Crossref

IJBSM October 2024, 15(10): 01-07

Article AR5698

Research Article

Natural Resource Management

DOI: HTTPS://DOI.ORG/10.23910/1.2024.5698

Study on the Engineering Properties of Whole Garlic Bulbs and Garlic Cloves for Effective Design of Processing Machinery

P. D. Jadhav[1], S. V. Gupta[2], B. N. Patil[1], P. H. Bakane[1], S. M. Ghawade[3] and S. D. Jadhao[4]

[1]Dept. of Agricultural Process Engineering, [2]Dept. of Farm Structures, [3]Dept. of Horticulture, [4]Dept. of Soil Science and Agricultural Chemistry, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra (444 104), India

Open Access

Corresponding priyankajadhav100197@gmail.com

0009-0007-5428-0377

ABSTRACT

The present experiment was conducted from February, 2024 to March, 2024 at the Department of Agricultural Process Engineering, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India to investigate the various engineering properties of garlic bulbs and garlic cloves. The engineering properties viz., physical, gravimetric and frictional properties, were studied for whole garlic bulbs and garlic cloves by considering their importance in developing different agricultural and post-harvest processing machinery. The weight 11.41 g, length (polar diameter) 33.69 mm, width (equatorial diameter) 29.51 mm, thickness 27.58 mm, arithmetic mean diameter 30.26 mm, geometric mean diameter 30.10 mm, shape index 0.88, sphericity 0.90, surface area 63.05 cm^2, cross-sectional area 53.75 cm^2, bulk density 449.50 kg m^{-3}, true density 930.45 kg m^{-3}, porosity 51.69%, moisture content 56.70% and angle of repose of garlic bulb 50.54° were obtained. Similar properties were determined for garlic cloves. The L, a and b values for garlic bulb and garlic cloves were 82.95, 0.23, 10.66 and 74.42, 0.28, 12.48, respectively. The water activity of garlic was found to be 0.98±0.02. The coefficient of friction of the garlic bulb and garlic cloves was measured for the selected testing surfaces such as mild steel (MS), stainless steel (SS), wood, glass and fiberglass which was considered in hopper design. The compression force required to loosen the cloves from the garlic bulb was calculated as 61 N. By integrating these engineering properties into the design process, manufacturers can develop equipments or machineries that are more efficient, durable and capable of producing high-quality garlic products.

KEYWORDS: Diameter, density, engineering properties, garlic, post-harvest processing

***Citation* (VANCOUVER):** Jadhav et al., Study on the Engineering Properties of Whole Garlic Bulbs and Garlic Cloves for Effective Design of Processing Machinery. *International Journal of Bio-resource and Stress Management,* 2024; 15(10), 01-07. HTTPS://DOI.ORG/10.23910/1.2024.5698.

Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

Conflict of interests: The authors have declared that no conflict of interest exists.

RECEIVED on 12th August 2024 RECEIVED in revised form on 07th October 2024 ACCEPTED in final form on 20th October 2024 PUBLISHED on 23rd October 2024

1. INTRODUCTION

Garlic (*Allium Sativum*, L.) is one of the most important root vegetable and spice all over the world (Bakhtiari and Ahmad, 2015). Garlic cloves are the economic part of plants and are used as planting material for the vegetative propagation of garlic (Masoumi, 2006; Seelothu et al., 2024). It belongs to the Alliaceae family and has been widely used to treat different diseases since ancient times (Kaur et al., 2019). The chemical composition of fresh garlic was as moisture 66.67%, dry matter 33.43%, crude fat 0.52%, crude protein 7.87%, ash 1.33% and crude fiber 0.73% according to Odebunmi et al. (2009). S-allyl-cysteine sulfoxide (ACSO) is one of the most important compounds responsible for the medicinal properties of garlic. Garlic has anti-inflammatory, anti-microbial, anti-cancer and anti-oxidant effects (Labu and Rehman, 2019). After China, India is one of the leading producers of garlic with a production of 3.3 mt. The total area and production of garlic in Maharashtra was approximately 3,134 ha and 17,868 t, respectively in 2022–23 (Anonymous, 2022). For designing storage structures, handling equipment and post-harvest processing machinery engineering properties are considered as crucial parameters (Kaur et al., 2019). The engineering properties of garlic bulbs and garlic cloves studied in the present research work include physical properties, mechanical properties and gravimetric properties.

Garlic curing, grading, storage, peeling, bulb breaking, clove separation, dehydration, grinding and several other unit operations were involved in the garlic processing (Singh et al., 2022). In the food industry, garlic is used in both fresh and dehydrated states. Garlic can be made into different forms such as flakes, powder, slices and oil (Bahnasawy, 2007). Mohsenin (1986) described the methods to determine the average diameter of an agricultural product in different directions. However, to determine the size of a sample measurements taken in three major directions i.e. major, intermediate and minor diameters were sufficient. Size and shape parameters are more often used to describe any seed, fruit and vegetables whereas density difference is useful to detect the quality of agricultural commodities. Frictional properties such as the coefficient of friction and angle of repose play a major role in the design of storage bins, hoppers, chutes, pneumatic conveying systems, screw conveyors, forage harvesters, threshers, etc (Sahay and Singh, 1996).

Bakhtiari and Ahmad (2015) investigated garlic cloves' moisture-dependent physical and aerodynamic properties to design and develop pneumatic garlic clove metering systems. The study revealed that the true density increased and terminal velocity decreased with an increasing moisture content within the obtained range. Rai et al. (2022) studied the different engineering properties of garlic cloves including linear dimension, geometric mean diameter, sphericity, angle of repose, bulk density, true density and porosity, etc. Masoumi et al. (2006) determined and compared the physical attributes of two types of Iranian garlic cloves. The results show the significant effect of moisture content ($p<0.01$) on the unit density, bulk density and porosity of the cloves. Lack of information about the engineering properties of garlic becomes an obstacle in the development of advanced agriculture and processing equipment. The present research work aims to determine the engineering properties of whole garlic bulbs and garlic cloves which play a key role in the design and development of post-harvest processing machinery for garlic. These engineering properties include weight, moisture content, geometric mean diameter, arithmetic mean diameter, sphericity, shape index, coefficient of friction, angle of repose, bulk density, true density, porosity, water activity, colour and force required to break the garlic bulb (compression force), etc.

2. MATERIALS AND METHODS

2.1. *Sample preparation*

The present research work was conducted from February, 2024 to March, 2024 at the Department of Agricultural Process Engineering, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India. The whole fresh garlic bulbs were brought from the field under the Research Unit of Chilli and Vegetables, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola. The procured sample was cleaned manually and all foreign matter such as dust, dirt and the damaged bulb was removed. The selected whole garlic bulbs and garlic cloves are shown in Figures 1 and 2, respectively.

2.1.1. *Weight*

The weight of selected individual whole garlic bulbs and garlic cloves was recorded by digital electronic weighing balance with a precision of ±0.01 g.

Figure 1: Whole garlic bulb

Figure 2: Garlic cloves

2.1.2. Physical (linear) dimensions

The polar diameter (D_p)/length, equatorial diameter (D_e)/width and thickness (T) of whole garlic bulbs and garlic cloves were measured using a vernier calliper (Mitutoyo, Model No. CD-6VC) with an accuracy of 0.01 mm. The polar diameter is the distance from the garlic crown to the point of root attachment of the garlic and the equatorial diameter is the maximum garlic width in the plane perpendicular to the polar diameter (Bahnasawy, 2007). Fifty (50) whole garlic bulbs and garlic cloves were selected to determine their physical dimensions. With the help of linear dimensions the arithmetic mean diameter (D_a), geometric mean diameter (D_g), surface area (SA), cross-sectional area (CSA), sphericity (Φ) and shape index were calculated using the following relationship (Mohsenin, 1986; Bahnasawy, 2007; Gautam et al., 2016; Singh et al., 2018; Dikkar et al., 2024),

Geometric mean diameter $(D_g)=(D_p \times D_e \times T)^{1/3}$, (mm) (1)

Arithmetic mean diameter $(D_a)=(D_p \times D_e \times T)/3$, (mm) (2)

Surface area, $(SA)= \pi/4 \times D_p \times D_e$, ($mm^2$) (3)

Cross-sectional area,$(CSA)=\pi/4(D_p \times D_e \times T)^{2/3}$ (mm^2) (4)

Sphericity, $(\Phi)=(D_p \times D_e \times T)^{(1/3)}/D_p$ (5)

Shape index$=De/\sqrt{(D_p \times T)}$ (6)

2.1.3. Moisture content

The moisture content of the garlic bulb and garlic cloves was determined by using the convection oven method. Selected garlic bulb and clove samples were heated at 105±0.5°C for 24–36 h until a constant weight was obtained. The samples were removed from the oven, cooled in a desiccator and the final weight was recorded. The percent (%) moisture content was determined using equation (7) given below (Singh et al., 2022).

M.C. (% W.B.)=(Initial weight of garlic bulb-Final weight of garlic bulb)/Initial weight of garlic bulb×100 (7)

2.1.4. Gravimetric properties

Gravimetric properties, i.e., true density, bulk density and porosity are essential in post-harvest handling and storage. The true density is the weight of the sample divided by its true volume. By the liquid displacement method, the volume was determined with the help of a toluene reagent using a measuring cylinder (equation 8). The true density of the whole garlic bulb and garlic clove was calculated using equation (9) (Mohsenin, 1986; Dress, 2011; Singh et al., 2022).

Volume (m^3)=Weight of displaced toluene, (kg)/Weight density of toluene, (kg m^{-3}) (8)

True density (kg m^{-3})=(weight of Sample, kg)/(volume of sample, m^3) (9)

The bulk density is the ratio of the mass of the sample to the volume of the container. A known volume of a container filled with samples (garlic bulbs or garlic cloves) with the top surface levelled was taken. The weight of the sample (garlic bulb or garlic cloves) from the container was recorded and the same procedure was used to calculate the bulk density according to the equation (10) given below (Sahay and Singh, 1996; Dress, 2011; Singh et al., 2022; Vinayak et al., 2022). The same procedure was repeated five times.

Bulk density (kg m^{-3})=(Actual weight of sample, MS (kg)/(Volume of the container, VC (m^3)) (10)

Porosity (ε), expressed as a percentage and calculated using true and bulk density with the help of equation (11) (Sahay and Singh, 1996; Bakhtiari, 2015; Singh et al., 2018),

Porosity (%)=(True density-Bulk density)×100/True density (11)

2.1.5. Mechanical properties

The angle of repose was determined with the help of height (H) and the diameter (D) of the conical heap formed on the natural fall of the sample. The process was replicated five times and the mean was recorded for both garlic bulbs and garlic cloves. It was calculated using equation (12) (Sunitha et al., 2016; Teferra, 2019; Gautam et al., 2021; Singh et al., 2022)

Angle of repose $(Ø)=\tan^{-1}(2H/D)$ (12)

Where, Ø= Angle of repose (°), H= Height of pile (mm) and D= Diameter of disc (mm)

The inclined plane method was used to determine the coefficient of static friction. A sample was placed on the test surface at the top edge. The test surface was manually tilted until the sample started to slide over the surface provided. The same process was followed for garlic bulbs and cloves. The angle at which the bulb or clove starts to slide is measured using a protractor and recorded as the angle of internal friction. The tangent of the angle of internal friction was recorded as the coefficient of friction. It was determined for stainless steel (SS), mild steel (MS), wood, fiberglass and glass using the equation given below (13) (Sahay and Singh, 1996; Bahnasawy, 2011; Gautam et al., 2021; Singh et al., 2022).

$$\text{Coefficient of friction } (\mu)=\tan\theta'' \quad (13)$$

Where, μ=Coefficient of friction, θ=Frictional angle, (°)

The compression force was calculated to determine the force required to loosen the cloves from the whole garlic bulbs. A texture analyser (TA.XT plus, Stable Micro Systems, Godalming, UK) was used to measure the force required to loosen the cloves from the whole bulb using a compression plate (P/75). The probe settings applied were: a pre-test speed of 3 mm s^{-1}, a test speed of 2 mm s^{-1} and a post-test speed of 10 mm s^{-1} for 10 samples of whole garlic bulbs.

2.1.6. Water activity (A_w)

The water activity (A_w) is the ratio of vapour pressure exerted by the water in the food (P) to the vapour pressure of pure water (P_0) at the same temperature (Mohsenin, 1986). Food preservation, food storage, food quality and food security depend on the water activity of food. (Sandulachi, 2012). A digital water activity meter (AquaLabLite - DECAGON) was used for the measurement of the water activity of garlic and it shows the water activity (0–1) and temperature (4–50°C) on display.

2.1.7. Colour

Colour is a vital quality attribute that influences consumer choices and product marketing. Its measurement and analysis are important for post-harvest handling and quality evaluation (Pathare et al., 2013). For colour determination of garlic bulbs and cloves, a digital colorimeter (Chroma Meter CR400, by KONICA MINOLTA, INC., Made in Japan) was used. Before the colour determinations, the colorimeter should be calibrated by using a standard white reflector plate. The colour space is divided into three-dimensional (L, a and b) rectangular areas. The L (lightness) axis moves vertically from 0 (perfectly black) to 100 (perfectly white) in terms of the reflectance or is clear during transmission. (Barrett et al., 2010).

3. RESULTS AND DISCUSSION

The bulk of whole garlic bulbs and garlic cloves were selected for the determination of their engineering properties. The results obtained in the present investigation are discussed in this section by relating them to previous research findings.

3.1. Physical properties

3.1.1. Weight and moisture content

In the present investigation, the average weight of the whole garlic bulb was 11.41±2.77 g which is lower than values obtained by Masoumi et al., 2006. The physiological loss of weight in garlic bulbs was initiated from the second month of its storage (Kaur et al., 2019). The present study revealed the range for weight of single garlic cloves from 0.35 to 1.74 g with a mean of 0.80±0.30 g which shows agreement with the results derived by Singh et al. (2022). The average moisture contents of whole garlic bulb and garlic clove obtained by the standard method were 56.70% and 33.66±8.12%, respectively. Similar results were reported by Kimura et al. (2017) and Channabasamma (2014). The engineering properties of agricultural commodities are influenced mostly by their moisture content. The variation in moisture content between garlic bulbs and garlic cloves is presented in figure 3, which shows that garlic bulbs have a greater moisture content (%) than garlic cloves.

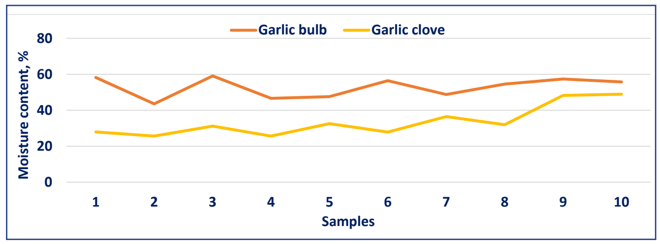

Figure 3: Variation in the moisture content of garlic bulb and garlic cloves

3.1.2. Axial dimensions

The size of garlic bulbs and garlic cloves were obtained from the measurement of its polar diameter (length), equatorial diameter (width) and thickness and found to vary in the ranges from 26.61–39.72 mm, 23.55–34.37 mm and 21.70–35.07 mm, respectively for whole garlic bulb whereas 22.31±3.46, 9.02±1.84 and 6.72±1.27 mm, respectively for garlic cloves. Similar trend was followed for whole bulb of Iranian garlic variety (Masoumi et al., 2006) and for garlic cloves (Singh et al., 2022). The average geometric mean diameter and arithmetic mean diameter of the whole garlic bulb were 30.07±2.27 mm and 30.23±2.29 mm, respectively, which are in accordance with the previous results derived by Kaur et al., (2019). The measured mean arithmetic mean diameter and geometric mean diameter of the garlic clove were 12.68±2.19 and 11.06±2.01 mm, respectively which is similar to results by Dress (2011). A comparison between garlic bulbs and garlic cloves based on arithmetic mean diameter (AMD) and geometric mean diameter is shown in figures 4 and 5, respectively.

To determine the shape of the garlic bulb, the shape index was used. A shape index >1.5 indicates an oval shape of a garlic bulb, whereas a shape index <1.5 indicates a spherical-shaped garlic bulb. The estimated mean value for the shape

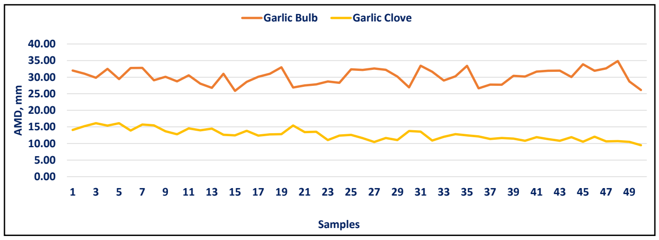

Figure 4: Comparison between arithmetic mean diameter of garlic bulbs and garlic cloves

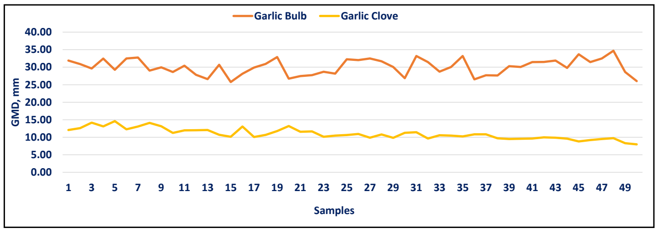

Figure 5: Variation between geometric mean diameter of garlic bulbs and garlic cloves

index was 0.97±0.10, which shows that all selected garlic bulbs are spherical and similar to the results reported by Rathinakumari et al. (2015). The mean value of the shape index for garlic clove was 0.74±0.88 which is important in the design of peeling, sorting and grading machines.

The sphericity parameter shows the shape character of material relevant to a sphere with the same volume (Sahay and Singh, 1996). The mean value of the sphericity of

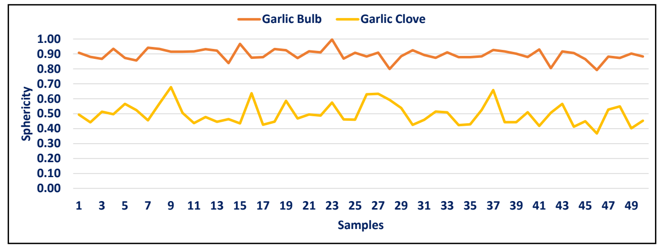

Figure 6: Variation in the sphericity of garlic bulbs and garlic cloves

whole garlic bulb was 0.90±0.04 which is similar to the result (0.86) reported by Tullo (2023) but higher than the result (0.56) obtained by Haciseferogullari et al., (2005). The average sphericity of garlic clove was calculated to be 0.50±0.58 which is in agreement with the result (0.053±0.03) reported by Singh et al., (2022). The surface area and cross-sectional area of garlic bulbs calculated in the present study ranged from 38.6 to 87.5 cm^2 and from 31.3 to 76.2 cm^2, respectively. According to Bahnasawy (2007), the size of garlic bulbs in the present varies from small to medium size. The variation in the sphericity of garlic bulbs and garlic cloves is presented in figure 6 which shows the spherical shape of garlic bulbs.

The maximum, minimum and mean values of physical properties of whole garlic bulbs and garlic cloves were presented in table 1 along with standard deviation and coefficient of variation.

Table 1: Physical properties of garlic bulbs and garlic cloves

Sl. No.	Content	Maximum		Minimum		Mean		Standard deviation (SD)		Coefficient of variance (CV, %)	
		GB	GC	GB	GC	GB	GC	GB	GC	GB	GC
1.	Weight (g)	20.70	1.74	7.64	0.35	11.41	0.80	2.77	0.30	24.31	38.03
2.	Polar diameter/Length (mm)	39.72	28.67	26.61	15.60	33.69	22.31	3.21	3.46	9.53	15.53
3.	Equatorial Diameter/ Width (mm)	34.37	13.69	23.95	5.69	29.51	9.02	2.63	1.84	8.92	20.44
4.	Thickness (mm)	35.07	10.35	21.70	4.11	27.58	6.72	2.73	1.27	9.90	18.86
5.	Arithmetic mean diameter (mm)	34.87	16.11	25.85	9.46	30.26	12.68	2.25	1.66	7.43	18.28
6.	Geometric mean diameter (mm)	34.69	14.61	25.76	7.98	30.10	10.98	2.23	1.51	7.39	18.16
7.	Sphericity	1.00	0.68	0.79	0.37	0.90	0.50	0.04	0.07	4.22	1.17
8.	Surface area (cm^2)	87.5	6.70	38.6	2.00	63.05	3.90	4.85	1.08	7.69	0.99
9.	Shape index	1.05	1.04	0.68	0.49	0.88	0.74	0.08	0.11	9.29	1.19
10.	Cross-sectional areas (cm2)	76.2	6.1	31.3	2.1	53.75	3.86	5.17	1.02	9.62	0.97
11.	Moisture content (%)	59.05	48.94	43.57	25.63	52.80	33.66	2.38	8.12	4.20	0.24

GB: Garlic bulb; GC: Garlic clove

3.1.3. Water activity and colour

Generally, garlic bulbs are compact, uniform and white in colour. The water activity of garlic was found to be 0.98±0.002 and is responsible for microbial activities and the stability of the product. The measured average L, a and b values for whole garlic bulbs were 82.95, 0.23 and 10.66, respectively. Additionally, the mean values of L, a and b for garlic cloves were 74.42, 0.28 and 12.48, respectively. Higher L values indicate the white colour of garlic bulbs. Kaur et al. (2019) reported a greater L value for the garlic variety PG-18. The variation in colour between garlic bulbs and garlic cloves based on the L, a and b values is presented in figure 7.

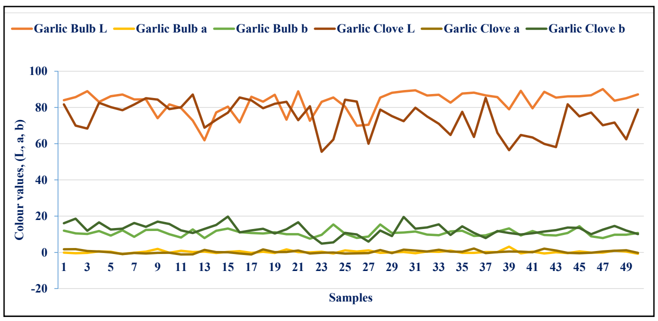

Figure 7: Colour variation between garlic bulbs and garlic cloves

3.2. Gravimetric properties

The bulk density, true density and porosity are included in the gravimetric properties. In the present investigation for the whole garlic bulb, the average bulk density, true density and porosity were determined as 449.50 kg m^{-3}, 930.45 kg m^{-3} and 51.69%, respectively. The bulk density obtained in the present study follows the result recorded by Rathinakumari et al. (2015) and true density is in agreement with Kaur et al. (2019). However, for garlic cloves, the bulk density ranged from 492.3 to 536.5 kg m^{-3} which is similar to the results reported by Bakhtiari and Ahmad (2015). The true density and porosity of garlic cloves were calculated to be 1,235.6±14.86 kg $m^{-3}$and 58.36±2.50%, respectively which follows the results obtained by Rathinakumari et al. (2015).

3.3. Frictional properties

Frictional properties play a vital role in the designs of bins, silos and storage structures etc. The angle of repose depicts the flowing ability of agricultural commodities, and it increases with increasing moisture content (Sahay and Singh, 1996). In the present study, the angle of repose of the whole garlic bulb and garlic cloves ranged from 46.97°–53.61° and 36°–40°, respectively which are in agreement with the results reported by Channabasamma (2014). The measured average values of the coefficient of friction of garlic bulbs on mild steel (MS), stainless steel (SS), wooden, glass and fiberglass surfaces were 0.42±0.04, 0.34±0.07, 0.46±0.07, 0.30±0.04 and 0.38±0.05, respectively. However, for garlic cloves, these values obtained were 0.40±0.05, 0.35±0.09, 0.45±0.05, 0.31±0.02 and 0.36±0.08, respectively. A similar trend was obtained for garlic bulbs in the case of mild steel and glass surfaces (Rathinakumari et al., 2015). These properties are important for the movement of products during processing. The maximum force required to break the single garlic bulb was presented by the graph obtained using a texture analyser (Figure 8). The force required to loosen the garlic cloves from the bulb ranges from 26–93 N with an average value of 61±21.89 N. All these physical, gravimetric and mechanical properties are advantageous for designing agricultural and processing equipment for garlic crop and improve their operational accuracy.

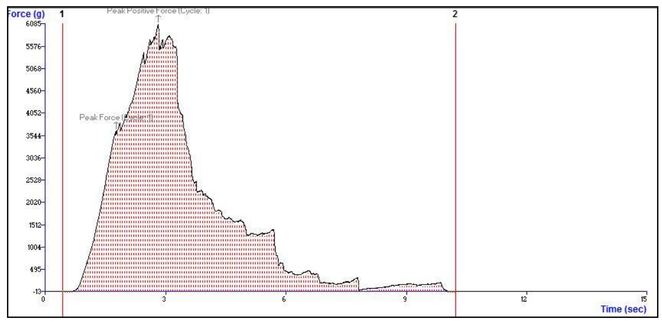

Figure 8: Graph representing the maximum force (g) required to break the garlic bulb using a texture analyser

4. CONCLUSION

The sphericity obtained for garlic bulb and cloves was 0.80 and 0.50, respectively, indicating the garlic shape is close to the sphere. The average moisture contents of garlic bulbs and cloves were obtained as 56.70% and 33.66%, respectively and the average water activity of garlic was 0.98±0.002. The colorimeter recorded a greater L value for the garlic bulbs than for cloves.

5. ACKNOWLEDGMENT

The authors are grateful and wish to acknowledge the overall support offered by the Department of Agricultural Process Engineering, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola in the actualization and publication of this entire research work. This study belongs to part of my PhD research work.

6. REFERENCES

Bahnasawy, A.H., 2007. Some physical and mechanical properties of garlic. International Journal of Food Engineering 3(6), 1–18. DOI: 10.2202/1556-3758.1136.

Bakhtiari, M.R., Ahmad, D., 2015. Determining physical and aerodynamic properties of garlic to design and develop a pneumatic garlic clove metering system.

Agricultural Engineering International: CIGR Journal 17(1).

Barrett, D.M., Beaulieu, J.C., Shewfelt, R., 2010. Color, flavor, texture, and nutritional quality of fresh-cut fruits and vegetables: desirable levels, instrumental and sensory measurement, and the effects of processing. Critical Reviews in Food Science and Nutrition 50(5), 369–389.

Channabasamma, B.B., 2014. Development of a motorized garlic bulb breaker (Doctoral dissertation).

Dikkar, P.M., Dsouza, P.M., Moses, S.C., Aalam, R.N., 2024. Physical and engineering parameter of garlic. International Journal of Plant & Soil Science 36(6), 208–212.

Dress, A.M., 2011. Physical and mechanical properties of garlic relating rubbing and planting machines. Misr Journal of Agricultural Engineering 28(3), 571–588.

Gautam, A., Jogdand, S.V., Naik, R.K., Trivedi, J., 2021. Study of engineering properties of N-53 onion bulb. In Biological Forum–An International Journal 13(4), 80–84.

Gautam, A., Khurana, R., Manes, G.S., Dixit, A.K., 2016. Studies on engineering properties of pelleted carrot (*Daucus carota* L.) seeds. International Journal of Bio-resource and Stress Management 7(5), 1044–1048.

Haciseferogullari, H.M., Ozcan, F., Demir S., Calisir 2005. Some nutritional and technological properties of garlic. Journal of Food Engineering 68, 463–469.

Kaur, G.J., Dhall, R.K., Singh, A.K., Chawla, N., 2019. Engineering properties and storage behaviour of newly developed garlic (*Allium sativum* L.) varieties. Agricultural Research Journal 56(2), 355–358.

Kimura, S., Tung, Y.C., Pan, M.H., Su, N.W., Lai, Y.J., Cheng, K.C., 2017. Black garlic: A critical review of its production, bioactivity, and application. Journal of Food and Drug Analysis 25(1), 62–70.

Labu, Z., Rahman, M., 2019. Proven health benefits of garlic-a review. Department of Pharmacy; World University of Bangladesh (WUB): Dhanmondi, Dhaka, Bangladesh, 1205.

Masoumi, A.A., Rajabipour, A., Tabil, L.G., 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. Physical properties of plant and animal material. (revised) Gordon and Breach science publishers New York.

Pathare, P.B., Opara, U.L., Al-Said, F.A.J., 2013. Colour measurement and analysis in fresh and processed foods: a review. Food and Bioprocess Technology 6, 36–60.

Rathinakumari, A.C., Channabasamma, B.B., Kumaran, G.S., 2015. The physical and mechanical properties of garlic bulbs and cloves (*Allium sativum* L.) are relevant to the development of garlic bulb breakers. International Journal of Tropical Agriculture 33(2), 1881–1887.

Sahay, K.M., Singh, K.K., 1996. Unit operations of agricultural processing, New Delhi: Vikas Pub. House Pvt. Ltd.

Sandulachi, E., 2012. Water activity concept and its role in food preservation. Meridian Ingineresc (4), 40–48.

Seelothu, R., Medda, P.S., Dutta, B., Ghosh, A., Khalko, S., 2024. Impact of diverse plant growth regulators on quality traits of garlic (*Allium sativum* L.). International Journal of Bio-resource and Stress Management 15, 01–07.

Singh, K.P., Chandel, N.S., Potdar, R.R., Jat, D., Agrawal, K.N., Hota, S., 2018. Assessment of engineering properties of proso millet (*Panicum miliaceum*). Journal of Agricultural Engineering 55(2), 42–51.

Singh, S.N., 2022. Design and development of rotary disc type garlic clove peeling machine. Agricultural Engineering International: CIGR Journal 24(1), 228–238.

Sunitha B., Sujatha B., Girish B., Rajkiran, B., Ramana, M.V., Determination of physical properties of onion (*Arka kirthiman*). International Journal Processing and Post Harvest Technology 7(1), 36–41.

Teferra, T.F., 2019. Engineering properties of food materials. In Handbook of farm, dairy and food machinery engineering (45–89). Academic Press.

Tullo, A., 2022. Study on some engineering properties of holeta local variety garlic (*Allium sativum* L.) grown in Ethiopia. American Journal of Food Science and Technology 1(2), 1–7.

Vinayak, M., Ramana, C., Haribabu, B., Reddy, K.M., 2022. Determination of physical properties of FYM for the development of FYM Shredder cum Spreader. International Journal of Bio-resource and Stress Management 13, 1398–1402.