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IMPACT OF MOISTURE CONTENT ON ENGINEERING PROPERTIES OF KODO MILLET WITH AND WITHOUT HUSK

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ABSTRACT

Physical properties of grains play role in quality assessment, processing and equipment design. A study was conducted to determine the physical properties of two commonly grown varieties of kodo millet grains with and without husk in the moisture content range 15.45-25.8% db. The mean values of physical properties such as length, width, thickness, sphericity, surface area, volume, true density, porosity, 1000 grains mass, static angle of repose and dynamic angle of repose increased with increase in moisture content. No significant impact of addition of moisture on sphericity of grains with husk was observed and bulk density decreased with increase in moisture. The grains with husk have high mean values of geometric properties than grains without husk. However, bulk density, true density and static angle of repose was higher in case of grains without husk than grains with husk. Between the millet variety, grains of ALT-1 variety have slightly high mean values of physical properties than TNS-86 variety.

Keywords: Minor millet; Kodo; Physical Properties; Bulk density; Angle of repose.

ABBREVIATIONS

GWH	Grains With Husk
GWOH	Grains Without Husk
GWHA	Grains With Husk ALT-1 variety
GWHT	Grains With Husk TNS-86 variety
GWOHA	Grains Without Husk ALT-1 variety
GWOHT	Grains Without Husk TNS-86 variety
L	Length
W	Width

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T	Thickness
D_G	Geometric mean diameter
D_A	Arithmetic mean diameter
Φ	Sphericity
S	Surface area
V	Volume
δ_{bd}	Bulk density
δ_{td}	True density
P	Porosity
M_t	1000 grains mass
$\theta_f°$	Angle of repose
θ_f °	Dynamic angle of repose

1. INTRODUCTION

In recent years, demand of nutritional rich, gluten free, and low glycemic index foods as well as sustainable food crops has increased. There is a shift in interest towards millets at consumer and food processing sector levels. Millets belongs to *Poaceae* family of plants and are round shaped cereal seeds present in various size and colors based on the variety. Millets are small seeded grasses and major staple food in the semi- arid tropics of Asia and Africa. Millet crops are called "underutilized/neglected" have superior photosynthesis and dry matter production capacities, with low inputs requirement, high disease and insect resistance, minimal synthetic fertilizers and pesticides requirements. Millets have crop duration of 60-100 days[1]. The cultivation of millets adds diversity, increases soil fertility and reduces dependence on chemical pesticides and fertilizer. Millets are major food in underdeveloped countries due to their tolerance to harsh climate conditions. They provide good quantity and quality of macro and micro-nutrients, phytochemicals and rich in sulphur containing amino acids. Millets are mainly classified into major, minor and Pseudo millets based on their global cultivation and utilization. Minor millets include: Barnyard millet (*Echinochloa spp.*), kodo millet (*Paspalum scrobiculatum*), Little millet (*Panicum sumatrense*), Guninea millet (*Brachiaria deflexa*), Browntop millet (*Urochloa ramose*), Teff (*Eragrostis tef*) and fonio (*Digitaria exilis*)[2]. Kodo millets is believed to be originated in India around 3000 year ago and also known as Kodra, Kodon, and Kodua[3]. Tropical and subtropical regions are best suited for its cultivation[4,5]. Kodo millet is a high yielding crop having crop duration of 80-135 days and considered as the highest drought resistance among the millets [5]. It provides 346 kcal, 59.2 g of carbohydrates, 10.6 g of proteins, 4.2 g fat, and 10.2 g of fiber per 100g of grains. It also contains 4.4 g of minerals, 27 mg of calcium, 188 mg of phosphorous and 0.5 mg of iron, 0.09 mg of riboflavin[6–8]. Kodo millet consists of phenolic compounds which have antioxidants, anti-ulcerate, anti-glycemic and hypo-cholesterolemic properties[9,10]. However, these are least preferred crops by the farmers might be due to their lower yield and less

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utilization at industry level. Exploration of millet crops provides sustainability, diversity, economic empowerment, nutritional and health security to the world. Millets are mostly consumed as chapati, porridge, dosa, pasta and biscuits etc. The utilization of millets in manufacture of baby foods, snack foods and dietary foods will be beneficial to increase their demand on consumer level. Various food processing unit-operations such as pearling, grinding, mixing, packaging and transportation are carried out to transform the grains into various products. The physio-chemical properties of grains reveal the relations between structure and molecular components of food. Addition of moisture as pre- treatment in food engineering plays an important role in grain milling, drying, extrusion, baking and other thermal and mechanical processes. It leads to easily separation of husk from seed.

Husk is hard, indigestible outermost layer of the grain, made up of structural and protective compounds. The key components present is husk are cellulose, hemicellulose, lignin, silica waxes and phenolic compounds. On addition of moisture, cellulose and hemicellulose swell and soft which result in increases in size of the grain. However, phenolic compounds leached and lignin and silica remain stable. The outer layer of grain has more cellulose than lignin. The chemical composition of finger millet and barnyard millet husk analysis reveals that chemical composition of cellulose, hemicellulose, and lignin is 38.01%, 31.48% and 16.25% in finger millet husk and 34.5%, 32.16% and 21.31% in barnyard millet husk[11]. The addition of moisture into the grains during the pre-treatment process helps in loosening the bond between husk and seed and easily separation of seed from the husk[12]. The dehusking is a unit operation in which outermost layer of seed is removed from inner layer by mechanical action. Dehusking leads to reduction in size, water hydration capacity, viscosity and total weight of the grains[13].

The physical properties such as size, shape, sphericity, surface area, volume, density, porosity, color and angle of repose are important in designing handling, processing and storage equipment or determining the efficiency. These parameters also help in evaluating and retaining the quality of the millets. Physical properties ensure the efficiency and accuracy in process design, help to match material behavior to machine capabilities in equipment selection. Proper measurement and understanding of grain physical properties are important to the efficiency of equipment operation, quality preservation of the product and minimization of material loss. The physical properties of agricultural commodities at different moisture content have been determined such as millet [14],coffee[15] cumin seeds[16], minor millet[17] caper seed[18], sunflower seed[19] guar seeds[20]. However, literature review showed that there is not enough published research on impact of variation of moisture content on physical properties of kodo millet grains with and without husk. Physical properties are essential for the development of mechanical dehulling equipment for better threshing efficiency and storage. However, data on commonly grown variety of kodo millet is lacking. Hence, the present study emphasizes the impact of variation of moisture

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content range from 15.45 to 25.8% db on the physical properties of the ATL-1 and TNS-86 varieties of kodo millet grain with and without husk.

2. MATERIAL & METHODS

Commonly cultivated varieties of kodo millets i.e. ATL-1 and TNS-86 were selected for this research work. The samples were procured from a farm in the northwestern region of India. The samples are grains with husk ALT-1 variety (GWHA), grains with husk TNS-86 variety (GWHT), grains without husk ALT-1 variety (GWOHA), and grains without husk TNS-86 variety (GWOHT) for the present investigation. Grains were properly cleaned manually for removal of foreign matters such as dirt, stone, and chaff, immature and broken grain. Impact of variation in moisture on important physical properties was determined using standard techniques.

Sample preparation:

Initial Moisture content of the samples was 12% db. Physical properties of millets are determined at moisture content range of 15–25% db, since harvesting, transportation, storage and dehulling operations of minor millets are performed in this range. Grain samples of desired moisture content levels were prepared by adding calculated amount of distilled water in accordance with the following equation[21] and mixed thoroughly.

$$Q = W_I\left(\frac{m_f - m_i}{100 - m_f}\right) \qquad (1)$$

where, Q is the weight of water to be added (g); W_I is the initial weight of grain sample (g); m_i is the initial moisture content of grain sample (% db) and m_f is the final moisture content of grain sample (% db).

Grain samples were sealed in polyethylene bags of 300 μ thickness and kept in a refrigerator maintained at 4±1°C for 7 days to reach uniform moisture content. The moisture contents of the samples were equilibrated to 15.45% db, 20.4% db and 25.4% db by Standard oven method (140°C for 1 hour). The required quantity of sample was randomly taken out of refrigerator and allowed to warm up to room temperature about 2 hours before starting the test. All the measurements were replicated three times at the selected moisture content.

Geometric properties

Shape and size: The size of the kodo millet grains with and without husk was determined by measurement of seed Length (L), Width (W) and Thickness (T). The length (major diameter) was the highest dimension, thickness (minor diameter) and the width (intermediate diameter) of the grain. Randomly 10 grains from each variety were selected for determination of L, W and T by using vernier caliper with a least count of 0.02mm.

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Geometric Mean Diameter (D_G): Geometric mean diameter and arithmetic mean diameter(D_A) was calculated with the following formula proposed by [22]

$$D_G = (L \times W \times T)^{\frac{1}{3}} \qquad (2)$$

$$D_A = \frac{L + W + T}{3} \qquad (3)$$

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

Sphericity(Φ): Sphericity (Φ) is used to determines the shape of the grain. The sphericity is expressed in percent[22]

$$\Phi = \frac{D_G}{L} \qquad (4)$$

Where, D_G = Geometric mean diameter and L= longest intercept(length).

Surface area (S, mm^2): For measuring the Surface area (S) of millet grain, the following formula was used [23].

$$S = \frac{\pi B L^2}{(2L - B)} \qquad (5)$$

Where, $B=(WT)^{0.5}$; S = Surface area, mm^2; L= Length, mm

Volume (V, mm^3): volume was determined using the formula, proposed by[23]

$$V = \frac{\pi B^2 L^2}{6(2L - B)} \qquad (6)$$

Where, $B= (WT)^{0.5}$; V= volume, mm^3; L= Length, mm

Gravimetric Properties

Bulk Density (δ_{bd}, kg/m^3): Bulk density is the ratio of mass of the sample to its total volume. Bulk density was determined using a container of known volume. The sample was taken into the container for the known volume, tapped and weighed. The bulk density(δ_{bd}) was determined by taking the weight of sample in fixed volume[22].

$$\delta_{bd} = \frac{W}{V} \qquad (7)$$

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Where, δ_{bd}= bulk density; W= weight of sample(kg); V= volume of sample including pore space(m^3).

True density (δ_{td}, kg/m^3): The True density (δ_{td}) is defined as the ratio of mass of grain to the true volume occupied. It is determined using toluene displacement technique[22]. 50 ml of toluene was taken in a measuring jar. A known weight of sample was poured to the measuring jar and rise in the toluene level was recorded. According to study by [18] the absorption of toluene(C_7H_8) is less as compared to water. The volume of grain will be equal to toluene displaced(Singh & Goswami, 1996).

$$\delta_{td} = \frac{M}{V} \qquad (8)$$

Where, δ_{td}= True density; M= Mass of sample (kg); V= volume of toluene displaced

Porosity (P, %): Porosity accounts for the intra-granular spaces in the seeds. Porosity was calculated from the bulk density and true density using the following formula and expressed in percentage[24].

$$P, \% = 1 - \frac{\delta_{bd}}{\delta_{td}} \times 100 \qquad (9)$$

Where, δ_{bd} = bulk density; δ_{td} = True density.

Weight of 1000 grains (M_t, g): Thousand seeds weight was calculated by weighing the randomly selected 100 seeds using a precision balance (Citizen CY 204, Hamburg, Germany), reading to an accuracy of 0.1 mg. weight of 100 seeds was multiplied with 10 to get thousand seed weight [25].

Angle of repose (θ_f ,°): Angle of repose is the angle between base and slope of the cone formed on a free vertical fall of grains on to a horizontal plane. The angle of repose is important for determining the maximum angle of a pile of grain in the horizontal plane and is important in the filling of a flat storage facility. The angle of repose is measured by using topless bottomless cylinder. The cylinder was placed on raised circular plate. The cylinder was placed on the raised circular plate and filled with seeds. The cylinder was raised slowly to make a cone of sample. The height (H, cm) and diameter of cone (D, cm) of the sample was measured to calculate the angle of repose by following equation.

$$\theta_{f,}^{\circ} = tan^{-1} \frac{2H}{D} \qquad (10)$$

Where, H- Height of cone; D- Diameter of cone.

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Dynamic angle of repose ($\theta_{e,}$°): Dynamic angle of repose was determined in a fiberglass box measuring 20×20×20 cm with a removable front panel [26]. The front panel of the box was quickly removed after filling the box with sample. Allowing the seeds to flow out and to attain a natural slope[27]. The dynamic angle of repose (θ_e) was calculated using the following equation [28].

$$\theta_e,^\circ = tan^{-1}\frac{2H}{X} \qquad (11)$$

Where, H – height of flow; X- distance of flow

Statistical analysis: The results are expressed as the Mean±SD and linear regression equation along with coefficient of determination was determined using statistical Package for the social sciences (SPSS) software statistics v29 owned and developed by IBM.

3. RESULT AND DISCUSSION

Principal dimensions

Length, width and thickness are useful in estimating the size of the grains that is essential to design handling and processing machinery. The mean values for the principal dimensions of grains increased with increase in moisture content from 15.45 to 25.80% db (Table 1). Water gets absorbed in the intra-cellular spaces of grains and causes expansion. This further results in the increased geometric and arithmetic diameters, surface area and volume. Very high correlation was observed between principal dimensions and grain moisture content.

Table 1: Physical properties of Kodo millet grains with and without husk as a function of moisture content.

Sample	M,% (db)	L(mm)	W(mm)	T(mm)	D_G(mm)	D_A(mm)	S (mm^2)	V (mm^3)
GWHA	15.45	2.40±0.02	2.38±0.02	1.64 ±0.03	2.11±0.02	3.13±0.10	12.66±0.28	4.17±0.14
	20.4	2.47±0.02	2.44±0.02	1.67±0.02	2.16±0.02	3.37±0.10	13.27±0.28	4.47±0.14
	25.8	2.52±0.03	2.50±0.02	1.69±0.01	2.20±0.01	3.57±0.09	13.78±0.24	4.73±0.12
GWHT	15.45	2.39±0.03	2.36±0.01	1.61±0.02	2.09±0.01	3.04±0.07	12.41±0.18	4.04±0.08
	20.4	2.44±0.02	2.39±0.03	1.64±0.03	2.12±0.02	3.21±0.11	12.94±0.33	4.25±0.17
	25.8	2.48±0.01	2.45±0.03	1.67±0.02	2.16±0.01	3.39±0.08	13.42±0.25	4.49±0.13
GWOHA	15.45	2.12±0.02	2.09±0.02	1.28±0.02	1.78±0.02	1.90±0.08	8.91±0.27	2.43±0.11
	20.4	2.19±0.01	2.14±0.02	1.41±0.01	1.88±0.01	2.22±0.06	9.95±0.21	2.89±0.09
	25.8	2.24±0.02	2.18±0.04	1.48±0.02	1.93±0.01	2.42±0.07	10.60±0.24	3.18±0.11
GWOHT	15.45	2.09±0.01	2.06±0.02	1.28±0.02	1.77±0.02	1.86±0.07	8.79±0.24	2.39±0.10
	20.4	2.16±0.01	2.12±0.03	1.34±0.02	1.83±0.01	2.05±0.06	9.41±0.21	2.65±0.09
	25.8	2.22±0.01	2.15±0.02	1.42±0.05	1.89±0.02	2.27±0.09	10.08±0.31	2.94±0.14

(Data presented are the mean value± standard deviation, n=3).

Length

Grain length is major physical property influences the processing behaviour, drying and milling efficiency, market grade, appearance and storage properties. The increase in length with increase in moisture content was observed in this investigation (Fig 1). The variation in length parameter of grains with husk ALT-1 variety (GWHA) and grains with husk TNS-86 variety (GWHT) ranged from 2.40 to 2.52 mm and 2.39-2.48 mm, respectively. In case of grains without husk, the increase in length was 2.12 to 2.24 mm for grains without husk ALT-1 variety (GWOHA) and 2.09 to 2.22 mm for grains without husk TNS-86 variety (GWOHT) (Table 1). The relationship between the length parameter as a function of moisture content (M=15.45-25.8%db) represented mathematically as follows:

$L_{(GWHA)} = 0.0116M+2.23$ (R^2 =0.98)

$L_{(GWHT)} = 0.0089M+2.25$ (R^2=0.99)

$L_{(GWOHA)} = 0.0112M+ 1.95$ (R^2 =0.97)

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$L_{(GWOHT)}$= 0.012M+1.912 (R^2 =0.99)

Very strong positive linear relationship of grain length with change in moisture can be observed in case of grains with husk TNS-86 variety (GWHT) and grains without husk TNS-86 variety (GWOHT)(R^2=0.99). Grains with husk TNS-86 variety (GWHT) shows lower slope than GWHA, which indicates smaller change in length with moisture absorption. Grains without husk ALT-1(GWOHA) also shows slightly lower slope than grains with husk ALT-1 variety (GWHA). However, grains without husk TNS-86 variety (GWOHT) shows the highest slope which indicates that this grains sample is most sensitive to moisture change in term of length parameter.

Width

Width represents the horizontal size of the grains. It is important for designing the processing equipment such as dehullers and graders. The variation in width with change in moisture content is given in Fig 1. The increase in width parameter for grains with husk ALT-1variety (GWHA) was 2.38-2.5 mm and 2.36-2.45 mm for grains with husk TNS-86 variety (GWHT) within moisture range. There was increase in width with increase in moisture from 2.09 to 2.18 mm and 2.06-2.15 mm in case of grains without husk ALT-1 and TNS 86 variety respectively (Table 1). The regression equations presenting the linear relationship of width as a function of moisture content(M=15.45-25.8%db) along with coefficient of determination are presented as below:

$W_{(GWHA)}$ = 0.0116M+2.20 (R^2 =0.99)

$W_{(GWHT)}$= 0.0085M+2.22 (R^2=0.98)

$W_{(GWOHA)}$= 0.0085M+ 1.96 (R^2 =0.99)

$W_{(GWOHT)}$= 0.0085M+1.94 (R^2 =0.98)

Grains with husk ALT-1 variety (GWHA) and grains without husk ALT-1 variety (GWOHA) shows the very strong positive linear relationship whereas Grains with husk TNS-86 variety (GWHT) and grains without husk TNS-86 variety (GWOHT) shows the good positive linear relationship. The highest slope (0.0116) in Grains with husk ALT-1 variety (GWHA) suggests the highest increase in Width parameter per unit change in moisture. Same slopes (0.0085) in the other three samples also indicate similar responses to change in moisture.

Thickness

The Fig 1 represents the variation in thickness within the moisture content range from 15.45-25.8% db. Thickness determines the force needed to break or dehusk the grains. Thickness of grain influences the packaging size. It was observed that there was an increase in thickness in grains with husk ALT-1(GWHA) variety from 1.64-1.69 mm within the given moisture content. The

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change in thickness was from 1.61 to 1.67 mm in case of grains with husk TNS-86 variety (GWHT). The variation in thickness parameter within the 15.45 -25.8%db moisture content in case of grains without husk ALT-1 and TNS-86 variety, varies from 1.28-1.48 mm and 1.288-1.42 mm, respectively (Table 1). The Positive linear relationship between thickness and moisture content(M=15.45-25.8%db) of grains is presented mathematically as below:

$T_{(GWHA)}= 0.0054M+1.55$ ($R^2=0.98$)

$T_{(GWHT)}= 0.0054M+1.53$ ($R^2=0.98$)

$T_{(GWOHA)}= 0.0196M+ 0.99$ ($R^2=0.96$)

$T_{(GWOHT)} = 0.00132M+1.08$ ($R^2=0.99$)

Grains without husk TNS-86 variety (GWOHT) has the very strong positive linear relationship (R^2=0.99) while Grains without husk ALT-1variety (GWOHA) has strong positive linear relationship. Thickness changes rapidly in case of Grains without husk ALT-1 variety (GWOHA), moderately in case of Grains without husk TNS-86 variety (GWOHT) with respect to moisture. All the principal dimensions increase linearly with increase in moisture content. It was observed that principal dimension of both varieties of grains with husk are significantly greater than grains without husk. In case of grains with husk, the total expansion was largest along the length and least along the thickness. This may be due to different cell arrangements in the grains and seeds. The grains with husk of ALT-1 variety (GWHA) have greater principal dimension and grains without husk TNS-86 variety (GWOHT) has lower principal dimension. Among varieties, ALT-1 variety grains have slightly higher mean principal dimensions than TNS-86 variety (Table 1). Linear relationship was observed between moisture content and principal dimension of each sample with coefficient of determination (R^2). High coefficient of determination (R^2> 0.99) showed that on the moisture gain of kodo millet grains with and without husk increase the mean principal dimensions within the experimental moisture range. High positive linear correlation between principal dimensions and moisture content can be observed.

Geometric properties

It is evident from the Table 1 that geometric mean diameter, arithmetic mean diameter, surface area and volume increased with increase in moisture content. The increase in physical properties may be due to increase in the principal dimensions of grains [29]. The sphericity of grains shows the ability of grains to roll rather slide in the hopper which plays an important role in designing of a hopper and conveying equipment of the grains. The sphericity of grains with husk and without husk is presented in Table 1. There is no significant change in value of sphericity as a function of moisture content for grains with husk (GWH) and increase in sphericity was observed in case of grains without husk (GWH) (Fig 2). The positive correlation between geometric properties and moisture content can be observed for all sample except sphericity of grains with husk which shows non-significant relationship. A very high correlation can be observed between these properties and moisture content.

Geometric mean Diameter

An increase in geometric mean with increase in moisture content can be observed (Fig 1). Geometric mean diameters of grains give better average size of non- spherical materials, and designing screening equipment. Geometric mean diameters of grains ranged from 2.11-2.20 mm, 2.09 -2.16 mm, 1.78-1.93 mm, and 1.77-1.8 for grains with husk ALT-1 variety (GWHA), grains with husk TNS-86 variety (GWHT), grains without husk ALT-1 variety (GWOHA), and grains without husk TNS-86 variety (GWOHT), respectively (Table 1). The regression equation between geometric mean diameter as a function of moisture content(M=15.45-25.8%db) is presented below:

$D_{G(GWHA)}$= 0.0087M+1.97 (R^2 =0.99)

$D_{G(GWHT)}$= 0.0068M+1.98 (R^2=0.99)

$D_{G(GWOHA)}$= 0.0144M+1.56 (R^2 =0.95)

$D_{G(GWOHT)}$= 0.0116M+1.58 (R^2 =0.99)

All samples show very strong positive linear correlation (R^2 =0.99) except grains without husk ALT-1 variety (GWOHA). However, grains without husk ALT-1 variety (GWOHA) is most responsive to Moisture and grains with husk TNS-86 variety (GWHT) is least responsive to moisture content.

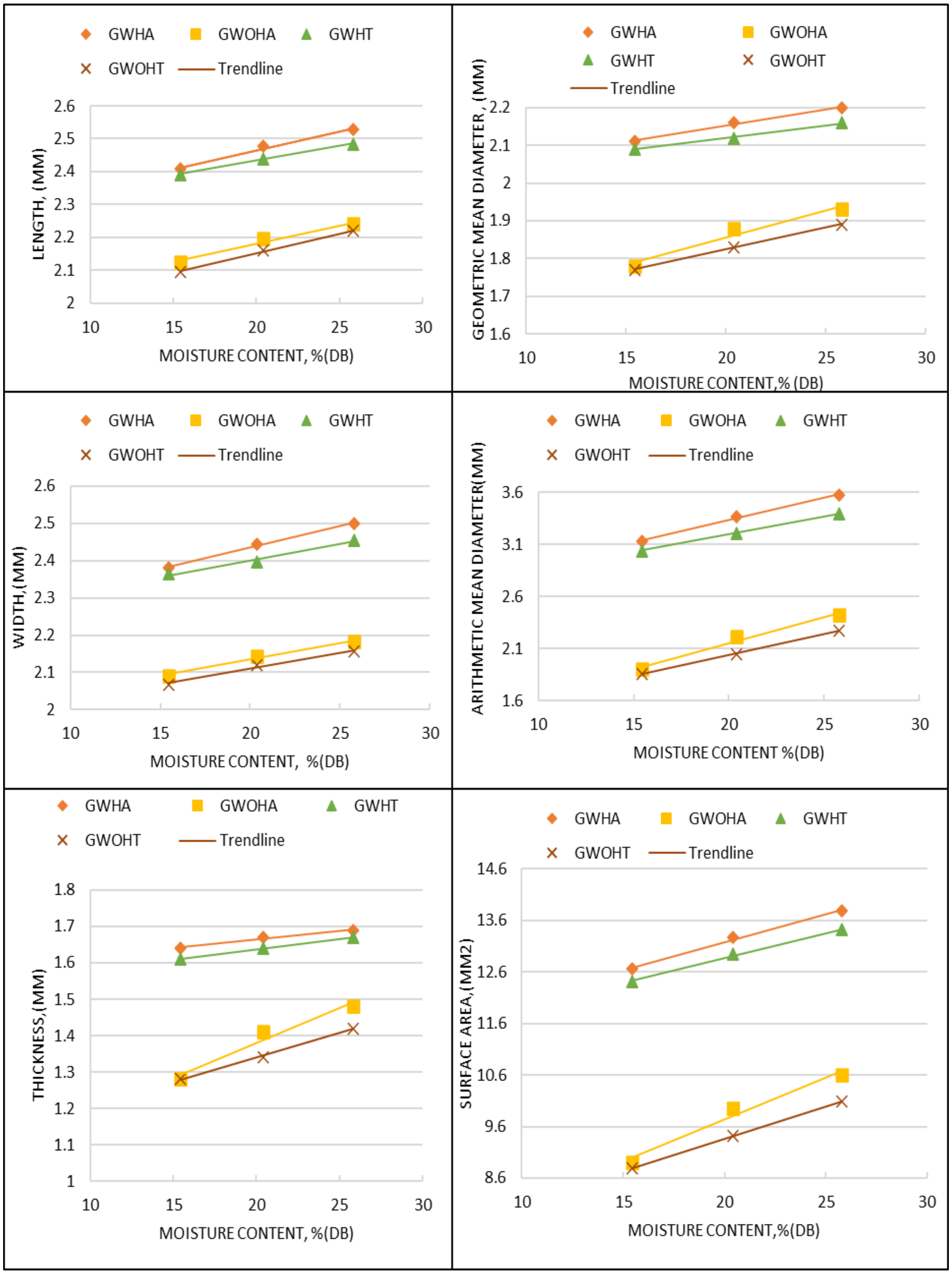

Fig. 1: Effect of moisture on the geometric properties of millet grains. GWHA-Grain With Husk ALT-1; GWHT-Grain With Husk TNS-86; GWOHA-Grain Without Husk ALT-1; GWOHT-Grain Without Husk TNS-86.

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Arithmetic Mean diameter

An arithmetic mean diameter gives average size of grains and is useful in design of mills, grinders and blenders. An arithmetic mean diameter of grains with husk ALT-1 variety (GWHA), grains with husk TNS-86 variety (GWHT) varied from 3.13-3.57mm and 3.04-3.39 mm, respectively. It varies from 1.90- 2.42 mm and 1.86- 2.27 mm in case of grains without husk ALT-1 variety (GWOHA), and grains without husk TNS-86 variety (GWOHT), respectively (Table 1). The Fig. 1 represents the variation in arithmetic mean diameter within the moisture content range from 15.45-25.8% db. The regression equation between Arithmetic mean diameter and moisture content (M=15.45-25.8%db) along with coefficient of determination is presented below:

$D_{A(GWHA)} = 0.0424M+2.48$ ($R^2 = 0.99$)

$D_{A(GWHT)} = 0.0338M+2.51$ ($R^2 = 0.99$)

$D_{A(GWOHA)} = 0.050M+1.15$ ($R^2 = 0.97$)

$D_{A(GWOHT)} = 0.397M+1.24$ ($R^2 = 0.99$)

High linear correlation can be observed between Arithmetic mean diameter and moisture content. All samples shows strong model fit. Grains without husk TNS-86 variety (GWOHT) increase rapidly with moisture and other samples shows slower increase with respect to moisture.

Surface area

Accurate surface area estimation is required for design of dryers, conveyors and aeration bins. The Fig. 1 represents the variation in surface area as a function of moisture. Surface area of grains also increases with increase in moisture content. The surface area of grains with husk ALT-1 variety (GWHA) and grains with husk TNS-86 variety (GWHT), varied from 12.66-13.78 mm^2 and 12.41-13.42 mm^2 respectively. However, surface area in case of grains without husk ALT-1 variety (GWOHA) and grains without husk TNS-86 variety (GWOHT), varied from 8.91-10.60 mm^2 and 8.79-10.08 mm^2 respectively (Table 1). The regression equation of surface area as function of moisture(M=15.45-25.8%db) along with coefficient of determination is presented as follow:

$S_{(GWHA)} = 0.108M+11.017$ ($R^2 = 0.99$)

$S_{(GWHT)} = 0.097M+10.92$ ($R^2 = 0.99$)

$S_{(GWOHA)} = 0.162M+6.47$ ($R^2 = 0.97$)

$S_{(GWOHT)} = 0.124M+6.86$ ($R^2 = 0.99$)

All samples show the linear high correlation between surface area and moisture content. Grains with husk TNS-86 variety (GWHT) shows the strong increase in surface area with increase in moisture content. Grains without husk (GWH) shows moderate increase and grains with husk TNS-86 variety (GWHT) shows least increase in surface area with respect to moisture content.

Volume

Volume of grains plays an role in design of storage equipment, drying system, heat transfer equipment and material handling equipment. Volume for grains with husk ALT-1 variety (GWHA) and grains with husk TNS-86 variety (GWHT), varied from 4.17-4.73 mm^3 and 4.04-4.49 mm^3 for moisture content 15.45-25.8% db respectively. In case of grains without husk ALT-1(GWOHA) and grains without husk TNS-86 variety (GWOHT), volume varies from 2.43-3.18mm^3 and 2.39-2.94 mm^3 respectively. The variation in volume with increase in moisture content is given in Figure 2. The linear regression equations between volume and moisture content(M=15.45-25.8%db) are given below:

$V_{(GWHA)}$= 0.054M+3.34 (R^2 =0.99)

$V_{(GWHT)}$= 0.043M+3.36 (R^2=0.99)

$V_{(GWOHA)}$= 0.072M+1.35 (R^2 =0.97)

$V_{(GWOHT)}$= 0.053 M+1.56 (R^2 =0.99)

The grains with husk ALT-1 variety (GWHA), grains with husk TNS-86 variety (GWHT), grains without husk TNS-86 variety (GWOHT), shows excellent fit (R^2= 0.99) and grains without husk ALT-1(GWOHA) shows very good fit (R^2=0.97). The grains with husk ALT-1 variety (GWHA) is most sensitive to moisture and grains with husk TNS-86 variety is least sensitive to moisture.

Sphericity

The variation in sphericity with change in moisture content is given in Fig 2. There is no significant impact of variation in moisture on sphericity parameter of grains the sphericity of for grains with husk (GWH) for both varieties lies between 0.86 to 0.87 within moisture content. The sphericity in case of grains without husk (GWOH) increases with increase in moisture content from 0.84 to 0.86 (Table 2). The regression equations of sphericity and moisture content(M=15.45-25.8%db) of grains along with coefficient of determination are presented below:

$\Phi_{(GWHA)}$= 0.001M+0.847 (R^2 =0.72)

$\Phi_{(GWHT)}$= 0.001M+0.847 (R^2=0.72)

$\Phi_{(GWOHA)}$= 0.0019M+0.810 (R^2 =0.99)

$\Phi_{(GWOHT)}$= 0.0009M+0.826 (R^2 =0.92)

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Grains without husk ALT-1 variety (GWOHA) shows the very strong correlation and Grains without husk TNS-86 variety (GWOHT) shows strong correlation of sphericity and moisture content. Grains with husk (GWH) for both varieties show moderate correlation.

It can be observed that geometric dimension such as size, surface area, sphericity and volume of grains with husk are significantly greater than grains without husk. The increase in geometric properties upon addition of moisture have been reported for millet [14], barnyard millet [29], cumin seeds [16], coffee beans [15], soyabean [30], green wheat [31].

Gravimetric properties

Table 2: Physical properties of two varieties of kodo millet grains with and without husk as a function of moisture content.

Sample	M,%(db)	Φ	δ_{bd}kg/m^3	δ_{td}kg/m^3	P, %	M_t, gm	θ_f°	θ_e °
GWHA	15.45	0.86±0.003	636.66±5.77	1123.33±15.27	43.31±0.84	5.912±0.17	24.76±0.72	32.63±0.62
	20.4	0.87±0.003	626.66±15.27	1127.33±11.54	44.20±1.56	6.238±0.02	25.16±1.17	38.06±0.57
	25.8	0.87±005	616.66±5.77	1132.66±35.11	45.22±1.64	6.501±0.17	25.57±0.67	44.17±1.66
GWHT	15.45	0.86±0.007	630±8.16	1122.64±25.16	43.03±2.20	5.861±0.22	24.31±1.00	33.24±1.24
	20.4	0.87±0.006	623.33±5.77	1130.35±5.77	45±0.22	6.1±0.11	25.22±0.72	37.06±0.51
	25.8	0.87±0.004	616.64±11.54	1135.36±15.27	45.57±1.64	6.39±0.17	25.43±0.23	43.5±0.79
GWOHA	15.45	0.84±0.003	866.66±5.75	1263.33±15.27	31.39±0.56	4.317±0.10	25.42±0.83	32.57±0.12
	20.4	0.85±0.005	846.66±5.75	1293.33±15.27	34.52±1.19	4.526±0.14	25.96±0.72	33.03±1.69
	25.8	0.86±0.008	786.64±5.75	1316.66±5.77	40.25±0.17	4.596±0.12	26.26±1.17	40.14±0.28
GWOHT	15.45	0.84±0.004	863.33±5.76	1256.64±20.81	31.28±1.32	4.156±0.09	25.26±0.29	31.99±1.07
	20.4	0.84±0.004	830±17.32	1286.66±15.27	35.49±0.91	4.361±0.08	25.41±1.35	34.88±1.81
	25.8	0.85±0.006	784.66±5.77	1313.33±5.77	40.10±0.38	4.399±0.16	26.18±0.70	39.64±0.62

(Data presented are the mean value± standard deviation, n=3).

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Bulk density

Density plays an role in designing the storage bins and to determine the purity and maturity level of grains. Bulk density decreased with increase in moisture level from 15.45-25.8% db as shown in Table 2. The bulk density decreased with the increase in moisture content (Fig.2). The mean values for bulk density of grains without husk ALT -1 variety (GWOHA) and grains without husk TNS-86 variety (GWOHT) decreases from 866.66 to 786.64 kg/m^3 and 863.33 to 784.66 kg/m^3, respectively (Table 2). On the other hand, bulk density for grains with husk ALT variety (GWHA) and grains with husk TNS-86 variety (GWHT) decreases from 636.66-616.66 kg/m^3 and 630 to 616.64 kg/m^3 respectively. This may be due to structural properties and increase in inter granular space with increase in moisture. Grains without husk has higher bulk density than grains with husk. Grains of ALT-1 variety have comparatively higher bulk density values than TNS-86. The negative regression equations with coefficient of determination (R^2) of bulk density of grains with respect to moisture content(M=15.45-25.8%db) are presented below:

$\delta_{bd(GWHA)}$ =-1.9312M+666.35 (R^2= 0.99)

$\delta_{bd(GWHT)}$ = -1.2881M+649.8 (R^2=0.99)

$\delta_{bd(GWOHA)}$ = -7.7806M+993.22 (R^2=0.93)

$\delta_{bd(GWOHT)}$ = -7.4171M+979.08 (R^2=0.99)

All the samples show very strong negative linear relationship which indicates that as moisture increase, bulk density decreases. The strongest decrease occurs in grains without husk ALT -1 variety (GWOHA) and grains without husk TNS-86 variety (GWOHT) (steeper slopes: -7.7). Similar trend has been observed for millets [14], caper seeds [18], cumin seeds[16], karingda seeds [32], and sunflower seeds [27].

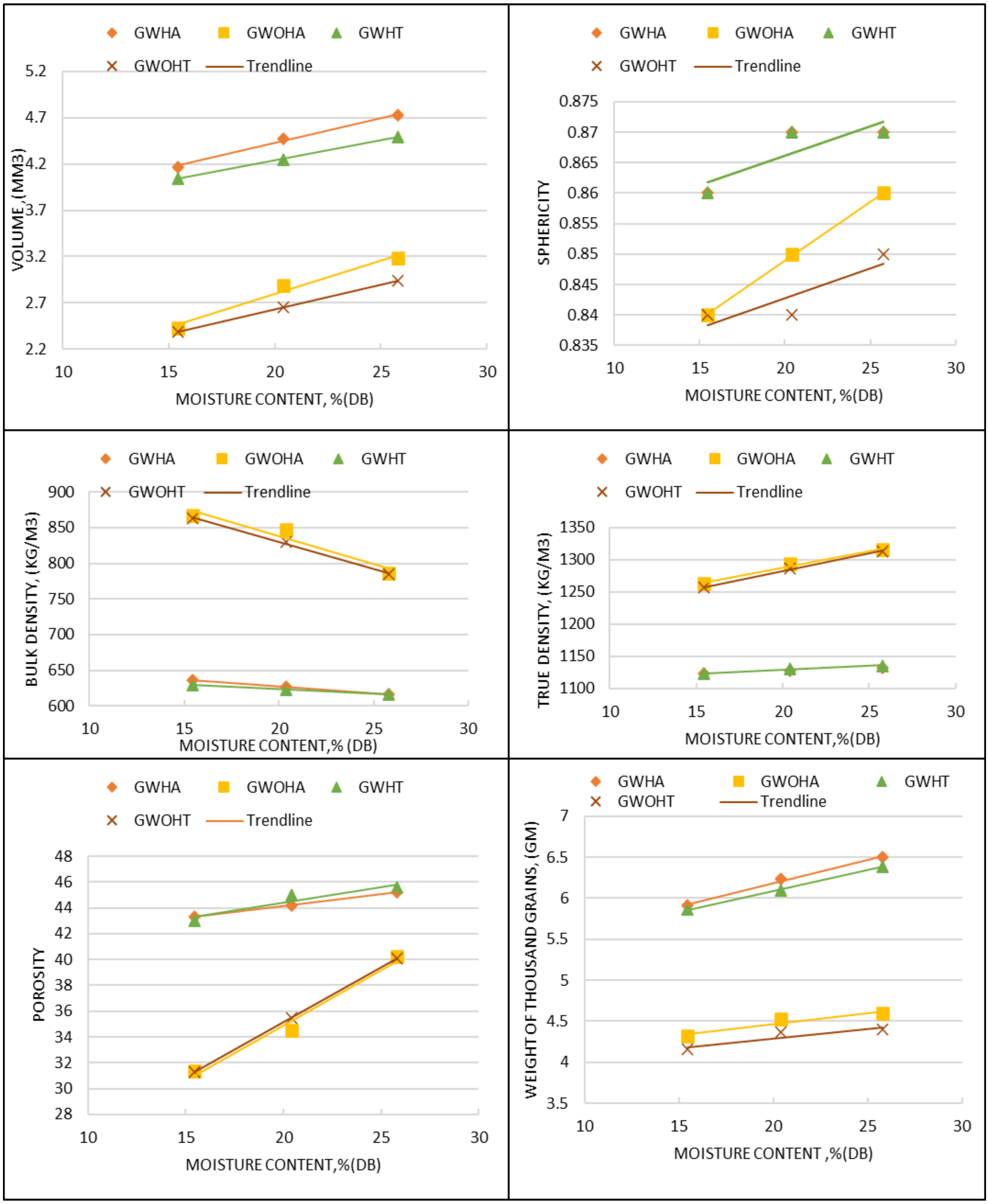

Fig. 2: Effect of moisture on the gravimetric properties of millet grains. GWHA-Grain With Husk ALT-1; GWHT-Grain With Husk TNS-86; GWOHA-Grain Without Husk ALT-1; GWOHT-Grain Without Husk TNS-86.

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True density

True density is critical in designing equipment for density-based separation such as gravity tables, flotation tanks, handling and storage system. The true density of grains increased as moisture content increased from 15.45-25.8%db (Table 2). Fig. 2 represents the variation in true density with respect to moisture level. The increase in true density is due to more grain mass increase in comparison to its volume increase as moisture content increases (Singh et al., 2010). The values for true density range from 1263.33 kg/m^3 to 1316.66 kg/m^3 for grains without husk ALT variety (GWOHA) and 1256.64- 1313.33 kg/m^3 for grains without husk TNS-86 variety (GWOHT). Similarly, the true density of grains with husk ALT variety (GWHA) and grains with husk TNS-86 variety increase from 1123.33-1132 kg/m^3 and 1122.64- 1135.66 kg/m^3 respectively (Table 2). The true density of grains without husk is greater than grains with husk. The significant positive relationship can be seen with true density and moisture content(M=15.45-25.8%db) as presented below:

$\delta_{td(GWHA)} = 0.9027M+1109.2$ (R^2=0.99)

$\delta_{td(GWHT)} = 1.2196M+1104.4$ (R^2= 0.97)

$\delta_{td(GWOHA)} = 5.1401M+1185.5$ (R^2=0.99)

$\delta_{td(GWOHT)} = 5.4691M+1172.9$ (R^2= 0.99)

All samples show excellent fit ($R^2 \geq 0.97$). The grains without husk (GWOH) shows the greater change in true density than grains with husk (GWH) with respect to moisture. Similar result was observed in millets [14], cumin seeds [16], sunflower seeds[33], and coffee[15]. However, a linear decrease in true density with increase in moisture content was reported in pumpkin seeds [27], karingda seeds [32], green wheat [31] and caper seeds [18].

Porosity

Porosity is the vital physical property for packaging and airflow through grains. Porosity is important for designing fluidized bed dryers, tray and bin dryers and aerated storage systems. Porosity increased with increase in moisture content as shown in Fig 2. The grains with husk has more porosity than grains without husk (Table 2). The porosity for grains with husk (GWH) for both varieties ranged from 43.03-45.57% within the moisture range. The porosity of grains without husk (GWOH) for both varieties ranged from 31.28-40.25% as a function of moisture content (Table 2). The porosity depends on true and bulk densities and varies due to difference in shape and size of different grains. The linear equation with coefficient of determination(R^2) of porosity with increase in moisture content (M=15.45- 25.8%db) is presented below:

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$P_{(GWHA)}$= 0.1846M+40.45 (R^2= 0.99)

$P_{(GWHT)}$= 0.2433M+39.534 (R^2 =0.89)

$P_{(GWOHA)}$= 0.8591M+17.731 (R^2= 0.97)

$P_{(GWOHT)}$= 0.8522M+18.11 (R^2= 0.99)

Grains with husk ALT -1 variety (GWHA), grains without husk ALT -1 variety (GWOHA), grains without husk TNS-86 variety (GWOHT) shows the very strong positive linear relationship(R^2=0.99). Grains with husk TNS-86 variety (GWHT) shows the strong positive linear relationship(R^2=0.89). Grains without husk (GWOH) shows much higher sensitivity than grains with husk (GWH) towards change in moisture. Similar results have been reported in millets [14], cumin seeds[16], sunflower seeds [33] and soyabean [30]. However, a decrease in porosity with increase in moisture content was reported in pumpkin seeds [27], green wheat [31], coffee [15], karingda seeds [32] and caper seeds [18].

Thousand grain weight

Thousand grain weight helps in setting calibration for sorting equipment, including size graders, seed sorter and air-screen cleaners. Variation in thousand grain mass with moisture content indicated that grain mass increased linearly with increase in grain moisture content. The grains with husk have more thousand grain mass than grains without husk (Fig.2). The mean thousand grain weight increased with respect to moisture content varies from 15.45 to 25.8%db (Table 2). Thousand grains weight of four samples namely, grains with husk ALT-1 variety (GWHA), grains with husk TNS-86 variety (GWHT), grains without husk ALT -1 variety (GWOHA) and grains without husk TNS-86 variety (GWOHT) increased from 5.912- 6.501 g, 5.861- 6.39 g, 4.317-4.596 g, 4.156-4.399 g, respectively, with the increase in moisture content from 15.45 to 25.8% db (Table 2). The regression equation of thousand grain weight and moisture content (M=15.45-25.8%db) of grain is given below:

$M_{t\,(GWHA)}$= 0.0568M+5.0501 (R^2=0.99)

$M_{t\,(GWHT)}$= 0.0512M+5.0659 (R^2=0.99)

$M_{t\,(GWOHA)}$= 0.0267M+3.9301 (R^2= 0.90)

$M_{t\,(GWOHT)}$= 0.0232M+3.828 (R^2= 0.84)

Grains with husk (GWH) shows the very strong positive linear relationship(R^2=0.99). Grains without husk ALT -1 variety (GWOHA) shows the strong positive linear relationship(R^2=0.90) and grains without husk TNS-86 variety (GWOHT) shows the good positive linear relationship(R^2=0.84). Grains with husk (GWH) shows greater thousand weight of grains response

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to change in moisture as compared to grains without husk (GWOH) towards change in moisture. A significant relationship between thousand grain weight and moisture content was observed. Similar results of linear increase in thousand grain mass with increase in moisture content was reported for caper seeds [18], cumin seeds (Singh & Goswami, 1996), soyabean [30], coffee [15] and barnyard millet (Singh et al., 2010).

Angle of Repose

The angle of repose plays a vital role in designing the storage equipment. The angle of repose depends on surface roughness of grains and seeds. The angle of repose is important for determining the maximum angle of pile of grain in the horizontal plane and is important in the filling of a flat storage facility. The change in static angle of repose with respect to increase in the moisture content is plotted in Fig 3. The angle of repose increased with increase in the moisture content from 15.45-25.8%db (Table 2). The filling angle of repose for grains with husk ALT-1 variety (GWHA) ranged from 24.76˚- 25.57˚ and range from 24.31˚-25.43˚ for grains with husk TNS-86 variety (GWHT). Similarly, the angle of repose for grains without husk ALT-1 variety (GWOHA) range from 25.42˚-26.26˚, and for grains without husk TNS-86 variety (GWOHT) range from 25.26˚- 26.18˚, respectively (Table 2). The angle of repose shows a significant positive correlation with variation in moisture content (15.45- 25.8%db)

$\theta_{f(GWHA)} = 0.0782+23.556$ (R^2=0.99)

$\theta_{f(GWHT)} = 0.01072M+22.784$ (R^2= 0.86)

$\theta_{f(GWOHA)} = 0.0808M+24.22$ (R^2= 0.96)

$\theta_{f(GWOHT)} = 0.0897M+23.773$ (R^2= 0.88)

Grains of with and without husk of ALT-1 variety shows very strong positive linear relationship and Grains of with and without husk of TNS-86 variety shows strong positive relationship. Grains without husk (GWOH) show higher sensitivity towards change in moisture content.

Similar trend of increase has been reported in cumin seeds(Singh & Goswami, 1996), karingda seeds [32], minor millets [17], green wheat [31], caper seeds [18], and sunflower seeds [33].

Dynamic angle of Repose

Dynamic angle of repose ensures the consistent flow of grains and it is used to design the correct hopper angle and conveyor system design. The change in dynamic angle of repose with respect to increase in the moisture content is plotted in Fig. 3. The dynamic angle of repose also increased with increase in moisture level (Table 2). The dynamic angle of repose for grains with husk ALT-1 variety (GWHA) and grains with husk TNS-86 variety (GWHT) varies from 32.63˚-44.17˚ and

33.24˚-43.5˚ respectively. It varies from 32.57˚-40.14˚ for grains without husk ALT-1 variety (GWOHA) and 31.99˚-39.64˚ for grains without husk TNS-86 variety (GWOHT)(Table2). It may be due to more stickiness of surface of the seeds that confines the ease of seeds sliding on each other. The equation presenting relationship between emptying angle of repose of grains and moisture content (15.45- 25.8%db) for each sample is presented below:

$\theta_{e(GWHA)}$= 1.1152M+15.369 (R^2= 0.99)

$\theta_{e(GWHT)}$= 0.9943M+17.5 (R^2=0.98)

$\theta_{e(GWOHA)}$= 0.7402M+20.035 (R^2=0.81)

$\theta_{e(GWOHT)}$= 0.7413M+20.27 (R^2=0.98)

Grains with husk ALT-1 variety (GWHA), grains with husk TNS-86 variety (GWHT) and grains without husk TNS-86 variety (GWOHT) shows the very strong positive linear relationship. However, grains without husk ALT-1 variety (GWOHA) shows moderate to strong relationship. Grains with husk (GWH) has higher sensitivity towards moisture than grains without husk (GWOH).

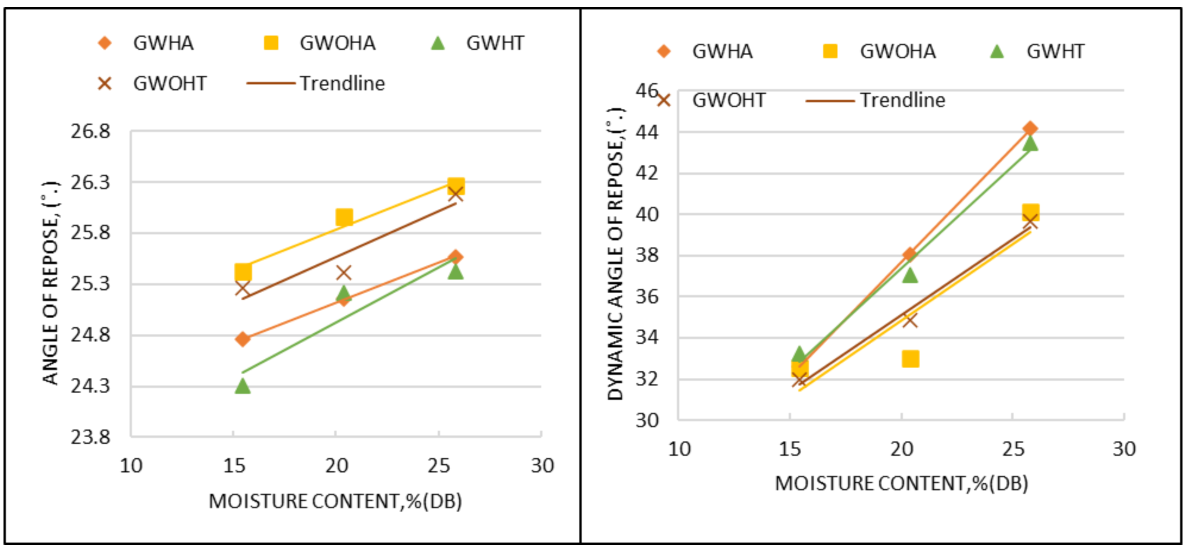

Fig. 3: Effect of moisture on Static angle of repose and Dynamic angle of repose of millet grains. GWHA-Grain With Husk ALT-1; GWHT-Grain With Husk TNS-86; GWOHA-Grain Without Husk ALT-1; GWOHT-Grain Without Husk TNS-86

CONCLUSION

The physical properties of grains play an important role in design of agro-processing machines such as thresher, sheller, husker, cleaning unit, conveying, milling etc. The physical properties such as principal dimensions, geometric and arithmetic mean diameter, surface area, volume, true density, porosity, Static and dynamic angle of repose increase significantly with increase in moisture content for each sample. However, sphericity for grains with husk show no significant relationship with increase in moisture content. Bulk density decreased with increase in moisture content. The grains with husk (GWH) have greater values of all physical properties as compare to grains without husk (GWOH). However, the bulk density and true density of grains without husk (GWOH) is higher than grains without husk (GWH). Among varieties, ALT-1 variety sample has slightly higher values than TNS-86 variety.

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Miss Jaismeen kaur Maan – Methodology, writing original draft preparation, data curation, software, review and final draft formation.

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