Effect of moisture content on engineering properties of oats (Avena sativa L.)

Brar, H.S.*, G.K. Sidhu, A. Singh

(Department of Processing and Food Engineering, Punjab Agricultural University, Ludhiana, Punjab, India)

Abstract: The present study was undertaken to investigate the effect of moisture content on engineering properties of OL-09 variety of oat grains. Different engineering properties such as length, width, thickness, geometric mean diameter, volume, surface area, sphericity, bulk density, true density, porosity, angle of repose and angle of internal and external friction were determined in a moisture range of 8%-14% (wet basis, w.b) using standard methods. The physical properties such as length, width, thickness, geometric mean diameter, volume, surface area and sphericity significantly ($P < 0.05$) increased from 15.01 to 16.19 mm, 3.06 to 3.60 mm, 2.78 to 3.11 mm, 5.03 to 5.65 mm, 37.00 to 52.98 mm3, 76.03 to 94.80 mm^2 and 33.58% to 35.01%, respectively as the moisture content increased from 8% to 14%.In the same moisture range, bulk density decreased from 474.32 to 408.19 kg/m^3, while true density, porosity and thousand grain weight increased from 1017.54 to 1132.90 kg/m^3, 53.35% to 63.94% and 41.45 to 44.84 g, respectively. Frictional properties like angle of repose, coefficient of internal friction and coefficient of external friction for wooden surface and galvanized iron sheet increased from 21.26 to 25.46°, 0.67 to 0.76, 0.55 to 0.70 and 0.49 to 0.63 with increase in moisture content in same range, respectively. The coefficient of determination, obtained R2 for the considered various engineering properties showed a close correlation with increase in moisture content.

Keywords: oats, engineering properties, moisture content, physical properties, frictional properties

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1 Introduction

Oats (*Avena sativa* L.), locally known as "javi", ranks 6^{th} in world cereal production following wheat, maize, rice, barley and sorghum.There has been an increase in oats use for human food in recent years due to its high nutritional value. Oat accumulates 389 kcal energy, 66.3 g carbohydrates, 6.9 g dietary fiber, 16.9 g protein and 4 g beta glucan per 100 g (Anon, 2013).

Engineering properties of agricultural products are the most importantly needed to determine the proper standards of design of grading, conveying, processing and packaging systems (Tabatabaeefar and Rajabipour, 2005). The major moisture-dependent physical properties of biological materials are sphericity, size, volume, surface area, thousand grain weight, bulk density, true density, porosity, angle of repose and friction against various surfaces including internal friction (Aydin, 2007). The knowledge of these engineering properties of the agricultural products is important for the appropriate storage procedure, design, dimensioning, manufacturing and operating different equipment used in post-harvest processing (Corrêa et al., 2007). The knowledge of sphericity, size and densities would be valuable in designing the planting, threshing and grading process equipment. The frictional properties such as the angle of repose and the coefficient of external and internal friction are important factors in design of seed bins, impact and shear action milling equipment and other storage structures including the compressibility and flow behaviour of materials (Mirzaee et al., 2009; Gharibzahedi et al., 2010). The knowledge of frictional properties is essential for designing mechanical units in machines and for selecting harvesting, cleaning, sorting, storage and processing parameters (Kabas et al., 2007).

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***Corresponding author: H.S. Brar,** Department of Processing and Food Engineering, Punjab Agricultural University, Ludhiana, Punjab, India. Email: brarharpreet565@gmail.com.

The processes that occur between a particle and the friction surface are termed as external friction, whereas internal friction takes place between particles (Grochowicz, 1994).

Hence, the objective of this study was to evaluate some engineering properties of oats viz., size, shape, volume, bulk density, true density, porosity, angle of repose and angle of internal and external friction as a function of moisture content. Information on these properties of grains may be important in design, dimensioning, development and operation of different equipment used in post-harvest operations.

2 Materials and methods

2.1 Materials

The OL-09 variety of oats used in the present study was obtained from Punjab Agricultural University farms, Ludhiana and stored at ambient conditions till starting of experiment. The grains were cleaned and dust, broken, fragmented and distorted grains were removed from the samples before the experiments. The initial moisture content was measured by standard hot air oven method (AACC, 2000). The desired moisture content i.e. 8%, 11% and 14% (wb) was obtained by drying the grains in a tray dryer at 40˚C-45˚C or by spraying with pre-calculated amounts of distilled water (Balasubramanian, 2001). Samples were thoroughly mixed and then sealed in separate polyethylene bag. The rewetted samples were kept at 5˚C in a refrigerator for 7 d to enable the moisture to distribute uniformly throughout the sample. Before starting the test, the required quantities of the samples were taken out of the refrigerator and allowed to warm up to the room temperature (25±2˚C) for about 2 hours (Saciliket al., 2003).

2.2 Methods

To determine the size of oat grain, 100 grains were randomly selected. Three major perpendicular dimensions namely length (L), width (W) and thickness (T) were measured using a digital caliper (Digimatic CD-6” R, Mitutoyo Corporation, Japan; least count: 0.01 mm). These dimensions were used to calculate the derived geometric properties i.e. geometric mean diameter (D_g) and sphericity index (ϕ) (Mohsenin, 1980). The volume (V) and surface area (S) of grain was calculated using equations given by Jain and Bal (1997).

Thousand grain weight (M_{1000}) was determined by counting 100 grains and weighing them in an electronic balance (A&D GF-1200; least count: 0.01 g) and then multiplied by 10 to give the mass of 1000 grains. Bulk density (γ) of the grains was determined using a cylinder of known volume and electronic balance (least count: 0.01 g). A known mass of the sample was filled into the cylinder and volume of the sample was noted down and calculated as mass divided by volume (Jha, 1999). The toluene displacement method was used to determine the true density of oat samples (Jha, 1999). Porosity of bulk grains was computed from the values of true density and bulk density (Mohsenin, 1980).

Angle of repose (θ) of oat was calculated from the height and diameter of the naturally formed heap of the grains on a circular plate (Visvangathan et al., 1996; Jha, 1999; Kingsley et al., 2006). The coefficient of external friction was determined w.r.t. two surfaces: plywood and galvanized iron sheet (Stepanoff, 1969; Irtwange and Igbeka, 2002). The coefficient of internal friction was determined w.r.t. grain to grain friction (Irtwange and Igbeka, 2002). A small square shaped wooden box of dimension 10 cm×10 cm×5 cm was put into a large wooden box used as a guided frame of dimensions 19 cm×14.5 cm×5 cm (Figure 1). The small wooden box was tied with a fine copper wire attached to a fixed pulley. The other end of copper wire was tied to a pan. The guided frame was first filled with grains. The weight (W_1) was put on the pan so as to just slide the empty small box over filled guided frame. Thereafter a fixed amount of grains (W) was put into the small box and the weight required for just sliding the filled small box (W_2) was observed. The coefficient of friction between the chord and pulley was assumed to be 0.5 (Sethi et al., 1992). The coefficient of internal friction was calculated as Equation 1:

$$\mu_i = (W_2 - W_1) / W \quad (1)$$

Where, μ coefficient of internal friction.

Figure 1 Apparatus setup for internal friction

2.3 Statistical analysis

Statistical analysis was performed using Data Analysis Tool in Microsoft Excel (2010). ANOVA: Single Factor was used to determine significant differences between means, with the significance level taken at $P < 0.05$. LSD test was used to perform multiple comparisons between means, with the significance level $P < 0.05$. The graphical representations and linear regression equations of the data were also developed by Microsoft Excel (2010) to relate interaction between moisture content and the investigated engineering properties of oat grains.

3 Results and discussion

The R^2values obtained for both dimensional and frictional properties of oat grains showed a strong correlation between grain moisture content and observed properties (Table 1). The axial dimensions such as length, width and thickness exhibited a significant increase from 15.01 to 16.19 mm, 3.06 to 3.61 mm and 2.78 to 3.11 mm, respectively (Table 1) (Figure 2).

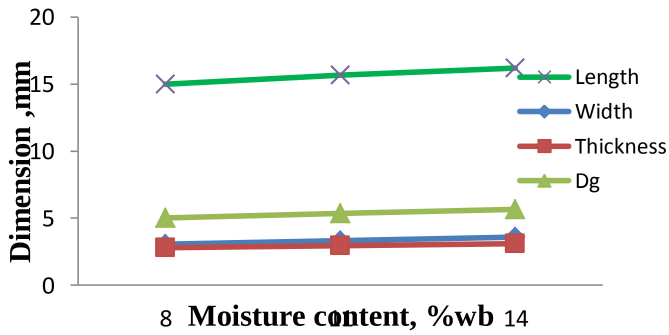

Figure 2 Effect of moisture content on linear dimensions

Study conducted by Karimi et al. (2009) showed a similar trend for wheat grains. Such dimensional changes are important in determining aperture size in the design of handling and processing equipment.

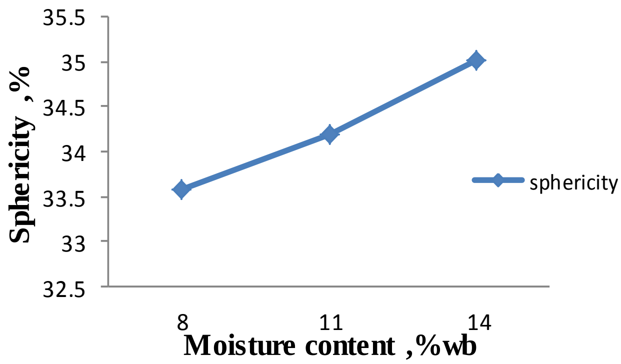

Figure 3 Effect of moisture content on sphericity

Similarly, the geometric diameter, sphericity (Figure 3), grain volume and surface area of oat grains increased from 5.03 to 5.65 mm, 33.58% to 35.01%, 37.00 to 52.98 mm^3 and 76.03 to 94.8 mm^2 (Figure 4), respectively as the moisture content increased (Table 1). The increases in properties were due to proportional changes occurred in the dimensions of oat grains. The results reported by Karababa (2006) and Baümleret al.(2000) for safflower seed and popcorn kernels, respectively showed similar trend.

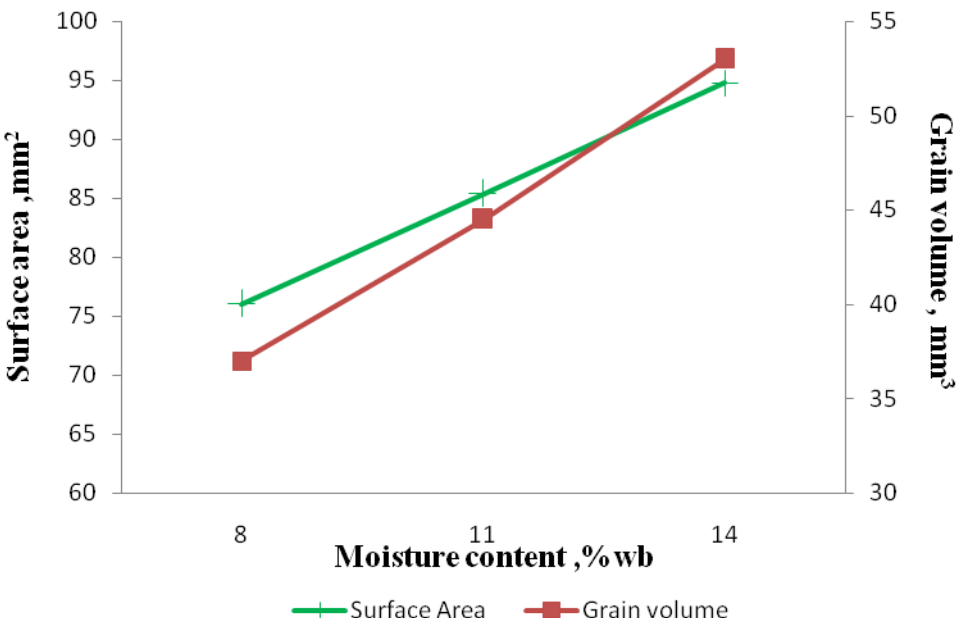

Figure 4 Effect of moisture content on surface area and grain volume

The thousand grain weight of oat grains exhibited increase from 41.45 to 44.84 g/thousand grains as increase in moisture content takes place (Table 1) (Figure 5). The similar trend was reported by Bagherpouret al. (2010) and Coskunet al. (2006) for lentil and sweet corn seeds, respectively for thousand grain weight.

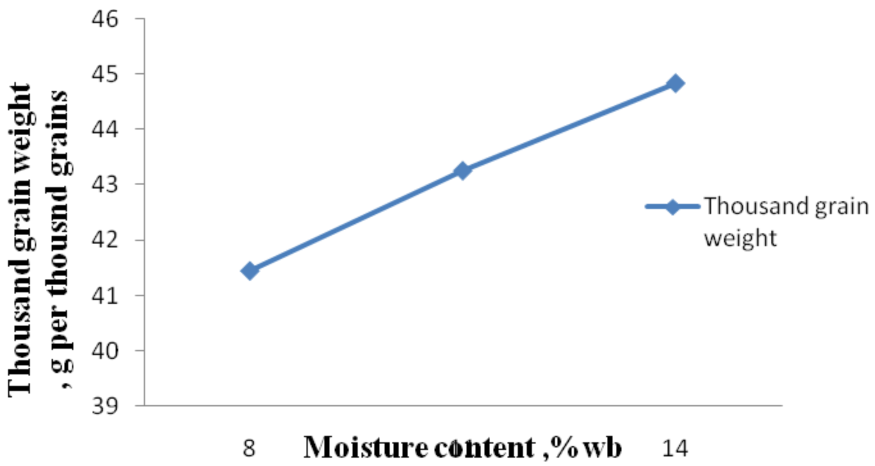

Figure 5 Effect of moisture content on thousand grain weight

Bulk density changed from 474.32 to 436.44 kg/m^3 with a negative coefficient against moisture content, demonstrated a decrease in bulk density with an increase in moisture (Table 1). The decreasing relation was due to the fact that an increase in mass owing to moisture gain in the oat grains was lower than the accompanying volumetric expansion of the bulk (Pradhanet al., 2008). Carman (1996) and Gupta and Prakash (1990) also reported negative relationship of bulk density against moisture content.

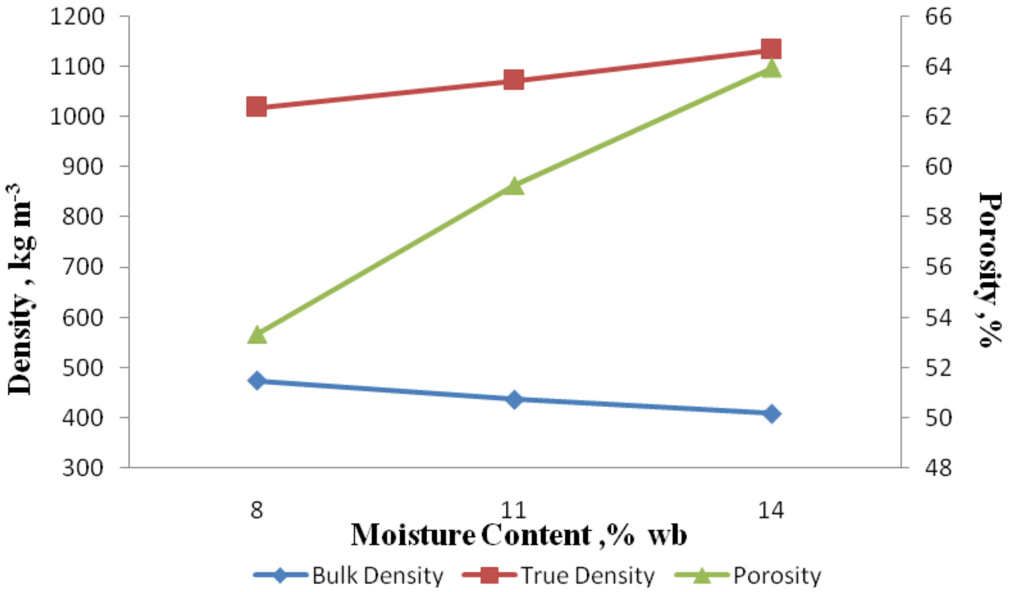

Figure 6 Effect of moisture content on density and porosity

Whereas, the true density and porosity showed an increasing trend from 1017.54 to 1132.90 kg/m^3 and 53.35% to 63.94%, respectively (Table 1) (Figure 6). The increase in true density might be attributed to the relatively lower true volume as compared to the corresponding weight of the oat grains attained due to adsorption of water. A similar result was reported by researcher Ghadgeet al.(2008). The increase in porosity could be attributed due to the expansion and swelling of oat grains with increase in moisture that might have resulted in more void space between the grains and increase in the bulk volume. This was also exhibited in the reduction of bulk density with increase in moisture content. Baryeh (2002) and Kabaset al. (2005) reported similar trend of increasing porosity for millet and cactus pear, respectively.

Table 1 Variation in engineering properties of oat grains at different moisture content

Parameter	Moisture content ,%wb			Regression equation	R^2
	8	11	14		
Length,mm	15.01 ±0.85 ^{a}	15.67 ±0.97 ^{b}	16.19 ±0.94 ^{c}	0.20M$_c$+ 15.263	0.9992
Width ,mm	3.06 ±0.15 ^{a}	3.31 ±0.18 ^{b}	3.60 ±0.26 ^{c}	0.09 M$_c$+ 3.03	1.0000
Thickness ,mm	2.78 ±0.22 ^{a}	2.95 ±0.17 ^{b}	3.11 ±0.18 ^{c}	0.09 M$_c$+ 2.76	0.9838
Geometric mean diameter ,mm	5.03 ±0.19 ^{a}	5.34 ±0.17 ^{b}	5.65 ±0.21 ^{c}	0.15 M$_c$+ 4.97	0.9976
Sphericity,%	33.58 ±1.70 ^{a}	34.19 ±1.7 ^{b}	35.01 ±1.61 ^{c}	0.38 M$_c$+ 33.07	0.9971
Grain volume ,mm^3	37.00 ±4.11 ^{a}	44.49 ±4.04 ^{b}	52.98 ±6.04 ^{c}	3.13 M$_c$+ 36.67	0.9980
Surface area ,mm^2	76.03 ±5.53 ^{a}	85.36 ±5.68 ^{b}	94.80 ±6.78 ^{c}	3.68 M$_c$+ 76.33	0.9991
Thousand grain weight ,gms	41.45 ±0.45 ^{a}	43.26 ±0.39 ^{b}	44.84 ±0.34 ^{c}	1.33 M$_c$+ 40.41	0.9998
Bulk density ,kgm^{-3}	474.32 ±2.64 ^{a}	436.44 ±5.97 ^{b}	408.19 ±3.4 ^{c}	-33.00M$_c$+ 505.33	0.9924
True density ,kgm^{-3}	1017.54 ±24.81 ^{a}	1072.12 ±27.57^{ab}	1132.90 ±30.81^{bc}	57.95 M$_c$+ 958.11	0.9992
Porosity ,%	53.35 ±1.37 ^{a}	59.28 ±0.54 ^{b}	63.94 ±1.01 ^{c}	5.30M$_c$+ 48.27	0.9952
Angle of repose ,°	21.26 ±0.35 ^{a}	23.13 ±0.08 ^{b}	25.46 ±0.27 ^{c}	2.10M$_c$+ 19.08	0.9960
Coefficient of internal friction , μ_i	0.67 ±0.02 ^{a}	0.73 ±0.02 ^{b}	0.76 ±0.02 ^{c}	0.47 M$_c$+ 0.63	0.9672
Coefficient of external friction for plywood , μ_W	0.55 ±0.02 ^{a}	0.63 ±0.02 ^{b}	0.70 ±0 ^{c}	0.076 M$_c$+ 0.476	0.9999
Coefficient of external friction for galvanised iron , μ_{GI}	0.49 ±0.02 ^{a}	0.55 ±0.02 ^{b}	0.63 ±0.02 ^{c}	0.067 M$_c$+ 0.423	0.9949

Where M_c is moisture content (% wb)

Note: Mean values ±standard deviations with the same letter are not significantly different (*P*<0.05)

Angle of repose (θ) showed an increasing trend from 21.26˚ to 25.46˚ as the moisture content increased (Table 1) (Figure 7). The increase may be due to increasing force of friction between the grains. Force of friction increased due adsorbed water into grains with increase in moisture content, thus increasing the force of friction between the grains and grain experiences retardation during its flow. Similar trends had been reported by Nimkar and Chattopadhyay (2001) for green gram for lentil seeds and Kingsley et al. (2006) for dried pomegranate seeds.

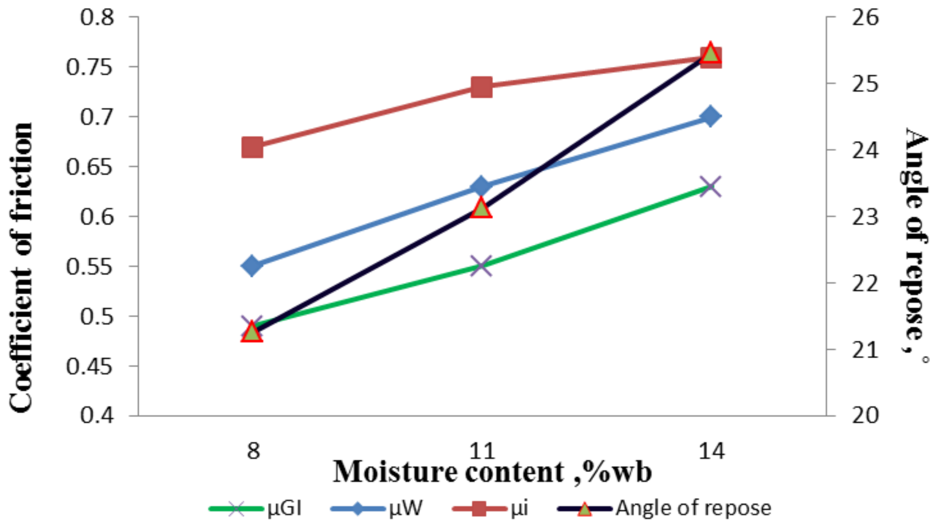

Figure 7 Effect of moisture content on frictional properties

Coefficient of internal friction (μ_i), external friction for galvanised iron (μ_{GI}) and plywood (μ_W) for oat grains exhibited increase from 0.67 to 0.76, 0.49 to 0.63 and 0.55 to 0.70, respectively as the moisture content increased (Table 1) (Figure 7). It was also observed that material surface has greater impact on coefficient of external friction than the moisture content. The highest value was observed at 14% with plywood surface and the lowest one at 8% with galvanised iron sheet (Figure 6). The reason for the increased friction coefficient at higher moisture content may be because of water present in the grain, offering a cohesive force on the surface of contact (Garnayak et al., 2008). The least coefficient of external friction may be owing to smoother and more polished surface of the galvanised iron sheet as compared to plywood. Similar increasing trends of coefficient of external friction for plywood and galvanised iron sheet were reported by Gupta and Das (1997) and Çalısıret al.(2005) for sunflower seed and rapeseed, respectively. Kibar and Öztürk (2008) also found in their study that the angle of internal friction increased with increase in moisture content for soybean.

4 Conclusions

The average length, width and thickness of oat grains were 15.01, 3.06 and 2.78 mm, respectively at 8% and increased linearly with the increase in moisture content. Derived geometric properties such as geometric mean diameter, sphericity, grain volume and surface area increased as the moisture content increased. The thousand grain weight (41.45-44.84 g), angle of repose (21.26-25.46˚), coefficient of internal friction (0.67-0.76), external friction for galvanized iron(0.49-0.63), external friction for wooden surface (0.55-0.70), true density (1017.54-1132.90 kg/m^3) and porosity (53.35%-63.94%) increased whereas the bulk density (474.32-408.19 kg/m^3) showed a decreasing trend as moisture content increases. So it can be concluded that there is a significant difference in the engineering properties of oat grains with different moisture content which will directly affect the design and development of processing equipment.

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