



AMERICAN JOURNAL OF FOOD SCIENCE AND TECHNOLOGY (AJFST)

ISSN: 2834-0086 (ONLINE)

VOLUME 1 ISSUE 2 (2022)



PUBLISHED BY: E-PALLI, DELAWARE, USA

Study on Some Engineering Properties of Holeta Local Variety Garlic (*Allium Sativum L.*) Grown in Ethiopia

Abe Tullo^{1*}

Article Information

Received: December 15, 2022**Accepted:** December 29, 2022**Published:** December 31, 2022

Keywords

Angle of Repose, Bulk Density, Garlic, Physical Properties, Sphericity

ABSTRACT

Garlic (*Allium Sativum L.*) is an important root vegetable that can be used as a spice in meals and has historically been used as a remedy for various ailments in Ethiopia. The physical properties of the garlic bulbs and cloves were determined for use in the prototype design. The result showed that the equatorial diameter, polar diameter, thickness, geometric mean diameter, arithmetic mean diameter, sphericity, shape index, surface area, moisture content, hundred garlic bulb weight, bulk density, and angle of repose of the garlic bulbs were 45.89, 42.86, 30.43, 39.08 and 39.71 mm, 0.86, 1.34, 17.08 cm², 66%, 2530 g, 596.70 kg/m³, and 49.7° for garlic bulbs, respectively. Similarly, the result of the width, length, thickness, geometric mean diameter, arithmetic mean diameter, sphericity, shape index, surface area, hundred garlic cloves weight, bulk density, and angle of repose of the garlic bulbs were 14.44, 31.02, 11.63, 17.15, and 20.07 mm, 0.57, 1.27, 4.06 cm², 239.4 g, 468.4 kg/m³, and 37.56° for garlic cloves, respectively. Therefore, these physical and mechanical properties of garlic bulbs and cloves were used in designing machine parts.

INTRODUCTION

Garlic (*Allium sativum L.*) belongs to the family Alliaceae and genus *Allium* and is a shallow root vegetable (Seifu *et al.*, 2017). The *Allium* plant is the maximum essential vegetable plant used as a seasoning in maximum Ethiopian dishes. Among them, onion (*Allium cepa L.*) and garlic (*Allium sativum L.*) are acknowledged as “kitchen queens”, and are taken into consideration as one of the maximum vital herbs for mass manufacturing in Ethiopia (Selvaraj *et al.*, 2014). Garlic is the most used root vegetable after onions in Ethiopia. It has been used in many communities in Ethiopia as a flavoring agent in food and as a medicinal plant for various ailments (Addis and Abebaw, 2017), grown both during the main rainy season and under irrigated conditions (CSA, 2018). Garlic is processed into dehydrated products such as flakes, powders, pickles, canned goods, and bottles. Garlic products are sought after in the domestic market for catering and snack industries and are also exported to prominent markets to gain commercial value overseas (Channabasamma, 2014).

The physical properties of garlic bulbs and cloves are essential for the design and development of the separating device. The size and sphere of the bulb determine the distance between the rubber rollers in the design of the garlic clover. High bulk density affects structural loads (Channabasamma, 2014). Sajid *et al.* (2014) reported that the moisture content of garlic (*Allium sativum L.*) was 64.58%. Odebunmi *et al.* 2010 and Kimura *et al.* 2017 also reported 65 and 58.6% moisture content in garlic, respectively. Masoumi *et al.* (2006) compared some physical properties of two common types of Iranian garlic cloves (white and pink), their study results showed that at different moisture levels ranging from 34.9% to 56.7% w.b.

Channabasamma (2014) reported the dimensions of the garlic bulb, such as the pole diameter; The diameter and thickness of the equator are 61.25, 43.21, and 36.00 mm. Manjunatha *et al.* (2008) estimated the physical properties of garlic with 40.50% moisture content on a wet basis namely shape compared with standard chart, diameter, length, width, and thickness in micrometers digital with 0.01 mm accuracy. The length, width, and thickness of shrimp are 1.92-2.91, 0.78-1.32, and 0.69-0.99 cm, respectively (Bahnasawy, 2007). Dress (2011) studied the physical properties of garlic and cloves, for garlic bulbs: The length (L) ranged from 53.3 to 73.5 mm with an average value of 59.9 mm. The width (W) varies from 51.6 to 67.2 mm with an average value of 58 mm. Thickness (T) varies from 39.6 to 51.5 mm with an average value of 45.2 mm, for garlic cloves: Length (L) varies from 13.9 to 36.6 mm with a price average value is 26.4 mm. The width (W) varies from 6 to 20 mm with an average value of 11.9 mm. The thickness (T) varies from 4.1 to 13.5 mm with an average value of 8.5 mm. Bakhtiari and Ahmad (2015) found that the mean length, width, and thickness of garlic cloves were 32.0, 21.8, and 20.9 mm, respectively.

The geometric and arithmetic mean diameters of garlic ranged from 2.53 to 4.93 and 2.53 to 5.02 cm, respectively, depending on the bulb size type (Bahnasawy, 2007). Channabasamma (2014) and Rathinakumari *et al.* (2015) found that the geometric mean diameters of garlic bulbs and garlic cloves were 45.70 mm and 12.55 mm, respectively. Dress (2011) studied some physical properties of garlic bulbs and garlic cloves, for garlic bulbs: The diameter of the arithmetic means ranged from 49.5 to 60.6 mm with an average value of 54.4mm. The geometric mean diameter varies from 48.92 to 59.31 mm with a mean of 53.85 mm, for garlic cloves: The arithmetic means diameter varies from 9.4 to 22.3

¹ Oromia Agricultural Research Institute, Addis Ababa; Haramaya University, Haramaya, Ethiopia

* Corresponding author's e-mail: abesokore@gmail.com

mm with an average value of 15.6 mm. The geometric mean diameter varies from 7.6 to 20.6 mm with a mean of 13.7 mm. Bakhtiari and Ahmad (2015) estimated the geometric and arithmetic mean diameters of garlic cloves to be 24.4 mm and 24.9 mm, respectively.

The shape index is used to evaluate the shape of garlic bulbs. It is very important in the design of the sorting and grading machine, it is also used in the peeler. On the other hand, garlic bulbs are considered oval if the shape index is >1.5 ; it is considered spherical if the shape index is <1.5 (Bahnasawy, 2007 Channabasamma, 2014). The shape index ranged from 1.36 to 1.5 for garlic bulbs reported by Bahnasawy (2007) and 0.45 for garlic cloves by Channabasamma (2014). According to Rathinakumari *et al.* (2015), the bulb shape index of garlic is 0.74. One hundred garlic bulbs and clove's weight are important in the design of sheds, seed containers, and the capacity of transport tools (Bahnasawy, 2007). The mean weight of cloves (g) was recorded as the mean weight of ten randomly sampled cloves after drying (Tadesse, 2015). Channabasamma (2014) found that the weights of one hundred garlic bulbs and garlic cloves ranged from 2270.7 to 4849.0 and 260.0 and 392 g, respectively. Dress (2011) reported some physical properties of garlic bulbs and garlic cloves, for garlic bulbs: weight from 45.3 to 87.6 g with a mean value of 62.5 g, and for cloves garlic: weight from 0.24 to 5.2 g with a mean value of 1.49 g. Bakhtiari and Ahmad (2015) estimated the average thousand-grain mass to be 6783.0–8159.3 g. Rathinakumari *et al.* (2015) estimated some physical, mechanical, and aerodynamic properties of garlic at 60.92% moisture content on a dry basis, with a sphericity of 0.51. Dress (2011) has studied some physical properties of garlic bulbs and garlic cloves, the mean spherical value for garlic bulbs is 0.9, and for garlic cloves, the mean spherical value is 0.53. According to Channabasamma (2014), the bulb sphere of garlic is 0.74. Dress (2011) studied some physical properties of garlic bulbs and garlic cloves. For garlic bulbs, the surface ranged from 75.2-110.5 cm² with an average value of 91.4 cm² while for garlic cloves, the surface ranged from 1.8 to 13.3 cm² with an average value is 6.1 cm². The surface of garlic and clove bulbs ranges from 53.31 to 136.4 cm² (Bahnasawy, 2007). Bakhtiari and Ahmad (2015) estimated that the average surface area of garlic cloves increased from 1718.3 to 2029.1 mm² (17.18 to 20.29 cm²).

Rathinakumari *et al.* (2015) found the garlic bulb and clove's bulk densities were 453.5 kg/m³ and 424.94 kg/m³, respectively. Dress (2011) studied the physical properties of garlic bulbs and cloves. For garlic bulbs, bulk densities ranged from 0.4 to 0.55 g/cm³, with an average value of 0.45 g/cm³. On the other hand, the bulk density of one garlic clove averaged 0.57 g/cm³, ranging from 0.45 to 0.61 g/cm³. Bakhtiari and Ahmad (2015) calculated that the average bulk density of garlic cloves increased from 476.3 to 567.4 kg/m³. Masoumi *et al.* (2006) reported 468.8 to 612.8, and 510.2 to 672 kg/m³ for white and pink garlic cloves, respectively. The angle

of repose of garlic bulbs reported by Bahnasawy (2007) and Dress (2011) was 41.52 to 45.04° and 26 to 30.5°, respectively. Dress (2011) also reported that the angle of repose of garlic cloves was 39.5–41° (average 38.7°). Manjunatha *et al.* (2008) studied some of the physical and mechanical properties of garlic bulbs in the moisture content range of 23.05 to 40.50% (w.b.), where the angle of repose increased from 25.53° to 37.50°, respectively. In a separate study, according to Channabasamma (2014), values for garlic bulbs and cloves ranged from 48.64-57.99° and 37-40° respectively.

The farmers of Arsi and West Arsi Zones of Oromia Regional State requested Asella Agricultural Engineering Research Center for a machine to separate cloves from garlic bulbs for planting due to the tedious and time-consuming the traditional method of garlic separation from a compound garlic bulb by hand, which results in hand injuries. There is a machine designed and developed for separating cloves from a garlic bulb in India and China. However, Those machines were very expensive and, designed and constructed for garlic varieties available in India and China. Therefore, Those machines need modification and additional costs due to big differences in the engineering properties of Ethiopian garlic varieties from those countries' garlic varieties. Considering the problems mentioned above, to design and construct a low-cost and effective garlic bulb separating machine from raw material available in Ethiopia, studying the engineering properties of the garlic bulb and clove is very important with the objective of determining the physical and mechanical properties of garlic grown in Ethiopia.

MATERIALS AND METHODS

Experimental Location

The study was conducted at the Asella Agricultural Engineering Research Center and the Kulumsa Agricultural Research Center. Determination of some engineering properties of the garlic bulbs and cloves was carried out at the Asella Agricultural Engineering Research Center (AAERC). The moisture content of garlic was analyzed at the Kulumsa Agricultural Research Center (KARC).

Experimental Materials

A 50 kg garlic bulb of Holeta local variety was obtained from Holeta local market. The study samples were packed in polyethylene plastic bags, transported to Kulumsa Agricultural Research Center (KARC), and stored at room temperature (25°C) for conduction of moisture content and engineering properties of garlic.

Determination of the Physical Properties of Garlic Bulbs and Cloves

Moisture content of garlic

Fifteen kilograms of garlic cloves were randomly obtained from the bulk samples, cleaned manually, and removed of all foreign matter such as dust, dirt, stones, chaff, and damaged cloves.

The moisture content of garlic bulbs and cloves was determined by the convection method proposed by Madamba *et al.* (1994). Three samples of 15g each were weighed and placed in the oven. The sample was heated at 100 ± 0.5 °C until a constant weight was reached, then the sample was removed and cooled in a desiccator for weighing on an electronic balance. Moisture content was calculated according to the following formula and expressed as a percentage (Channabasamma, 2014).

$$M_{c db} = \frac{W_i - W_f}{W_f} \times 100 \quad (1)$$

Where $M_{c db}$ = moisture content dry base,
 W_i = initial weight of the sample,
 W_f = final weight of the sample.

Linear dimensions

100 garlic bulbs and cloves were randomly selected and their linear dimensions were measured to an accuracy of ± 0.01 mm using a digital caliper (Model CD6BSMitutoyo Corporation, Japan). For garlic bulbs, equatorial diameter (D_e), pole diameter (D_p), and thickness (T) were measured. For garlic cloves, the main dimensions of length (l), width (b), and thickness (t) were measured (Bahnasawy, 2007; Channabasamma, 2014).

Geometric mean diameter

The geometric mean diameter (D_g) of the garlic bulbs and cloves was calculated using equation 22 (Bahnasawy, 2007; Channabasamma, 2014):

$$D_g = (D_e D_p T)^{\frac{1}{3}} \quad (2)$$

Where;

D_g = geometric mean diameter, mm,
 D_e = equatorial diameter, mm,
 D_p = polar diameter, mm;
 T = thickness, mm.

Arithmetic mean diameter

The arithmetic means diameter (D_{am}) of the garlic bulbs and cloves was calculated using equation 23 (Bahnasawy, 2007; Channabasamma, 2014):

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

Where;

D_{am} = arithmetic mean diameter, mm.
 D_e = equatorial diameter, mm,
 D_p = polar diameter, mm;
 T = thickness, mm.

Shape index

The shape was calculated using equation 24 (Bahnasawy, 2007; Channabasamma, 2014):

$$\text{Shape index} = \frac{D_e}{\sqrt{D_p \cdot T}} \quad (4)$$

Where;

D_e = equatorial diameter, mm,
 D_p = polar diameter, mm,
 T = thickness, mm.

Sphericity

The sphericity (ϕ) of the cloves was calculated using equation 25 (Bahnasawy, 2007; Channabasamma, 2014):

$$\phi = \frac{D_g}{l} = \frac{(lb t)^{\frac{1}{3}}}{l} \quad (5)$$

Where;

D_g = geometric mean diameter, mm
 l = length, mm,
 b = width, mm,
 t = thickness, mm.

Surface Area

The surface area of the bulk sample was found by analogy with a sphere of the same geometric mean diameter, using the following relationship (Dress, 2011):

$$S = \phi \times D_g^2 \quad (6)$$

Where;

S = surface area in cm^2 ,
 D_g = geometric mean diameter in cm.

Bulk density

Samples of bulbs and garlic cloves were poured to the upper level into containers of known volume. The excess sample was removed to keep the top surface perfectly flat and even. Make sure the bulbs and garlic cloves were not broken in any way. The sample inside the vessel was then weighed using an electronic balance. Bulk density was the ratio of the mass of the sample to the volume of the container (Mohsenin, 1986). This procedure was repeated 5 times (Channabasamma, 2014).

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

Where;

ρ_b = bulk density, kg/m^3 ,
 M_s = Weight of sample in container, (kg),
 V_c = Volume of the container, (m^3).

One hundred garlic bulbs and cloves weight

100 garlic bulbs and 100 garlic cloves were randomly selected and weighed on an electronic scale (model PS200/2000/C/2 RADWAG, Poland) to an accuracy of ± 0.001 g and this procedure was repeated 5 times (Channabasamma, 2014).

Angle of repose

The dynamic angle of the repose of bulbs and cloves was measured by the emptying method. A metal vessel 125 mm long, 125 mm wide, and 200 mm high was used to determine the dynamic angle of repose of the bulb/cloves. A detachable front panel 200mm high and 125 mm wide was used to separate the material laterally. After filling and lining up the garlic sets in the container, I quickly pulled the front panel up and pushed it up so the garlic bulbs/garlic cloves poured out. Garlic bulbs/cloves slide out of the container through the open side, forming an inclined surface. After stabilizing the slope of the material, the angle of repose was calculated from the height and length of the garlic sample remaining in the box. This procedure was repeated three times with

different samples and average values were calculated (Channabasamma, 2014).

$$\theta = \tan^{-1} \frac{H}{L} \quad (8)$$

Where;

θ = angle of repose in degree,

H = height of the sample in mm,

L = length of the sample in mm.



Figure 1: Determination of an angle of repose of garlic bulbs/cloves

Data Analysis

All experiments were performed in triplicate. The collected data were analyzed by analysis of variance (ANOVA) using statistical software R (version 3.4.3, 2017). The results are presented using the mean value and standard deviation (mean \pm standard deviation).

RESULTS AND DISCUSSIONS

The design of garlic bulb processing unit operation is designed based on the physical properties of garlic bulbs and cloves, such as pole and equatorial diameter, length, width, thickness, average diameter, geometric mean diameter, sphericity, weight, bulk density, and angle of repose of garlic bulbs and cloves (Channabasamma, 2014). The engineering properties of garlic bulbs and cloves, namely the dimensions, and physical and mechanical properties of garlic bulbs and cloves, are discussed in the following sections.

Dimensional properties of garlic bulbs and cloves

Records of dimensional characteristics of the garlic bulb and clove samples such as equatorial diameter,

polar diameter, thickness, geometric mean diameter, and average diameter are presented in Table.3.1. Accordingly, the values were 45.89, 42.86, and 30.43 mm for the first three of the parameters, respectively. Similarly, the values for the remaining two parameters indicated in the list are 39.08 and 39.71 mm, respectively. Channabasamma (2014) reported garlic bulb size such as pole diameter, equatorial diameter, and thickness was 61.25, 43.21, and 36.00 mm, respectively, which is higher than the values obtained in this study. The garlic clove sizes such as width, length, thickness, geometric mean diameter, and mean diameter were 14.44, 31.02, 11.63, 17.15, and 20.07 mm, respectively. Other size records such as length, width, and thickness were shown as 27.30, 10.18, and 7.42 mm as reported by Channabasamma (2014), which are lower than the results obtained from the present finding. Dress (2011) reported the dimensions of garlic bulbs as 59.90 mm in length, 58.00 mm in width, and 45.20 mm in thickness, which is higher than the result obtained in this work, and for the garlic cloves, values were 26.4 mm in length, 11.9 mm in width, and 8.5 mm in thickness, which again is lower than the results obtained in this work.

Table 1: Dimensional properties of garlic bulbs and cloves at 66% m.c.d.b

Variables	D _e (mm)	D _p (mm)	T(mm)	D _g (mm)	D _{am} (mm)
Bulb	45.89 \pm 7.97	42.86 \pm 7.35	30.43 \pm 5.62	39.08 \pm 6.42	39.71 \pm 6.44
Cloves	14.44 \pm 3.06	31.02 \pm 4.21	11.63 \pm 3.31	17.15 \pm 2.89	20.07 \pm 6.48

Where; D_e = equatorial diameter, D_p = polar diameter, T = thickness, D_g = geometric mean diameter, D_{am} = arithmetic mean diameter; all values are means of triplicates \pm standard deviation

Bakhtiari and Ahmad (2015) also found the mean length, width, and thickness of garlic cloves were 32.0, 21.8, and 20.9 mm, respectively, which are higher than the results of the present work. However, values of dimensions of the hundred garlic cloves were comparable with the values of 1.92 to 2.91, 0.78 to 1.32, and 0.69 to 0.99 cm

of length, width, and thickness, respectively, of fifteen cloves, which were reported by Bahnasawy (2007). The spacing between the rollers was selected based on these sizes (Channabasamma, 2014).

The geometric average diameters of 100 bulbs and garlic cloves were 39.08 mm and 17.15 mm, respectively. These

values are lower than the 45.70 mm geometric mean diameter of garlic bulbs and higher than the 12.55 mm geometric mean diameter of garlic cloves reported by Channabasamma (2014) and Rathinakumari *et al.* (2015). Bakhtiari and Ahmad (2015) also estimated the geometric average diameter of garlic cloves to be 24.40 mm, which is higher than the current estimate. The geometric average diameters of the garlic bulbs and cloves determined in this work showed lower values than the geometric mean diameter of garlic bulbs which ranged from 48.92 to 59.31 mm and of the cloves, which ranged from 7.6 to 20.60 mm as reported by Dress (2011). However, the geometric mean diameter of values was comparable with those (2.53 to 4.93 cm) of fifteen Egyptian garlic varieties reported by Bahnasawy (2007).



Figure 2: Dimensional measurement for garlic bulbs and cloves

Physical characteristics of garlic bulbs and cloves

The surface area, sphericity, and shape index values for one hundred bulbs and cloves are shown in Table 2. The surface areas of bulbs and garlic cloves were 17.08 cm² and 4.06 cm² respectively. These values are less than 75.2 to 110.5 cm² (with a mean value of 91.4 cm²) and 53.31 to

The mean values of the arithmetic average diameters of the one hundred garlic bulbs and cloves were 39.71 mm and 20.07 mm, respectively. These values were lower than the corresponding values of bulbs, which ranged from 49.5 to 60.6 mm (with a mean value of 54.4 mm) as reported by Dress (2011). However, the arithmetic means diameter (20.07 mm) of the one hundred cloves was within the range of 9.4 to 22.30 mm (with the mean value of 15.6 mm) recorded by the same author. The arithmetic means diameter values recorded for the cloves in this work were less than the 24.90 mm for cloves reported by Bakhtiari and Ahmad (2015). On the other hand, these values of the garlic cloves were comparable with the 2.53 to 5.02 cm range reported for fifteen Egyptian garlic varieties (Bahnasawy, 2007).



Figure 3: Moisture content test of garlic

136.4 cm² of garlic bulbs reported by Dress (2011) and Bahnasawy (2007), respectively. However, the values for garlic cloves were in agreement with the values of 1.8 to 13.3 cm² reported by Dress (2011). The values for the cloves (17.08 cm²), were found to be close to the 17.18 to 20.29 cm² of those reported by Bakhtiari and Ahmad (2015).

Table 2: Physical properties of garlic bulbs and cloves at 66% m.c.d.b

Variables	Wt of 100 Pieces (g)	BD (kg/m ³)	AR(°)	SA(cm ²)	Φ	SI
Bulbs	2530 ± 77.13	596.7 ± 36.67	49.7 ± 2.06	17.08 ± 6.94	0.86 ± 0.03	1.34 ± 0.23
Cloves	239.4 ± 9.07	468.4 ± 20.94	37.56 ± 1.89	4.06 ± 1.17	0.57 ± 0.07	1.27 ± 0.12

Where; Wt = weight of 100 garlic bulb and clove, BD = bulk density, AR = angle of repose, SA = surface area, Φ = sphericity, SI = shape index; all values are means of triplicates ± standard deviation

The sphericity of garlic bulbs and cloves were 0.86 and 0.57, respectively. These values are comparable with the 0.9 and 0.53 of the garlic bulbs and cloves, respectively, reported by Dress (2011) and with the 0.559 of garlic cloves reported by Haciseferogullari (2005). These values were greater than 0.74 for garlic bulbs and 0.51 for the cloves, as reported by Channabasamma (2014) and Rathinakumari *et al.* (2015).

The shape index was 1.34 and 1.27 for bulbs and cloves, respectively. The bulb and clove shape index values were higher than 0.74 for garlic bulbs reported by Rathinakumari *et al.* (2015) and 0.45 for garlic cloves by Channabasamma (2014), but less than the 1.36 to 1.5 for

garlic bulbs reported by Bahnasawy (2007). Garlic bulbs are considered spherical because the garlic bulb shape index is <1.5 (Channabasamma, 2014). Therefore, the current result showed the shapes of both garlic bulbs and cloves of the studied Holeta variety are spherical. The shapes of garlic bulbs and cloves are very important in selecting the clearance between rollers.

Physical properties of garlic bulbs and cloves such as weight of one hundred pieces, moisture content, bulk density, and angle of repose are presented in Table 3.2. The weights of one hundred pieces were 2530 and 239.4 g for garlic bulbs and cloves, respectively. These values were greater than the 45.3 to 87.6 g (with the mean value

of 62.5 g) of garlic bulbs and 0.24 to 5.2 g (with the mean value of 1.49 g) of the cloves reported by Dress (2011) and less than the 260 to 392 g of the garlic cloves reported by Channabasamma (2014) and the 6783.0 to 8159.3g for one thousand pieces or 678.3 to 815.93 g for one hundred pieces of garlic cloves by Bakhtiari and Ahmad (2015). The weight of one hundred pieces determined in this work was comparable with the weight of a similar number of cloves reported by Channabasamma (2014), which ranged from 2270.7 to 4849g. These characteristics are used in the design of the machine hopper capacity. The moisture contents of garlic cloves in this work were 66% db. Kimura *et al.* (2017) and Channabasamma (2014) reported the moisture contents of garlic of 58.6% and 59.36%, respectively, which are lower than the present finding. However, Odebunmi *et al.* (2010) and Sajid *et al.* (2014) reported moisture content of 65 and 64.58%, respectively, which are relatively close to the result obtained in this work.

The bulk densities recorded in this study were 596.70 and 468.40 kg/m³ for garlic bulbs and cloves, respectively. These values were greater than the 453.50 kg/m³ and 424.94 kg/m³ reported for bulbs and cloves, respectively (Rathinakumari *et al.*, 2015). The values were also greater than the 453.5 and 424.94 kg/m³ reported by Channabasamma (2014) for garlic bulbs and cloves, respectively. The values were in agreement with the 476.3 to 567.4 kg/m³ reported by Bakhtiari and Ahmad (2015) for garlic cloves. The values were less than the 468.8 to 612.8, and 510.2 to 672 kg/m³ reported by Masoumi *et al.* (2006) for white and pink cloves of garlic, respectively.

The angle of repose of bulb and cloves of broken garlic were 49.7 and 37.56o, respectively. The results obtained in this work were greater than the values reported by Bahnasawy (2007) and Dress (2011), which ranged from 41.52 to 45.04o and 26 to 30.5o (with a mean value of 28.5o) for garlic bulbs, respectively. Dress (2011) also reported 39.5 to 41o (with a mean value of 38.7o) for garlic cloves which are more close to the current finding. However, the findings for bulbs and cloves were comparable to the 48.64 – 57.99° and 37 – 40°, respectively, reported by Channabasamma (2014). These results were used to determine the inclination of the feed hopper and the accommodation chute of the garlic bulb separator. The feed hopper and collection chute were fixed at an angle of 77.27 and 45° respectively, which was greater than the angle of repose of the bulb and clove of broken garlic. This made the cloves easier to pour.

CONCLUSIONS AND RECOMMENDATIONS

Garlic (*Allium sativum L.*) is the most widely used root vegetable after onions and is mainly produced as a seasoning for food and has medicinal value for various diseases in Ethiopia. This research work has concluded that the engineering properties of Holeta's local variety of garlic bulbs and cloves were determined to generate data that was used for designing the prototype machine. The dimensional properties of garlic bulbs, based on 100

pieces sample, were 45.89 mm equatorial diameter, 42.86 mm polar diameter, and thickness of 30.43 mm. Similarly, the dimensional properties of the cloves were 31.02 mm in length, 14.44 mm in width, and 11.63 mm in thickness. Other physical properties of garlic bulbs indicated average values of 17.08 cm² for surface area, 0.86 for sphericity, 2530 g, as the weight of hundred bulbs, moisture content of 66%, bulk density of 596.7 kg/m³, angle of repose of 49.700, and shape index of 1.34. Likewise, the cloves exhibited an average surface area of 4.06 cm², sphericity value of 0.57, 239.4 g weight of hundred clove pieces, 468.4 kg/m³ bulk density, 37.560 the angle of repose, and 1.27 shape index as physical and mechanical properties of garlic cloves. These physical and mechanical properties were used in designing machine parts. The studies of engineering properties of other garlic varieties should be considered in the future.

REFERENCES

- Addis, W., & Abebaw, A. (2017). Determination of heavy metal concentration in soils used for cultivation of *Allium sativum L.* (garlic) in East Gojjam Zone, Amhara Region, Ethiopia. *Cogent Chemistry*, 3(1), 1419422.
- Bahnasawy, A.H. (2007). Some physical and mechanical properties of garlic. *International Journal of Food Engineering*, 3(6).
- 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).
- Channabasamma, B.B. (2014). Development of a Motorized Garlic Bulb Breaker (Doctoral dissertation). <http://krishikosh.egranth.ac.in/handle/1/81244>.
- CSA (Central Statistical Agency). (2018). The federal democratic republic of Ethiopia central statistical agency agricultural sample survey 2017/18. Report on area and production of major crops. *Stat Bull* 586(1), Addis Ababa, Ethiopia, p 11–23
- Dress, A.M. (2011). Physical and mechanical properties of garlic relating rubbing and planting machines. *Misr Journal of Agricultural Engineering*, 28(3), 571-588.
- Hacıseferoğulları, H., Özcan, M., Demir, F. and Çalırsır, S. (2005). Some nutritional and technological properties of garlic (*Allium sativum L.*). *Journal of food engineering*, 68(4), 463-469.
- Kimura, S., Tung, Y.C., Pan, M.H., Su, N.W., Lai, Y.J. and 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.
- Madamba, P.S., Driscoll, R.H. and Buckle, K.A. (1994). Bulk density, porosity, and resistance to airflow of garlic slices. *Drying Technology*, 12(4), 937-954.
- Manjunatha, M., Samuel, D.V.K. and Jha, S.K. (2008). Some Engineering Properties of Garlic (*Allium sativum L.*). *Journal of Agricultural Engineering*, 45(2), 18-23.

- 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). *Physical Properties of Plant and Animal Material*. (revised) Gordon and Breach science publishers New York.
- Odebunmi, E.O., Oluwaniyi, O.O. and Bashiru, M.O. (2010). Comparative proximate analysis of some food condiments. *Journal of Applied Sciences Research*, 6(3), 272-274.
- Rathinakumari, A.C., Channabasamma, B.B. and 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.
- Sajid, M., Butt, M.S., Shehzad, A. and Tanweer, S. (2014). Chemical and mineral analysis of garlic: a golden herb. *Pakistan Journal of Food Sciences*, 24(1), 108-110.
- Seifu, W., Yemane, T., Bedada, S., Alemu, T. and Boshoftu, E. (2017). Evaluation of Different Mulching Practices on Garlic (*Allium sativum* L.) Growth Parameters under Irrigated Condition in Fiche, North Shoa Ethiopia. *Evaluation*, 7(9).
- Selvaraj, T., Tadele, S. and Amin, M. 2014. White rot (*Sclerotium cepivorum* Berk)-an aggressive pest of onion and garlic in Ethiopia: An overview. *Journal of Agricultural Biotechnology and Sustainable Development*, 6(1), 6-15.