Research Article

# Evaluation of physical properties of oat grain (*avena sativa*)

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**Abstract**

This study on oat grains was performed to investigate the effect of moisture content on the selected physical properties because the knowledge about the physical properties of oat grain is important for designing processing machineries. For this purpose, moisture content of grains were varied from 6.33% to 21.47%, wet basis (wb). Grain geometric parameters such as average length, width, thickness, geometric mean diameter, surface area, volume, thousand grain weight, bulk density, true density, porosity, angle of repose and coefficient of friction on plywood, mild steel and galvanized iron were determined in this range. In the given moisture content range grain geometric parameters such as average length, width, thickness, geometric mean diameter, surface area, volume, thousand grain weight, projected area, true density, porosity, angle of repose and coefficient of friction on plywood, mild steel and galvanized iron increased but bulk density decreased with increase in moisture content. The average length, width, thickness, volume and geometric mean diameter of oat grains increased significantly ($p<0.01$) from 7.5354 to 8.6252 mm, 2.3144 to 2.5446 mm, 1.5534 to 1.8522 mm, 8.0972 to 28.7557 mm3 and 2.99 to 4.5766 mm respectively, with increase of moisture content. Thousand grain weight increased from 18.058 to 32.221 g. A linear significant increase of grain surface area from 28.1841 to 63.0216 was observed in the moisture range. Bulk density decreased linearly ($p<0.01$) from 729.5 to 540.073, true density increased linearly from 1250 to 1809.797, whereas porosity increased significantly ($p<0.01$) from 41.65 to 70.15. Angle of repose significantly increased from 26.86 to 38.7456. In this moisture range, the coefficient of friction was highest on mild steel surface and lowest on galvanized iron surface.

**Keywords:** Oat; Physical property; Moisture content; Geometric dimensions; machine design

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## Introduction

Oats (*Avena sativa*) have been used both as food and feed for the last one thousand years. Oats rank around sixth in the world cereal production statistics following wheat, maize rice, barley and sorghum. In 2014, worldwide production of oats was 22.7 million tons, drove by Russia with 5.3 million tons or 23% of the world aggregate with other significant makers was Canada, Poland, and Australia. They have been considered as poor man's nourishment and utilized for the most part as porridge, oat dinner and so on. From the ancient times oats are used as health food because of the excellent nutritional and functional properties and mainly grown in India for fodder purposes only. Oats contain lipids that are rich in unsaturated fats (about 80 percent) and essential fatty acids like linoleic acid. Oats contain exceptional cancer prevention agents, called avenanthramides, and additionally the vitamin E-like mixes, tocotrienols and tocopherols [1]. Oat protein contains significant amounts of basic amino acids in contrast with wheat [2, 3]. They are an amazing wellspring of solvent fiber as β-glucan. β-glucan is found in the cell walls in oats, has excellent functional properties and is well known for lowering serum cholesterol and blood sugar.

The physical properties of oat grains, like other grains, are essential and important for designing the processing equipment for further handling and post-harvest processing. Various types of cleaning, grading and separation equipment are designed on the basis of physical properties of grains [4]. Physical properties affect conveying characteristics of solid materials by air or water and cooling and heating loads of food materials.

The knowledge on the physical properties of a crop is essential for proper design of processing equipment. The size distribution and characteristic dimensions of grain is important for the design of equipment for cleaning, sorting and separation [5]. The bulk density is used to determine the capacity of storage and transport, while the true density is useful to design proper separation equipment. Moreover, porosity of the grain mass determines the resistance to airflow during aeration and drying operation [5, 6]. Frictional properties, for example, angle of repose and coefficient of friction are imperative properties for the outline of grain compartments and other stockpiling structures [7]. These properties are influenced by elements, for example, size, frame and moisture content of the grain. The review of literature showed that there is a lack of information on physical properties of oat grains for wide ranges of moisture content.

Hence, the knowledge of these physical properties are necessary for designing processing machines after harvesting like cleaner, grader and dehuller. The properties of different types of grains and seeds have been determined by other researchers also [8-13]. They studied the physical properties of different commodities but no one determined the physical properties of oat grains which needs to be processed properly and hygienically in continuous mode. No published literature is available on the physical properties of oat grains as a function of moisture content. The present study was, therefore, aimed to determine moisture dependent physical properties such as spatial dimensions, geometric mean Demeter, surface area, volume, 1000 grain weight, bulk density, true density, porosity, projected area, angle of repose and coefficient of friction on plywood, mild steel and galvanized iron of oat grains (variety KENT) between 6.33% and 21.47% (wb) moisture content.

## Materials and Methods

The oat grains (Variety KENT) were obtained from the Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana for this study. Grains were cleaned using cleaner cum grader developed by CIAE, Bhopal (Capacity: 300 kg/h) to remove foreign matters, brokens and immature grains etc. Then stored at room temperature (25±2 °C) in plastic bins for further study. Moisture content of the sample was determined by hot air oven [14]. Test samples of wanted moisture content set up by including estimated measure of distilled water finished by blending and sealing in LPDE packs. The normal starting moisture content was observed to be 7.29% wb. The grain moisture content range was selected between 6.33% to 21.47% wet basis because the harvesting is being practiced at about higher moisture content i.e. 21% and transportation, storage, handling and processing operations of the crop are performed at about lower and safe moisture content i.e. 6%.

The weight of the samples was recorded on an analytical balance (Model: TB403, Denver Instrument) of accuracy 0.001g in triplicate, and their average value was recorded. The sample was divided into lots that were conditioned for moisture content in the range of 6.33–21.47% wb. by adding predetermined amounts of distilled water calculated from the following Eq. (1) [15]:

$$Q = W \times \frac{(Mf - Mi)}{(100 - Mf)} \quad (1)$$

The sample were kept at 5°c in a refrigerator for one week for uniform distribution of moisture throughout the sample. Before each test, the required quantity of sample was taken out of refrigerator and allowed to attain ambient temperature before carrying out the experiment. All experiments were replicated in triplicate manner and average values were used in the analysis.

### *Measurement of Properties*

*Size and shape*

To determine the average size, 50 grains were randomly selected, and length, Width, Thickness of the grains were measured using a digital micrometer (least count 0.01 mm) (Mitutoya Corporation, Japan). The geometric mean diameter and Volume were calculated by using following Eqs. (2), (3) and (4) [16, 17]:

$$Dg = (LWT)^{1/3} \quad (2)$$

$$V = \pi B^2L^2/6(2L - B) \quad (3)$$

Where,

$$B = (WT)^{0.5} \quad (4)$$

The surface area of oat grain was obtained using the geometric mean diameter by analogy of a sphere [9, 18] as Eq. (5):

$$A_s = \pi D^2_g \quad (5)$$

*Thousand grain weight*

Thousand grain weight was determined by randomly selecting 100 grains from the overall sample, measuring their weight on a digital electronic balance with an accuracy of 0.001 g, and multiplying by 10 to get the mass of 1000 grains [19].

*Bulk density*

Bulk density was considered as the ratio between the mass of a sample of grain and the total volume occupied by it. It was determined using a container of known volume [7, 9].

*True density*

True density defined as the ratio between the mass of the sample grains and the actual volume occupied. It was determined for five moisture contents (in the range of 6.33% –21.47% wb. using toluene displacement method with three replications [12].

*Porosity*

Porosity of the grain bed was defined as the fraction of space in a bed of grains that is not occupied by the grains. The percentage porosity was calculated using the following Eq. (6) [17]:

$$\varepsilon = (1-\frac{\rho b}{\rho t})\ 100 \qquad (6)$$

*Angle of repose*

Angle of repose is the angle with the horizontal at which the material will stand when piled. The angle of repose was determined using a topless and bottomless cylinder of known dimensions. The cylinder was placed at the center of a raised circular plate and was filled with oat grains. The cylinder was raised slowly until the grains formed a cone on the circular plate of known diameter. To determine the angle of repose, the grains were allowed to fall freely from a hopper over a disc of known diameter to assume a natural slope. The angle of repose was then calculated from the measurement of the height and the radius of the cone using the following Eq. (7) [20]:

$$\emptyset = \tan^{-1} \frac{2H}{D} \qquad (7)$$

*Coefficient of friction*

Coefficient of friction of oat grains was determined for the displacement of grains on mild steel, plywood and galvanized iron surfaces with three replications. A wooden box was filled with oat grain and placed on these surfaces as mentioned above. The total weight required to move the box with grains was recorded. This value was used to calculate the coefficient of friction at this surfaces.

The total weight required to make the box with grain slide uniformly over the friction surface was used to measure the coefficient of friction as Eq. (8) [21].

$$\mu = \frac{F}{N} \qquad (8)$$

*Statistical Analysis*

The experimental results were subjected to analysis of variance (ANOVA) using AGRES (version 7.01) software and least significant difference test was used to describe the means with 99% confidence.

## Results and Discussion

### *Geometrical Parameters*

The length, width, thickness and geometric mean diameter increased significantly ($p \leq 0.01$) from 7.5354 to 8.6252 mm, 2.3144 to 2.5446 mm, 1.5534 to 1.8522 mm and 2.99 to 4.5766 mm respectively, with increase of moisture content 6.33% to 21.47% wb of oat grains and results are presented in **Figure 1**. The increase in size could be attributed to the expansion of the grain as a result of moisture absorption in the intercellular spaces inside the grains [22]. The dependence of these properties with moisture content could be represented by the following Eqs. (9) to (12):

$$L = -0.0067m^2 + 0.2477m + 6.353 \quad (R^2 = 0.9062) \tag{9}$$

$$W = 0.0006m^2 - 0.003m + 2.3154 \ (R^2 = 0.9914) \tag{10}$$

$$T = -0.0001m^2 + 0.0223m + 1.4289 \ (R^2 = 0.9846) \tag{11}$$

$$D_g = 0.0013m^2 + 0.0675m + 2.5462 \ (R^2 = 0.9878) \tag{12}$$

Similar trends were reported in this moisture content range for jatropha, guna, chickpea, neem nut and barley [8, 23-26].

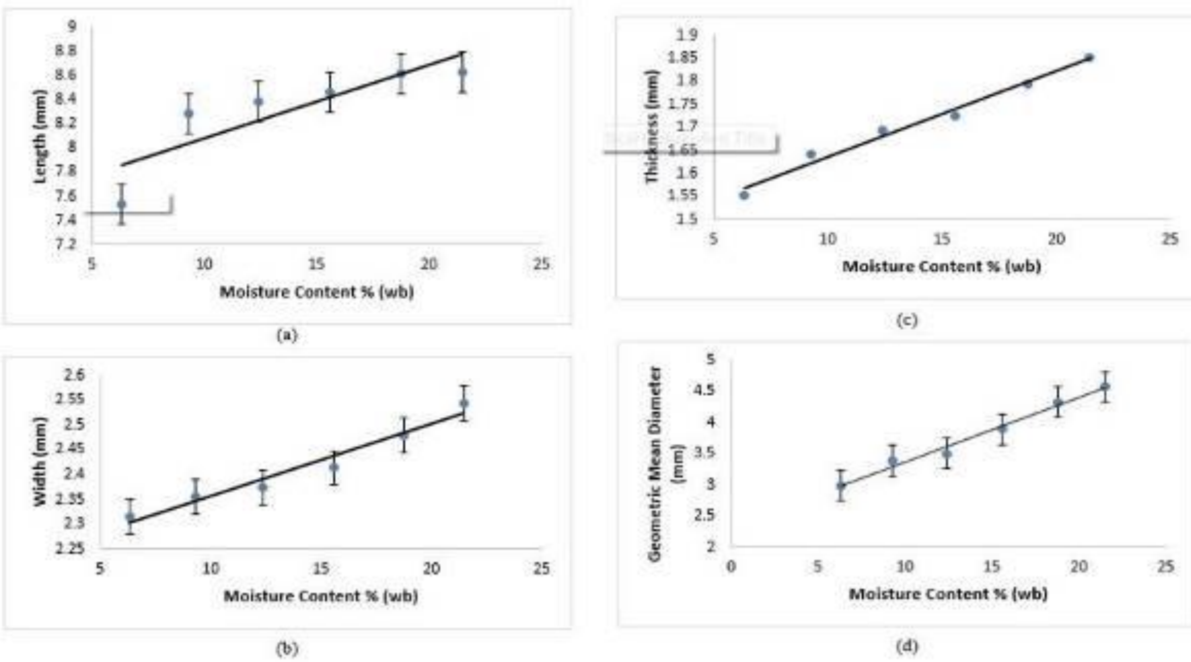


**Figure 1** Effect of moisture content on (a) length (b) width (c) thickness and (d) geometric mean diameter of oat

*Volume*

Volume was calculated from the spatial dimensions of the oat grains. The results are presented in **Figure 2**. Volume displayed significant differences with change in moisture content of the grain. The values of the volume increased from 8.0972 to 28.7557 mm$^3$ in the moisture range from 6.33% to 21.47 % wb. The increase in volume might have been caused by a proportional increase in the length, width and thickness. The relationship between moisture content (% wb) and volume of the grain could be represented by the following polynomial Eq. (13):

$$V = 0.0498m^2 - 0.0641m + 7.0347 \quad (R^2 = 0.9939) \tag{13}$$

Similar trend in the entire moisture range were observed where an increase in volume of the grains, were reported for okra, pea and barley [25, 27, 28].

*Surface Area*

The surface area increased from 28.1841 to 63.0216 mm$^2$ with increase in moisture content from 6.33% to 21.47% wb moisture content. The results are presented in **Figure 3**. The relation between surface area and moisture content is given by the Eq. (14):

$$A_S = 0.0334m^2 + 1.3344m + 19.176 \ (R^2 = 0.9924) \tag{14}$$

Other researchers has also reported similar trend in whole moisture range for grains of Scarlett barley, jatropha, karanja kernel, rice, fenugreek and lin grain [19, 24, 25, 29, 30, 31].

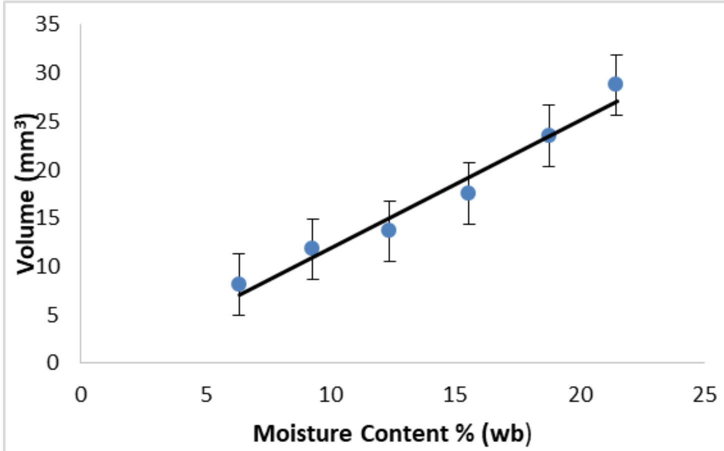


**Figure 2** Effect of moisture content on volume of oat

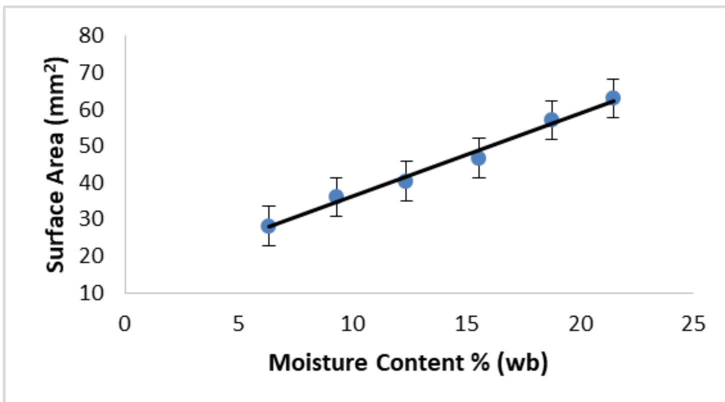


**Figure 3** Effect of moisture content on surface area of oat

*Thousand grain weight*

The variation of thousand grain weight of oat with moisture content, is presented in **Figure 4**, which showed that thousand grain weight increased from 18.058 g to 32.221 g as the moisture content increased from 6.33% to 21.47% wb ($p \leq 0.01$). It was found to be a linear function of moisture content and the relationship could be expressed using the following Eq. (15):

$$W_s = -0.0295m^2 + 1.7441m + 8.1574 \ (R^2 = 0.9807) \qquad (15)$$

Similar linear increase had been noted for gram [8], for soybean [9], for cumin grains [12], for faba bean [32], for red kidney bean [33] and for barley [25].

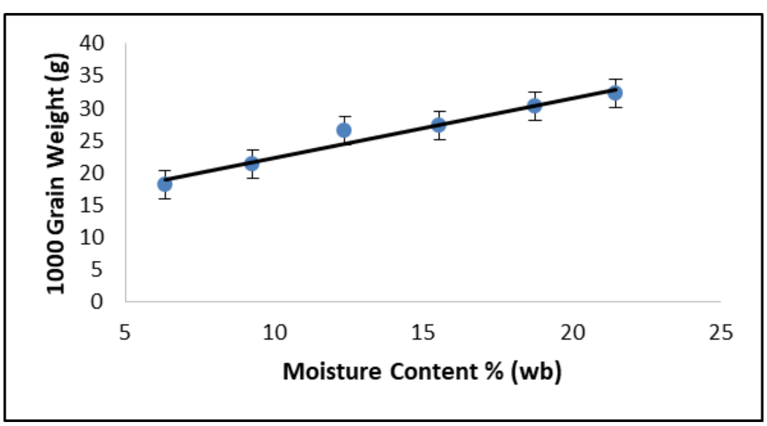


**Figure 4** Effect of moisture content on thousand grain weight of oat

*Bulk density*

Bulk density of oat at different moisture content varied significantly ($p \leq 0.01$) and decreased from 729.5 to 540.073 kg/m$^3$ when moisture content increased from 6.33% to 21.47% wb. **Figure 5** (a). This behavior could be attributed to the fact that the increased mass of the sample associated with increased moisture was lower than the volume expansion experienced by the grains [25]. This would cause the effect of having greater compaction (higher bulk density) in dry oat compared with wet oat. The relationship of bulk density of oat and moisture content can be expressed by the following Eq. (16):

$$\rho_b = -0.239m^2 - 6.1236m + 777.15 \ (R^2 = 0.9903) \qquad (16)$$

Similar trends were found for Koto and Manisoba cultivar at moisture content (wb.) range of 14.8% – 17.9% and 13.0% – 17.0%, respectively [34], for chickpea [35] and for locust bean seed [36].

*True density*

It was found that the true density of oat increased from 1250 to 1809.797 kg/m$^3$ as the moisture content of the oat increased from 6.33% to 21.47% wb. It could be seen from Figure 5 (b) that true density had a linear relationship with moisture content and could be represented in Eq. (17) as:

$$\rho_t = -0.365m^2 + 48.87m + 951.25 \ (R^2 = 0.9762) \qquad (17)$$

Similar trends of true density have been reported for various materials like green gram [14], guna grains [23], barley [25], cotton [37] and Lentil grain [38].

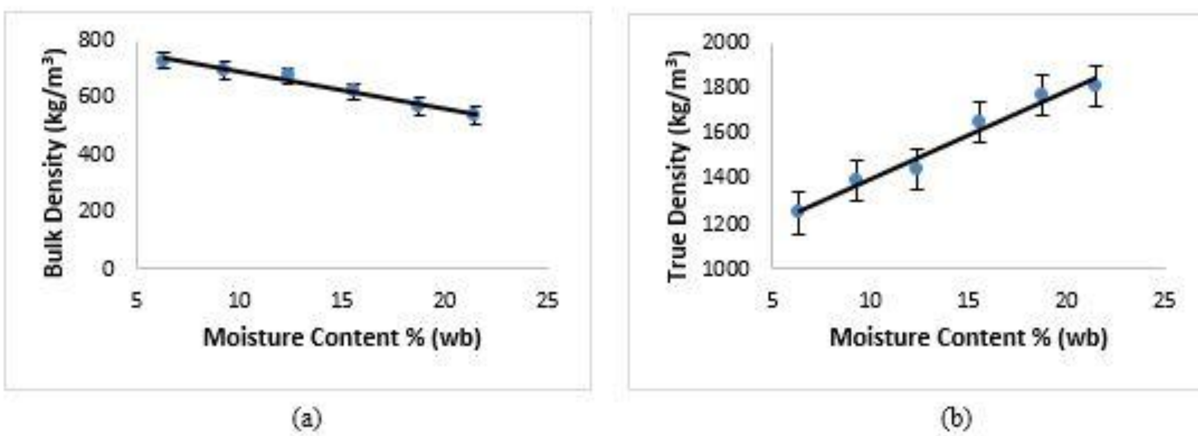


**Figure 5** Effect of moisture content on (a) bulk density and (b) true density of oat

*Porosity*

It was observed that when moisture content increased from 6.33% to 21.47% wb porosity increased significantly ($p \leq 0.01$) from 41.65 to 70.15% as shown in **Figure 6**. The relationship between the value of porosity and the moisture content can be expressed in Eq. (18) as:

$$\varepsilon = -0.0364m^2 + 2.9229m + 24.816 \ (R^2 = 0.9843) \qquad (18)$$

Similar behaviors were reported for beniseeds, pumpkin, and pigeon pea seeds [39].

*Angle of repose*

The experimental results of angle of repose with respect to moisture content are shown in **Figure 7**, exhibiting a significant increase of angle from 26.86° to 38.7456° ($p \leq 0.01$) with moisture content from 6.33% to 21.47% wb. The trend could be due to the fact that moisture in the surface layer of the grain kept them bound together by surface tension [29]. The angle of repose is of paramount importance in the design of hopper openings, side walls and storage structures in the bulk of grains per ramp [22]. The linear relationship between the angle of repose and the moisture content can be described by the following Eq. (19):

$$\Theta = -0.0187m^2 + 1.3196m + 18.986 \ (R^2 = 0.9911) \quad (19)$$

Similar behavior of the angle of repose with respect to moisture content were observed for buckwheat (Koto, Koban and Manisobacvs), barley, sorghum, jatropha and karanja [24, 25, 29, 34, 40].

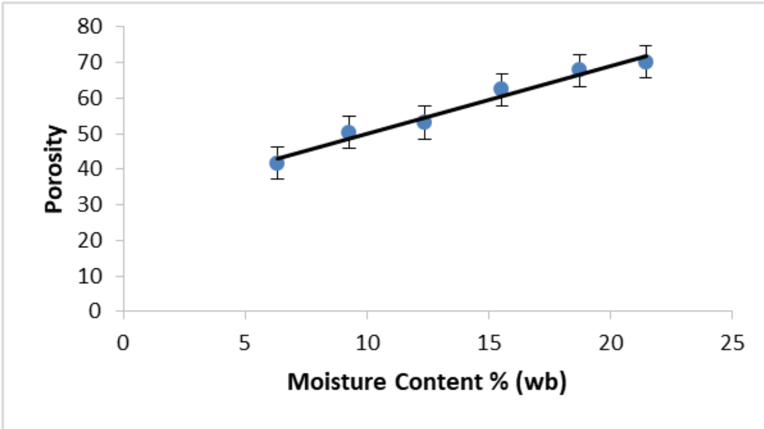


**Figure 6** Effect of moisture content on porosity of oat

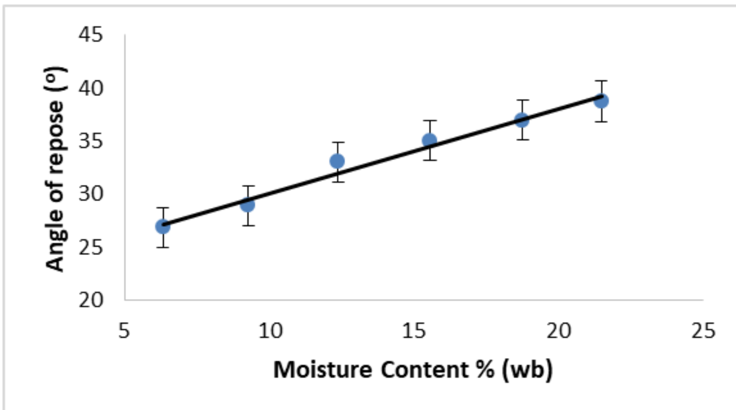


**Figure 7** Effect of moisture content on angle of repose of oat

*Coefficient of friction*

Variation of coefficient of friction for oat on three surfaces (plywood, mild steel, and galvanized iron) with moisture content is shown in **Figure 8**. The coefficient of friction increased significantly with moisture content for all the surfaces. This was due to the increased adhesion between the grain and the material surfaces at higher moisture contents leading to higher $\mu$ values. Similar results have been reported for faba bean [32]. The coefficient of friction ranged from 0.3375 to 0.5757, 0.286 to 0.6434, and 0.2633 to 0.4874, respectively for plywood, mild steel, and galvanized iron surfaces in the experimental moisture content range. Variation of static coefficient of friction with moisture content of oat is expressed in Eqs. (20) to (22) as:

$$\mu_{GI} = -0.0006m^2 + 0.0301m + 0.1093 \ (R^2 = 0.9652) \quad (20)$$

$$\mu_{Ms} = -0.0021m^2 + 0.0792m - 0.1114 \ (R^2 = 0.9681) \quad (21)$$

$$\mu_{pw} = -0.0002m^2 = 0.0211m + 0.2106 \ (R^2 = 0.9914) \quad (22)$$

Similar increase found in the friction coefficient of buckwheat (Koto cultivar) with moisture content [34]. Other researchers also found that as the moisture content increased, the coefficient of friction also increased [29, 32, 41]. At low moisture contents particles of grain tend to be elastic [42, 43]. As moisture content increased, the grain particles became more elastic and were able to deform requiring increased force to break the bonds between sliding grain and surfaces.

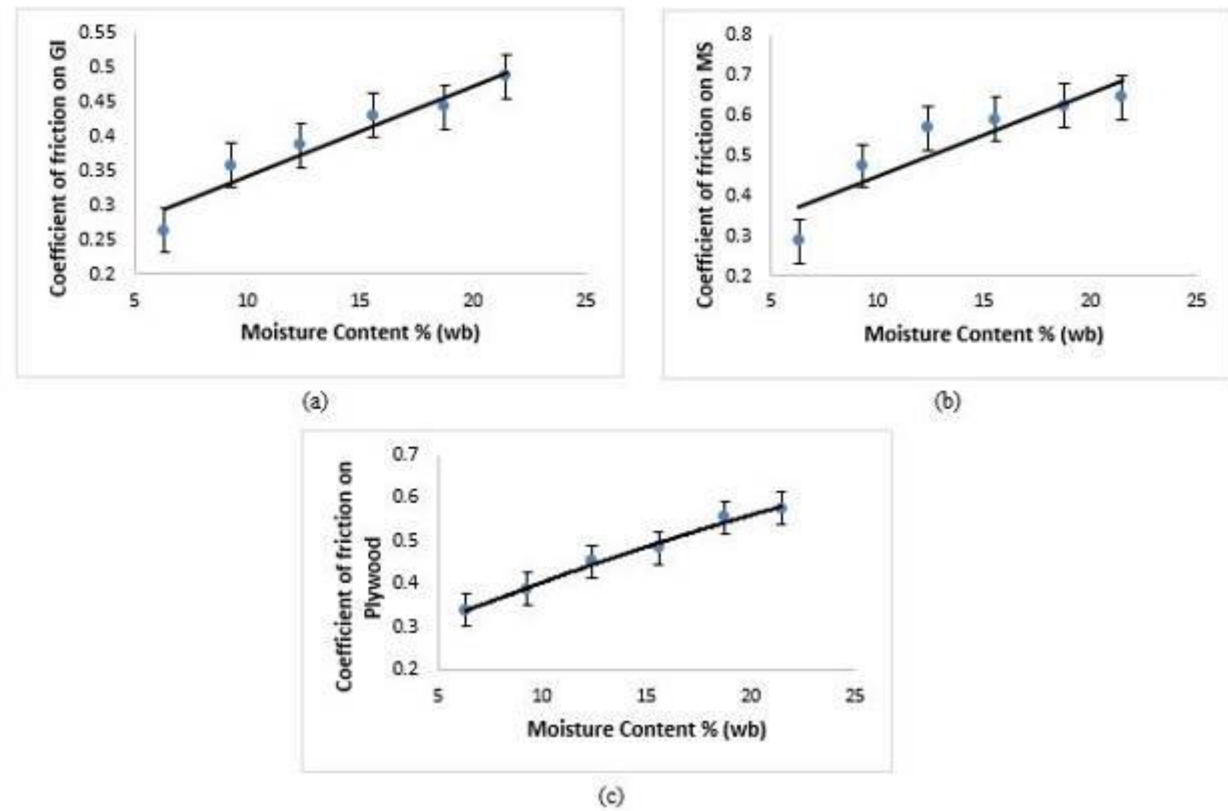


**Figure 8** Effect of moisture content on coefficient of friction of oat on (a) galvanized iron (b) mild steel and (c) plywood surface

The coefficient of friction at all moisture contents was highest on mild steel followed by plywood and galvanized iron. This was due to the smoother surface of galvanized iron as compared to plywood and mild steel. The order reported for locust bean seed is plywood followed by mild steel and galvanized iron sheet [36]. However, no variation existed between plywood and galvanized iron for lentil seeds [38].

## Conclusions

Effects of moisture content on physical properties of oat grains were studied. In this study, the values of physical dimension of oat such as length, width, thickness, geometric mean diameter, surface area, volume, thousand grain weight, true density, porosity, angle of repose and coefficient of friction on mild steel, plywood and galvanized iron surface increased in the moisture range from 6.33% to 21.47% wb significantly ($p \leq 0.01$) whereas bulk density decreased ($p \leq 0.01$) with increasing moisture content in this range from 6.33% to 21.47% wb. The changes in physical properties of oat with moisture content may be used in processing machines design and operations. This study provides information for oat processing in India that will help in selection of proper material handling and processing machines. So, these properties will be very much helpful in designing different machineries for processing of oat grains.

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