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Studies on physical and engineering characteristics of maize, pearl millet and soybean

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Abstract
Evaluation of physical and engineering characteristics of food material are crucial for efficient equipment design. In the present study the above characteristics were accessed for maize, pearl millet and soybean at moisture content 6.40%, 7.95% and 5.25% in the order. Data revealed that highest length, breadth and thickness (L,B,T) and geometric mean diameter (GMD) was found in maize. Test weight and thousand kernel weight ranged between 718.33 g to 791.33 g and 10.72 g to 330.21 g in the sequence, being highest for maize in both cases. The average bulk density and true density were 0.72 to 0.79 g/cc, 1.04 to 1.24 g/cc, respectively. Soybean exhibited maximum porosity trailed by maize and pearl millet. Among the grains, pearl millet had highest internal friction while maize and soybean portray the highest external friction. Referring to angle of repose, soybean showed highest value followed by maize and pearl millet.

Keywords: physical, engineering properties, maize, pearl millet, soybean, grain

1. Introduction

Together with wheat and rice, maize and pearl millet majorly contribute in the staple diet, widely acceptable and utilized for food and feed purpose. Unfortunately, maize and pearl millet are considered a stigma, linked to poor man's cereal and also underutilized but over the last 2-3 decades, trend has totally changed. In the recent years, maize and pearl millet are leading crops for addressing the food insecurity, hunger, adverse climate challenges and many more. In addition, concerted and vigorous measures are being taken to combat the malnutrition, especially protein energy malnutrition with corresponding source like legumes. Legumes are the cheapest but have abundance of protein in which soybean holds adequate amount of protein and oil. Besides, fiber and micronutrients are abundantly present in pearl millet while protein and functional components are contained in maize. Although agriculturists have direct role in raising the crops yet utilization and demand of the crop still remains the decisive factor. Thus, to explore the potential of conventional grains, relevant machinery and equipment for processing operation is considered necessary. Furthermore, for efficient, adequate, effective and economical equipment design, knowledge of physical properties of grains at particular moisture content is of paramount importance (Bhise *et al.,* 2014) [6]. The engineering properties are essential for the process design and manufacturing of food products and any factor affecting the handling and processing of food can be defined as engineering property. These properties can be divided into a number of categories such as optical, thermal, structural or geometrical, electrical and mechanical properties. The structural differences between the food materials alter these engineering properties. It encompasses the practical application of food science to develop efficient industrial production, storage, packaging and physical distribution of nutritious and convenient foods that are safe and uniform in quality. Physical properties are important to establish a convenient reference data for their mechanization and processing (Chukwu and Orhevba 2011) [7]. For the better quality of the finished product and the maximum efficiency of the processing and handling machines, it is essential to understand the physical and engineering laws governing their response. Kochhar and Hira (1997) [19] also reported the need of physical properties of the grains to design equipment and facilities for handling processing and storage. Likewise understanding of engineering properties and their corresponding significance such as coefficient of external friction for designing conveying, grain flow (mass and hopper) and storage structures; coefficient of internal friction for determining the compressibility of material for packaging, physical properties for efficient functioning of various types of agricultural machines (Sifters, Pneumatic transport systems, Sowing and seed harvesting machines etc), storage systems and handling systems (Amin *et al*., 2004; Sitkei, 1987) [2, 21]; bulk density, true density and porosity for sizing hopper and storage facilities (Gana *et al.,* 2014) [10].

Porosity for drying purpose (Varnamkhasti *et al.,* 2007) [24]; frictional properties for better dehulling, harvesting, transportation, separating process, cleaning operations (Vishwakarma *et al.,* 2012, Wani *et al.,* 2017) [25, 26], angle of repose for designing equipment for mass flow and structures for storage (Isik and Unal, 2007) [14]. Nowadays engineers greatly focuses in the design of storage structures of crops and in the selection of storage equipment. Both structural properties and features of the stored material are important in the design of storage equipment and facilities.

Regardless of all significance, limited literature is available on physical and engineering characteristics and their dependency on operational and processing parameters for proper, adequate and efficient equipment designs. Soybean, maize and pearl millet and are being utilized for preparation of different processed products, convenient products, flour and as additive in different formulation by food industry. Taking into account, conventional and underutilized cereals like pearl millet, maize and the principal legume i.e soybean was considered for assessing the physical and engineering properties.

2. Material and Methods

2.1 Material

Maize (PMH1), Soybean (SL958) and Pearl millet (PCB164) were procured from Director Seed, Punjab Agricultural University, Ludhiana. The grains were stored in cold storage room until analysis.

2.2 Methods

2.2.1 Moisture

Moisture was determined by oven drying method at 130ºC for 1.5 hour till constant weight obtained (AACC 2000, 44.15A) [1].

2.2.2 Dimensions (Length, Breadth and thickness)

5 grains were randomly picked from the lot and were put on the illuminated glass of the overhead projector and an image was focused. The image was drawn by placing tracing paper on screen and measured with scale in all three orientations. Readings were taken in triplicate.

$$\text{Length of grain (a)} = \frac{\text{Length obtained from image}}{\text{Magnification ratio}}$$

$$\text{Breadth of grain (b)} = \frac{\text{Breadth obtained from image}}{\text{Magnification ratio}}$$

$$\text{Thickness of grain (c)} = \frac{\text{Thickness obtained from image}}{\text{Magnification ratio}}$$

2.2.3 Geometric mean diameter (GMD) and Sphericity

These were calculated using the following relationship

$$GMD = (LWT)^{1/3}$$

$$\text{Sphericity} = \frac{(LWT)^{1/3}}{L}$$

2.2.4 Test weight

The grain weight of randomly selected 1000 ml grains was determined in triplicate.

2.2.5 Thousand kernel weight

100 grain of each sample was randomly collected from various lots and weighed using electronic balance (corrected to 0.01g) at predetermined moisture content. The weight of sample was multiplied with 10 to obtain average thousand kernel weight (Bart-Plange *et al.,* 2012, Tavakoli *et al.,* 2010) [3, 22].

2.2.6 Bulk density

Grains were filled in measuring cylinder up to certain level from the constant height followed by weighing. Bulk density is ratio of mass and volume. (Varnamkhasti *et al.,* 2008) [24].

2.2.7 True density/Particle density

The true density was measured by kerosene oil displacement method (Mohsenin, 1986) [20].

2.2.8 Porosity

Porosity was analyzed using the relationship of bulk density and particle density.

$$\varepsilon = \frac{\rho b - \rho t}{\rho t} \times 100$$

ρ_b = bulk density
ρ_t = true density

2.2.9 Coefficient of internal friction

A smaller box was put in a larger dimension box. Both the boxes were filled with grains levelled to brim (Kaur *et al.,* 2017) [17].

$$\text{Coefficient of internal friction} = \frac{(W_2 - W_1)}{W}$$

W = Weight of material in small box
W_1 = Weight required to slide the smaller box when empty
W_2 = Weight required to slide the smaller box when filled with grains

2.2.10 Coefficient of external friction

Wooden surface was used for determining the coefficient of external friction. Weight required to just slide the empty box and grain filled box was determined (Kaur *et al.,* 2017) [17].

$$\text{Coefficient of external friction } (\mu e) = \frac{(W_2 - W)}{W}$$

W_1 = Weight to cause sliding of box when empty
W_2 = Weight to cause sliding of box filled with sample material
W = Weight of material in the box

2.2.11 Angle of repose

Angle of repose gives indication of nature of pile formed by the material. It is angle with respect to horizontal at which material stands when piled. The apparatus consists of hollow cylinder and plywood plate. The cylinder was filled with grains and inclined slowly allowing the grains to fall gradually until it was empty. The height and radius of assumed slope was measured using the scale. The average reading of triplicate was recorded for accuracy. (Firouzi and Alizadeh 2012) [9].

$$\Theta = \tan^{-1} 2h/r$$

h= height of slope
r= radius of slope

3. Results and Discussion

3.1 Moisture

The moisture content for maize, 6.4%; pearl millet, 7.97% and soybean, 5.25% was recorded. Earlier literature reported that various physical parameters of grains are the function of moisture content (Bhise *et al.,* 2014) [6]

3.2 Dimensions

Understanding dimensions and GMD is required for betterment of sorting, quality check, efficient packaging models and transportation route. Length, breadth and thickness were found to be highest for maize followed by soybean and pearl millet in the sequence which suggests requirement of more storage space and transportation area in case of maize. The products average size and mean standard deviation affects the quality of processing by organising and designing the structural elements, their dimensions along with screen holes. Further, the shape and size of grains are important in the electrostatic separation of agricultural products from unwanted materials and in the development of grading and sizing machinery.For this reason mostly thickness, length and width are the basic parameters for carrying any unit operation. Maize had highest L: B: T (1.10, 0.93 and 0.66 cm) followed by soybean (0.61, 0.45 and 0.44 cm) and pearl millet (0.12, 0.06 and 0.06 cm) as depicts in Table 1. Dimensions of soybean were slightly less than those reported for the same at moisture content (10%) d.b (Bhise *et al.,* 2014) [5]. Hence, the results follow the trend that lower moisture content leads to reduced dimensions.

3.3 Geometric mean diameter (GMD) and Sphericity

Sphericity of grain signifies the ability of grain to roll rather than slide in grain hopper, feeding drum, delivery tube etc. Hence, higher value of sphericity, more ability of grain to roll which is important attribute for designing grain hopper and grain conveying equipment (Gana *et al.,* 2014) [10]. Pearl millet exhibited the lowest value of GMD which suggested its small size followed by soybean and maize. Least value of sphericity was observed in pearl millet and quite closer values in maize and soybean. Working with different variety of soybean (Kibar and Ozturk, 2008) [18] showed higher values for GMD and sphericity, Baryeh (2002) [4] reported higher value of sphericity for pearl millet.

3.4 Test weight and thousand kernel weight

The lesser the moisture content, the lower the thousand kernel weight (Bhise *et al.,* 2014) [6]. Maize had the highest thousand kernel weight (330.21 g) which indicates heavy grain in contrast to others and the highest test weight (791.33 g) followed by pearl millet (723.00 g) and soybean (718.33 g) as can see in Table 1. Results confirmed the TKW for maize and soybean was less than those showed at higher moisture content (Bhise *et al.,* 2014) [5]. These properties help in the simulation and design of food processes and in the computer-aided process engineering. They also gives information about the product quality, its acceptance by the consumers of different groups and their behavior towards the product.

Table 1: Physical properties of grains

Parameter	Grain		
	Maize	**Pearl millet**	**Soybean**
Moisture content (%)	6.40±0.05	7.97±0.31	5.25±0.12
Length (cm)	1.10±0.04	0.12±0.44	0.61±0.02
Breadth (cm)	0.93±0.02	0.06±0.02	0.45±0.01
Thickness (cm)	0.66±0.03	0.06±0.01	0.44±0.02
GMD	0.88±0.04	0.07±0.01	0.49±0.03
Sphericity	0.80±0.03	0.58±0.03	0.80±0.02
Test weight (g)	791.33±4.16	723.00 ±1.00	718.33±0.58
Thousand kernel weight (g)	330.21±5.86	10.72±2.16	83.96±1.38

3.5 Bulk density

Principle of cleaning is based on densities of the seeds. Grain densities have been found important for breakage susceptibility and hardness studies (Heidarbeigi *et al.*, 2009) [12]. The average value of bulk density was found to be 0.79 g/cc for maize, 0.78 g/cc for pearl millet and 0.72 g/cc for soybean (Table 2). Bhise *et al.,* (2014) [6] in their studies reported that bulk density of maize at 10% moisture content was (1194.92 kg/m^3) while those found to be in soybean at 10% moisture content was 620.91 kg/m^3(Bhise *et al.,* 2014) [5] and those reported for pearl millet at 7.4% moisture content was 701.2 kg/m^3 (Baryeh, 2002) [4]. Thus, it was found that bulk density of pearl millet and maize was almost same (0.79 g/cc) whereas the particle density of soybean (1.24 g/cc) and pearl millet was same. The discrepancy of results could be attributed to varietal difference in case of soybean and pearl millet however followed the fashion, lower the moisture content of grain, higher the bulk density.

3.6 True/Particle density

The significance of evaluating density for designing of storage bins and silos (Waziri and Mittal, 1997)[27], stability of feed pellet and wafers (Gustustafson and Kjelgard, 2000)[11], determining the purity of seeds (Jaeger, 1997)[15], maturity evaluation (Fashina, 1996)[8] and mechanical compressing of ensilages (Ige, 1997)[13]. Density is utilized in separation of materials with different specific gravities and densities. True density, bulk density and porosity are also useful in sizing grain hoppers, storage facilities, drying processes, heat and mass transfer during aeration. In addition, true density is useful for knowing the dielectric properties of cereal grains (Karimi *et al.,* 2009) [16]. Particle density of all three grains ranged from 1.04-1.24 g/cc, being highest for soybean as shown in Table 2. The findings were in good correlations with those reported for maize (Bhise *et al.,* 2014) [6], soybean (Bhise *et al.,* 2014) [5], and pearl millet (Baryeh, 2002) [4] and followed trend i.e lower the moisture content, lesser is the particle density.

Table 2: Engineering properties of grains

Parameter	Grain		
	Maize	**Pearl millet**	**Soybean**
Bulk density (g/cc)	0.79±0.01	0.78±0.01	0.72±0.01
Particle density (g/cc)	1.04±0.36	1.22±0.2	1.24±0.01
Porosity (%)	37.13±0.42	36.2±1.78	42.13±0.92

3.7 Porosity
The resistance of bulk grain to air flow is the function of porosity and kernel size. It ensures better heat exchange, aeration during heating, drying and cooloing operations (Theertha *et al.,* 2014) [23]. The porosity increases with increase in moisture content (Kaur *et al.,* 2017) [17]. Similar suit was followed by the results of maize (37.13%) at 6.40% moisture content, for pearl millet (36.20%) at 7.97 and for soybean 42.13% at 5.25% moisture content than reported maize (52.61%) at 10% moisture content (Bhise *et al.,* 2014) [6], for pearl millet (48%) at 7.5% moisture content, for soybean (42.53%) at 10% moisture content (Bhise *et al.,* 2014) [5].

3.8 Coefficient of Friction
The frictional losses are the detrimental factors for checking the efficiency of the machine which has to be overcome by providing extra power to the equipment. Internal and external coefficient of friction values were recorded and presented in Table 3. Both the parameters were assessed on a wooden surface. Pearl millet showed minimum value of internal friction while maize and soybean showed quite close values of external friction. Earlier researchers recorded the values of static friction for maize, pearl millet and soybean grains.

Table 3: Coefficient of friction of grains on wooden surface

Attributes	Grain		
	Maize	**Pearl millet**	**Soybean**
Internal friction (g/g)	0.431±0.03	0.276±0.08	0.463±0.05
External friction (g/g)	0.43±0.05	0.5±0.01	0.45±0.04
Angle of repose (in degrees)	25.734±1.5	22.685±2.10	27.339±3.14

3.9 Angle of repose
Angle of repose depicts the maximum angle at which heap of loose solids will stand without sliding (Wani *et al.,* 2015)[26]. The angle of repose determines the maximum angle of a pile of grain in the horizontal plane. It is important in the filling of a flat storage facility when grain is not piled at a uniform bed depth but is peaked (Mohsenin, 1986)[20]. Additionally, it is beneficial for designing equipment for mass flow, storage structure and determining the contour of a pile. Maximum value for angle of repose in soybean followed by maize and pearl millet in the order having values 27, 25.73, 22 degrees, respectively (Table 3) which were close to those reported for maize (Bhise *et al.,* 2014)[6], higher than soybean (Bhise *et al.,* 2014)[5], at 10% moisture content, lower than pearl millet at 8.00% moisture content. Discrepancy of results in case of soybean and pearl millet could be attributed to varietal difference.

4. Conclusion
It is evident from the study maize that is larger in size, weight; exhibits more bulk density, true density and porosity in contrast to pearl millet and soybean whereas internal and external friction and angle of repose of soybean was more in comparison to other grains. As equipment design crucially depends on the physical and engineering properties of grain for easy modus operandi; efficient, proper and economical equipment design, hence the studied varieties would be explored with greater ease.

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