Analyzing the Physical Characteristics of Garlic for Agricultural and Machinery Applications

ABSTRACT

Garlic, a globally cherished spice from the *Allium Sativum L.* family, holds immense importance in Indian agriculture as the second-largest producer worldwide. With India contributing 10.4% to the global garlic production, totaling 3.27 million metric tons in 2022, the physical properties of garlic become integral in engineering design. This research navigates through experiments on garlic slices' bulk density, considering moisture levels, and explores the mechanical aspects affecting peeling and processing machinery. Moisture content considerations for storage, odor/flavor impact, and even the friction coefficient concerning bulb size underscore the complexity of garlic's engineering dynamics. By unraveling these properties, this study aims to fuel advancements in cultivation practices, machinery design, and processing technologies, enhancing efficiency and product quality in the agricultural and food engineering sectors.

Keywords: Physical properties of garlic, shpericity, friction coefficient, rupture force.

1. INTRODUCTION

Garlic, belonging to the *Allium Sativum L.* family, is a highly popular spiceworldwide.Indiaranksasthesecond-largestglobalgarlicproducer,contributing10.4% of the world's production with a substantial 3.27 million metric tons in 2022. In engineering design, the physical properties of garlic play a pivotal role in the development of specialized machinery and processes for planting, harvesting, and processing. The bulb size and shape influence the design of planting and harvesting equipment, ensuring optimal efficiency in handling different garlic varieties. Madamba *et al*. (1993) experimented on the bulk density of garlic slices at different moisture levels (ranging from approximately 3 to 65% MC wet basis) and determined by weighing the contents of a container of known volume. The porosity was calculated using its relationship with bulk and apparent densities. The mechanical properties, including firmness and integrity of the garlic cloves and skin layers, are crucial considerations for machinery that peels and processes garlic. The moisture content affects the design of storage systems to prevent mold and decay. Masoumi et al. (2006) compared some physical properties of two common types of Iranian garlic cloves (white and pink) and it was observed that at different moisture range from 34.9% to 56.7% w.b., the bulk density, true density and porosity of cloves were significantly affected by moisture content ($p < 0.01$). Bakhtiari (2015) observed that increasing moisture content from 35.8% to 60.5% w.b. Studies showed that as moisture content increased, the true density decreased from 1146.4 to 1109.3 kg/m^3.The characteristic odor and flavor, key components in garlic's appeal, impact the design of processing equipment in the food industry. The friction coefficient decreased with increasing bulb size, where it was the highest (0.8) for the small bulbs on the concrete surfaces; on the other hand, the lowest values (0.36) were recorded for the large bulbs on the iron surfaces (Bahnasawy, 2007). The crushing load of the cloves ranged from 55.6 to 155.0 N, depending on the bulb size. The force required for loosening the cloves from the bulb ranged from 110 to 272 and 101 to 320 N on the horizontal and vertical positions of the bulbs (Bahnasawy, 2007). Engineers must consider the weight, uniformity, and scape presence for efficient sorting and packaging machinery. Bayat and Rezvani (2012) studied the parameters which affect the mechanical properties of garlic. The skin strain increased and consequently stiffness decreased when moisture contents were higher than 20%. Moreover, moisture content, thickness, burst pressure and strain at breakage of skins increased with the increase of incubation in relative humidity while the stress and stiffness decreased. By understanding and leveraging these physical properties, engineers can develop technologies that enhance the entire garlic production and processing chain, contributing to improved efficiency and product quality in the agricultural and food engineering sectors. This study aspires to fill a critical knowledge gap, shedding light on the engineering aspects of garlic, which can subsequently inform advancements in cultivation techniques, harvesting methodologies, and the development of innovative processing machinery.

2. MATERALS AND METHODS

This research delves into the thorough investigation of the physical properties of*Agrifound White (G-41)*variety of garlic within the controlled environment of the laboratory at Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.). The study focuses on essential aspects such as moisture content, bulk density, true density, porosity, and mechanical properties of garlic cloves.

2.1 Linear dimension of clove (Length, Width and Thickness)

The principal dimensions (Length, Width and Thickness) of randomly selected garlic clove were determined by using vernier callipers (Fig. 1) and by using following formulae.

$$L = \frac{\sum_{k=1}^{n} l}{n} \quad ...(1)$$

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

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

Where,

L = Lenght of individual clove, mm;

W = Width of individual, mm; and

T = Thickness of individual, mm.

2.2 Geometric mean diameter (Dg)

The geometric mean diameter value was determined by using following formulae (Mohsenin*et al.*, 1986). Equation for determining geometric mean diameter (D_g) is given below.

$$D_g = (LWT)^{1/3} \quad ...(4)$$

Where,

D_g = Geometric mean diameter, mm;

L, W, T = Length, width and thickness of bulb or clove of garlic respectively.

2.3 Sphericity

The 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, 1996).Sphericity of clove was calculated by formula given below (Mohsenin*et al*., 1986).

$$\varphi = \frac{(LWT)^{\frac{1}{3}}}{L} \quad ...(5)$$

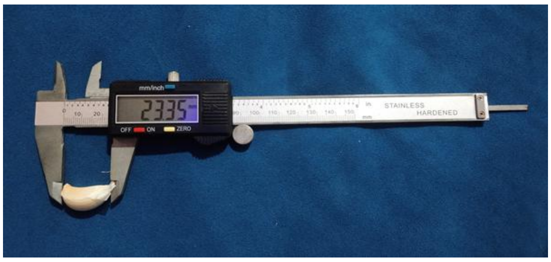
Where,

φ = Sphericity

L = Average length of cloves, mm;

W = Average width of cloves, and

T = Average thickness of cloves.



(a) Length

(b) Width

(c) Thickness

Fig. 1: Dimensions of garlic clove

2.4 Moisture content of garlic (db)

TheMoisture content of garlic was determined by oven dry method. Three sample of 15g garlic were collected and cleaned manually, then heated by oven at 100 ± 0.5°C until constant weight was obtained (Mohsenin, 1986). Moisture content of garlic was determined by;

$$M.C. = \frac{W_w - W_d}{W_d} \times 100 \qquad ...(6)$$

Where,

M.C. = Moisture content, %;

W_w = Weight of garlic before drying, g; and

W_d = Weight of garlic after drying, g;

2.5 Bulk density of garlic clove (ρ_b)

The bulk density is defined as the ratio of the total weight of the sample to the total volume of the sample. The bulk density of garlic clove was determined by filling a 250 ml test tube with the garlic cloves at a constant rate and then weighing the cloves (Bakhtiari, 2015) and calculated by using following formula;

$$\rho_b = \frac{M_s}{V_c} \qquad \dots (7)$$

Where,

ρ_{t} = Bulk density, g/cm^3;

M_s= Mass of sample, m; and

V_s = Volume of sample, m^3.

2.6 True density

The true density of garlic clove was determined by using the liquid displacement method. The solvent Toluene (C7H8) was used to determine the true density of onion bulbs (Singh and Goswami, 1996). The known volume of toluene was taken in a 100 ml measuring cylinder and twenty individual garlic cloves of nine grades were weighed and each grade clove was dropped into the measuring cylinder. The change in volume describe the true density of garlic clove. This procedure was replicated five times. The true density of the sample was calculated using the formula given below (Mohsenin, 1986).

$$[\text{True volume of bulb}]\ (\text{cc}) = [\text{Final toluene level}] - [\text{Initial toluene level}] \quad \dots (8)$$

$$\text{True density}(\text{kg/m}^2) = \frac{\text{weight of garlic (kg)}}{\text{True volume of garlic}(\text{m}^3)} \qquad \dots (9)$$

2.7 Porosity

The porosity of a garlic clove is the percentage of its space that is not taken up by the garlic clove. The value of porosity is calculated from the value of true density and bulk density (Mohsenin, 1986).

$$\sigma = \frac{\rho_t - \rho_b}{\rho_t} \qquad \dots (10)$$

Where,

σ = Porosity, %;

ρ_t = True density, kg/m^3; and

ρ_b = Bulk density, kg/m^3.

2.8 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). The device consisted of a 30-by-30-centimeter rectangular platform with a 10-centimeter circular plate positioned at the centre. A funnel larger than the circular plate was placed beneath the platform on the same axis. A 30 × 30 × 30 centimetre hollow rectangular block was put and featuring a sliding door at the bottom, over the rectangular platform and seeds are placed into it. The funnel's lid and door were maintained close. An optical scale was used to track the sliding door opening. The angle of repose (ɵ) was calculated by following formulae;

$$ɵ = \tan^{-1}\frac{2H}{D} \qquad ...(11)$$

Where,

H = Height of cone, cm; and

D = Diameter of cone, cm.

2.9Coefficient 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 static coefficient of friction of garlic clove was determined by a calibrated tilting table against three surfaces namely, galvanized iron sheet, aluminium and mild steel sheet (Bahnasawy, 2007). The coefficient of friction was calculated by using following equation given by Sahay and Singh (1996).

$$\mu = \tan(ɵ) \qquad ...(12)$$

Where,

μ = coefficient of friction; and

ɵ = Angle when sliding start, degree.

2.10Rupture force

The rupture force is the smallest amount of force needed to break the sample. The TA. HDPlusC texture analyser was used to determine the rupture force of the garlic clove. The equipment was calibrated in terms of weight and distance before each sort of test was performed. Similarly, the movement was calibrated. The cross ensures the sample's conformance to the prescribed deformation. After calibrating the texture analyser, a sample of garlic was placed on it. Depending on the parameters, various probes were used for different experiments to get the force-time curves. The amount of force required to rupture or deform the item was calculated using the graph, and the procedure was repeated ten times to achieve the mean value.

3. RESULTS AND DISCUSSION

3.1 Dimension of garlic clove

The main dimension (length, L), intermediate dimension (width, W), and minor dimension (thickness, T) was calculated from randomly selected 100 garlic cloves. The seed metering mechanism was determined based on seeds of the largest possible size of garlic clove.

Table 1: Physical properties (length, width, weight, thickness, GMD and sphericity of garlic clove.

Particular	Length, mm	Width, mm	Weight, g	Thickness, mm	GMD, mm	Sphericity
Range (R)	21.13-34	6.43-14	0.81-1.79	5.96-13.16	10.95-16	0.39-0.66
Mean ($\bar{x}$)	27.32	10.13	1.18	9.23	13.56	0.50
S.D.(σ)	3.07	1.53	0.24	1.65	1.14	0.05
CV	11.23	15.10	21.03	17.91	8.43	10.63

The maximum width, length and thickness of garlic cloves observed as 14, 34, and 13.16 mm respectively. The mean value of length, width and thickness of 100 garlic clove was 27.32, 10.12, and 9.23 mm, respectively. The range for geometric mean diameter was 10.95-16 mm and mean value of geometric mean diameter of 100 seed was 13.56 mm. The mean weight of garlic clove was 1.18 g. The observed data was presented in Table 1.

3.2 Sphericity of seed

Sphericity was calculated for defining the curve of cell of metering unit in order to hold the seed before putting it in the seed tube. The sphericity of the seeds was determined by measuring their length, width and thickness. The sphericity of the seeds shows that the garlic seed was uneven in shape. The smoothness of flow and loading of seed to metering units were also affected by sphericity. The mean value of sphericity of the garlic was 0.50. The maximum and minimum value of sphericity obtained from selected 100 seed was 0.66 and 0.39, respectively. The values of sphericity of garlic cloves is presented in Table 1.

3.3 Geometric mean diameter

The mean geometric diameter of clove was observed as 13.56 and ranged between 10.95-16 mm presented in Table1.

3.4 Weight of thousand seed

The 10 random sample of 1000 garlic clove was collected for calculating mean value of thousand seed weight. The mean value of weight of seed was calculated as 842.59g for 10 random samples and the standard deviation for calculated data was 5.63.

3.5 Bulk density

Bulk density is defined as the ratio of weight and volume of seed. The volume of garlic clove was determined with 250 ml measuring cylinder and weight of garlic clove was determined with electronic balance. The range of bulk density of garlic clove was obtained as 404 kg/m^3 to 440 kg/m^3. Mean bulk density was found to be 420.30±8.41 kg/m^3. The values were depicted in Table 2.

3.6 True density

The 250 ml measuring cylinder were used with 10 ml toluene for determining true density of garlic clove.The mean value of true density of garlic clove was obtained by toluene displacement method was 573.40±20.97 kg/m^3. The range of true density varies from 529.20-629.83 kg/m^3. The values were presented in Table 2.

3.7 Porosity

The porosity of garlic clove was calculated by true density and bulk density of garlic clove. The results were depicted in Table 2. The mean value of porosity of garlic clove was determined as 26.58±1.50%. The porosity of garlic clove was ranged between 23.47-30.14%.

Table 2: Bulk density, true density, porosity and moisture content of garlic clove.

Observations	Bulk density, kg/m^3	True density, kg/m^3	Porosity, %	Moisture content, %
Mean ($\bar{x}$)	420.30±8.41	573.40±20.97	26.58±1.50	63.21±1.31
Range	404.00-440.00	529.20-629.83	23.47-30.14	60.01-66.30
S.D.(σ)	13.57	33.83	2.42	2.11
CV	0.03	0.06	0.09	0.03

3.8 Moisture content of garlic

The moisture content of garlic is a significant parameter for studies on garlic drying, storage, bulb breaking and peeling. The oven dry method was used to determine moisture content of seed. Three samples of 15 g each were weighed and placed in oven. The samples were heated to 100°C±0.5°C for 30 minutes. After obtaining a steady weight, the samples were analyzed. The moisture content of garlic clove was ranged from 60.01-66.30% and mean value of moisture content was 63.21±1.31%. The moisture content of seed affects the bulk density of seed and angle of repose (Table 2).

3.9 Angle of repose of garlic clove

The angle of repose is the angle formed by the material with regard to the horizontal. The inclination of side of hopper should be greater than the angle of repose for free flow of garlic clove from hopper to the metering mechanism. The mean value of angle of repose of garlic clove for 5 samples was calculated as 37.40±1.18°and standard deviation was 1.4. The details of data were shown in Table 3.

3.10 Coefficient of static friction of garlic clove

Place the object at one end of the track and slowly lift that end of instrument to create a ramp. The angle (ɵ) at which the block starts to slip was noted down. Then by putting values in equation 12, value of coefficient of friction can be calculated. The coefficient of friction was calculated for aluminum, M.S. sheet and G. I. sheet. The value of coefficient of friction of M.S. Sheet was ranged between 0.35 to 0.38, for aluminum 0.38 to 0.40 and for G.I. Sheet 0.38 to 0.41. The mean value of coefficient of variation for M.S. Sheet, aluminum and G.I. Sheet were 0.37±0.01, 0.39±0.01 and 0.40±0.01 respectively shown in Table 3.

Table 3: Angle of repose and coefficient of friction of garlic clove

Particular	Angle of repose, degree	Coefficient of friction in different surfaces		
		M.S. sheet	Aluminum	G.I. sheet
Range (R)	35-40	0.35-0.38	0.38 – 0.40	0.38 – 0.41
Mean ($\bar{x}$)	37.40±1.18	0.37±0.01	0.39±0.01	0.40±0.01
S.D.(σ)	1.90	0.01	0.01	0.01
CV	5.07	2.98	2.25	2.59

3.11 Rupture force

A semi-automatic texture analyzer can compute the impact force on the garlic clove for a single impact. Garlic cloves suffer more damage as the impact increases. The mean value of ten samples from the rupture test garlic clove was 2679 g (26N) at a moisture level of 64.02%, as shown in Table 4 and. The Fig.2 was representing the bearing level of garlic force when we applied external force on it. It was determined that the damage percentage rises after 26 N, hence the impact from the metering unit should be less than 26 N to cause the least amount of harm to the garlic cloves.

Table 4: Rupture force of garlic clove

Particular	Peak positive force, g
Range (R)	2311-3221
Mean ($\bar{x}$)	2679.20±211.33
S.D.(σ)	340.97
CV	12.73

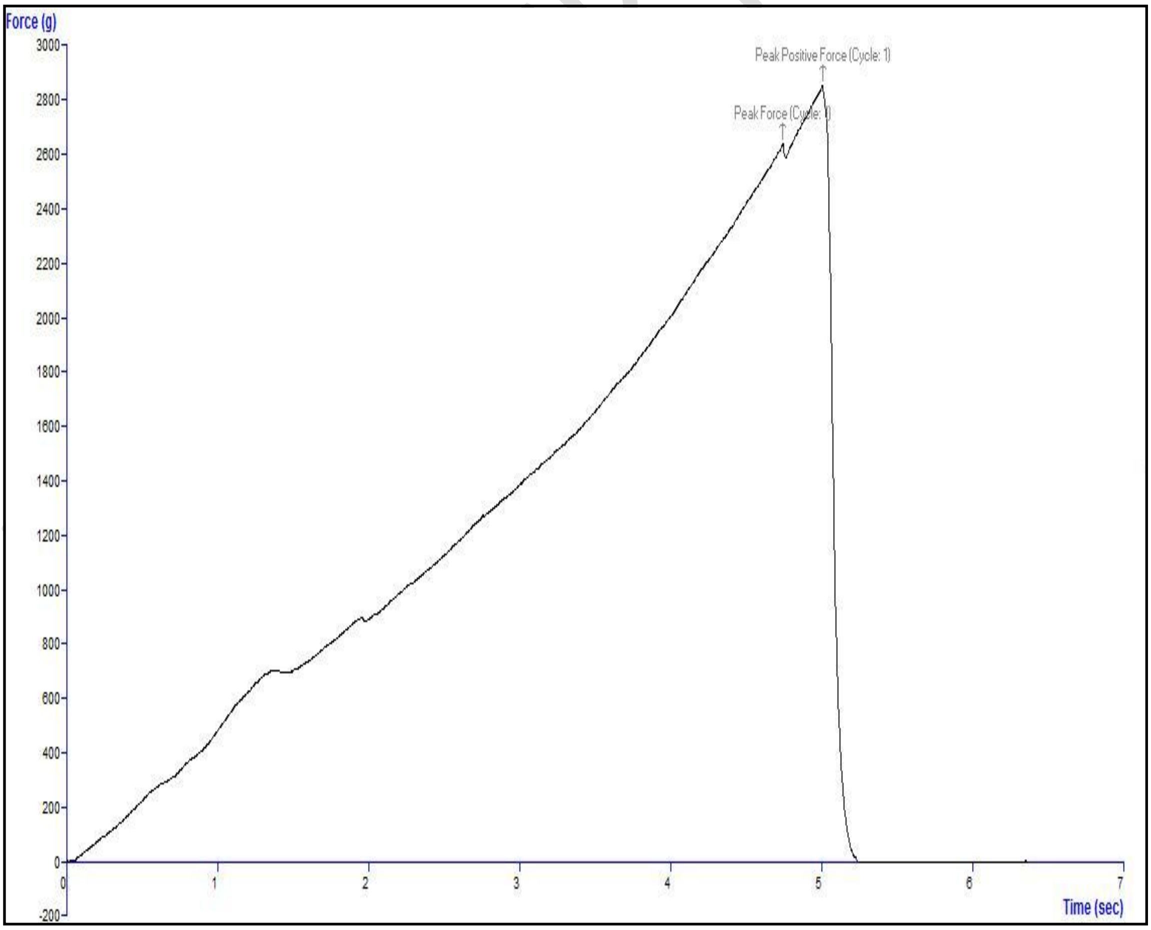


Fig. 2: Force vs time graph of garlic clove by texture analyzer

4. CONCLUSION

In conclusion, the intricate physical properties of garlic, from moisture content to mechanical attributes, illuminate its pivotal role in agricultural and food engineering. These properties profoundly influence the design of machinery for planting, harvesting, and processing, impacting efficiency and quality. The geometric mean diameter and sphericity of the garlic clove were observed to be 13.56 mm and 0.50, respectively. The bulk density, true density and weight of 10 random samples of garlic cloves were observed to be 420.30 kg/m^3, 573.40 kg/m^3 and 832.59 g, respectively. The angle of repose of the garlic clove was measured to be 37.40°, and the coefficients of friction for M.S. sheet, aluminum and G.I. Sheet were measured to be 0.37, 0.39 and 0.40, respectively. The average rupture forces for the garlic cloves were observed to be 26N at 64.02% moisture content.This study bridges a critical knowledge gap, laying the foundation for advancements in cultivation, harvesting methodologies, and innovative processing machinery, ultimately contributing to the enhanced efficiency and quality of garlic production in the agricultural and food engineering sectors.

REFERENCES

Bahnasawy, A. H. 2007. Some physical and mechanical properties of garlic. International Journal of Food Engineering, 3(6): 1-18.

Bakhtiari, M. R. and Ahmed, D. 2015. Determining physical and aerodynamic properties of garlic to design and develop of pneumatic garlic clove metering system. Agricultural Engineering International: CIGR Journal, 17(1): 59-67.

Bakhtiari, M. R. and Loghavi, M. 2009. Development and evaluation of innovative garlic clove precision planter. Journal of Agricultural Science and Technology, 11(2): 125-136.

Bayat, F., and Rezvani, S. M. 2012. Effect of harvesting time and moisture on mechanical properties of garlic (*Allium sativum* L.) skin. Agricultural Engineering International: CIGR Journal, 14(3): 161-167.

Madamba, P. S., Driscoll, R. H. and Buckle, K.A. 1993. Bulk density, porosity and resistance to airflow of garlic slices. Drying Technology, 11(7): 1837-1854.

Masoumi, A. A., Rajabipour, A., Tabil, L. G. and Akram, A. A. 2006. Physical attributes of garlic (*Allium sativum* L.). Journal of Agricultural Science and Technology (JAST): 8(1): 15-23.

Mohsenin, N. N. 1986. Gordon and Breach Science Publishers, New York, :8-11.

Sahay, K. M. and Singh, K. K. 1996. Unit Operations of Agricultural Processing. Vikas Publishing House Pvt. Ltd., : 7-13.

Singh, K. K. and Goswami, T. K. 1996. Physical properties of cumin seed. Journal of Agricultural Engineering Research, 64(2): 93-98.