to an increase in length, width, and thickness (Sahoo & Srivastava, 2002) [23]. AMD increased uniformly from 1.47 to 1.80 mm, GMD increased uniformly from 1.66 to 1.77 mm, and Sphericity increased uniformly from 1.47 to 1.73 respectively. The coefficient of determination for these properties ranges from 0.955 to 0.962.

The surface area of the proso millet increased with an increase in the moisture content from 8.661 to 9.933 mm^2. Similarly, the surface volume increased from 1.709 to 3.213 mm^3. Increase in linear dimensions of grain reason for an increase in the surface area and surface volume respectively. The coefficient of determination for these properties ranges from 0.919 to 0.954.

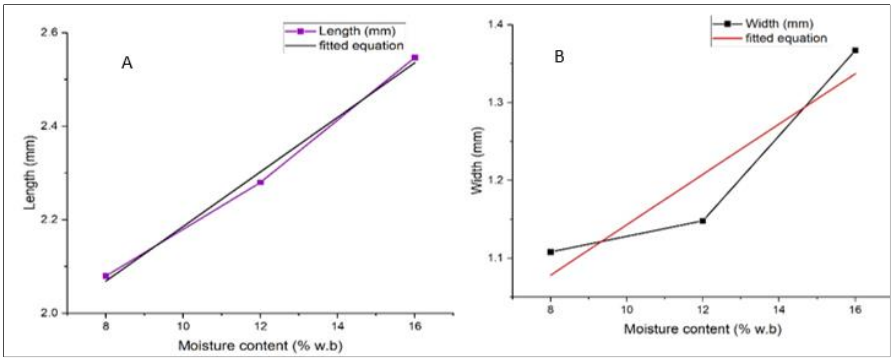
Dimensional properties of proso millet were found to be significantly different at a 5% significance level ($p < 0.05$).

Similar trends were documented for soybean (Deshpande *et al*., 1993) [10], chickpea (Dutta *et al*., 1988) [11], millet (Baryeh, 2002) [6], and proso millet (K. P. Singh *et al*., 2018) [26], pumpkin seeds (Igbozulike & Amamgbo, 2019) [12].

Table 1: Dimensional properties of Proso millet at 8%, 12% and 16% moisture levels

Dimensional properties	8% M.C	12% M.C	16% M.C
Length (mm)	2.08±0.176[b]	2.28±0.328[b]	2.547±0.082[a]
Width (mm)	1.108±0.10[b]	1.148±0.151[b]	1.367±0.094[a]
Thickness (mm)	1.398±0.063[b]	1.478±0.199[b]	1.722±0.249[a]
GMD (mm)	1.66±0.0237[b]	1.697±0.048[b]	1.777±0.036[a]
AMD (mm)	1.473±0.0623[b]	1.557±0.134[b]	1.806±0.116[a]
Surface volume (mm^3)	1.709±0.222[b]	2.076±0.551[b]	3.213±0.704[a]
Surface area (mm^2)	8.661±0.250[b]	9.054±0.516[b]	9.933±0.408[a]
Sphericity	1.473±0.062[b]	1.560±0.133[b]	1.737±0.213[a]

All the values are mean ± SD of 10 replications. Values with different superscripts differ significantly ($p < 0.05$). AMD-Arithmetic mean diameter, GMD-Geometric mean diameter.



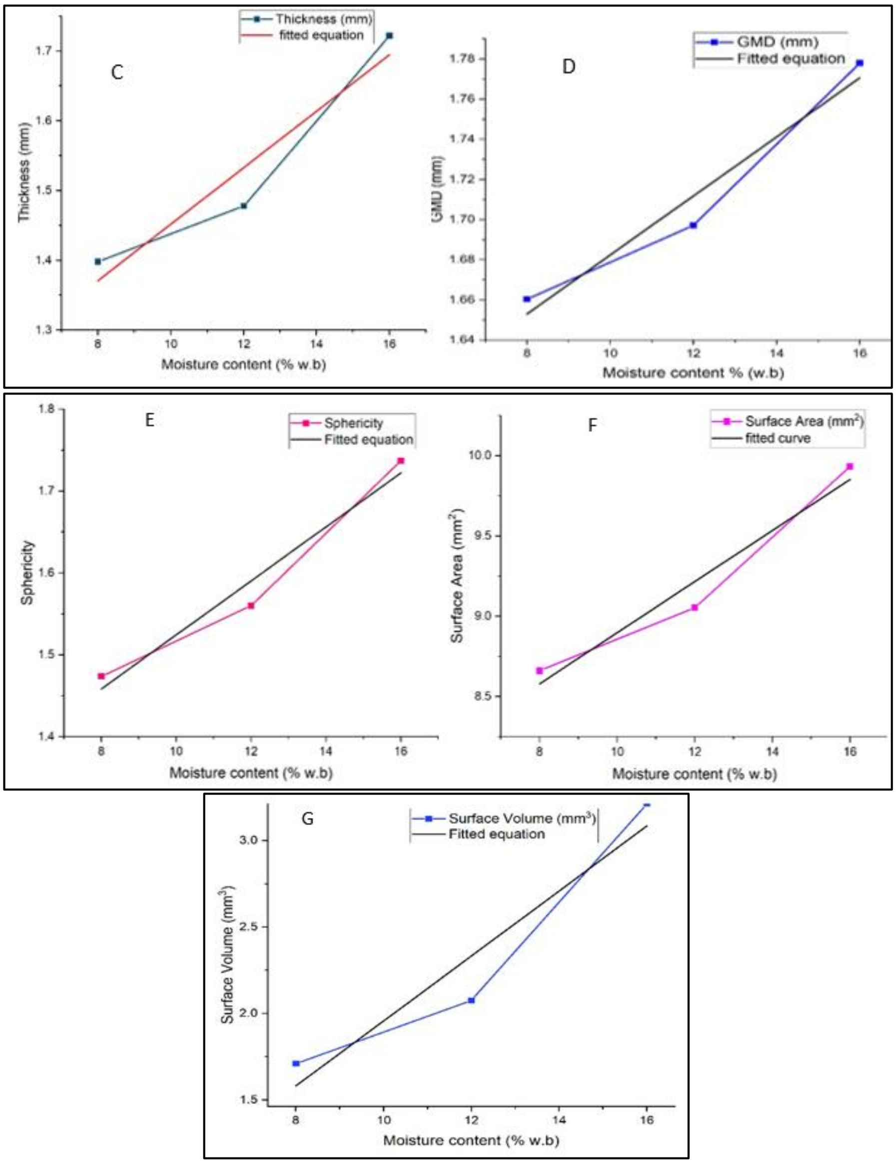


Fig 1: Effect of moisture on dimensional properties.

Gravimetric properties

The bulk density of the proso millet at different moisture levels varied significantly ($p < 0.05$) from 756.835 to 731.414 kg m^{-3} Fig 2, (H). The bulk density of proso millet decreased when the moisture content increased from 8% to 16% (w.b). This is attributed to the increased mass of the grain because an increase in moisture caused less volume expansion of grains, that is, the volume of air entrained between wetter grains was greater than the volume of inter-grain air in drier grains. The relationship between moisture content and bulk density is given in Table 4. The R^2 value for bulk density is 0.970.

The true density of proso millet at different moisture levels varied from 1356.192 to 1484.97 kg/m³ Fig 2, (I). The effect of moisture content on the true density of proso millet showed an increase concerning moisture content from 8% to 16%. The increase in true density is attributed to an increase in the weight of the grain. The linear equation was presented in table.4 and the R^2 value for true density is 0.999.

The porosity of the proso millet increased with an increase in moisture content from 8% to 16% as depicted in Fig 2, (J). The results also showed that the porosity of proso millet ranged from 44.19% to 50.74%. Since the porosity depends on the bulk and true densities, the magnitude of variation in porosity depends on these factors only. The best-fitted equation shown in table 4.0

Bulk density, true density, and porosity values of proso millet were found to be significantly different at a 5% significance level ($p < 0.05$).

Similar trends were reported for pomegranate seeds (Kingsly *et al*., 2006) [15], barbunia seeds (Cetin, 2007) [7], green wheat (Al-Mahasneh & Rababah, 2007) [1], pearl millet (Ojediran *et al*., 2010) [20], and soybean (Kakade *et al*., 2019) [14].

Table 2: Gravimetric properties of Proso millet at 8%, 12%, and 16% moisture levels

Gravimetric properties	8%	12%	16%
Bulk density (Kg/m³)	756.835±0.5^a	747.991±0.27^b	731.414±0.27^c
True density (Kg/m³)	1356.192±0.28^c	1417.432±0.5^b	1484.97±0.5^a
Porosity (%)	44.193±0.027^c	47.228±0.03^b	50.745±0.01^a
Thousand grains weight (g)	5.465±0.5^a	5.995±0.27^a	6.210±0.5^a

All the values are mean ± SD, n = 3. Values with different superscripts differ significantly ($p < 0.05$).

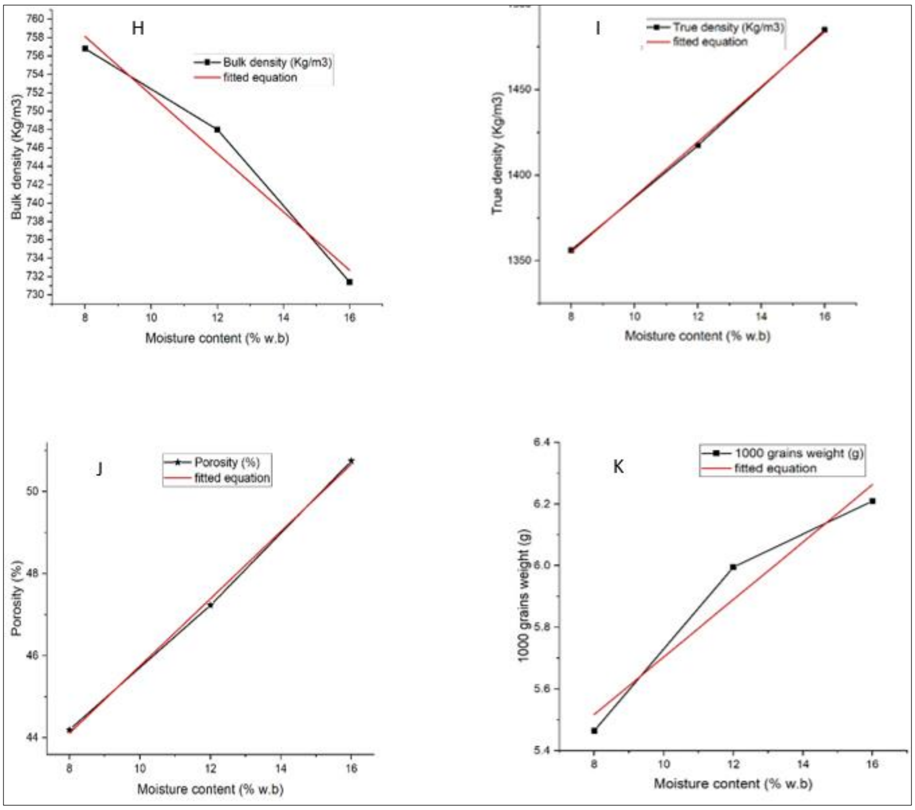


Fig 2: Effect of moisture on gravimetric properties.

Frictional properties

The frictional property such as coefficient of static friction for different surfaces and Angle of repose of proso millet was found to be statistically significant ($p< 0.05$) at different moisture levels (Table 3).

The coefficient of static friction of proso millet obtained on five structural surfaces against moisture content in the range of 8 to 16 percent (w.b) was shown in Fig. 3 (L). It was found that the coefficient of static friction increased with the increase in the moisture level of the proso millet against all the structural surfaces. Cardboard surfaces showed the highest coefficient of static friction and lowest coefficient of static friction found in glass surfaces among all the structural surfaces. The R^2 values for the coefficient of static friction range from 0.881 to 0.999. The best-fit equations were shown in table 4.

A similar trend was followed for barnyard millet (K. P. Singh *et al.*, 2010) [26] and in minor millets (Balasubramanian & Viswanathan, 2010) [4].

The Angle of repose showed an increasing trend with moisture content Fig. 3, (M). The Angle of repose ranges between 41.886° to 47.376°. This can be attributed to the moisture in the surface layer of the grain that keeps them bound together by the surface tension effect (Pradhan *et al.*, 2008) [21]. The Angle of repose is important in the design of openings of hoppers, pending side walls, and storage structures in the bulk of seeds per ramp. Therefore, the moisture content of the grains should be taken into account when designing such equipment and structures. The linear relationship between the Angle of repose and the moisture content is given in table 3.0.

The obtained results are similar to the values obtained by Baryeh, (2002) [6] for millets, and Balasubramanian & Viswanathan, (2010) [4] for minor millets.

Table 3: Frictional properties and Hardness of Proso millet at 8%, 12%, and 16% moisture levels

1. Coefficient of static friction	**8% M.C**	**12% M.C**	**16% M.C**
Wooden surface	0.663±0.032^{b}	0.753±0.050^{ab}	0.788±0.032^{a}
Cardboard	0.9±0.05^{a}	0.933±0.12^{a}	0.95±0.01^{a}
Plyboard	0.55±0.05^{a}	0.623±0.14^{a}	0.696±0.01^{a}
Fibreboard	0.66±0.01^{a}	0.68±0.16^{a}	0.693±0.02^{a}
Glass surface	0.59±0.036^{c}	0.67±0.06^{b}	0.773±0.025^{a}
2.Angle of repose °	41.886±2.10^{a}	45.75±4.91^{a}	47.376±0.89^{a}
3.Hardness (kg)	1.43±0.165^{a}	1.13±0.125^{b}	0.74±0.117^{c}

All the values are mean ± SD of 3 replications. Values with different superscripts differ significantly ($p < 0.05$).

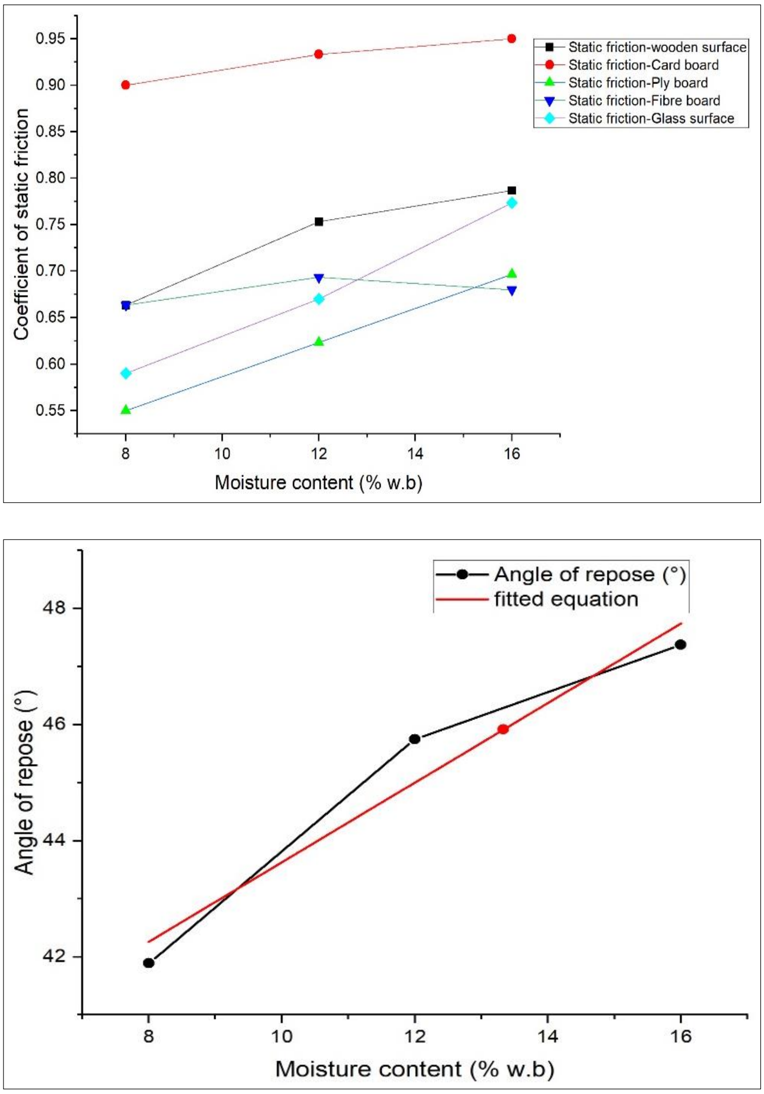


Fig 3: Effect of moisture on frictional properties.

Mechanical properties

Hardness showed a decreasing trend with an increase in moisture content from 8 to 16 percent Fig. 4, (N). The hardness values range from 1.43 to 0.74 kg. At high moisture levels, grain became brittle and more susceptible to fracture. It suggests that more power was required to break the seed with less moisture. Kingsly *et al*. 2006 [15] found that the hardness of dried pomegranate seeds reduced linearly from 87 N to 50 N as moisture content increased from 6.0 to 18.13 percent (d.b) and for minor millets.(Balasubramanian & Viswanathan, 2010) [4].

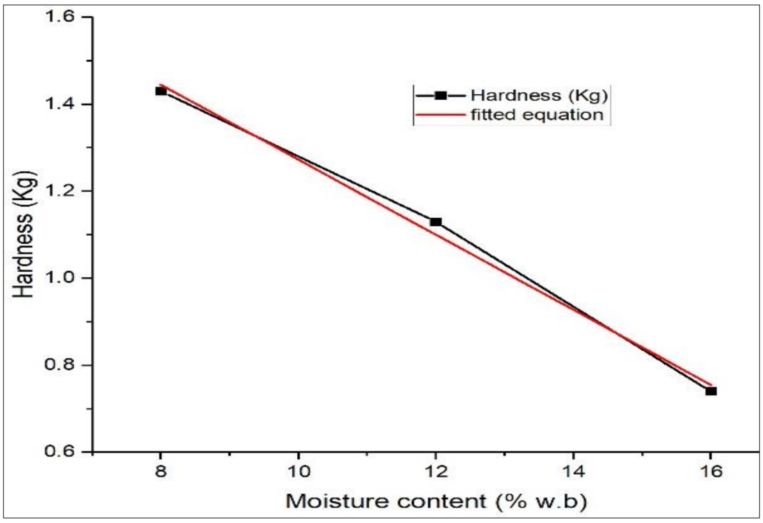


Fig 4: Effect of moisture on the hardness of proso millet.

Table 4: Best fit equations for Physical properties

Properties	Fitted Equation	R^2
Dimensional properties		
Length (mm)	Length = 1.602 + 0.05838 M	0.993
Width (mm)	Width = 0.8192 + 0.03237 M	0.862
Thickness (mm)	Thickness = 1.047 + 0.04050 M	0.921
GMD (mm)	GMD = 1.535 + 0.01471 M	0.955
AMD (mm)	AMD = 1.195 + 0.03294 M	0.960
Surface volume (mm^3)	Surface Volume = 0.0776 + 0.1880 M	0.919
Surface area (mm^2)	Surface area = 7.307 + 0.1591 M	0.954
Sphericity	Sphericity = 1.195 + 0.0349 M	0.962
Gravimetric properties		
Bulk density (Kg/m^3)	Bulk density = 783.5 - 3.178 M	0.970
True density (Kg/m^3)	True density = 1226 + 16.10 M	0.999
Porosity (%)	Porosity = 37.56 + 0.8189 M	0.998
Thousand grains weight (g)	1000 grains weight = 4.773 + 0.093 M	0.944
Coefficient of static friction u_s		
Wooden surface	u_s = 0.5494 + 0.01542 M	0.934
Card board	u_s = 0.8528 + 0.006250 M	0.964
Ply board	u_s = 0.4033 + 0.01833 M	0.999
Fibre board	u_s = 0.6305 + 0.004584 M	0.881
Glass surface	u_s = 0.4028 + 0.02292 M	0.994
Angle of repose °	Angle of repose = 36.77 + 0.6862 M	0.948
Hardness (kg)	Hardness = 2.135 - 0.08625 M	0.944

Conclusion

The physical properties of proso millet are useful for designing various processing equipment for proso millet. The physical properties of proso millet at 8%, 12%, and 16% (w.b) moisture levels were analyzed. The physical properties such as dimensional properties, frictional properties, true density, and thousands of grain weight increased as the moisture level increased. The bulk density decreased from 756.835 to 731.414 kg m^{-3} and hardness decreased from 1.43 to 0.74 kg as the moisture level increased. This information might be useful in designing equipment for crop production, material handling, and processing of proso millet.

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References

1. Al-Mahasneh MA, Rababah TM. Effect of moisture content on some physical properties of green wheat. Journal of Food Engineering. 2007;79(4):1467-1473. https://doi.org/10.1016/j.jfoodeng.2006.04.045
2. Amin MN, Hossain MA, Roy KC. Effects of moisture content on some physical properties of lentil seeds. Journal of Food Engineering. 2004;65(1):83-87. https://doi.org/10.1016/j.jfoodeng.2003.12.006
3. AOAC. Association of Official Analytical Chemists (AOAC) Official Methods of Analysis of AOAC International. 2019. https://www.aoac.org/official-methods-of-analysis-21st-edition-2019/
4. Balasubramanian S, Viswanathan R. Influence of moisture content on physical properties of minor millets. Journal of Food Science and Technology. 2010;47(3):279-284. https://doi.org/10.1007/s13197-010-0043-z
5. Bangar SP, Ashogbon AO, Dhull SB, Thirumdas R, Kumar M, Hasan M, *et al*. Proso-millet starch: Properties, functionality, and applications. International Journal of Biological Macromolecules. 2021;190:960-968. https://doi.org/10.1016/j.ijbiomac.2021.09.064
6. Baryeh EA. Physical properties of millet. Journal of Food Engineering. 2002;51(1):39-46. https://doi.org/10.1016/S0260-8774(01)00035-8
7. Cetin M. Physical properties of barbounia bean (*Phaseolus vulgaris* L. cv. 'Barbounia') seed. Journal of Food Engineering. 2007;80(1):353-358. https://doi.org/10.1016/j.jfoodeng.2006.06.004
8. Chakraborty SK, Chandel NS, Kotwaliwale N, Sadvatha RH, Fasake VD, Mishra SS, *et al*. Characterisation of Properties for Karanj (*Pongamia pinnata*) Seeds and Kernels in Relation to Bulk Handling and Processing Applications. Agricultural Research. 2007;7(3):280-289. https://doi.org/10.1007/s40003-018-0319-5
9. Das S, Khound R, Santra M, Santra DK. Beyond bird feed: Proso millet for human health and environment. Agriculture (Switzerland), 2019, 9(3). https://doi.org/10.3390/agriculture9030064
10. Deshpande SD, Bal S, Ojha TP. Physical Properties of Soybean. Journal of Agricultural Engineering Research. 1993;56(2):89-98. https://doi.org/10.1006/jaer.1993.1063
11. Dutta SK, Nema VK, Bhardwaj RK. Physical properties of gram. Journal of Agricultural Engineering Research. 1988;39(4):259-268. https://doi.org/10.1016/0021-8634(88)90147-3
12. Igbozulike AO, Amamgbo N. Effect of Moisture Content on Physical Properties of Fluted Pumpkin Seeds. Journal of Biosystems Engineering. 2019;44(2):69-76. https://doi.org/10.1007/s42853-019-00015-z
13. Jagtap PS, Subramanian R, Singh V. Influence of Soaking on Crushing Strength of Raw and Parboiled Rice. International Journal of Food Properties. 2008;11(1):127-136. https://doi.org/10.1080/10942910701272320
14. Kakade A, Khodke S, Jadhav S, Gajabe M, Othzes N. Effect of Moisture Content on Physical Properties of Soybean. International Journal of Current Microbiology and Applied Sciences. 2019;8(04):1770-1782. https://doi.org/10.20546/ijcmas.2019.804.206

15. Kingsly ARP, Singh DB, Manikantan MR, Jain RK. Moisture dependent physical properties of dried pomegranate seeds (Anardana). Journal of Food Engineering. 2006;75(4):492-496. https://doi.org/10.1016/j.jfoodeng.2005.04.033
16. Koocheki A, Razavi SMA, Milani E, Moghadam TM, Abedini M, Alamatiyan S, Izadkhah S. Physical properties of watermelon seed as a function of moisture content and variety. International Agrophysics. 2007;21(4):349-359.
17. Kumar SR, Sadiq MB, Anal AK. Comparative study of physicochemical and functional properties of pan and microwave cooked underutilized millets (proso and little). LWT. 2020;128:109465. https://doi.org/10.1016/j.lwt.2020.109465
18. Mohsenin NN. Physical Properties of Plant and Animal Materials. Routledge, 2020.
19. Monirul Islam, Chowdhury M, Sarker RI, Bala BK, Hossain MA. Physical properties of gram as a function of moisture content. International Journal of Food Properties. 2001;4(2):297-310. https://doi.org/10.1081/JFP-100105195
20. Ojediran JO, Adamu MA, George DLJ. Some physical properties of Pearl millet (*Pennisetum glaucum*) seeds as a function of moisture content. African Journal of General Agriculture. 2010;6(1):39-46.
21. Pradhan RC, Naik SN, Bhatnagar N, Swain SK. Moisture-dependent physical properties of Karanja (*Pongamia pinnata*) kernel. Industrial Crops and Products. 2008;28(2):155-161. https://doi.org/10.1016/j.indcrop.2008.02.006
22. Sahay KM, Singh KK. Unit operations of agricultural processing (reprint). Vikas Publishing House Pvt. Limited, 2004.
23. Sahoo PK, Srivastava AP. PH-Postharvest Technology. Biosystems Engineering, 2002;83(4):441-448. https://doi.org/10.1006/bioe.2002.0129
24. Singh KK, Goswami TK. Physical Properties of Cumin Seed. Journal of Agricultural Engineering Research. 1996;64(2):93-98. https://doi.org/10.1006/jaer.1996.0049
25. Singh KP, Chandel NS, Potdar RR, Jat D, Agrawal KN, Hota S. Journal of Agricultural Engineering, 2018, 55(2).
26. Singh KP, Mishra HN, Saha S. Moisture-dependent properties of barnyard millet grain and kernel. Journal of Food Engineering. 2010;96(4):598-606. https://doi.org/10.1016/j.jfoodeng.2009.09.007
27. Sologubik CA, Campañone LA, Pagano AM, Gely MC. Effect of moisture content on some physical properties of barley. Industrial Crops and Products. 2013;43:762-767. https://doi.org/10.1016/j.indcrop.2012.08.019
28. Thilagavathi T, Kanchana S, Banumathi P, Hemalatha G, Vanniarajan C, Sundar M, *et al*. Physico-Chemical and Functional Characteristics of Selected Millets and Pulses. Indian Journal of Science and Technology. 2015;8(S7):147. https://doi.org/10.17485/ijst/2015/v8is7/70075
29. Vilche C, Gely M, Santalla E. Physical Properties of Quinoa Seeds. Biosystems Engineering. 2003;86(1):59-65. https://doi.org/10.1016/S1537-5110(03)00114-4