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Moisture dependent physical, thermal and functional properties of little millet (Variety: BL-6)

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Abstract
Little millet or kutki is a type of small millet which is highly nutritious and is found all over India especially in marginal and degraded lands. The variety BL-6 locally found in Chhattisgarh was evaluated for its moisture dependence on physical, thermal and functional properties. Physical properties of raw little millet grains varied significantly with increase in moisture content in the range studied (6.02-20.05% (db)). Length (2.10-2.72 mm), width (1.35-1.76 mm), thickness (1.01-1.60 mm), AMD (1.49-2.02 mm), GMD (1.41-1.96 mm), Ds (0.84-1.15 mm), De (1.24-1.71 mm), aspect ratio (64.54-65.14), sphericity (67.04-72.65), surface area (5.33-10.34 mm^2), volume (1.05-2.89 mm^3), thousand grain weight (1.92-2.88 g), angle of repose (27.19-38.29°) and coefficient of friction (in the surfaces *viz.*, glass (0.47-0.58), plywood (0.41-0.59), rubber (0.59-1.22) and mild steel (0.54-0.69) increased significantly with increase in grain initial moisture content. However, the properties such as, bulk density (745.38-699.53 kg/m^3), true density (1149.55-980.97 kg/m^3) and porosity (49.23-28.34%) decreased with the increase in grain moisture. Also, the thermal conductivity (0.066-0.112 W/m.K) increased and thermal resistivity (1533.33-896.33 °C cm/W) decreased significantly in the moisture range of 6.02-20.05% (db). Functional properties, *viz.*, hydration capacity (6.46×10^{-}4-7.53×10^{-4} g/1000 grains) varied with grain moisture content, hydration index (33.81- 22.46%) decreased, swelling capacity (3.67×10^{-4} to 1.30 ×10^{-3} mL/1000 grains) and swelling index (17.10-35.45%) increased in the studied moisture range.

Keywords: Physical, decreased, swelling capacity

1. Introduction

Millets are dry land climate compliant crops which are highly nutritious and essential for health and growth of mankind. They belong to the grass family, Graminae (FAO, 1972) [7] and the term "millet" inexplicitly refers to several types of small seeded annual grasses (FAO and ICRISAT, 1996) [8]. These are staple foods of many developing nations, especially drylands of Asia and Africa where more than 97% of millets are produced and consumed. Millets are classified as major and minor millets based on their grain size. Major millets include sorghum (*Sorghum bicolor*), pearl millet (*Pennisetum glaucum*) and finger millet (*Eleusine coracana*); whereas minor millets include foxtail millet (*Setaria italica*), little millet (*Panicum sumatrense*), kodo millet (*Paspalum scrobiculatum*), proso millet (*Panicum miliaceum*) and barnyard millet (*Echinochloa esculenta*). Africa is the home to most of the millets which later got domesticated to other parts of the world. Today millets are cultivated in almost 93 countries, where only 7 countries have more than 1 Mha area under millets. In North American and European countries, millets are slowly gaining popularity due to their gluten-free and hypoglycemic property (Bora, 2013) [3].

Despite their superior nutritional quality, their consumption has decreased over the years in India, because of the drudgery in the processing of millets (Chethan and Malleshi, 2007) [4]. Also, the consumption pattern has been noted to be declined because of the decline in area, production and productivity of millets as compared to other cereal crops due to various reasons. One of the most prominent reasons could be that millets being lesser remunerative crops compared to other cash and high value crops. In spite of all these millets occupy a substantial area under cultivation as they are grown in the unfertile lands with limited resources. However, because of the presence of nutritive elements and beneficial uses of millets, various products are being developed and processes are also being mechanized to revive their production and consumption. Little millet is indigenous to south-east Asia and is grown all over India up to altitudes of 2100 m. Although little millet has received very little attention from plant breeders, it can sustain well under conditions where no other edible plants can survive. It matures between 2.5 to 5 months.

The yield is generally less than 0.5 t/ha, but under favorable conditions, may reach close to 1 t/ha (Silas, 2001). in an area of 0.26 Mha in 2016 (IIMR estimates based on FAO/DES-GOI data, 2016) [8]. It contains phosphorus, iron and protein (7-12%) with a well-balanced amino acid profile. About 65% carbohydrates in the form of non-starchy polysaccharides and dietary fiber is also found in little millet (Menon, 2004) [13].
Study of physical, thermal and functional properties of grains are important in designing and handling of equipments and also in the storage and processing of grains. Influence of moisture content on the engineering properties of agricultural materials are essential in easy understanding of the design of machines, structures, processes and controls for development and determination of efficiency of operation of a particular equipment and also in retaining the quality of final product. So, the study on moisture dependence was taken up so as to find and exploit these properties and find new uses.

2. Material and methods
2.1 Raw material
Little millet grains of variety BL-6 were procured from Krishi Vigyan Kendra, Jagdalpur, Bastar district of Chhattisgarh in the year 2019-20 (Fig. 1). The moisture content of little millet at the time of procurement was 18.56% (wb) which was brought down to 13.64% (wb) by drying under sun. Well dried and cleaned little millet was then transferred to metallic containers and stored safely in dry place to be used in the different experiments.

Fig 1: Little millet

Screen analysis was carried out to find out average grain size. For particle size analysis, a set of Indian Standard Screens with IS No. 170, 140, 120, 100, 85, 70, 60 and 50 along with cover was used for a sample size of 300 g and shook in a gyratory sieve shaker (GSS-8-MT, Macro Scientific Works Pvt. Ltd., Delhi, India) for 10 minutes.
Fineness modulus and average particle size of little millet sample was calculated as follows (Sahay and Singh, 2004):

$$FM = \frac{\text{Sum of weight fractions retained above each sieve}}{100} \quad (1)$$

$$D_p = 0.135\ (1.366)^{FM} \quad (2)$$

Where
FM = Fineness modulus
D_p= Average particle size, mm

2.2 Moisture adjustment
Different properties of little millet samples were determined in the moisture content range of 6.62 - 20.05% (db). Amount of water to be added to obtain desired range was calculated by the following equation (Balasubramanian and Viswanathan, 2010) [1].

$$Q = W_i \frac{m_f - m_i}{100 - m_f} \quad (3)$$

Where
Q = weight of water to be added, g
W_i = initial weight of sample, g
m_i = initial moisture content of sample, % db
m_f = final moisture content of sample, % db

After addition of water, the grain samples were kept in refrigerator (4±1 °C) in sealed polyethylene bags of 51 µm thickness for minimum 10 days. The equilibrated moisture contents of the samples were obtained to be 6.62, 8.36, 9.88, 15.80 and 20.05% (db). Before starting each experiment, the samples were taken out of the refrigerator and equilibrated at room temperature for 2 h. Moisture content was again measured using infrared moisture meter (MX-50, A&D Company Ltd., Japan; LC-0.01%).

2.3 Physical properties of little millet grains
2.3.1 Size and shape
Three different dimensions of 100 grains were determined manually using a digital vernier caliper (Titan Classic, India) with least count of 0.01 mm (Fig. 3.3). Following equations were used to determine the size and shape of the grains (Ramashia *et al*., 2018; Mishra *et al*., 2015) [18, 14].

$$D_g = (L \times W \times T)^{\frac{1}{3}} \quad (4)$$

$$D_a = \frac{L+W+T}{3} \quad (5)$$

$$D_s = \frac{(LW+WT+TL)^{1/2}}{3} \quad (6)$$

$$D_e = \frac{D_g+D_a+D_s}{3} \quad (7)$$

Where
D_g= Geometric mean diameter, mm
D_a = Arithmetic mean diameter, mm
D_s = Square mean diameter, mm
D_e = Equivalent diameter, mm
L = Length
W = Width
T = Thickness

The criterion used to describe shape of grain is sphericity which was calculated using the following expression (Mohsenin, 1980) [15].

$$S = \frac{D_g}{L} \quad (8)$$

Where, S is the sphericity of the grain.

2.3.2 Surface area

Surface area of the little millet grains was calculated using the following expression (Ramashia *et al.*, 2018) [18].

$$\text{Surface area } (mm^2) = \frac{\pi B L^2}{(2L - B)} \quad (9)$$

Where

$B = (WT)^{1/2}$

L = Length, mm

W = Width, mm

T = Thickness, mm

2.3.3 Volume

Volume of the little millet grains was determined using the equation given by Ramashia *et al.* (2018) [18].

$$\text{Volume } (mm^3) = \frac{\pi B^2 L^2}{6(2L - B)} \quad (10)$$

2.3.4 Aspect ratio

Aspect ratio in percentage was calculated by the following expression (Ramashia *et al.*, 2018) [18].

$$\text{Aspect ratio } (\%) = \frac{W}{T} \times 100 \quad (11)$$

2.3.5 Thousand grain weight

Thousand grain weight of little millet was determined by selecting manually 100 grains and determining the weight by a precision electronic weighing balance (ATX224, Shimadzu, Japan; LC- 0.0001 g). This weight was extrapolated to 1000 grains (Sangamithra *et al*., 2016) [21].

2.3.6 Bulk density

Bulk density was expressed in kg/m^3 and calculated as follows (Ramashia *et al*., 2018) [18].

$$\text{Bulk density} = \frac{\text{Sample weight}}{\text{Volume}} \quad (12)$$

2.3.7 True Density

The true density of little millet samples was determined using toluene displacement method and calculated using the following expression (Mohsenin, 1980) [15].

$$\text{True density} = \frac{W_a}{V_d} \quad (13)$$

Where,

W_a = Weight of sample in air, kg

V_d = Volume of displaced toluene, m^3

2.3.8 Porosity

Porosity was determined using the following expression (Mohsenin, 1980) [15] and expressed in percentage.

$$\text{Porosity} = 1 - \frac{\text{Bulk density}}{\text{True density}} \times 100 \quad (14)$$

2.3.9 Angle of repose

Angle of repose for little millet at different moisture contents was determined using the method described by Sahay and Singh (2004). The height of the cone formed due to free vertical fall of the grains inside the apparatus was recorded. The diameter of the base of the cone was 7 cm.

$$\theta = \tan^{-1}\left(\frac{2H}{D}\right) \quad (15)$$

Where

θ = Angle of repose, degree

H = Height of cone, mm

D = Diameter of cone, mm

2.3.10 Coefficient of friction

Coefficient of friction was determined using the procedure described by (Balasubramanian and Viswanathan, 2010) [1]. Four test surfaces namely; plywood, mild steel, glass and rubber were used for the study.

$$\mu = \frac{F}{N}$$

Where

μ = Coefficient of static friction

F = Frictional force or total weight added to the pan, g

N = Normal force or weight of the grain in container, g

2.4 Thermal properties of little millet grains

The thermal conductivity and resistivity of little millet grains in the experimental range of moisture contents were determined using thermal properties analyzer (TEMPOS, Meter Group, United States) (Fig. 2). A sensor use guide provided with the instrument was used to select the sensor. TR-3 sensor primarily designed for soil and other granular and porous materials was used in the experiment. A beaker was filled up to the top and the sensor was inserted completely. The instrument was operated in 1-min reading mode, where the sensor heats for 1 min and concurrently records the reading. Temperature measurements were taken at 1-min interval; readings of thermal conductivity and resistivity displayed on the screen were recorded.

Fig 2: Thermal properties analyzer

2.5 Functional properties of little millet

2.5.1 Hydration capacity and index

Hydration capacity per seed was determined according to the procedure given by Karkannavar *et al.* (2021) [11]. Hydration capacity per seed and hydration index were calculated using the following expressions.

$$\text{Hydration capacity per seed} = \frac{W_2 - W_1}{1000} \quad (16)$$

$$\text{Hydration index (\%)} = \frac{\text{Hydration capacity per seed}}{W_1} \times 100 \quad (17)$$

Where,
W_1= Weight of 1000 seeds before soaking, g
W_2= Weight of 1000 seeds after soaking, g

2.5.2 Swelling capacity and index

Swelling capacity per seed was determined according to the procedure given by Karkannavar *et al.* (2021) [11]. Swelling capacity per seed and swelling index were calculated using the following expressions.

$$\text{Swelling capacity per seed} = \frac{V_2 - V_1}{1000} \quad (18)$$

$$\text{Swelling index (\%)} = \frac{\text{Swelling capacity per seed}}{V_1} \times 100 \quad (19)$$

Where
V_1= Volume of 1000 seeds before soaking, mL
V_2= Volume of 1000 seeds after soaking, mL

3. Results and discussion

3.1 Average grain size of little millet

Average grain size of little millet grain samples was determined for further study. This was important to know the size distribution of grain mass of little millet and also to select the sound grain sample, and avoid immature grains. The percentage weight of grains retained on each sieve (BSS 10, 12, 14, 16, 18, 22, 25, 30 and pan) were recorded and distribution of different size of seeds is shown in Fig. 3. Maximum grains were retained on BSS sieve No. 18 (53.8%) followed by BSS sieve No. 16 (44.73%). Average grain size of little millet was calculated to be 0.5387 mm. Hence, the little millet grain samples retained on BSS sieve No. 16 and 18 were used in entire the experiments to avoid errors due to grain size. The experiment was replicated three times and average values are presented.

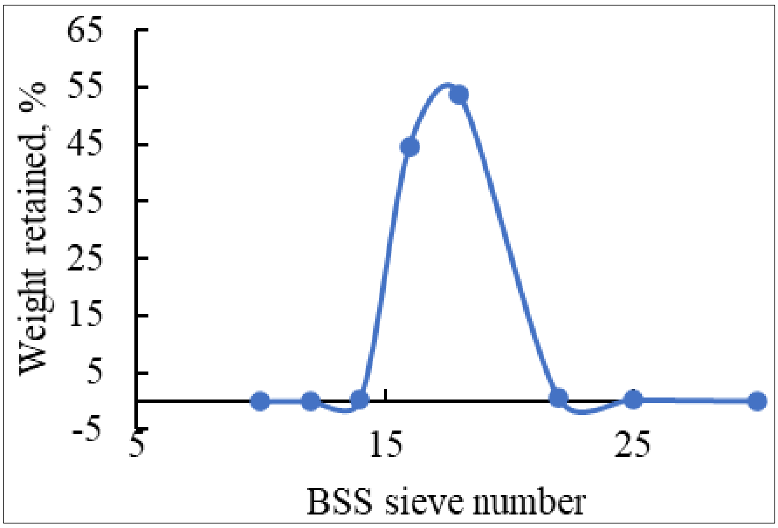

Fig 3: Sieve analysis of little millet grains

3.2 Effect of moisture content on physical, thermal and functional properties of little millet grains

3.2.1 Physical properties

The different physical properties of raw little millet grains at different levels of moisture content (6.62-20.05%, db) are presented in Table 1.

3.2.1.1 Length, width and thickness

Length, width and thickness of the grains was found to be increased linearly with the increase in moisture content. The length, width and thickness of grains increased from 2.10 mm to 2.72 mm, 1.35 mm to 1.76 mm and 1.01 mm to 1.60 mm, respectively as moisture increased from 6.62 to 20.05% (db) and the variation was found to be significant at $p \leq 0.05$. The variation in length, width and thickness of the seed with the variation in moisture content can be expressed as follows (Eqn. 20, 21 and 22).

Table 1: Dimensions of raw little millet at different moisture content

S. No.	Moisture content (%, db)	Length (mm)	Breadth (mm)	Thickness (mm)	AMD (mm)	GMD (mm)	Ds (mm)	De (mm)	Aspect ratio	Spher-icity	Surface area (mm^2)	Volu-me (mm^3)
1	6.62	2.10^{e}	1.35^{e}	1.01^{e}	1.49^{e}	1.41^{e}	0.84^{e}	1.24^{e}	64.54^{c}	67.04^{d}	5.33^{e}	1.05^{e}
2	8.36	2.14^{d}	1.39^{d}	1.08^{d}	1.54^{d}	1.47^{d}	0.87^{d}	1.29^{d}	65.07^{b}	68.99^{c}	5.78^{d}	1.19^{d}
3	9.88	2.24^{c}	1.44^{c}	1.10^{c}	1.62^{c}	1.56^{c}	0.91^{c}	1.36^{c}	64.80^{bc}	69.70^{b}	6.46^{c}	1.41^{c}
4	15.80	2.54^{b}	1.74^{b}	1.43^{b}	1.91^{b}	1.85^{b}	1.08^{b}	1.61^{b}	68.95^{a}	73.07^{a}	9.19^{b}	2.44^{b}
5	20.05	2.72^{a}	1.76^{a}	1.60^{a}	2.02^{a}	1.96^{a}	1.15^{a}	1.71^{a}	65.14^{b}	72.65^{b}	10.34^{a}	2.89^{a}
	SE m	0.12	0.09	0.11	0.11	0.11	0.08	0.07	0.82	1.14	0.99	0.37
	CD at α=5%	0.015	0.008	0.010	0.008	0.008	0.004	0.006	0.485	0.394	0.066	0.023

Values with different superscripts differ significantly at $p \leq 0.05$.

$$L = 0.0476M+1.7712\ (R^2 = 0.9900) \quad (20)$$

$$W = 0.0344M+1.1173\ (R^2 = 0.9401) \quad (21)$$

$$T = 0.0441\ M + 0.722\ (R^2 = 0.9975) \quad (22)$$

Where,
L = length of grain, mm
W = width of grain, mm
T = thickness of grain, mm
M = moisture content, % db

The increase in principal dimensions of the little millet seed with increase in moisture content was due to the fact that the grains swell up due to moisture absorption like other biological materials, thus increasing the size of the grains. In the past similar observation was made by Baryeh (2002) [2] indicating a good positive correlation between the principal dimensions and moisture content for little millets grains in the moisture range of 5 - 22.5%. Studies on soyabean (Deshpande *et al*., 1993; Tavakoli *et al*., 2009) [5, 25], maize (Sangamithra *et al*., 2016) [21] and finger millet (Powar *et al*., 2018) [17] also confirm such linear relationship.

3.2.1.2 Geometric and arithmetic mean diameter
Geometric mean diameter (GMD) and arithmetic mean diameter (AMD) of little millet increased linearly with the increase in moisture content. GMD and AMD increased from 1.41 mm to 1.96 mm and 1.49 mm to 2.02 mm for the range of moisture content evaluated (6.62 - 20.05%, db). The increase in GMD was found to be significant at $p \leq 0.05$. Mathematically, the relationship between GMD and AMD with moisture content can be expressed by the following equations (Eqn. 23 and 24).

$$GMD = 0.0433M+1.1234\ (R^2=0.9889) \quad (23)$$

$$AMD = 0.042M +1.2035\ (R^2 = 0.9895) \quad (24)$$

Where

M = moisture content, % db

Similar linear relationship between GMD, AMD and moisture content was observed for millets by Baryeh (2002) [2]. The increase in GMD and AMD of maize kernels has been reported as moisture content increased from 8.71-21.7% (db) (Sangamithra *et al*., 2016) [21]. Other studies for finger millet (Powar *et al*., 2018) [17] and kodo millet (Kumar *et al*., 2016) [12] also show similar increasing behaviour of GMD with the increase in moisture content.

3.2.1.3 Square mean (Ds) and equivalent diameter (De)
Ds and De were found to be increased linearly with increase in moisture content. They were found to be varied in the range of 0.84 to 1.15 mm and 1.24 to 1.71 mm, respectively with the variation in grain moisture from 6.62 to 20.05% (db). The increase in Ds and De were found to be statistically significant at $p \leq 0.05$ and mathematically expressed by the following relationships (Eqn. 25 and 26).

$$Ds = 0.0245\ M + 0.672\ (R^2 = 0.9890) \quad (25)$$

$$De = 0.0366M +0.9996\ (R^2 = 0.9893) \quad (26)$$

Where,

M is the moisture content, (%, db)

3.2.1.4 Aspect ratio (AR) and sphericity (S)
The aspect ratio (AR) of little millet grains was found to be increased initially with the increase in grain moisture up to 15.80% (db) but further increase in grain moisture did not increase the AR. The minimum AR of 64.54 was recorded at minimum moisture content of 6.62% (db). Similar trend was observed for the sphericity also with maximum value of 73.06 at 15.80% (db) of seed moisture and 67.04% (db) at 6.62% (db) moisture content. The variation with moisture was statistically significant and can be expressed by the following relationships (Eqns. 27 and 28).

$$AR = 0.3877M+61.766\ (R^2 = 0.9008) \quad (27)$$

$$S = 0.4843M+64.609\ (R^2 = 0.9395) \quad (28)$$

Where

M is the moisture content, (%, db)

Similar increasing trend was also observed for kodo millet (Kumar *et al*., 2016) [12], okra seed (Sahoo and Srivastava, 2002) [2], maize kernel (Sangamithra *et al*., 2016) [21] and finger millet (Powar *et al*., 2018) [17].

3.2.1.5 Surface area and volume
Surface area (SA) and volume (V) of the grains was observed to be increased with increase in moisture content. They increased from 5.33 to 10.34 mm^2 and 1.05 to 2.89 mm^3 in the moisture content range of 6.62 to 20.05% (db). The increase with moisture was statistically significant at $p \leq 0.05$ and can be related by the following relationship (Eqn. 29 and 30).

$$SA = 0.3932M+2.6438\ (R^2 =0.9909) \quad (29)$$

$$V = 0.1453\ M+0.0319\ (R^2 =0.9906) \quad (30)$$

Where
M is the moisture content, (%, db)

Similar finding has been reported for kodo millet by Kumar *et al*. (2016) [12]. An increase in surface area and volume has also been reported by Bayreh (2002) for millets when moisture content was increased from 5 to 22.5% (db). Similar results have been reported for finger millet (Powar *et al*., 2018) [17] and maize (Sangamithra *et al*., 2016) [21].

3.2.1.6 Thousand grain weight (TGW)
The influence of moisture content on TGW was determined for the little millet grains and the result is tabulated in Table 2. It was found that TGW increased with the increase in moisture content from 1.92 g to 2.88 g in the studied moisture range which significant at $p \leq 0.05$. Regression analysis gives the following relationship between TGW and moisture content (Eqn. 31).

$$TGW = 0.063\ M+1.178\ (R^2 = 0.779) \quad (31)$$

Where
M is the grain moisture content, % db

Table 2: Physical properties of little millet grains at different moisture content

S. No.	Moisture content (%, db)	TGW (g)	Bulk density (kg/m^3)	True density (kg/m^3)	Porosity (%)	Angle of repose (°)	Coefficient of Friction			
							Glass	Wood	Rubber	Mild steel
1	6.62	1.92^c	745.38^a	1149.55	49.23	27.19^c	0.47^c	0.41	0.59^d	0.54
2	8.36	2.23^c	740.27^{ab}	1132.37	46.56	29.32^c	0.48^{bc}	0.45	0.74^c	0.65
3	9.88	2.62^b	728.34^{bc}	1076.37	30.75	35.55^b	0.56^a	0.47	0.84^{bc}	0.66
4	15.80	2.77^{ab}	719.18^c	1000.55	33.88	36.95^{ab}	0.57^a	0.50	0.86^b	0.70
5	20.05	2.88^a	699.53^d	980.97	28.34	38.29^a	0.58^a	0.59	1.22^a	0.69
	Sem	0.18	8.16	33.90	4.25	2.19	0.02	0.03	0.05	0.33
	CD at α=5%	0.23	16.85	393.90	20.33	3.69	0.09	0.08	0.12	0.73

Values with different superscripts differ significantly at $p \leq 0.05$.

TGW of little millet grains recorded in the present investigation in the experimental range of grain moisture is at par with the earlier reported values with little variation, may be due to varietal difference and varied agronomical practices. Balasubramanian and Viswanathan (2010) [1] have also studied the influence of moisture content in the range of 11.1 to 25% (db) and reported similar linear increase of TGW from 2.3 to 6.1 g for little millet grains. Similar results have been reported for cumin seeds (Singh and Goswami, 1996) [24] and pumpkin seeds (Joshi *et al.*, 1993) [9].

3.2.1.7 Bulk density, true density and porosity

The variation in bulk density, true density and porosity with varying levels of moisture content for little millet grains is tabulated in Table 2. It was observed that bulk density, true density and porosity decreased linearly with the increase in moisture content. Bulk density decreased from 745.38 to 699.53 kg/m^3, true density decreased from 1149.55 to 980.97 kg/m^3 and porosity decreased from 49.23 to 28.34% with increase in grain moisture from 6.62 to 20.05% (db). Statistical analysis showed that decrease in bulk density with moisture was significant ($p \leq 0.05$), whereas that of true density and porosity non-significant ($p \leq 0.05$). The relationship between these parameters and grain moisture content can be expressed adequately by the following regression equations (Eqns. 32 to 34).

$$BD = -13.094M+1226.9 \ (R^2 = 0.939) \quad (32)$$

$$TD = -3.0622M+762.91 \ (R^2=0.957) \quad (33)$$

$$P = -1.3468 \ M+54.106 \ (R^2 = 0.630) \quad (34)$$

Where
M = moisture content, % (db)
BD = bulk density, kg/m^3
TD = true density, kg/m^3
P = porosity, %

Similar findings have been reported for minor millets by Balasubramanian and Viswanathan (2010) [1]. Shepherd and Bhardwaj (1986) [22] and Dutta *et al.* (1988) [6] have also reported similar decreasing trends in case of pigeon and gram. The decrease in bulk density may be due to the change in cell structure, volume and increase in weight due to moisture absorption by the grains. Decrease in true density shows that with increase in grain volume there is lesser increase in grain mass (Balasubramanian and Viswanathan, 2010) [1].

3.2.1.8 Angle of repose

The angle of repose of little millet grains was found to be increased linearly with the increase in moisture content. Angle of repose increased from 27.19° to 38.29° in the range of moisture content studied. At higher moisture content, the grains were held together more firmly resulting in increase in the angle of repose. Similar results have been reported by Balasubramanian and Viswanathan (2010) [1] for minor millets. Similar increasing trend was also observed for pumpkin seeds (Joshi *et al.*, 1993) [9], green gram (Nimkar and Chattopadhyaya, 2001) [16] and quinoa (Vilche *et al.*, 2003) [26].
The variation was significant statistically and is shown mathematically by the following equation (Eqn. 35).

$$\theta = 0.7668 \ M+24.149 \ (R^2 = 0.7686) \quad (35)$$

Where
θ = angle of repose, degree
M = moisture content, % (db)

3.2.1.9 Coefficient of friction (μ)

The effect of moisture content on coefficient of friction on different surfaces *viz.*, glass, wood, rubber and mild steel was studied. Coefficient of friction was found to be increased linearly with the increase in moisture content for all the surfaces. Highest value of μ (1.22) was observed for rubber surface at the highest moisture content of 20.05 % (db), whereas the lowest value of 0.41 was observed for the wood surface at lowest moisture content of 6.62% (db). Variation in coefficient of friction was statistically significant at $p \leq 0.05$ in case of glass and rubber surfaces, whereas non-significant in case of plywood and mild steel surfaces.
The variation in coefficient of friction at different surfaces is expressed mathematically by the following equations (Eqns. 36 to 39):

$$\mu_g = 0.0077M+0.4366 \ (R^2 = 0.7138) \quad (36)$$

$$\mu_w = 0.0118M+0.3394 \ (R^2 = 0.922) \quad (37)$$

$$\mu_r = 0.0382M+0.3878 \ (R^2 = 0.8615) \quad (38)$$

$$\mu_{ms} = 0.0088M+0.5389 \ (R^2=0.6051) \quad (39)$$

Where

M = moisture content, % db

Previous studies also show similar increasing trend of coefficient of friction on different surfaces for millets. According to earlier findings little millet exhibited least coefficient of friction (0.28) against mild steel surface at lowest moisture content of 11.1% and maximum (0.61) at highest moisture content of 25% (Balasubramanian and Viswanathan, 2010) [1]. At higher moisture content, the water present in the grains may offer increased adhesive force on the contact surface which results in increase in the coefficient of friction of the grains (Balasubramanian and Viswanathan, 2010) [1].

3.2.2 Thermal properties

Thermal properties of little millet grains *viz.*, thermal conductivity and resistivity were determined in the moisture range of 6.62 to 20.05% (db) and presented in Table 3. It was observed that the thermal conductivity increased, whereas, resistivity decreased with the increase in seed moisture. The variation in thermal conductivity and resistivity with moisture was found to be statistically significant at $p \leq 0.05$ and can be expressed mathematically as follows (Eqn. 40 and 41).

$$K = 0.0029M + 0.0534 \quad (R^2 = 0.9148) \qquad (40)$$

$$R = -38.96\,M + 1645.7 \quad (R^2 = 0.832) \qquad (41)$$

Where

K = thermal conductivity, W/m K

R = resistivity, °C cm/W

M = moisture content, % (db)

Table 3: Thermal properties of raw little millet at different moisture content

S. No.	Moisture content (%, db)	Thermal conductivity (W/mK)	Resistivity (°C cm/W)
1	6.62	0.066[e]	1533.333[a]
2	8.36	0.082[d]	1233.333[b]
3	9.88	0.087[c]	1166.667c
4	15.80	0.096[b]	1033.333[d]
5	20.05	0.112[a]	896.333[e]
	SEm	0.00757908	107.1379
	CD at α=5%	0.00019944	4.405763

Values with different superscripts vary significantly at $p \leq 0.05$.

3.2.3 Functional properties

3.2.3.1 Hydration capacity and index

Hydration capacity of little millet grains ranged from 6.46 × 10^{-4} to 7.53 × 10^{-4} g per 1000 grains in the studied moisture range (Table 4). However, statistical analysis showed that the variation of hydration capacity with moisture content of the grains was not significant at $p \leq 0.05$.

Hydration index was found to be maximum (33.81%) at lowest moisture content of 6.62% (db) and minimum (22.46%) at maximum moisture content of 20.05% (db). This decrease was observed to be statistically significant at $p \leq 0.05$. Kamatar *et al.* (2013) [10] reported for different little millet varieties; hydration capacity in the range of 9.13 to 21.50%. Two varieties of proso millet showed hydration capacity to be 5.28 and 5.53 for DHPM-2769 and local proso millet, respectively; whereas hydration index was 117.07 and 118.41%, respectively as reported by Karkannavar *et al.* (2021) [11]. Significant difference was not observed between the varieties with respect to hydration index.

Table 4: Functional properties of little millet grains at different moisture content

S. No.	Moisture content	Hydration capacity (g/1000 grains)	Hydration index (%)	Swelling capacity (mL/1000 grains)	Swelling index (%)
1	6.62	6.49 × 10^{-4}	33.81	3.67 × 10^{-4}	17.10
2	8.36	7.53 × 10^{-4}	33.55	8 × 10^{-4}	30.79
3	9.88	7.28× 10^{-4}	27.88	8.33 × 10^{-4}	31.04
4	15.80	6.83× 10^{-4}	24.65	1.07 × 10^{-3}	33.96
5	20.05	6.46 × 10^{-4}	22.46	1.30× 10^{-3}	35.45
	SEm	2.14× 10^{-5}	2.30	1.55× 10^{-4}	3.26
	CD at α=5%	2.04 × 10^{-4}	7.19	4.23 × 10^{-4}	18.41

3.2.3.2 Swelling capacity and index

Swelling capacity of little millet grains ranged from 3.67 × 10^{-4} to 1.30 × 10^{-3} mL/1000 grains in the moisture range of 6.62 to 20.05% (db) (Table 4). Increase in swelling capacity with moisture content was observed and was found to be statistically significant at $p \leq 0.05$.

Swelling index of little millet grains ranged from 17.10 to 35.45% in the studied moisture range. However, the increase in swelling index with moisture was observed to be statistically non-significant at $p \leq 0.05$.

Swelling capacity of little millet was found to be 2.4 mL/1000 grains and swelling index was 60% (Reddy *et al.*, 2019). Kamatar *et al.* (2013) [10] reported swelling capacity of different little millet varieties to be in the range of 11 to 51%. The values obtained in the present study are much lesser than the previous reported values which may be due to varietal differences and other atmospheric conditions.

4. Conclusion

It was concluded from the study that physical properties namely, length, width, thickness, geometric and arithmetic mean diameter, square mean and equivalent diameter, aspect ratio, sphericity, surface area, volume, thousand grain weight, angle of repose and coefficient of friction, all were positively correlated with moisture content, whereas, bulk density, true density and porosity were negatively correlated. Thermal properties, *viz.*, thermal conductivity varied proportionally and resistivity was inversely proportional to moisture content in the studied range.

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6. References

1. Balasubramanian S and Viswanathan R. Influence of moisture content on physical properties of minor millets. Journal of Food Science and Technology. 2010;47(3):279-284.
2. Baryeh EA. Physical properties of millet. Journal of Food Engineering. 2002;51:39-36.
3. Bora P. Nutritional properties of different millet types and their selected products. Unpublished thesis, University of Guelph, Canada; c2013.
4. Chethan S and Malleshi NG. Finger millet polyphenols: Optimization of extraction and the effect of pH on their stability. Food Chemistry. 2007;105:862-870.
5. Deshpande SD, Bal S and Ojha TP. Physical properties of soybean. Journal of Agricultural Engineering Research. 1993;56(1):89-98.
6. Dutta SK, Nema VK and Bhardwaj RK. Physical properties of gram. Journal of Agricultural Engineering Research. 1988;39:259-268.
7. FAO. Sorghum and Millets in Human Nutrition. Food and Nutrition Series; c1972. p. 27.
8. FAO/ICRISAT. The World Sorghum and Millet Economies: Facts, Trends and Outlook. FAO, Rome, Italy and ICRISAT, Patancheru, Andhra Pradesh, India; c1996. p. 68.
9. Joshi DC, Das SK and Mukherjee RK. Physical properties of pumpkin seeds. Journal of Agricultural Engineering Research. 1993;54(3):219-229.
10. Kamatar MY, Hemalatha S, Meghana DR, Talawar S, Naik RK. Evaluation of little millet (*Panicum sumatrense*) land races for cooking and nutritional composition. Current Research in Biological and Pharmaceutical Sciences. 2013;2(1):7-11.
11. Karkannavar SJ, Shigihalli S, Nayak G, Bharati P and Govinkoppa N. Physico-chemical and nutritional composition of proso millet varieties. The Pharma Innovation Journal. 2021;10(1):136-140.
12. Kumar D, Patel S, Naik RK and Mishra NK. Study on physical properties of Indira kodo-I (*Paspalum scrobiculatum* L.) millet. International Journal of Engineering Research and Technology. 2016;5(1):39-45.
13. Menon MV. Small millets call for attention. Kissan World. 2004;4:63-64.
14. Mishra G, Joshi DC, Mohapatra D and Babu VB. Varietal influence on the microwave popping characteristics of sorghum. Journal of Cereal Science. 2015;65:19-24.
15. Mohsenin NN. Physical Properties of Plant and Animal Materials. Gordon and Breach Science, New York, USA; c1980.
16. Nimkar PM and Chattopadhyay PK. PH-Postharvest Technology: Some physical properties of green gram. Journal of Agricultural Engineering Research. 2001;80(2):183-189.
17. Powar RV, Aware VV, Shahare PU, Sonawane SP, Dhande KG. Moisture-dependent physical properties of finger millet grain and kernel (*Eleusine coracana* (L.) *Gaertn*). Journal of the Indian Society of Coastal Agricultural Research. 2018;36(1):48-56.
18. Ramashia SE, Gwata ET, Meddows-Taylor S, Anyasi TA and Jideani AIO. Some physical and functional properties of finger millet (*Eleusine coracana*) obtained in sub-Saharan Africa. Food Research International. 2018;104:110-118.
19. Sahay KM, Singh KK. Unit operations of Agricultural Processing. 2nd revised edition. Vikas Publishing House Pvt. Ltd.; 2004. p. 221-222.
20. Sahoo PK, Srivastava AP. Physical properties of okra seed. Biosystems Engineering. 2002;83(4):441-448.
21. Sangamithra A, Swamy GJ, Sorna PR, Nandini K, Kannan K, Sasikala S, *et al*. Moisture dependent physical properties of maize kernels. International Food Research Journal. 2016;23(1):109–115.
22. Shepherd H, Bhardwaj RK. Moisture-dependent physical properties of pigeon pea. Journal of Agricultural Engineering Research. 1986;35:227-234.
23. Silas TARK. MILLET: Post-harvest Operations Organization: Sokone University of Agriculture (SUA). Edited by AGSI/FAO: Danilo Mejia (Technical), Beverly Lewis (Language & Style); c2001. http://www.suanet.ac.tz.
24. Singh KK, Goswami TK. Physical properties of cumin seed. Journal of Agricultural Engineering Research. 1996;64(2):93-98.
25. Tavakoli H, Rajabipour A, Mohtasebi SS. Moisture dependent some engineering properties of soybean grains. Agricultural Engineering International: The CIGR Ejournal. Manuscript 1110. XI; c2009.
26. Vilche C, Gely M and Santalla E. Physical properties of quinoa seeds. Biosystems Engineering. 2003;86(1):59-65.