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Physical properties of maize kernels at different moisture content

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Abstract
Maize or corn (*Zea mays* L.) is an important cereal crop of the world. The average value of maize grain dimension was determined in this study at various moisture content. The average length (8.192), width (6.20) and thickness (4.30) of the soaked maize were linearly increased according to moisture content. Arithmetic mean diameter (6.21), Geometric mean diameter (6.00), Squire mean diameter (10.42), Equivalent diameter (7.55), Degree of sphericity (0.75), Aspect ratio (0.76), shape factor (6.43) and angle of repose of soaked maize were increased with an increase in moisture content. The bulk density, true density, and porosity of the maize grain were found to decrease with increasing moisture content. The bulk density of maize grain decreased linearly from 806.4 to 768.3 kg/mm^3. The true density of maize grain decreased linearly from 1109.4 to 1065.8 kg/mm^3 for maize, respectively. The porosity was calculated as a function of the bulk density and the true density of the grain. It was found to decrease linearly from 32.3 to 27.8 for maize grain. The angle of repose of maize is different at different moisture content. The moisture content of maize was 8, 10, 12, 14, and 16 and the angle of repose was found at this moisture content was 19.98, 21.12, 23.20, 24.96, and 27.98 respectively.

Keywords: Physical properties, bulk density, true density, angle of repose

1. Introduction

Maize (*Zea mays* L.), also known as corn, is the third most important cereal after wheat and rice. It is widely distributed throughout the world. Maize is a coarse grain and now it is being accepted as a staple diet as its demand is increasing year by year. In India, maize is the third most important cereal crop after rice and wheat in terms of area. Currently, 49 percent of maize output is used as poultry feed, 25 percent as food, 13 percent in starch and other industries, 12 percent as animal feed, and 1 percent as seed. Thus, maize has attained an important position as an industrial crop because 75% of its production is used in starch and feed industries (Anonymous, 2011) [2].

Maize is grown throughout the year in India. Maize production in India has increased over the years from 23 million metric tonnes in 2013-14 to 30 million metric tonnes in 2019-20 (FAO, 2019-20). Production of maize in India is dominated by Andhra Pradesh and Karnataka, which account to 38% of total production in India.

Knowledge of physical properties is important and necessary engineering data in the design of machines, storage structures, and processes. This basic information is valuable not only to engineers, but also to food scientists, processors, and other scientists who may want to exploit these properties and find new applications (Işik and Ünal, 2007) [20]. The determination of physical properties as a function of moisture content is critical for designing equipment for handling, conveying, separation, drying, aeration, storing, and processing (Sobukola and Onwuka, 2011) [21]. Size and shape, for example, are important in separating them from undesirable materials and in the development of sizing and grading machinery (Mohsenin, 1970) [12]. The material's shape is critical for predicting its drying behaviour analytically. The terms “bulk density”, “true density”, and “porosity” are used. There is major consideration in drying and aeration design and storage systems, as these properties influence mass resistance to air flow (Amin *et al*., 2004) [1].

2. Materials and Methods

India has the largest area under cereals. Maize is commonly grown as a coarse cereal in different parts of India. These cereals are also used to develop value-added products for many decades, and they have a large market for consumption. Maize (local variety) procured from the local market of Jabalpur was selected for the present investigation.

2.1 Measurement of physical properties of maize

The physical properties of maize are important to designing the processing machinery and equipment. The physical properties such as length, width, and thickness of soaked maize were considered for designing the drying, grading, and storage machine.

2.1.1 Thousand grain weight

1 kg of maize grains was approximately divided into 10 equal portions, and then 1000 numbers of maize grains were randomly picked from each portion and weighed using a digital electronic balance having an accuracy of 0.001g. Three replications were carried out to determine the mean value of a thousand grains of maize (Khedekar, 2013) [11].

2.1.2 Moisture content

The moisture content of the soaked maize was determined by the hot air oven method at 130 °C for 2 hours. According to the obtained result, moisture was added or reduced in the grain to check the physical properties of the grain at different moisture content. 10 gram of sample was immersed in distilled water (1:3) ratio in a 100 ml beaker. 10 g of soaked maize were taken out of the 100 ml beaker after two hours. With the help of tissue paper surface water was removed from the grain. Further moisture content of soaked maize was determined in three replicates using the hot air oven method according to the ASAE Standards S352.2 (ASAE, 1997) for maize.

$$\text{Moisture content(\%)} = \frac{\text{Initial moisture content-final moisture content}}{\text{Initial moisture content}} \times 100 \quad (3.1)$$

2.1.3 Determination of length (L), width (W) and thickness (T) of soaked grains

The length (l), breadth (b), and thickness (t) of maize grains were measured. The dimensions of grain kernels which were selected for the present investigation were measured in three orientations using a digital Vernier Caliper with 0.01 mm accuracy. An average of 20 randomly selected corn kernels was taken (Pordesimo *et al.*, 1990) [23].

The values of arithmetic mean diameter (AMD), geometric mean diameter (GMD), square mean diameter (SMD), equivalent diameter (EQD), degree of sphericity (Sp), aspect ratio (AR), shape factor (λ) and unit volume of soaked maize grains were computed by using the following equations.

$$\text{AMD} = \frac{L+W+T}{3} \quad (3.2)$$

$$\text{GMD} = \sqrt[3]{LWT} \quad (3.3)$$

$$\text{SMD} = \sqrt{LW+WT+TL} \quad (3.4)$$

$$\text{EQD} = \frac{AMD+GMD+SMD}{3} \quad (3.5)$$

$$Sp = \frac{GMD}{L} \quad \text{(Mohsenin, 1986) [14]} \quad (3.6)$$

$$AR = \frac{W}{L} \quad (3.7)$$

Where
L = length (mm)
W = width (mm)
T = thickness (mm)
AMD = arithmetic mean diameter
GMD = geometric mean diameter
SMD = square mean diameter
EQD = equivalent diameter
S_p = degree of sphericity
AR = aspect ratio

Major dimensions were used to calculate the surface area (S) of single grain (Jain and Ball, 1997) [25] as details below

$$S = \frac{\pi \times GMD \times L^2}{2L - GMD} \quad (3.8)$$

$$V_t = \frac{\pi \times GMD^2 \times L^2}{6(2L - GMD)} \quad (3.9)$$

Where,
V_t = unit volume
L = length (mm)
GMD = geometric mean diameter

Based on grain surface area and unit volume, the shape factor (λ) was calculated (Mc. Cube and smith, 1984) [26] as

$$\lambda = \frac{a}{b} \quad (3.10)$$

$$a = \frac{V_t}{W^4} \quad (3.11)$$

$$b = \frac{s}{6W^2} \quad (3.12)$$

Where
V_t = unit volume (mm³)
W = width (mm)
S = Surface area (mm²)

2.1.4 Equivalent diameter and sphericity

Equivalent diameter (D_p) and sphericity (ϕ) of corn kernels were determined using the equations (Mohsenin, 1970) [12], as given below.

$$D_p = (lbt)^{1/3} \quad (3.13)$$

$$\emptyset = \frac{(lbt)^{1/3}}{l} \quad (3.14)$$

Where,
l = Length of the grain, mm
b = Width of the grain, mm
t = Thickness of the grain, mm

2.1.5 Bulk density, True density and Porosity measurement

The bulk density was determined by filling a 1000 ml container with soaked maize grains to a height of about 150 mm, striking the top level, and then weighing the content. The ratio of weight of the sample to the volume occupied by it is expressed as bulk density, g/ml (Deshpande, Bal, and Ojha, 1993; Konak, Carmen, and Aydin, 2002) [22, 10].

$$\text{Bulk density} = \frac{\text{Weight of sample}}{\text{Volume of sample}} \quad (3.15)$$

The true density of the soaked maize grains was determined by the toluene displacement method. Soaked maize grains (about 5 g) were submerged in toluene in a measuring cylinder. The increase in volume due to soaked maize grains was noted as the true volume of soaked maize grains, which was then used to determine the true density of the soaked maize grains (Wandkar, 2013) [24].

$$\text{True density} = \frac{\text{Mass of grain}}{\text{Displaced volume}} \quad (3.16)$$

Porosity (έ) is the ratio of volume of internal pores to its bulk volume. It was calculated as the ratio of the difference between the true density and bulk density to the true density and expressed by Mohesnin (1986) [14] as:-

$$\acute{\varepsilon} = \frac{\rho_t - \rho_b}{\rho_t} \quad (3.17)$$

Where,
ρ_t= True density and
ρ_b = Bulk density

2.1.6 Angle of repose

The feature of the bulk material that shows the cohesiveness between the individual grains is called the angle of repose. The angle of repose increases as cohesiveness increases. Using an open-ended cylinder with a 15 cm diameter and 30 cm height, the angle of repose of soaked maize was calculated. The cylinder, which held soaked maize grains, was positioned in the middle of a plate with a circumference of 70 cm. slowly, the cylinder was lifted until a cone-shaped impression was made on the circular plate. The cone's height was measured. The following formula was used to determine the angle of repose (Wandkar, 2013) [24]:

$$\theta = \tan^{-1}(2h/d) \quad (3.18)$$

Where,
θ = angle of repose,
h = height of pile and
d = diameter of cone.

3. Result and Discussion

3.1 Physical properties of maize

The design of machinery and equipment for grading, sorting, separating, processing, such machinery and equipment depends on the qualities of maize. Without it, the outcome might not be as good. The primary physical features of biological materials are shape, size, mass, bulk density, true density, porosity, and static coefficient of friction against various surfaces (Mohsenin, 1986) [14].

3.1.1 Moisture Content

The moisture content was found to be used with the standard AOAC oven drying method. We took different moisture content like 8, 10, 12, 14, and 16% to find out the different physical properties of maize grains.

3.1.2 Thousand Grains of Weight

The weight of 1000 grains increases as the moisture content of the maize grains increases (Fig.1). The weight of the grains varies according to their moisture content. We found that the moisture content of the maize grains was 8, 10, 12, 14, and 16, and that the weight of the 1000 grains was 112.52 g, 136.92 g, 168.32 g, 192.35 g, and 223.14 g, respectively.

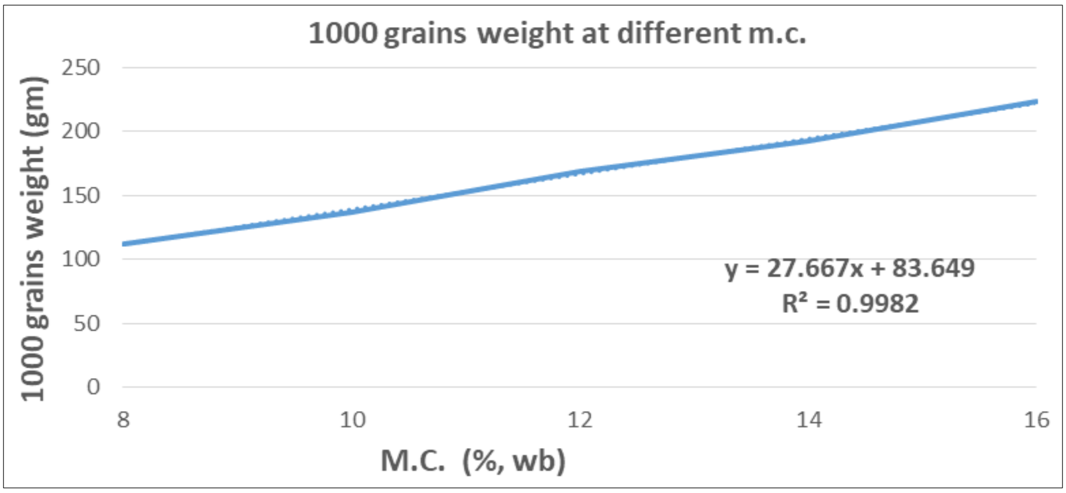

Fig 1: Effect of moisture content on 1000 grains weight of maize

3.1.3 Determination of length (L), width (W) and thickness (T) of soaked maize grains

The average value of maize grain dimension was determined in this study at various moisture content. The average length (8.192), width (6.20) and thickness (4.30) of the soaked maize were linearly increased according to moisture content.

Arithmetic mean diameter (6.21), Geometric mean diameter (6.00), Squire mean diameter (10.42), Equivalent diameter (7.55), Degree of sphericity (0.75), Aspect ratio (0.76), shape factor (6.43) and angle of repose of soaked maize were increased with an increase in moisture content by Khedekar, (2013) [11] and Deshmukh (2016) [5].

3.1.4 Bulk density, True density and Porosity measurement

The variation of bulk density and the true density of maize grain with moisture level are shown in Fig. 2. The bulk density of maize grain decreased linearly from 806.4 to 768.3 kg/mm^3. This decrease was due to the higher rate of increase in volume that relatively increased the weight (Konaki *et al*., 2002) [10]. The true density of maize grain decreased linearly from 1109.4 to 1065.8 kg/mm^3, respectively. This decrease in true density may be due to a higher rate of increase in grain volume compared to weight increase (Karabad, 2006) [8]. Fig. 3 show how the porosity of maize grain varies with moisture level. The porosity was calculated as a function of the bulk density and the true density of the grain. It was found to decrease linearly from 32.3 to 27.8 for maize grain (Baryeh, 2002) [4]. As the moisture content of the soaked maize grain increased, the values of true density, bulk density, and porosity decreased. The linear relationship between bulk density, true density, porosity and moisture content was developed, the linear regression equation was found to fit for maize densities and porosities (Table 1).

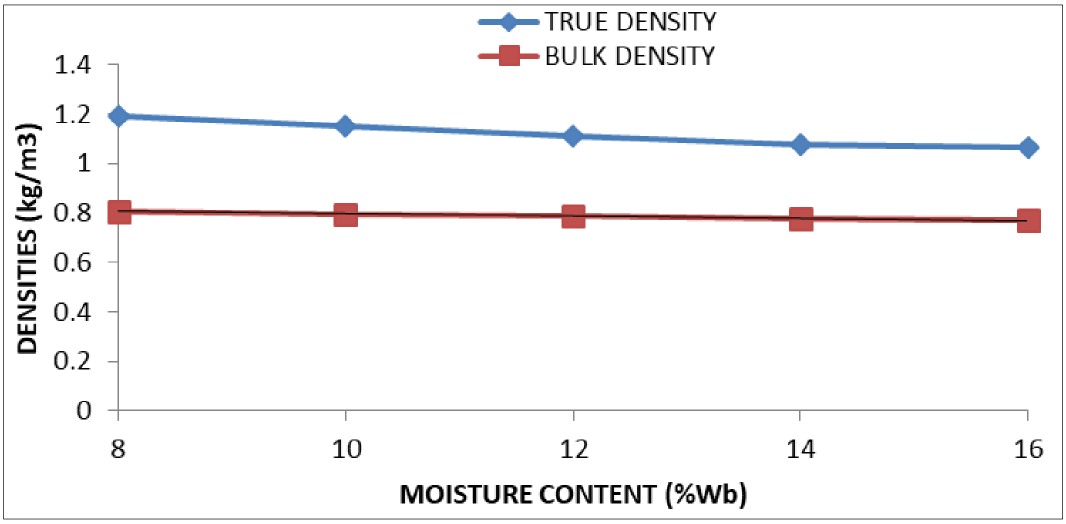

Fig 2: Effect of moisture content on true density and bulk density of maize grain

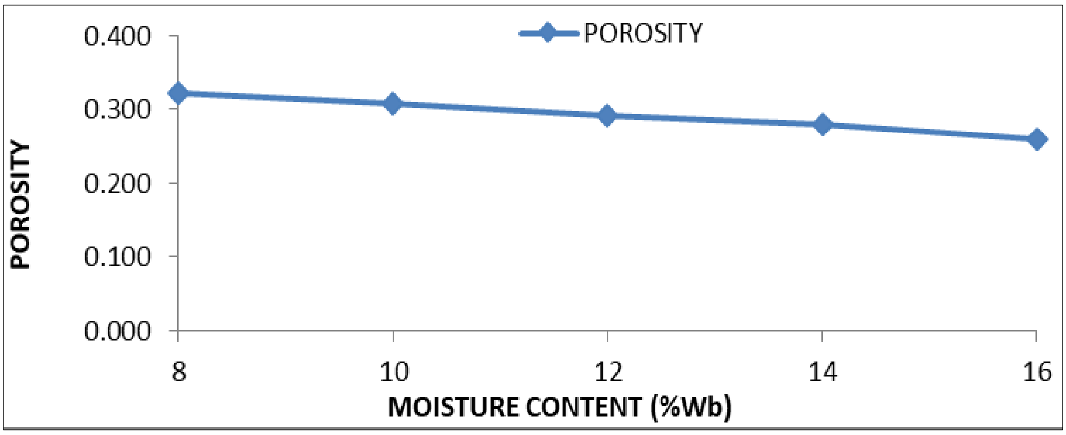

Fig 3: Effect of moisture content on porosity of maize grain

Table 1: Regression equations for physical properties of soaked maize

Properties	Range	mx+c	R^2
Bulk density	0.7683 - 0.8064	-0.009x + 0.815	0.995
True density	1.0658 - 1.1904	-0.032x + 1.215	0.965
porosity	0.259 - 0.323	-0.007x + 0.385	0.995

3.1.5 Angle of Repose

The angle of repose of maize grain increases as the moisture content of maize grain increases. The angle of repose is important to the design of feed hoppers, storage bins, chutes, pneumatic conveying systems, screw conveyors, forage harvesters, threshers, etc. (Singh and Sahay, 2001) [16]. The angle of repose of maize is different at different moisture content.

The moisture content of maize was 8, 10, 12, 14, and 16 whereas, the angle of repose was found at this moisture content was 19.98, 21.12, 23.20, 24.96, and 27.98 respectively.

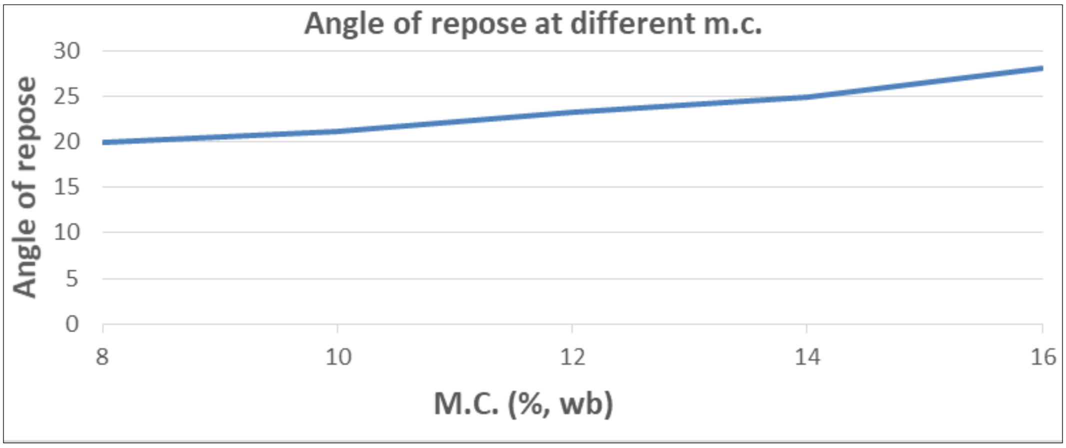

Fig 4: Effect of moisture content on angle of repose of maize

4. Conclusion

1. The average length (8.192), width (6.20) and thickness (4.30) of the soaked maize were linearly increased according to moisture content.
2. Arithmetic mean diameter (6.21), Geometric mean diameter (6.00), Squire mean diameter (10.42), Equivalent diameter (7.55), Degree of sphericity (0.75), Aspect ratio (0.76), shape factor (6.43) and angle of repose of soaked maize were increased with an increase in moisture content
3. The bulk density of maize grain decreased linearly from 806.4 to 768.3 kg/mm^3. The true density of maize grain decreased linearly from 1109.4 to 1065.8 kg/mm^3 for maize, respectively.
4. The porosity was calculated as a function of the bulk density and the true density of the grain. It was found to decrease linearly from 32.3 to 27.8 for maize grain.
5. The moisture content of maize was 8, 10, 12, 14, and 16 whereas, the angle of repose was found at this moisture content was 19.98, 21.12, 23.20, 24.96, and 27.98 respectively.

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