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Investigations on physical properties of maize in context of mechanical shelling and dehusking

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Abstract

Dehusking and shelling of are two crucial unit operations involved in post-harvest processing of maize. Physical characteristics of maize must be considered while designing the equipment to perform these operations. The given study was planned to investigate the physical properties such as principal dimensions, effective diameter, one thousand seed mass, sphericity, bulk and true densities, angle of repose and coefficient of static friction. The obtained mean value for maize grain for length, width, and thickness was 9.47±0.83 mm, 9.69±0.83 mm and 5.13±0.84 mm, respectively. The sphericity of the maize grain varied between, 0.737 to 0.998. The angle of repose of maize grain ranges between 27.1 and 32.1°. The mean value of the angle of friction was 29°, 27° and 25° for plywood, painted M.S. sheet and M. S. Sheet without paint, respectively.

Keywords: Physical properties, moisture content, maize grain, angle of repose, sphericity

Introduction

In India, agricultural production is based on mixed farming, which includes two major enterprises: crops and livestock. Farmers combine these two businesses to maximize family income by diversifying the use of their resources. As per study of Directorate of Maize Research, livestock production is contributing 7 percent to National GDP and a source of employment and ultimate livelihood for 70 percent of the population in rural areas. In other hand, climate change presents a major risk to long term food security as it may decline wheat and maize yields by 5-10 percent by 2050 (ICAR Vision-2050). So, the care is need to be taken for maize crop yield and livestock.

The maize is cultivated throughout the year in all states of the country for various purposes including grain, fodder, green cobs, sweet corn, baby corn, popcorn in peri-urban areas. The predominant maize growing states that contributes more than 80 percent of the total maize production are Andhra Pradesh (20.9%), Karnataka (16.5%), Rajasthan (9.9%), Maharashtra (9.1%), Bihar (8.9%), Uttar Pradesh (6.1%), Madhya Pradesh (5.7%), Himachal Pradesh (4.4%). Apart from these states maize is also grown in Jammu and Kashmir and North-Eastern states. Hence, the maize has emerged as important crop in the non-traditional regions i.e. peninsular India as the state like Andhra Pradesh which ranks 5th in area (0.79 m ha) has recorded the highest production (4.14 mt) and productivity (5.26 t ha^{-1}) in the country although the productivity in some of the districts of Andhra Pradesh is more or equal to the USA.

In the design of machines, storage structures, and processes, physical properties are vital and necessary engineering data. This fundamental knowledge is valuable not just to engineers, but also to food scientists, processors, and other scientists who may desire to exploit these qualities and develop new applications ((Işik E and Ünal, 2007) [10]. Physical qualities as a function of moisture content must be determined before handling, transporting, separation, drying, aeration, storage, and processing equipment can be designed (Sobukola and Onwuka, 2011) [20]. Size and shape are significant in sorting desired materials and in the creation of scaling and grading machines, for example (Mohsenin, 1970) [13]. For an analytical forecast of the material's drying behavior, the form of the material is critical (Isik E and Ünal, 2007) [10]. Bulk density, actual density, and porosity are all important factors to consider when constructing drying, aeration, and storage systems, as these variables impact the mass's resistance to air flow.

Information on the coefficient of friction is used in designing equipment for solid flow, storage systems, seed harvesting and handling systems (Amin *et al.*, 2004) [2] while angle of repose is used to study the flow ability of seeds and other powdery materials on various surfaces.

The angle repose is important in designing equipment for mass flow and structures for storage (Isik and Ünal, 2007) [10]. These properties have been studied for various crops such as African breadfruit seeds (Omobuwajo, *et al.* 1999) [16]; sorrel seeds (Omobuwajo *et al.*, 2000) [17]; bambara groundnut (Baryey, 2001) [7]; groundnut kernels (Olajide and Igbeka, 2003) [15]; hazel nut (Ozdemir and Akinci, 2004) [18]; rape seed (Calisir *et al.*, 2005) [8]; green wheat (Al-Mahansneh and Rababah, 2007) [1]; white speckled red kidney bean grains (Isik and Ünal, 2007) [10]; and recently locust bean seed (Sobukola and Onwuka, 2011) [20]. There is need for detailed information on the physical properties of these maize seeds for storage design machinery and processing. Therefore, the objective of this study was to investigate some physical properties of maize. The properties investigated include principal dimensions, effective diameter, one thousand seed mass, sphericity, bulk and true densities, porosity, angle of repose and coefficient of static friction.

Materials and Methods

Moisture content

The moisture content of the grain on the dry basis was determined using oven dry method. A maize grain sample weighing 25 gram was kept in air-oven at 100 C for 72 h. The weight of oven dried sample was taken with an electronic balance and the percent moisture content was calculated using following formula.

$$M_c(db) = \frac{W_s - W_d}{W_s} \times 100 \quad (1)$$

Thousand seed mass

The thousand seed mass of the seeds were determined. It was determined by direct weighing of clean 1000 seeds of an electronic balance (Mettler, model AE 240, Switzerland) with an accuracy of 0.001 g (Aviara *et al.*, 1999) [6].

Effective Diameter

The three linear dimensions namely length L, width W and thickness T, of the seeds were measured using a micrometer screw gauge (Model 436-25M, Starret, Brazil) to an accuracy of 0.01 mm. Effective diameter, (De), sphericity, (Φ), kernel volume (V) and surface area (S) were calculated as a function of the linear dimensions. The effective diameter (De) of the seed was calculated using the following formula (Jain and Bal, 1997) [11]:

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

Sphericity

According to Mohsenin (1970) [13], the degree of sphericity (Φ) was calculated using the expression below:

$$\Phi = \frac{(LWT)^{\frac{1}{3}}\,100}{L} \quad (3)$$

Surface area of a sphere having the same volume as that of the grain to the surface area of the grain. According to Kachru *et al.* (1994) [12],

$$\text{Sphericity} = \frac{d_i}{d_c} \quad (4)$$

Where,
DI = diameter of the largest inscribed circle, and
DC = diameter of the smallest circumscribed circle

Bulk Density

The bulk density is the ratio of the mass sample of the kernels to its total volume. It was determined by filling a 500 ml container with seeds from a height of 150 mm, striking off the top level without the seeds being compacted in any way and then the content was weighed (Singh and Goswami 1996) [19].

$$BD = \frac{W_s}{500\ ml} \quad (5)$$

Where,
Ws = weight of the sample, g,
The bulk density of maize cob with husk was determined on wet basis using the following formula.

$$BD_{cob} = \frac{W_{cob}}{V_{cob}} \quad (6)$$

$$BD_{core} = \frac{W_{core}}{V_{core}} \quad (7)$$

Where,
W cob = wet weight of cob samples, g,
V cob = volume of wet cob sample, cm^3

Using the toluene displacement technique, the true density (t) was calculated. Toluene was substituted for water because it is less readily absorbed by seedlings. It also has a low surface tension, which allows it to fill even small dips in a seed, and a low dissolving power. A 1000 ml graduated measuring cylinder was filled with 500 ml of toluene. After that, 300 g of seed was soaked in toluene. The displacement was measured and recorded. The ratio of kernel weight to volume of displaced toluene was used to calculate true density (t) (Aviara *et al.*, 1999; Ogunjimi *et al.*, 2002; Omobuwajo *et al.*, 1999) [6, 14, 16].

$$\rho_t = \frac{30gm}{V_2 - V_1} \quad (8)$$

Where; V_2 = final volume and V_1 = Initial volume

Terminal Velocity

The terminal velocity is the measurement of airflow rate at which the material will terminate from its position and remains suspended in the air tunnel. For the measurement of the terminal velocity of maize grain procedure suggested by Kachru *et al.* (1994) [12] was followed

Coefficient of Friction

The coefficient of friction was measured against different surfaces i.e. wood, painted M.S sheet and unpainted M.S. sheet. Three frictional properties viz. static, angle of friction by the inclined method and internal seed friction was measured as per the procedure by Kachru *et al.* (1994) [12].
The box of size 103 mm×103 mm×50 mm was tied by a cord passing over a pulley and a pan was attached to this cord. The weights (W_1) were put into the pan until the box starts to slide. The weight (W_1) was noted. Later, the box was filled with sample material and again the weights (W2) were put to cause sliding of the box. This weight (W_2) was also noted.

The static friction was determined at the weight when the box starts to slide on the base material. The mean reading represents the static friction on all the three surfaces.

$$\mu_s = \frac{W_1 - W_2}{W} \quad (9)$$

Where,
μs = coefficient of static friction
W1= weight to the sliding of empty box,
W2= Weight to the sliding of filled box,
W= Weight of material inside the box,

For determination of angle of friction by inclined method, the maize grain was filled in test box size 103 mm × 103 mm × 50 mm placed on the test surfaces at the top edge. A wooden block and a soft stopper were placed at the bottom sliding frame. The testing plane was tilted until the test sample began leaving an inclined surface, the plane was clamped in this horizontal was taken as angle of friction. The mean angle of friction was determined for individual surfaces. The angle of friction is calculated by using following relationship:

$$\mu = tan\theta \quad (10)$$

Where,
μ = Coefficient of friction and θ = Value of the angle

Results and Discussion

The measurement of length (L), width (W), thickness (T) of maize grain at a moisture content of 12 percent for maize seed. The obtained mean value for maize grain for length, width, and thickness was 9.47±0.83 mm, 9.69±0.83 mm and 5.13±0.84 mm, respectively. The percentage coefficient variation was observed to be 98.16 percent. The lengths of the maize cobs with husk of 20 different cobs were found to vary from 261.53 mm to 155.81 mm. The mean top diameter of the selected maize variety was found 49.58 mm, while the middle diameter was in the range of 46.80 mm and tip diameter was 37.24 mm. The mean density of maize cob with husk and maize core (after removing the grain and husk) were found in the range of 0.273 and 0.478 g/cm^3 of well dried cobs respectively. The sphericity of the maize grain varied between, 0.737 to 0.998. The weight of the thousand seed ranges between the 0.324 to 0.417 g for the selected grain samples. The mean weight of thousand seed was obtained 0.362 g. The bulk density is important consideration for the development of hopper and cleaning unit. The mean of bulk density was 0.1252 g/cm^3. The angle of repose of maize grain ranges from the 27.1 to 32.1°. Similarly, the mean value of angle of repose found to be 27.1°. The measured range of terminal velocity between 10.87 m/s to 13.6 m/s. the mean terminal velocity of maize grain is found 10.87 m/s. Observed range of angle of friction by inclined plane method was observed in range of 29° to 34°, 27° to 31° and 25° to 29° for the three selected base material viz. plywood, painted M.S. sheet and M. S. Sheet without paint, respectively. The mean value of the angle of friction was 29°, 27° and 25° for plywood, painted M.S. sheet and M. S. Sheet without paint, respectively.

Conclusion

The engineering properties, physical, frictional and terminal velocity of ear-head and grain were essential for design of dehusking and shelling system. The study of un-dehusked and dehusked cobs, maize seeds, were used in deciding hopper, concave, cob outlet dimensions, collecting/conveying units and sieve configurations. Average LWT 9.47±0.83mm, 9.69±0.83mm and 5.13±0.84mm. Coefficient of variation was 98.16 percent, the lengths of the maize cobs with husk vary from 261.53mm to 155.81mm. The top diameter of the selected maize variety is 49.58mm, middle diameter is 46.80 mm and tip diameter are 37.24mm. The densities of maize cob with husk and maize core (after removing the grain and husk) are rang of 0.273-0.478g/cm^3. The sphericity of the maize grain varied 0.737 to 0.998. The mean weight of thousand seed was obtained 0.362 grams and bulk density 0.1252g/cm3. Similarly, the mean value of angle of repose found to be 27.1 degree. The mean terminal velocity of maize grain is found 10.87m/s. The mean value of the angle of friction is 29°, 27° and 25°.

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