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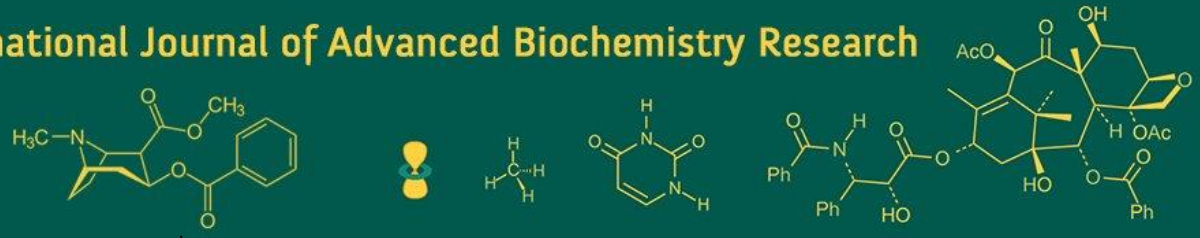

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# Investigating the physical and mechanical properties of onion (*Allium cepa* L.) seeds

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**Abstract**
Onion plays a crucial role in global food system and the top onion-producing countries in the world are China, India, United States of America and Turkey. These four countries account for more than 50% of the world's total onion production. India is one of the largest onion-producing countries in the world and onions are an important crop for the economy of the country. The physical and engineering characteristics of onion seed contains crucial data necessary for designing its metering mechanism, seed box configuration and other machinery parameters. The mean of major, intermediate and minor dimensions of the selected onion seeds were found as 2.93 mm, 2.16 mm and 1.57 mm with average geometric mean diameter as 2.15 mm. Similarly, average value of sphericity of the onion seeds, weight of 1000 onion seeds, bulk density and true density was observed as 0.73, 3.75 g, 450.81 kg/m$^3$ and 847.05 kg/m$^3$, respectively. The porosity and moisture content was found 47.11% and 10.47%. The average value of some mechanical properties such as angle of repose as 22.5$^o$ and coefficient of static friction for mild steel sheet, aluminum and galvanized iron sheet was observed as 0.165, 0.182 and 0.198, respectively.

**Keywords:** Onion seeds, physical properties of onion seeds, sphericity, bulk density, angle of repose and coefficient of friction

## Introduction
Onion (*Allium cepa* L.) is the one of the important horticulture commodity grown as vegetable and condiment crops throughout India. In India onion crop is mostly cultivated during *Rabi* season (60%) followed by 20% each in *Kharif* and late *Kharif* season (Pradhan *et al*., 2018). In India, onion is cultivated in an area of 1.54 million hectares with production of 25.44 million MT (NHB, 2023-24, first advance estimate). The prominent onion growing states in India are Maharashtra, Madhya Pradesh, Karnataka, Rajasthan, Bihar, Gujarat, Andhra Pradesh and West Bengal. The total area under onion crop cultivated in Chhattisgarh is about 23.68 thousand hectares with the production of 0.393 million tonnes (DA&FW, 2022-23 final estimate). Onion crop is grown either from seeds plant or set of both green and dry bulbs (Elhag and Usman, 2013) [5].

The investigation of physical properties of onion seeds is required for design and development of the seeder. The dimensions of onion seeds help to determine the size and shape of metering mechanism grooves or opening during designing. Bulk density, true density and porosity affect the structural loads of the machine. Likewise, the angle of repose plays a crucial role in the designing of seed metering unit. The study of coefficient of friction of the various surfaces affects the conveying of onion seeds through seed tubes.

Gajjer *et al.* (2019) [6] concluded that the size and uniformity of seeds play crucial roles in the design and development of seed planters. To optimize the metering mechanism of a planter, it's essential to assess the physical and mechanical properties of onion seeds. Parameters such as sphericity, thousand seed weight, bulk density, true density, angle of repose, and coefficient of static friction were examined. The average dimensions of the seeds were found to be 2.85 mm in length, 2.11 mm in width and 1.63 mm in thickness. Additionally, the mean geometric mean diameter, sphericity, and roundness of the seeds were determined to be 2.132 mm, 0.75 and 0.70, respectively. Bulk density ranged from 0.636 to 0.642 g cm$^{-3}$, while true density varied from 0.163 to 1.215 g cm$^{-3}$. The average porosity of onion seeds was calculated to be 46.22 percent. Furthermore, the thousand seed weight ranged from 3.502 to 3.664 g and the angle of repose varied between 37.23 and 40.69$^0$.

The coefficient of static friction was measured on four different materials: aluminum (0.36-0.40), MS sheet (0.53-0.57), GI sheet (0.32-0.36) and SS sheet (0.28-0.32).

Gautam *et al.* (2016) [7] studied that onion (*Allium cepa* L.) stands as a significant vegetable crop cultivated across India. The process of pelletizing onion seeds, involving the application of a seed coat, alters the seed's physical properties. An experiment was undertaken to investigate the physical attributes of pelleted onion seeds compared to their non-pelleted counterparts, utilizing the Punjab Naroya (PN) variety throughout the study. Physical properties such as size, shape, thousand grain weight, angle of repose, bulk density and coefficient of static friction hold significance from an engineering perspective. The seeds underwent pelletization in three ratios: 1:1, 1:2 and 1:3, indicating the seed-to-coating material ratio. The geometric mean diameters for these categories measured 2.45, 2.82 and 3.07 mm, respectively, whereas the geometric mean diameter for non-pelleted seeds was 2.00 mm. In laboratory observations, the average angles of repose for the investigated cultivars were 29.50°, 24.78° and 23.70° for Pelleted 1:1, 1:2, and 1:3 onion seeds, respectively, compared to 31.61° for non-pelleted seeds. Additionally, porosity values decreased progressively from non-pelleted to 1:1, 1:2, and 1:3 pelleted seeds, with the porosity of 1:3 Pelleted seeds being the lowest at 41.84%, whereas non-pelleted seeds exhibited the highest porosity at 53.3%.

Sunitha *et al.* (2016) [14] reported that India is the world's second-largest producer of onions, accounting for approximately 13 percent of the global onion output, just behind China. Onion cultivation spans across 1.0 million hectares in India, yielding 15.1 million tonnes with a productivity rate of 14.2 tonnes per hectare. However, the conventional broadcasting method of sowing onion seeds poses challenges such as uneven seed distribution, suboptimal bulb maturity, and heightened nutrient competition. Addressing these issues calls for the development of an animal-drawn onion seeder tailored for small-scale, rainfed farming with cost-effective operation. Evaluating the physical properties of onion seeds, including dimensions, weight, and mechanical characteristics, is crucial for designing the desired seed metering unit. For instance, the Artthi Kirthiman onion variety exhibits dimensions ranging from 2.50 to 2.95 mm in length, 1.75 to 2.24 mm in width, and 1.33 to 1.53 mm in thickness. Additionally, parameters such as geometric mean diameter, sphericity, weight, bulk density, true density, porosity and angle of repose were determined, providing valuable insights into the seed's behavior. Furthermore, the coefficient of static friction on glass and mild steel surfaces was measured, indicating frictional properties relevant for handling and processing onion seeds.

Pandiselvam *et al.* (2013) [10] analyzed certain frictional, mechanical, and aerodynamic properties essential for designing an onion umbels thresher were identified, assessed, and documented based on varying moisture content within the range of 9.8% to 29.6% (dry basis). With increasing moisture content from 9.8% to 29.6% (dry basis), both the angle of repose and terminal velocity exhibited an upward trend, rising from 28.11 to 37.41$^0$ and from 1.7 to 2.6 m/s, respectively. Conversely, the rupture force decreased from 116.73 to 40.14 N over the same moisture content range. Moreover, the static coefficient of friction of onion seeds demonstrated an increase across all four surfaces - plywood (ranging from 0.5191 to 0.6381), mild steel (from 0.4259 to 0.5976), galvanized iron (from 0.4334 to 0.5781), and stainless steel (from 0.2878 to 0.4981) - as the moisture content increased from 9.8% to 29.6% (dry basis).

Chhina and Sharma (2011) [3] conducted an assessment on the physical characteristics, including size, shape, thousand grain weight, angle of repose, bulk density, and coefficient of static friction, of three onion cultivars: Punjab Naroya (PN), Agri-found dark red (ADR) and Agrifound light red (ALR), comparing them with pelleted seeds. The geometric mean diameters were recorded as 1.85, 1.88, 1.95, and 4.3 mm for the onion cultivars PN, ALR, ADR and pelleted onion seeds, respectively. In laboratory observations, the average angles of repose for the cultivars were found to be 24.120, 25.140, and 25.180 for PN, ALR and ADR, respectively, and 19.210 for pelleted onion seeds.

## Materials and Methods

All the experiments of physical and mechanical properties of onion seeds were conducted at the Department of Agricultural Processing and Food Engineering, SVCAET&RS, IGKV, Raipur. Variety N-53 of onion seeds were selected for the study. The procedure involved for determination of dimensions of onion seed, geometric mean diameter (GMD), sphericity, weight of 1000 onion seeds, bulk and true density, moisture content, porosity, angle of repose, coefficient of static friction were discussed below:

### Dimensions of onion seed - Length, Width and Thickness

The dimensions (Length, Width and Thickness) of randomly selected onion seeds were determined by using digital Vernier Callipers with the least count of 0.01 mm and the physical dimensions were calculated i.e. length, width and thickness of onion seeds by using following formulae (Singhal and Samuel, 2003) [13].

$$L = \frac{\sum_{k=1}^{n} L}{n} \quad \text{---------- (1)}$$

$$W = \frac{\sum_{k=1}^{n} W}{n} \quad \text{---------- (2)}$$

$$T = \frac{\sum_{k=1}^{n} T}{n} \quad \text{---------- (3)}$$

Where,

L = Lenght of individual seed, mm.

W = Width of individual seed, mm.

T = Thickness of individual seed, mm.


a) Measurement of length b) Measurement of width c) Measurement of thickness

**Fig 1:** Dimensions of onion seed

**Geometric mean diameter ($D_p$)**

The geometric mean diameter ($D_p$) of onion seed was calculated by using the following equation (Mohsenin, 1986) [8].

$$D_p = \sqrt[3]{LWT} \quad ---(4)$$

Where,
L = Largest intercept (length), mm;
W = Width, mm; and
T = Thickness, mm.

**Sphericity (ϕ)**

Sphericity is defined as the ratio of the diameter of a sphere of the same volume as that of the particle and the diameter of the smallest circumscribing sphere or generally the largest diameter of the particle (Sahay and Singh, 1994) [12]. This parameter indicates the shape characteristics of onion seeds relative to the sphere having the same volume.

$$\text{Sphericity} = \sqrt[3]{\frac{\text{Volume of particles}}{\text{Volume of circumscribed sphere}}} = \sqrt[3]{\frac{LWT}{L}} \quad ---(5)$$

**Test weight (g)**

To obtain the test weight of onion seed, 1000 selected onion seeds were counted and weighed by using electronic balance with a least count of 0.001 g.

**Bulk density of seeds**

The bulk density is defined as the ratio of the total weight of the sample to the total volume of the sample. For the analysis of bulk density of onion seeds the sample is placed in a cylinder which has 96 mm of length and 70 mm of diameter. Before conducting the analysis, the sample is weighed inside the cylinder using an electronic weighing balance. The least count of the electronic weighing balance is 1g. The bulk density was calculated by using the following formulae (Mohsenin, 1986) [8].

$$b_d = \frac{W_t}{L \times \left(\frac{\pi d^2}{4}\right)} \quad ----------(6)$$

Where,
$b_d$ = Bulk density, kg/m$^3$;
$W_t$ = Weight of sample, kg;
L = Length of cylinder, m; and
d = Diameter of cylinder, m

**True density of seeds**

For the analysis of true density of the onion seed toluene displacement method is preferred. He toluene (C7H8) displacement technique removes the moisture absorbed by the onion seeds. Initially, 5 grams of onion seeds are placed into a graduated cylinder. This cylinder has a precision of 0.1 ml and contains 30 ml of toluene within a 100 ml measuring cylinder. The volume of toluene displaced by the seeds is then measured and examined as suggested by Tavakkoli *et al.* (2009) [15]. The operation was carried out ten times more for accurate results. Subsequent to it, the true density was formulated by using the following formula:

$$\rho_t = \frac{M}{V} \quad ----------(7)$$

Where,
$\rho_t$ = True density, kg/m$^3$
M = Mass of sample, kg; and
V = Volume of cylinder, m$^3$

**Porosity**

It is defined as the ratio of the volume of internal pores within the seeds to its bulk volume. It was examined as the ratio of the difference between true and bulk density to true density, expressed as a percentage.

$$P = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \quad ----------(8)$$

**Moisture content of onion seeds**

The Moisture content of garlic was determined by oven dry method. In this method the seeds are weighed, dried, and then weighed again according to standard recommendations. The moisture content of onion seeds can be represented as wet basis and dry basis. The moisture content of onion seed was determined using the air oven dried method. A sample of 5 g onion seed was kept in a hot air electric oven at 105±5 ºC for 24 hour for testing.

Subsequent to the removal of the onion seeds from oven it was placed in desiccators to reduce down to the room temperature. After cooling the sample, it was weight precisely. The loss in weight was calculated that shows the reduction in moisture content using the following equation:

$$MC\ (\%), db = \frac{w-d}{d} \times 100 \quad ----------(9)$$

Where,
MC = Moisture content on % basis.

w = Wet weight, g.
d = Dry weight, g.

**Angle of repose (ɵ)**
The height and diameter of the seed heap created by the seeds can be used to calculate the angle of repose (Mohsenin, 1986) [8]. The apparatus comprised a rectangular platform measuring 30 by 30 centimeters, with a 10-centimeter circular plate situated at its center. Beneath the platform, along the same axis, a funnel larger than the circular plate was positioned. Atop the rectangular platform, a hollow rectangular block measuring 300 × 300 × 300 millimeters was placed, featuring a sliding door at the bottom through which seeds were inserted. Both the lid and door of the funnel remained closed during the experiment. An optical scale was employed to monitor the opening of the sliding door. The angle of repose (ɵ) was determined using the following formulae.

$$\theta = \tan^{-1}\frac{2H}{D} \quad ---(10)$$

Where,
H = Height of cone, mm; and
D = Diameter of cone, mm.

**Coefficient of friction (μ)**
The friction force operating between surfaces of contact at rest with respect to each other is known as the static coefficient of friction. Coefficient of friction depends on the type of surface material. The coefficient of friction is crucial for designing hoppers. The static coefficient of friction of onion seeds was assessed using a calibrated tilting table against three different surfaces *i.e.*, galvanized iron sheet, aluminum and mild steel sheet (Bahnasawy, 2004) [1].
The coefficient of friction was calculated by following equation given by Sahay and Singh 1994 [12].

$$\mu = \tan(\theta) \quad ---(11)$$

Where,
μ = coefficient of friction; and
ɵ = Angle when sliding start, degree.

**Results and Discussion**
**Dimensions of onion seed - Length, Width and Thickness**
The linear dimensions (length, width, and thickness) of onion seeds were determined by measuring 100 randomly selected seeds shown in Table 1. The average major, intermediate, and minor dimensions were recorded based on the largest possible size of the seeds. The mean of major, intermediate and minor dimensions of the selected onion seeds were observed as 2.93 mm, 2.16 mm and 1.57 mm, respectively ranged between 2.77-3.05 mm, 1.79-2.37 mm and 1.23-1.92 mm, respectively.

**Geometric mean diameter ($D_p$)**
The geometric mean diameter was determined by measuring the length, width, and thickness of 100 randomly selected onion seeds. For the N-53 variety, the average geometric mean diameter was calculated to be 2.15 mm, falling within the range of 1.94-2.37 mm, as shown in Table 1.

**Sphericity (ϕ)**
The sphericity of onion seeds was assessed to design the curve of the cell of the metering unit, which holds the seed before placing it in the seed tube of machine. This assessment involved measuring the length, width and thickness of the seeds. The average sphericity value was determined to be 0.73, ranging from 0.65 to 0.81 also presented in Table 1. This indicates that the onion seeds do not possess a spherical shape.

**Test weight of onion seeds (g)**
The weight of thousand onion seeds from the 10 randomly selected samples was observed. The mean value of test weight of onion seeds was obtained as 3.75 g, ranging from 3.6-3.9 g presented in Table 1.

**Table 1:** Physical properties of onion seeds (length, width, thickness, GMD, sphericity and weight)

| Particulars | Length, mm | Width, mm | Thickness, mm | GMD, mm | Sphericity | Weight, g |
|---|---|---|---|---|---|---|
| Mean | 2.93 | 2.16 | 1.57 | 2.15 | 0.73 | 3.75 |
| Range | 2.77-3.05 | 1.79-2.37 | 1.23-1.92 | 1.94-2.37 | 0.65-0.81 | 3.6-3.9 |
| S.D. | 0.07 | 0.11 | 0.19 | 0.10 | 0.03 | 0.07 |
| CV% | 2.28 | 4.91 | 11.95 | 4.86 | 4.63 | 1.84 |

**Bulk density of seeds:** Bulk density refers to the weight to volume ratio of seeds. The seed box capacity of the machine was determined by considering the bulk density of onion seeds. An electronic weighing balance was utilized to weigh the seeds, while a 100 ml measuring cylinder was employed to measure their volume. The bulk density of onion seeds was observed to range from 438.12 kg/m³ to 461.51 kg/m³, with a mean value of 450.81 kg/m³. These values are detailed in Table 2.

**True density of seeds**
The true density of onion seeds was determined through the liquid displacement method using a 100 ml measuring cylinder and 30 ml of toluene ($C_7H_8$). This procedure facilitates the removal of absorbed water from the seeds. By measuring the net displaced volume of toluene ($C_7H_8$), we obtained a more precise outcome. The process was repeated ten times for accuracy. The mean true density of onion seeds was calculated as 847.05 kg/m³, with a range varying from 828.65 kg/m³ to 864.12 kg/m³. These true density values were also summarized in Table 2.

**Porosity**
The porosity of onion seeds was assessed based on both the bulk density and true density of the sample, as shown in Table 2. The porosity of onion seeds ranged from 44.31% to 49.62%. The mean porosity value was determined to be 47.11%.

**Moisture content of onion seeds**
The moisture content of onion seeds was assessed using the oven dry method, which is crucial for studying drying and storage conditions. Ten samples of 5 grams each were weighed and placed in a hot air electric oven at 103 °C for

24 hours. The moisture content of the onion seeds ranged from 7.82% to 13.92%, with a mean value of 10.47%. These moisture content values for onion seeds are presented in Table 2.

**Table 2:** Observation of weight of 1000 seeds, bulk density, true density, porosity and moisture content of onion seeds

| Particulars | Bulk Density, (kg/m$^3$) | True Density, (kg/m$^3$) | Porosity, (%) | Moisture Content, (%) |
|---|---|---|---|---|
| Mean | 450.81 | 847.05 | 47.11 | 10.47 |
| Range | 438.12-461.51 | 828.65-864.12 | 44.31-49.62 | 7.82-13.92 |
| SD | 8.82 | 11.19 | 1.50 | 2.00 |
| CV% | 1.96 | 1.32 | 3.19 | 19 |

**Angle of repose**

The angle of repose refers to the inclination formed between the base and the slope of a cone that results from material freely falling onto a horizontal surface. To determine the angle of repose for onion seeds, a cone was positioned on a flat surface, and samples of onion seeds were poured into it. The cone was then gradually lifted, allowing the seeds to naturally form a sloped heap. By measuring the height and diameter of the resulting seed heap, the angle of repose could be calculated. The average angle of repose for onion seeds was found to be 22.5º, with a standard deviation of 2.59º, falling within the range of 19.22 to 26.77º presented in Table 3.

**Coefficient of static friction:** The method of using an inclined plane was employed to determine the coefficient of static friction, employing surfaces such as aluminum, galvanized iron and mild steel sheets for testing. Onion seed samples were placed at the upper edge of each test surface. The angle of the surface was gradually increased until the onion seeds began to slide and detach from the inclined plane. The calculated values for the coefficient of friction were within the ranges of 0.148 to 0.195 for mild steel sheets, 0.155 to 0.231 for aluminum and 0.168 to 0.244 for galvanized iron sheets. The average coefficient of friction for mild steel sheets, aluminum and galvanized iron sheets was found to be 0.165, 0.182 and 0.198, respectively, as presented in Table 3.

**Table 3:** Angle of repose and coefficient of friction of onion seeds

| Particular | Angle of repose, degree | Coefficient of friction in different surfaces | | |
|---|---|---|---|---|
| | | M.S. sheet | Aluminum | G.I. sheet |
| Mean | 22.5 | 0.165 | 0.182 | 0.198 |
| Range | 19.22-26.77 | 0.148-0.195 | 0.155-0.231 | 0.168-0.244 |
| SD | 2.59 | 0.016 | 0.028 | 0.028 |
| CV% | 12 | 9.9 | 15.6 | 14.3 |

**Conclusion**

The physical properties of onion seeds play a critical role in the design of the machine influencing factors such as seed size, shape, weight, density, moisture content *etc*. Seed size and shape impact uniform planting depth and spacing, while seed weight and density affect seed flow and placement accuracy. Surface textures require special considerations to prevent damage and ensure proper seed-to-soil contact. Moisture content influences seed handling characteristics to prevent damage during planting. By accounting for these properties, onion seeder can achieve accurate and uniform seed placement, maximize germination rates, and optimize crop yields. The average measurements of the selected onion seeds namely, major, intermediate and minor dimensions were determined to be 2.93 mm 2.16 mm and 1.57 mm, respectively, resulting in an average geometric mean diameter of 2.15 mm. Similarly, the average sphericity of the onion seeds, along with the weight of 1000 seeds, bulk density, and true density, were recorded as 0.73, 3.75 g, 450.81 kg/m$^3$, and 847.05 kg/m$^3$, respectively. Porosity and moisture content were found to be 47.11% and 10.47%, respectively. Additionally, the average mechanical properties, including the angle of repose at 22.5º and the coefficients of static friction for mild steel, aluminum and galvanized iron sheets, were measured as 0.165, 0.182 and 0.198, respectively.

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