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Studies on engineering properties of onion bulbs cv. Phule Swami

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Abstract
Onion (*Allium cepa* L.) is an economically significant vegetable widely used as a spice and for its medicinal properties, containing numerous essential vitamins and minerals vital to the human diet. Despite progress in onion processing and storage, the diverse nature of onions cultivated in India urgently calls for a comprehensive database detailing their physical, frictional, and textural characteristics to enhance the accuracy and efficiency of post-harvest operations such as grading, sorting, and packaging. For this study, the popular onion variety Phule Swami, commonly grown in Maharashtra, India, was selected. Various physical, chemical, frictional, thermal, and textural properties of the onion bulbs were measured and analyzed.
The physical properties such as polar diameter (Dp), equatorial diameter (De), thickness (T), geometric mean diameter (Dgm), arithmetic mean diameter (Dam), shape index, sphericity, bulk density, true density, porosity, volume, surface area, eccentricity, projected area, dry matter, colour L*, colour a* and colour b* values were ranged from 43.23 to 65.23mm, 42.25 to 64.52 mm, 35.06 to 58.63mm, 40.01 to 62.72 mm, 40.18 to 62.79mm, 1.0 to 1.15, 0.89 to 0.97, 526.24 to 560.00 kg/m^3, 1084.26 to 1129.00kg/m^3, 50.39 to 51.47, 6580 to 7840 mm^3, 1074.54 to 2162.82 mm^2, 0.02 to 0.05, 268.63 to 540.70mm^2, 13.39 to 13.68%, 56.45 to 57.28, 14.22 to 14.56 and 8.24to 8.32, respectively. The chemical properties such as moisture content, carbohydrate content, ash content, protein content, fat content, inhibition DPPH, anthocynin content, reducing sugars, pH, total soluble soilids, pyruvic acid, ascorbic acid, total phenol and total flavonoids were ranged from 82.56 to 83.40%, 9.71 to 10.64%, 3.2 to 3.6%, 3.26 to 3.46%, 0.12 to 0.16%, 52.25 to 54.24%, 8.40 to 8.60mg/100g, 3.50 to 3.80g/100g, 5.88 to 5.94, 12 to 13 Brix, 14.20 to 14.52 µmole/g, 13.89 to 13.94 mg/100g, 56.23 to 57.63 mg GAE/100g and 25.24 to 26.18 mg CE/100g, respectively. The thermal property such as thermal conductivity was 0.51W/mK and specific heat was ranged from 3.62 to 3.74kJ/kgK. The frictional properties such as coefficient of static friction and angle of repose (ϕ) were ranged from 0.46 to 0.48 and 37.22 to 37.39°, respectively. The textural property i.e. firmness was ranged from 10.36 to10.68N.

Keywords: Phule swami, Onion, physical, chemical, frictional, thermal and textural properties

Introduction
The onion (*Allium cepa* L.) is a significant agricultural crop with a long-standing history of medicinal use. It is a staple food that has been cultivated and consumed for thousands of years (Sharma *et al*., 2020) [36]. As one of the most widely consumed vegetable crops in India, onion ranks second among bulb vegetables after tomato and is recognized across cultures and consumed globally. Belonging to the family *Amaryllidaceae*, onions are believed to have originated in Central Asia and the Mediterranean region, where they served as a vital food source for ancient civilizations like the Egyptians and Greeks. Onions are easy to cultivate and are extensively grown across the world, including in Europe, Asia, and the Americas (Tripathi and Lawande, 2016) [44]. For many farmers, onion cultivation serves as a major source of income (Sivashankar *et al*., 2023) [42].
Allium cepa L. is considered one of the oldest known bulb crops and is consumed globally. It is appreciated for its strong pungent flavor and is a key ingredient in the culinary traditions of numerous regions. Often referred to as the “queen of the kitchen,” onion holds a vital place in daily cooking (Selvaraj, 1976) [35]. The unique flavor of onion is attributed to the presence of sulfur-containing compounds (Konduru and Rains, 2015) [24].

The plant grows from an underground bulb made up of layered structures that serve as nutrient storage (Lim *et al.*, 2021) [25]. Onions are integral to a variety of culinary dishes including sauces, stews, and soups (Sami *et al*., 2021) [34]. They also enhance salads, burgers, and sandwiches and are commonly pickled for additional flavor (Berno *et al*., 2014) [11].

In 2023, global onion production reached 2310.8 lakh metric tonnes. In India, onions were cultivated across 15.43 lakh hectares, yielding 254.73 lakh metric tonnes with a productivity of 16.51 MT/ha. Maharashtra alone contributed 6.61 lakh hectares of cultivated area, with a production of approximately 89.05 lakh metric tonnes and a productivity of 13.47 MT/ha. The majority of onion production in India comes from Maharashtra, Madhya Pradesh, Rajasthan, Gujarat, and Bihar.

Onions are highly versatile and offer both nutritional and medicinal benefits (Sami *et al*., 2021) [34]. They are abundant in essential vitamins, minerals, potassium, folic acid, and other beneficial compounds. Onions contain vitamins A, B, and C, as well as minerals such as phosphorus, calcium, magnesium, and sulfur. They are also a good source of dietary fiber, aiding digestive health, and are packed with antioxidants that help protect the body from oxidative damage. Additionally, onions contain iron and offer a high-quality protein profile, measured in mg of amino acid per gram of protein. They are low in sodium, fat-free, and low in calories providing just 30 calories per serving while adding rich flavor to a variety of dishes (Shukla *et al*., 2019; Miladi *et al*., 2020; Thakre *et al*., 2023) [39, 27, 43].

Therefore, to develop appropriate processing technologies, comprehensive engineering properties of onion must be studied.

Materials and Methods

The present study was conducted at the Department of Agricultural Process Engineering, Dr. Annasaheb Shinde College of Agricultural Engineering and Technology, Mahatma Phule Krishi Vidyapeeth, Rahuri during year 2023-2025.

- **Physical Properties**

Average size

A vernier caliper having a least count of 0.01 mm was used to measure the dimensions *viz*., polar diameter (length), Equatorial diameter (width) and thickness of the onions (Fig.1) (Mohsenin, 1986 and Shelar *et al*., 2016) [29, 37].

The geometric mean diameter was calculated from the equation

$$D_{gm} = (D_p D_e T)^{1/3} \quad (1)$$

Where,

D gm-Geometric mean diameter, mm

Dp-Polar diameter (largest intercept length) of onions, mm.

The polar diameter is defined as the distance between the crowns of the bulb to the bottom part of the bulb from where roots germinate.

De-Equatorial diameter (width) of onions, mm. The equatorial diameter is the extreme breadth of an onion bulb measured perpendicular to the polar diameter.

T=Thickness of onions, mm. The thickness of an onion bulb measured perpendicular to the polar diameter and equatorial diameter.

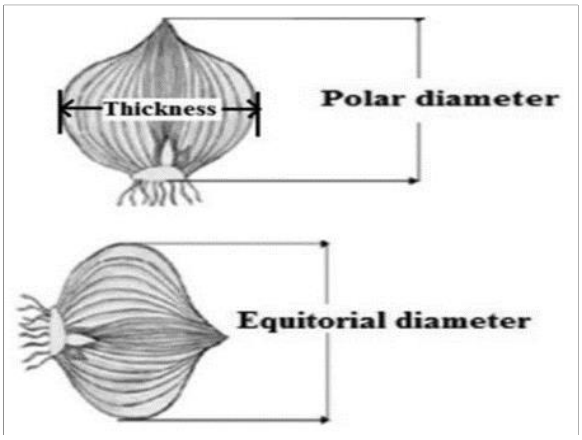

Fig 1: Diameters of onion

The arithmetic mean diameter (Dam) was the sum of all the three linear dimensions namely length, width and thickness of the sample divided by the total number of linear dimensions (Mohsenin, 1986 and Kakade *et al*., 2025) [29, 21].

$$D_{am} = \frac{(D_p + D_e + T)}{3} \quad (2)$$

Shape Index

Shape index was used to evaluate the shape of onion bulbs and it was calculate according to the following equation (AbdAlla, 1993) [2].

$$\text{Shape index} = \frac{D_e}{\sqrt{D_p \times T}} \quad (3)$$

The onion bulb was considered as oval if the shape index > 1.5, on the other hand, it was considered spherical if the shape index < 1.5.

Sphericity

Sphericity was calculated as per the following equation (Sahay and Singh, 1996; Kaveri and Tirupati, 2015 and Kakade *et al*., 2025) [33, 22, 21].

$$\text{Shericity} = \frac{(D_p D_e T)^{1/3}}{D_p} \quad (4)$$

Bulk density

Bulk density of onion was calculated by placing the sample of onion bulbs in a square box of 200×200×200 mm. The sample placed in the box was then weighed by using electronic balance with least count of 0.001g. Bulk density was calculated by using the following equation (Ghaffari *et al*., 2013 and Thakre *et al*., 2023) [17, 43].

$$\text{Bulk density}(kg|m^3) = \frac{\text{Weight of bulb(kg)}}{\text{Volume of box }(m^3)} \quad (5)$$

True density

The true density of the onion bulb was determined by the toluene (C_7H_8) displacement method in order to avoid water absorption by the sample. The true density was calculated using following equation (Ghaffari *et al*., 2013) [17].

$$\text{True density}(\text{kg}|\text{m}^3) = \frac{\text{Mass(kg)}}{\text{Volume(m}^3} \quad (6)$$

Porosity
It was estimated using the true and bulk density values. The porosity was calculated using following equation (Mohsenin, 1970) [28].

$$\text{Porosity}(\%) = 1 - \frac{\text{Bulk density}}{\text{True density}} \times 100 \quad (7)$$

Volume and surface area
The volume and surface area of an onion was determined on the basis on prolate spheroid of shape (Mohsenin, 1970) [28]. As per prolate spheroid shape, volume and surface area of the onion was calculated by using the following equation (Mohsenin, 1970) [28].

$$V = \frac{4}{3}(\pi a b^2) \quad (8)$$

Surface area was defined as the total area over the outside of the onion bulb. Surface area of the onion bulb was calculated by using the following equation.

$$S = 2\pi b^2 + 2\pi \frac{ab}{e} \sin^{-1} e \quad (9)$$

Where,
V-Volume, cm^3
S-Surface area, cm^2
A-Major axes of the ellipse of rotation, cm
B-Minor axes of the ellipse of rotation, cm
E-Eccentricity

$$e = \left[1 - \left(\frac{b}{a}\right)^2\right]^{1/2} \quad (10)$$

Projected Area
The projected area of onion was calculated by one fourth of the surface area. Based on the convex body, V is the volume and S is the surface area of that convex body (Polya and Szezo, 1951) [31].

$$\text{Projected area} = \frac{1}{4} \times \text{Surface area} \quad (11)$$

Colour
The colour of onion was analyzed with a Premier colour scan instrument (Make: BYK Gardner Instruments, Germany). The colour was expressed in dimensions of L*, a*, b* values (Kakade *et al.*, 2023a) [19, 20].

Dry matter
Bulbs was randomly selected from each treatment and cut into small pieces with the help of stainless steel knife. A known weight of the sample was dried in hot air oven at 60°C temperature till a constant weight was obtained. The per cent dry matter was calculated by the following formula (Eriballo *et al.*, 2022) [14].

$$\text{Dry matter } (\%) = \frac{\text{Dry weight}}{\text{Fresh weight}} \times 100 \quad (12)$$

- **Chemical Properties**

Moisture content (%): The moisture content was calculated using the formula (Ambrose *et al.*, 2020; Thakre *et al.*, 2023 and Kakade *et al.*, 2023b) [43, 19, 20].

$$\text{M wb}(\%) = \frac{\text{W1} - \text{W2}}{\text{W1}} \times 100 \quad (13)$$

Where,
M_{wb} = Moisture content, per cent wet basis
W1 = Initial weight of the sample, g
W2= Final weight of the sample, g

Total soluble solids (TSS,%)
The total soluble solids of onion was determined by using digital Hand Refractometer (PR-100) having 0 to 32 ° Brix range.

Carbohydrate
The carbohydrate content of an onion was determined by calculating the per cent remaining after all the other components have been measured (Gennaro *et al.*, 2009) [16].

Carbohydrate (%) = 100-(% moisture content + fat +% protein +% ash) (14)

Determination of ash content
Ash is an inorganic residue remaining after the material has been completely burnt at a temperature of 550 °C in a muffle furnace. The% ash content in the onion sample was calculated as as per AOAC, 1990 [9]:

$$\text{Ash content } (\%) = \frac{\text{Weight of ash}}{\text{Weight of sample taken}} \text{X100} \quad (15)$$

Determination of Crude Proteins
The powdered onion sample was tested for crude protein content according to the Kjeldahl's method as described in AOAC (1990) [9].

Determination of crude Fat
The crude fat in the powdered sample was determined using Soxhlet extraction for 24 hour as described in AACC (2000) [1].

The% crude fat in the sample was calculated using the formula:

$$\text{Crude Fat}(\%) = \frac{\text{Weight of fat}}{\text{Weight of sample taken}} \times 100 \quad (16)$$

Pyruvic acid
Pyruvic acid of onion bulbs was determined according to the modified method described by Anthon and Barrett (2003) [8].

Ascorbic acid
Ascorbic acid content was estimated titrimetrically using 2, 6-dichlorophenol indophenols dye as per the Association of Official Agricultural Chemists (AOAC, 1990) procedure (Shelke *et al.*, 2020) [9, 1].

Total Phenol
The total phenol analysis was performed using a slightly modified technique. The total phenolic content was calculated as gallic acid equivalent per 100 g fresh weight (GAE/100 g FW) (Singleton and Rossi 1965 and Marinova *et al.*, 2005) [41, 26].

Total flavonoids
The total flavonoids content of the onion sample was determined using aluminium chloride colorimetric methodology established by Zhishen *et al*., (1999) [45]. Catechin equivalent per 100 g fresh weight (CE/100 g FW) was used to calculate the total flavonoid content.

Antioxidant or scavenging activity
The antioxidant activity of the bulb after ozone exposure was determined by evaluating the free radical-scavenging effect on the 2, 2-diphenyl-picrylhydrazyl (DPPH) radical. The DPPH free radical-scavenging assay was performed by the method described by (Alothman *et al*., 2010). The percentage of inhibition of the DPPH radical was calculated as

$$\text{Percent inhibition of DPPH} = \frac{\text{Ac}-\text{As}}{Ac} \times 100 \qquad (17)$$

Where,
Ac-Absorbance of control and
As-Absorbance of sample

Anthocyanin content
The pH differential methodology reported by Shehata *et al*., (2020) [40] with minor changes was used to measure anthocyanin content. The following formula was used to quantify the anthocyanin pigment content (as cyaniding-3-glucoside equivalent).

$$\text{Anthocyanin content (mg/100g)} = \frac{\text{A}\times\text{MW}\times\text{DF}\times 103}{\epsilon\times 1} \qquad (18)$$

Where,
A-Absorbance difference i.e., ($A_{520\ nm}$-A_{700nm}) pH-$_{1.0}$-(A_{520nm}-A_{700nm}) $pH_{4.5,}$
MW-The relative molecular mass of cyaniding-3-glucoside,
DF-Dilution factor and
ϵ-26,000 molar extinction coefficient (L/mol cm) for cyaniding-3-glucoside.

Reducing sugars
Reducing sugars% was calculated by using the following equation (FSSAI, 2015).

$$\text{Reducing sugars (\%)} = \frac{\text{Diulution}\times\text{Factor of Fehling (in g)}\times 100}{\text{Weight of sample}\times\text{Titre value}} \qquad (19)$$

pH
The sample of 5g was measured and 45 mL of distilled water was added to the sample and homogenized for one minute. The solution was maintained at room temperature for 1 hour and the pH of the supernatant was measured using a pH meter. The electrode of the pH meter was directly dipped into the onion samples. Then on the screen of the pH meter, the pH of the sample was observed and recorded.

- **Frictional Properties**

Coefficient of Static Friction
Angle of rolling resistance of onion bulb was measured on mild steel surface by inclined plane method. The value of coefficient of static friction was calculated by using following equation (Khura *et al.,* 2011; Ghaffari *et al*., 2013) [23, 17].

$$\text{Coefficient of static friction (CoF)} = \tan\theta \qquad (20)$$

Where,
θ = Angle of rolling resistance

Angle of repose
Angle of repose is the angle between the base and the slope of the cone formed by vertical fall of granular material on a horizontal surface. The angle of repose of onion sample was calculated by using emptying method (Rathinakumari and Jesudas, 2015) [32].

The angle of repose was calculated by using the equation

$$\text{Angle of repose}(\theta) = tan^{-}\left(\frac{H}{L}\right) \qquad (21)$$

Where,
θ = Angle of repose, degree
H= Height of the remaining sample, mm
L= Length of sample, mm

- **Thermal Properties**

Thermal properties varied linearly with moisture content and calculated as follows.

Thermal Conductivity
Thermal conductivity is defined as ability to conduct heat i.e. the amount of heat that passes through a unit of time when there is a temperature gradient. With the help of mass fraction of carbohydrates, proteins, fat, ash and water; thermal conductivity was calculated by using following equation (Abhayawick *et al.,* 2002) [3].

$$k= 0.25X_c + 0.155\ X_p + 0.16\ X_f + 0.135\ X_a + 0.58\ X_w \qquad (22)$$

Where,
X_c, X_p, X_f, X_a and X_w are the mass fraction of carbohydrates, proteins, fat, ash and water, respectively k, the thermal conductivity (W/mK).

Specific heat
The specific heat of onion was calculated using the equation (Abhayawick *et al.*, 2002) [3].

$$C_p= 1.547X_c + 1.711\ X_p + 1.928X_f + 0.908\ X_a + 4.180X_w \qquad (23)$$

Where,
C_p is the specific heat capacity (kJ/kg K)

- **Textural Properties**

Firmness of onions
The firmness of onion bulbs was measured using a texture analyzer (Model: TMS-Pro Texture Analyzer, Make: Food Technology Corporation, USA), (Kakade *et al*., 2023a and Kad *et al*., 2016) [19, 20].

Results and Discussion
Physical properties
The physical properties of onion bulbs Cv. Phule Swami have been measured and recorded in Table1.

Table 1: Physical properties of Phule swami onion variety

Sr. No.	Physical properties	Mean*	Max. Value	Min. Value	SD	CV (%)
1	D_p, mm	55.42	65.23	43.23	5.55	10.02
2	D_e, mm	54.28	64.52	42.25	5.61	10.33
3	T, mm	47.13	58.63	35.06	5.17	10.97
4	D_{gm}, mm	52.12	62.72	40.01	5.26	10.09
5	D_{am}, mm	52.28	62.79	40.18	5.27	10.08
6	Shape index	1.06	1.15	1.00	0.03	2.97
7	Sphericity	0.94	0.97	0.89	0.02	1.94
8	Bulk density, kg/m^3	542.15	560.00	526.24	16.96	3.13
9	True density, kg/m^3	1103.94	1129.00	1084.26	22.85	2.07
10	Porosity,%	50.90	51.47	50.39	0.54	1.07
11	Volume, mm^3	7140	7840	6580	0.64	8.99
12	Surface area, mm^2	1791.83	2162.82	1074.54	621.32	34.67
13	Eccentricity	0.03	0.05	0.02	0.02	51.12
14	Projected area, mm^2	447.95	540.70	268.63	155.33	34.68
15	Dry matter,%	13.54	13.68	13.39	0.15	1.08
16	Lightness, L^*	57.01	57.28	56.45	0.47	0.84
17	Redness, a^*	14.38	14.56	14.22	0.17	1.18
18	Yellowness, b^*	8.27	8.32	8.24	0.04	0.50

*mean of fifty onion bulb samples

The mean polar diameter (Dp), equatorial diameter (De), and thickness (T) were recorded as 55.42 mm, 54.28 mm, and 47.13 mm, respectively, indicating a generally uniform shape. The geometric mean diameter (Dgm) and arithmetic mean diameter (Dam) were found to be 52.12 mm and 52.28 mm, respectively, with moderate coefficients of variation (CV), suggesting low variability among samples. The shape index (1.06) and sphericity (0.94) values confirmed the near-spherical shape of the bulbs. Based on obtained data onion bulb was considered spherical because its shape Index was < 1.5 (Bahnasawy *et al.*, 2004) [10]. Pavani *et al.*, (2017) [30] was reported similar sphericity of about 1.0±0.01 for *Bhima Super* variety. Similar results were also reported for shape index about 1.22 (Khura *et al.*, 2011) [23] and 1.27 (Kaveri and Thirupathi, 2015) [22]. The average bulk density and true density 542.15 kg/m^3 and 1103.94 kg/m^3, respectively, resulting in a porosity of 50.90%, which implies good airflow potential during storage and drying. Similar results were found for *Talaja red* onion (Dabhi and Patel, 2017) [12]. The mean volume and surface area were 7140 mm^3 and 1791.83 mm^2, respectively, supporting their suitability for processing operations. Surface area of the onion bulb was evaluated to know the exposer area of the onion bulb. Additionally, the eccentricity value of 0.03 indicates minimal deviation from a perfect sphere. The average projected area was 447.95 mm^2. The bulbs showed a dry matter content of 13.54%, essential for determining shelf life and processing quality. Color parameters (L^*: 57.01, a^*: 14.38, b^*: 8.27) indicated a uniform and appealing appearance, which is desirable for consumer acceptance. Overall, the low coefficients of variation for most properties suggest a high level of uniformity in the studied onion samples, which is beneficial for post-harvest handling and processing. Similar results were also reported by Pavani *et al.*, (2017) [30] for *Bhima Super* variety. In another study on *red*, *white* and *yellow* onion bulbs also reported similar results (Ghaffari *et al*., 2013) [17].

Chemical Properties

The chemical properties of onions Cv. Phule Swami were measured and recorded in Table 2.

Table 2: Chemical properties of Phule Swami Onion variety

Sr. No.	Chemical properties	Mean*	Max. Value	Min. Value	SD	CV (%)
1	M.C.,%	83.01	83.40	82.56	0.42	0.51
2	Carbohydrate,%	10.08	10.64	9.71	0.50	4.91
3	Ash,%	3.40	3.60	3.20	0.20	5.88
4	Protein,%	3.37	3.46	3.26	0.10	3.04
5	Fat,%	0.14	0.16	0.12	0.02	14.29
6	Inhibition DPPH,%	53.33	54.24	52.25	1.01	1.88
7	Anthocynin, mg/100g	8.50	8.60	8.40	0.10	1.18
8	Reducing Sugars, g/100g	3.63	3.80	3.50	0.15	4.20
9	pH	5.91	5.94	5.88	0.03	0.52
10	TSS, ° Brix	12.33	13.00	12.00	0.58	4.68
11	Pyruvic acid, µmole/g	14.36	14.52	14.20	0.16	1.11
12	Ascorbic acid, mg/100g	13.92	13.94	13.89	0.03	0.18
13	Total Phenol, mgGAE/100g	56.70	57.63	56.23	0.81	1.42
14	Total flavonoids, mg CE/100g	25.56	26.18	25.24	0.54	2.10

The mean moisture content was found to be 83.01%, indicating high water content typical of fresh onions. A similar result was reported by Amita *et al.* (2021), they found the moisture content to be 83.09±0.55%, with a standard deviation of 2.80 and a CV of 0.03%. The average carbohydrate content was 10.08%, contributing significantly to the energy value. The ash content, representing total mineral content, was 3.40%, and the protein content was 3.37%, reflecting the nutritional quality of the bulbs. The fat content was minimal at 0.14%, supporting the classification of onion as a low-fat food. These values are consistent with findings from other studies on onion varieties as reported by Dinkecha and Muniye (2017) [13]. They found the carbohydrates, ash, protein and fat to be 16.77±1.1 to 21.87±0.4 g/100g, 4.14±0.12 to 8.3±0.14%, 8.6±0.03 to 10.84±1.23% and 0.68±0.7 to 0.85±0.12% respectively. Antioxidant activity measured as DPPH inhibition was high at 53.33%, indicating strong free radical scavenging potential. The bulbs contained 8.50 mg/100g of anthocyanin and 3.63 g/100g of reducing sugars, contributing to both nutritional and sensory attributes. The pH was slightly acidic at 5.91, suitable for maintaining storage quality. Total soluble solids (TSS) averaged 12.33 °B, suggesting good sweetness and flavor. Pyruvic acid content, which influences pungency, was 14.36 µmole/g. Additionally, ascorbic acid (vitamin C) was measured as 13.92 mg/100g, indicating good antioxidant content. The total phenol and total flavonoid contents were 56.70 mg GAE/100g and 25.56 mg CE/100g, respectively, further highlighting the onion's health-promoting properties. Similar results were reported by Kakade *et al*. (2023a) and Kakade *et al*. (2023b) [19, 20] for onions.

Frictional Properties

Frictional properties *viz.*, coefficient of friction and angle of repose of onion Cv. Phule Swami are presented in Table 3.

Table 3: Frictional properties of Phule Swami Onion variety

Sr. No.	Frictional Properties	Mean	Max Value	Min Value	SD	CV (%)
1	Coefficient of static friction (CoF)	0.47	0.48	0.46	0.01	2.13
2	Angle of repose (ϕ)°	37.39	37.39	37.22	0.16	0.42

The frictional properties of the onion bulbs were evaluated to understand their behavior during handling and processing. The coefficient of static friction (CoF) was found to have a mean value of 0.47, with minimal variation (CV: 2.13%), indicating a consistent surface interaction with different contact materials. The mean angle of repose was recorded at 37.39°, with a low coefficient of variation (0.42%), suggesting uniform flow characteristics of the bulbs when piled. These results indicate that the onion bulbs possess good flowability and moderate frictional resistance, which are advantageous for designing storage bins, hoppers, and conveying systems, ensuring efficient post-harvest handling and processing operations. Similar results of angle of repose were obtained 43.6±2.904° for *Bhima super* variety (Pavani *et al*., 2017) [30].

Thermal Properties

Thermal properties i.e. thermal conductivity and specific heat varied linearly with moisture content and calculated and recorded in Table 4.

Table 4: Thermal properties of Phule Swami Onion variety

Sr. No.	Thermal properties	Mean*	Max. Value	Min. Value	SD	CV (%)
1	Thermal Conductivity, W/mK	0.51	0.51	0.51	0.00	0.39
2	Specific Heat, kJ/kgK	3.69	3.74	3.62	0.06	1.74

The thermal properties of Phule Swami Onion variety were analyzed to support the design of thermal processing and storage systems. The mean thermal conductivity was observed to be 0.51 W/mK, with negligible variation (CV: 0.39%), indicating a uniform heat transfer capacity across the samples. The specific heat was measured at an average of 3.69 kJ/kg K, showing minimal variability (CV: 1.74%). These consistent thermal properties suggest that the Phule Swami Onion variety has stable and predictable behavior during processes involving heat transfer, such as drying, cooling, and thermal treatments, ultimately ensuring uniform quality and energy efficiency during post-harvest handling and processing. A similar result was reported by Abhayawick *et al.* (2002) [3].

- **Textural Properties**

Table 5: Textural properties of Phule Swami Onion variety

Sr. No.	Textural properties	Mean	Max Value	Min Value	SD	CV (%)
1.	Firmness, N	10.50	10.68	10.36	0.16	1.55

The textural properties of the Phule Swami Onion variety were evaluated to assess its mechanical strength and suitability for handling and processing. The mean firmness was recorded as 10.50 N, with a maximum value of 10.68 N and a minimum of 10.36 N, resulting in a low coefficient of variation (1.55%) (Table 5). The high firmness value reflects good structural integrity, which is beneficial for withstanding mechanical stresses during harvesting, transportation, and storage, while also contributing to consumer preference for crispness and freshness. Overall, the uniform firmness of the Phule Swami Onion variety confirms its suitability for both fresh market and processing applications. Firmness values for onion bulbs typically range from 8 to 12 N, as observed in the research by Ambrose (2020), which examined various onion varieties for their textural properties.

Conclusion

The mean polar diameter, equatorial diameter, thickness, geometric mean, arithmetic mean diameter, shape index, sphericity, bulk density, true density, porosity, volume, surface area, eccentricity, projected area and dry matter content for the Phule Swami onion variety were found to be 55.42, 54.28, 47.13, 52.12, 52.28 mm, 1.06, 0.94, 542.15 kg/cm^3, 1103.94 kg/cm^3, 50.90%, 7140mm^3, 1791.83mm^2, 0.03 and 447.95 mm^2, 13.54%, respectively. Colour values i.e. L*, a* and b* were 57.01, 14.38 and 8.27, respectively.

The chemical properties *viz.*, moisture content, carbohydrate, ash, protein, fat, inhibition DPPH, anthocynin content, reducing sugars, pH, TSS, pyruvic acid, ascorbic acid, total phenol and total flavonoids were 83.01%, 10.08%, 3.40%, 3.37%, 0.14%, 53.33%, 8.50 mg/100g, 3.63g/100g, 5.91, 12.33ºB, 14.36µmole/g, 13.92 mg/100g, 56.70 mgGAE/100g and 25.56mg CE/100g, respectively.

The thermal properties i.e. thermal conductivity and specific heat were 0.51 W/m K and 3.69 kJ/kg K, respectively. The coefficient of static friction was 0.47 whereas, angle of repose (ϕ) was 37.39º. The firmness of Phule Swami Onion variety was 10.50 N.

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