Asian Journal of
Biological Sciences

OPEN ACCESS

Physical Properties of Garlic Bulbs and Cloves: Effect of Variety and Location

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ABSTRACT

Background and Objective: Garlic is one of the most significant bulb vegetables and is widely used as a spice and flavoring agent in cuisines worldwide, including Ethiopia. It is a fundamental ingredient in various dishes across numerous countries. The objective of this study was to determine the effects of garlic variety and location on the physical properties of garlic bulbs and cloves. **Materials and Methods:** The 4 released and seven promising garlic varieties were grown using a Randomized Complete Block Design (RCBD) at Chefe Donsa and Debre Zeit. The physical properties of garlic bulbs and cloves, including length, width, thickness and several diameters, as well as surface area, shape index, bulk density, aspect ratio and sphericity were determined. These properties were measured to evaluate the effects of variety and location. Statistical analysis was conducted with SAS software, version 9.4, to identify significant differences. **Results:** The results showed that garlic bulb size varied with lengths between 36.32 to 40.67 mm, widths from 30.50 to 34.07 mm and thicknesses from 25.24 to 29.21 mm. Clove dimensions ranged from 19.11 to 23.28 mm in length, 7.6 to 11.17 mm in width and 5.55 to 8.13 mm in thickness. Location significantly affected parameters like width, arithmetic mean diameter and bulk density for bulbs and all measured parameters for cloves. **Conclusion:** Therefore, this study established a better understanding of the effects of variety and growing location on the physical properties of garlic bulbs and cloves of eleven varieties. The variation in these properties was considered during the design of the various processing equipment used for garlic.

KEYWORDS

Physical properties, bulb, clove, grown location, ethiopian garlic varieties

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INTRODUCTION

Garlic (*Allium sativum* L.) is a prominent vegetable crop within the *Allium* genus, valued globally for both its production and economic significance. As a member of the Alliaceae family, it originates from Central Asia[1] and is extensively grown worldwide, including in Ethiopia. Globally, Ethiopia stands at 15th place, while China ranks first, contributing over 78% of the total world garlic production, amounting to 22.27 million ton[2]. Altogether, garlic is cultivated on 1,199,929 ha, yielding approximately 17,674,893 ton[1]. In Ethiopia, garlic covers 15,381 ha, producing around 138,664.3 ton[3]. Garlic is valued for its flavour and has extensive commercial importance because of its wide medicinal value and application in food and

ISSN: xxxx-xxxx (Online)
ISSN: 1996-3351 (Print)
https://doi.org/10.3923/ajbs.2024.858.866

Received: 10 Aug. 2024
Accepted: 23 Sep. 2024
Published: 31 Dec. 2024

pharmaceutical preparations[4]. Organosulfur compounds, which are thought to be the basis of garlic's flavour, aroma and potential health benefits, are abundant in garlic[5]. There is no doubt that garlic is one of the best natural foods that contains functional and nutraceutical components that contribute greatly to human health. Because of their health-promoting perspectives, accessibility and low price, functional and nutraceutical foods have become very popular worldwide[6]. Garlic is widely used as a spice in both fresh and dehydrated forms within the food industry. It is processed into various dehydrated products, including flakes, slices and powder. Primarily, garlic is consumed as a seasoning in a variety of prepared foods, such as mayonnaise, tomato sauce, salad dressings, meat sausages and pickled products[7].

Knowledge of physical properties such as length, width, thickness, arithmetic and geometric mean diameter, volume, surface area and weight of the garlic varieties are necessary to design sorting and grading machines, for quantification of bruises, abrasions and damage in handling process[8]. Therefore, knowledge of the basic physical properties of garlic is necessary for the development and fabrication of equipment and machinery[4]. Processing techniques for garlic, including bulb breaking, peeling, dehydration and grinding, are largely determined by its physical properties. Peeling, in particular, is a critical step that must be done before any subsequent processing[9,10].

Research has been conducted on various aspects of garlic properties and their implications. Tullo[11], investigated the engineering properties of the Holeta Local Variety of garlic grown in Ethiopia. Galgaye and Deresa[12], examined the effect of different garlic genotypes on phenotype, growth, yield-related attributes and nutritional quality in the Bule Hora agro-ecology. Additionally, Kumbar *et al.*[13] explored the physical and mechanical properties of the G-282 garlic clove variety to aid in the development of a garlic clove planter. Furthermore, Zilpilwar *et al.*[14] determined the physical and mechanical properties of garlic bulbs and cloves to design a garlic bulb breaker. However, there have been no studies reported on how the variety of garlic and its growth location affect the physical properties of eleven garlic bulbs and their cloves. Therefore, the main purpose of this study was to evaluate the potential status of released and promising garlic varieties in terms of the physical properties of their bulbs and cloves, based on different varieties and growing locations.

MATERIALS AND METHODS

Sample preparation: This research was carried out between May, 2023 and June, 2024 under the Food Science and Nutrition Research program at the Ethiopian Institute of Agricultural Research. Eleven released and promising garlic varieties, as shown in Table 1, were collected from the Cool Season Vegetable and Fruit Program at the Debre Zeit Agricultural Research Centre. All garlic varieties were planted in the field in three blocks with an RCBD design in replication. These garlic varieties were grown under different agroecological conditions and locations with varying soil characteristics, as presented in Table 2, during

Table 1: Released and promising garlic varieties/genotypes

Variety name	Year of released	Breeder
Chefe	2015	Debre Zeit Agricultural Research Centre/EAIR
G.009/06	Promising	
G.020/03	Promising	
G.025/04	Promising	
G.030/04	Promising	
G.041/04	Promising	
G.054/03	Promising	
G.084/06	Promising	
Holeta	2015	
Kuriftu	2010	
Tsedey	1999	

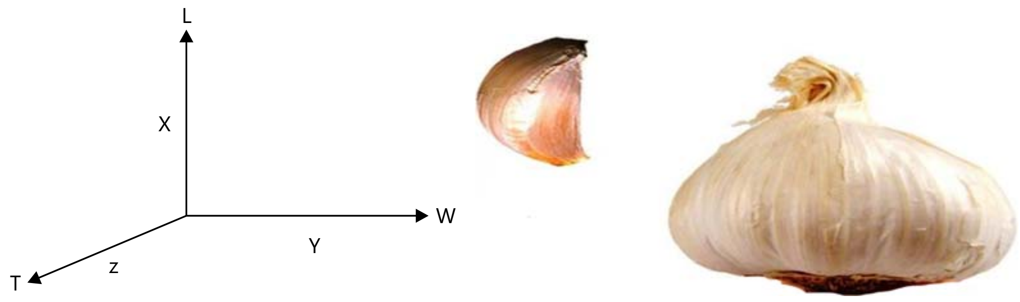

Fig. 1: Three principal dimensions of garlic bulbs and cloves[19]

Table 2: Soil characteristics of debre zeit and chefe donsa grown locations[15]

Tested soil parameter's	Cultivation locations Debre Zeit	Chefe donsa
pH (1:2.5 H_2O)	7.31	8.27
Total nitrogen (%)	0.08	0.07
Available P (Olsen Method)	19.52	9.91
Organic matter (%)	1.14	1.26
CEC (meq/100g)	29.67	62.52
Exchangeable K (cmol(+)/kg)	0.73	1.06
Texture group	Heavy clay	Clay

CEC: Cation exchange capacity

the same season. The samples were cleaned by removing foreign matter such as dust, debris and defective bulbs and sorted to remove broken and spoilt cloves. Care was taken to ensure that only normal garlic bulbs and cloves were used.

Determination of physical properties

Linear dimensions: The size (length, width and thickness) of garlic is crucial for designing peeling machines, as it influences the cylinder-concave clearance[9]. There are two types of garlic bulb diameter: Polar and equatorial diameter. The polar diameter of a garlic bulb is the distance between its crown and root attachment point also known as length. Equatorial diameter refers to the width of garlic perpendicular to the polar diameter. As shown in Fig. 1, the three principal dimensions of garlic bulbs were determined by randomly selecting and measuring 15 bulbs and cloves from each variety using a caliper with an accuracy of 0.01 mm. To calculate the geometric mean diameter (Dg), arithmetic mean diameter (Da), surface area (SA), shape index (SI), aspect ratio (Ra) and sphericity (φ) of the bulbs and cloves, the following relationships from methods[16-18] were used:

$$\text{Arithmetic mean diameter } (D_a, \text{mm}) = \frac{(L+W+T)}{3} \quad (1)$$

$$\text{Geometric mean diameter } (D_g, \text{mm}) = (L\times W\times T)^{1/3} \quad (2)$$

$$\text{Surface area } (S_A, \text{mm}^2) = \frac{\pi\,(L\times W)}{4} \quad (3)$$

Shape index: Shape index is used to evaluate garlic bulbs' shape and their cloves. It was calculated according to the following equation[7]:

$$\text{Shape index} = \frac{W}{\sqrt{L\times W}} \quad (4)$$

The garlic bulb and clove are considered an oval if the shape index>1.5, on the other hand, it is considered spherical if the shape index <1.5.

Sphericity: The sphericity expresses the shape character of the bulb and clove relative to that of sphere of same volume. Sphericity was calculated using the standard formula assuming that the volume of the solid is equal to the volume of a triaxial ellipsoid with intercepts L, W and T and that of the diameter of the circumscribed sphere is the longest intercept 'L' of the ellipsoid. The sphericity (ϕ) of the bulb and cloves was calculated using the formula given by Kaur *et al.*[4] and Bakhtiari[20]:

$$\text{Sphericity } (\phi) = \frac{Dg}{L} = \frac{(LWT)^{1/3}}{L} \quad (5)$$

where, Dg is geometric mean diameter.

Bulk density: Garlic bulbs and cloves were poured into a 500 mL graduated cylinder from a height of about 150 mm, until the cylinder was full. This allowed for the measurement of bulk density. A wooden plank was used to level off any excess material before the contents of the cylinder were weighed. The garlic bulb's bulk density (ρb) was calculated by dividing the mass (M) by the cylinder's volume (Vb) of 500 mL, with the result expressed in grams per milliliter[4]:

$$\text{Bulk density (g / mL)} = \frac{M}{Vb} \quad (6)$$

Statistical analysis: The SAS software (Version 9.4) was used to perform statistical analysis of variance on the data for each parameter under a randomized complete block design or the means were further compared using the Least Significant Difference (LSD) test to determine the degree of significance. At $p\leq 0.05$, it was determined that the differences were significant.

RESULTS AND DISCUSSION

The composition and physical property of vegetables is significantly influenced by genetics and environmental factors such as rainfall, temperature, soil type and their interactions[21,22]. To investigate variations in physical properties, data from 11 garlic cultivars were analyzed across different locations. Table 3 compares the physical characteristics of garlic bulbs of the 11 varieties grown in two distinct environments. The effects of variety and environment on the physical properties of garlic bulbs and cloves are detailed in Table 3-4, respectively.

Table 3 shows the effect of variety on the dimensional properties of garlic bulb varieties. The dimensional properties difference of the garlic bulb varieties was significant ($p<.05$) among the varieties, indicating that these would require some variation in the processing equipment design. The average length of the garlic bulb ranged from 36.32 to 40.67 mm, while the corresponding width ranged from 30.50 to 34.07 mm and the thickness from 25.29 to 29.21 mm. Comparisons in terms of length and width indicated that the Tsedey variety had the longest bulbs, with Chefe having the shortest, illustrating genetic influence on bulb length. The Holeta variety exhibited the widest and thickest bulbs, in contrast to Kuriftu with the narrowest width and Chefe with the thinnest bulbs. This result exceeded those reported by Hacıseferoğulları *et al.*[8] which were 27.24, 14.46 and 9.25 mm for garlic bulbs. On the other hand, as reported by Galgaye and Deresa[12], the values for the length and width of Holeta, Chafe, Kuriftu and Tsedey grown in the Bule Hora agro-ecology are higher than those observed in this study.

The arithmetic and geometric mean diameters are crucial for designing equipment related to vegetables, highlighting the importance of accurate geometric measurements in improving processes and enhancing equipment efficiency[23]. The arithmetic and geometric mean diameters of garlic bulb varieties ranged from 30.85 to 33.81 and 30.44 to 33.44 mm, respectively. These values were lower than the length and width

Table 3: Physical properties of the 11 garlic varieties that grown across two locations at same season

	Physical properties of bulbs									
Variety	L	W	T	D_a	D_g	S_A	SI	BD	Ra	Φ
Chefe	36.32^{c}	31.00^{dc}	25.24^{c}	30.85^{c}	30.44^{c}	896.83^{c}	0.92^{ba}	0.36^{ed}	0.85^{ba}	0.84^{ebdac}
G.009/06	37.35^{bc}	32.78^{bac}	27.87^{ba}	32.67^{bac}	32.41^{bac}	965.22^{bac}	0.94^{a}	0.37^{dc}	0.88^{a}	0.87^{a}
G.020/03	38.89^{bac}	33.88^{ba}	27.24^{bac}	33.33^{ba}	32.96^{ba}	1036.71^{a}	0.94^{a}	0.36^{ed}	0.88^{a}	0.85^{bdac}
G.025/04	38.76^{bac}	32.86^{bac}	28.65^{a}	33.43^{ba}	33.14^{ba}	1000.83^{bac}	0.92^{ba}	0.40^{a}	0.85^{ba}	0.86^{ba}
G.030/04	38.65^{bac}	33.51^{ba}	27.85^{ba}	33.34^{ba}	33.00^{ba}	1023.51^{ba}	0.93^{a}	0.39^{bac}	0.86^{a}	0.85^{bac}
G.041/04	37.68^{bc}	32.06^{bdac}	27.01^{bac}	32.25^{bac}	31.94^{bac}	948.16^{bac}	0.92^{ba}	0.38^{bc}	0.85^{ba}	0.85^{bdac}
G.054/03	39.49^{ba}	32.04^{bdac}	27.22^{bac}	32.92^{bac}	32.53^{ba}	998.04^{bac}	0.90^{bc}	0.28^{g}	0.81^{bdc}	0.83^{edc}
G.084/06	38.08^{bac}	31.96^{bdc}	26.71^{bac}	32.25^{bac}	31.88^{bac}	954.92^{bac}	0.92^{ba}	0.40^{ba}	0.84^{bac}	0.84^{ebdc}
Holeta	38.82^{bac}	34.07^{a}	29.21^{a}	34.03^{a}	33.76^{a}	1039.77^{a}	0.94^{a}	0.37^{ed}	0.88^{a}	0.87^{a}
Kuriftu	37.97^{bc}	30.50^{d}	26.06^{bc}	31.51^{bc}	31.12^{bc}	911.64^{bc}	0.90^{c}	0.35^{ef}	0.80^{dc}	0.82^{e}
Tseday	40.67^{a}	32.27^{bdac}	28.52^{ba}	33.81^{a}	33.44^{a}	1032.96^{a}	0.89^{c}	0.34^{f}	0.79^{d}	0.82^{ed}
CV	5.79	5.47	7.96	5.41	5.49	10.51	2.18	3.48	4.45	2.92
LSD	2.59	2.07	2.54	2.07	2.08	120.35	0.02	0.01	0.04	0.03
Location										
Chefe Donsa	38.88^{a}	33.69^{a}	27.06^{a}	33.21^{a}	32.82^{a}	1030.87^{a}	0.93^{a}	0.38^{a}	0.87^{a}	0.84^{a}
Debre Zeit	37.97^{a}	31.20^{b}	27.77^{a}	32.31^{b}	32.02^{a}	934.32^{b}	0.91^{b}	0.35^{b}	0.82^{b}	0.84^{a}
CV	5.79	5.47	7.96	5.41	5.49	10.51	2.18	3.48	4.45	2.92
LSD	1.11	0.88	1.08	0.88	0.89	51.32	0.01	0.01	0.02	0.01

Values in the mean and in a column that shares the same superscript are not significant at ($p \leq 0.05$). L: length, W: Width, T: Thickness, Da: Arithmetic mean diameter, Dg: Geometric mean diameter, SA: Surface area mm^2, SI: Shape index, BD: Bulk density g/cm^3, Ra: Aspect ratio and Φ: Sphericity

Table 4: Physical properties of eleven garlic clove varieties grown in two locations

	Physical properties of clove								
Variety	L	W	T	D_a	D_g	S_A	SI	Ra	Φ
Chefe	20.53^{fe}	9.10^{ed}	6.50^{cb}	12.04^{ef}	10.60^{gfe}	355.85^{fge}	0.80^{ba}	0.45^{bac}	0.52^{bc}
G.009/06	22.05^{bdc}	9.83^{bcd}	6.87^{cb}	12.91^{bdc}	11.38^{dc}	409.89^{dc}	0.80^{ba}	0.45^{bac}	0.52^{bc}
G.020/03	21.0^{fde}	9.12^{ecd}	6.67^{cb}	12.28^{ed}	10.79^{dfe}	374.11^{dfe}	0.77^{bac}	0.43^{bdc}	0.51^{c}
G.025/04	21.52^{dec}	9.82^{bcd}	6.50^{cb}	12.61^{ecd}	11.04^{de}	385.60^{dfce}	0.84^{a}	0.46^{bac}	0.52^{bc}
G.030/04	22.18^{bdac}	8.98^{ed}	5.55^{d}	12.24^{ed}	10.27^{gf}	333.06^{hfg}	0.82^{ba}	0.42^{dc}	0.47^{d}
G.041/04	22.72^{ba}	10.12^{bc}	8.05^{a}	13.63^{ba}	12.26^{ba}	476.44^{ba}	0.75^{bc}	0.45^{bac}	0.54^{bac}
G.054/03	19.11^{h}	8.60^{ef}	6.20^{cd}	11.30^{gf}	10.03^{gh}	319.18^{hg}	0.79^{bac}	0.45^{bac}	0.52^{bc}
G.084/06	22.55^{bac}	10.17^{ba}	7.22^{b}	13.31^{bc}	11.78^{bc}	436.55^{bc}	0.80^{ba}	0.46^{bac}	0.53^{bc}
Holeta	20.00^{fhg}	7.60^{f}	5.68^{d}	11.09^{g}	9.47^{h}	282.88^{h}	0.71^{c}	0.39^{d}	0.48^{d}
Kuriftu	23.28^{a}	11.17^{a}	8.13^{a}	14.19^{a}	12.81^{a}	517.36^{a}	0.81^{ba}	0.48^{ba}	0.55^{ba}
Tseday	19.65^{hg}	9.72^{bcd}	7.22^{b}	12.19^{ed}	11.12^{dce}	388.40^{dce}	0.82^{ba}	0.50^{a}	0.57^{a}
CV	4.96	9.16	12.13	5.36	6.83	13.84	8.73	9.70	6.16
LSD	1.23	1.01	0.96	0.78	0.88	62.63	0.08	0.05	0.04
Location									
Chefe Donsa	22.40^{a}	8.89^{b}	6.33^{b}	12.54^{a}	10.75^{b}	369.92^{b}	0.75^{b}	0.40^{b}	0.48^{b}
Debre Zeit	20.26^{b}	10.06^{a}	7.23^{a}	12.51^{a}	11.35^{a}	408.14^{a}	0.84^{a}	0.50^{a}	0.56^{a}
CV	4.96	9.16	12.13	5.36	6.83	13.84	8.73	9.70	6.16
LSD	0.48	0.43	0.33	0.33	0.37	26.7	0.03	0.02	0.02

Values in the mean and in a column that shares the same superscript are not significant at ($p \leq 0.05$). L: length, W: Width, T: Thickness, Da: Arithmetic mean diameter, Dg: Geometric mean diameter, SA: Surface area mm^2, SI: Shape index, Ra: Aspect ratio and Φ: Ssphericity

and higher than the thickness. Tseday was reported to be the highest whereas Chefe variety was the lowest in arithmetic and geometric mean diameters, with no significant difference between other varieties for both diameters. The values of this study were in agreement with those reported by Bahnasawy[7], where the geometric mean diameters of garlic bulbs ranged from 2.53 to 4.93 cm and the arithmetic mean diameters ranged from 2.53 to 5.02 cm, depending on the bulb size categories.

The results showed that the surface area, sphericity, aspect ratio and shape index of the garlic bulb varieties ranged from 896.83 to 1039.77 cm^2, 0.82 to 0.87, 0.79 to 0.88 and 0.89 to 0.94, respectively. Holeta had the highest surface area, indicating its superior growth potential, while Chefe had the smallest.

The highest shape index (0.94) was observed in G.009/06, G.020/03 and Holeta, indicating more spherical bulbs, whereas Tsedey had the lowest shape index (0.89). This value is lower than the range reported by Bahnasawy[7], which was 1.36 to 1.5 for bulbs. The shape index is crucial in the design of sorting and grading machines and also in the use of peeling machines.

Bulk density of garlic bulbs varied from 0.28 to 0.40 g/cm^3, being highest in G.025/04 and G.020/03, suggesting superior storage properties, while the lowest was seen in G.054/03. This figure closely aligned with the 478.75 kg/m^3 noted by Hacıseferoğulları *et al*.[8] for Turkish garlic bulbs, yet is below the 892 to 1007 kg/m^3 range cited by Bahnasawy,[7]. The aspect ratio (Ra) and sphericity (Φ) among garlic bulb variety and locations provide intriguing insights into bulb shapes. G.009/06, G.020/03 and Holeta exhibit the highest sphericity values, all at 0.87, indicating a more spherical shape. On the other hand, Kuriftu and Tseday have the lowest sphericity values, with Kuriftu at 0.80 and Tseday at 0.79, suggesting a less spherical shape. In terms of aspect ratio (Ra), G.009/06, G.020/03 and Holeta also stand out with the highest values at 0.88, implying a relatively elongated shape compared to others. On the other hand, G.054/03 shows the lowest aspect ratio value at 0.81, indicating a more spherical shape. When comparing locations, bulbs from Chefe Donsa generally have higher sphericity values than those from Dabre zeit. However, both locations exhibit similar aspect ratio values. These results highlight the significant difference in garlic bulb shapes, which is essential for breeding programs, for designing different processing equipment and for market preferences. In conclusion, genotypes such as Holota and G.025/04 consistently displayed superior physical characteristics, highlighting the importance of genotype selection in breeding programs and cultivation methods to enhance garlic production based on specific physical properties.

Effect of location on physical properties of garlic bulb variety: The physical properties of the garlic cultivars were evaluated across two growing locations, Chefe Donsa and Debre Zeit, revealing significant differences attributable to varying environmental conditions and soil types (Table 3). Garlic bulbs grown in Chefe Donsa exhibited a greater average length (38.88 mm) than those grown in Debre Zeit (37.97 mm), indicating more favorable growth conditions in Chefe Donsa for bulb elongation. The width of the bulbs was also significantly greater in Chefe Donsa (33.69 mm) than in Debre Zeit (31.20 cm), underscoring the critical role of location in determining bulb width. Although the thickness of the bulbs from Debre Zeit was slightly higher (27.77 cm) than that from Chefe Donsa (27.06 mm), the difference was not statistically significant, suggesting that thickness is less influenced by location. Both arithmetic and geometric mean diameters were higher in Chefe (33.21 and 32.82 mm, respectively) compared to Debre Zeit (32.31 and 32.02 mm), with significant differences. The surface area of bulbs was notably larger in Chefe Donsa (1030.87 cm^2) than in Debre Zeit (934.32 cm^2), highlighting Chefe Donsa's superior environmental and soil conditions for bulb growth. The shape index was slightly higher in Chefe variety (0.93) than in Debre Zeit (0.91), indicating the presence of more spherical bulbs in Chefe Donsa. Bulb density was significantly higher in Chefe variety (0.87 g/cm^3) compared to Debre Zeit (0.82 g/cm^3), suggesting denser bulbs in Chefe Donsa, potentially leading to better quality and storability. The aspect ratio was higher in Chefe Donsa (0.38) compared to Debre Zeit (0.35), indicating that the bulbs in Chefe Donsa are sturdier. There was no significant difference in sphericity values between the two locations, suggesting that location did not significantly influence this particular property. Overall, Chefe Donsa demonstrated more favourable conditions for cultivating garlic with superior physical properties. The physical properties of garlic bulbs and cloves, such as diameter, thickness, surface area, weight, size, color and yield, are significantly influenced by their cultivation location[24,25]. These findings emphasize the need to take into account the cultivation location when evaluating the physical properties of garlic, as environmental conditions play a key role in determining these properties.

Effect of variety and location on the physical properties of garlic cloves: The physical properties of garlic cloves are important for designing effective processing equipment. These properties include such as length, width, thickness, geometric mean diameter, sphericity, bulk density, true density, porosity, coefficient of friction and angle of repose[4,11] must be considered. Understanding these properties is essential for creating machinery that efficiently stores, transports, peels and cuts garlic cloves.

Table 4 shows the effect of variety and grown location on the physical properties of improved garlic clove of eleven varieties, grown in Chefe Donsa and Debre Ziet during the 2021/2022 main rainy season, which showed significant variation across nearly all measured factors. Significant statistical differences were found in all physical properties among the varieties across both locations, highlighting the genetic and location influence on these variations. The study observed the physical properties of garlic cloves from eleven different varieties and found significant differences among the varieties for most measured properties ($p<0.05$). Clove length ranged from 19.11 (G.025/04) to 23.28 mm (Kuriftu), with the Kuriftu variety having the longest cloves. Clove width varied from 7.60 (Holeta) to 11.17 mm (Kuriftu), with the Kuriftu variety again having the widest cloves. Thickness ranged from 5.55 (G.030/04) to 8.13 mm (Kurftu), with Kurftu being the thickest. The results were in agreement with the values of length, width and thickness 27.8, 12.73 and 9.45 mm respectively, as reported by Kumbar *et al.*[13] for G-282 variety and almost in agreement with the values 23.88, 9.42 and 7.33 mm which were reported for unpeeled garlic clove by Kaur *et al.*[4]. Zilpilwar *et al.*[14] found that Sidth-40 cloves measured around 27.3 mm in length, 10.18 mm in width and 7.42 mm in thickness. In contrast, Baladi cloves were roughly 26.27 mm long, 11.95 mm wide and 10.24 mm thick, highlighting a considerable size difference between the two varieties, greater than observed in this study.

The arithmetic and geometric mean diameters of vegetables play a crucial role in designing agricultural processing equipment by providing essential physical parameters for efficient equipment design and machine development and also enhancing the efficiency and effectiveness of agricultural processing operations[26,27]. The arithmetic and geometric mean diameter of garlic clove ranged from 11.09 (Holota) to 14.19 mm (Kuriftu) and 9.47 (Holeta) to 12.81 mm (Kurftu), respectively, being this value lower than the length and higher than width and thickness. On the other hand, Kuriftu leading in both diameters.

The values of this study were lower than that was reported by Kumbar *et al.*[13]. The surface area of garlic cloves varied between 282.88 to 517.36 mm^2 which means Holeta has the smallest area where whereas Kuriftu has the largest. The surface area of the clove has been reported to be 702.71 mm^2[18], which is lower than the range of this study and higher than that reported by Zilpilwar *et al.*[14] which is 253.60 mm^2.

The results showed that the sphericity, aspect ratio and shape index of the garlic clove variety ranged between 0.47 (G.030/04) and 0.57 (Tseday), 0.39 (Holeta) and 0.50 (Tseday) and 0.71 (Holeta) and 0.84 (G.025/04), respectively. Sphericity, aspect ratio and shape index surface area of garlic clove variety of G-282 have been reported to vary from 0.43 to 0.67, 0.44 to 0.54[18] and 1.36 to 1.50 for clove[7], respectively. The value of shape index of clove showed that it is spherical because the shape index is less than 1.5.

Location also influenced the physical properties: cloves from Chefe were longer (22.40 mm) compared to Debre zeit (20.26 mm), while width (10.06 mm), thickness (7.23 mm), geometric mean diameter (11.35 mm), surface area (408.14 mm^2), sphericity index (0.84), aspect ratio (0.50) and shape factor (0.56) were all higher in cloves from Debre zeit. These findings indicate that both variety and growing location significantly impact garlic clove physical properties, with the Kuriftu variety, Debre zeit location consistently showing superior physical attributes. The results that were reported by Boussaa *et al.*[28] provided a better understanding of the effect of environmental conditions on physical properties of pomegranate fruits to obtain good appearance and nutritional quality. The dimensions, bulk density and crushing load of garlic cloves can vary depending on the bulb size category and the location where they are grown[7,29]. Specifically, the physical properties of garlic cloves including length, width, thickness, surface area and bulk density are influenced by their growing location[30]. These findings highlighted the significance of considering the environmental conditions of the cultivation area to enhance the quality of garlic bulbs and cloves.

CONCLUSION

Garlic is one of the most significant bulb vegetables, widely used as a spice and flavoring agent in cuisines worldwide, including Ethiopia. It is a fundamental ingredient in a variety of dishes across numerous countries. The variety and growing location of garlic strongly affect the physical properties of the bulb and clove, which are taken into consideration when designing various garlic processing equipment. The result presented in this study is crucial for garlic breeding programs in Ethiopia and other countries using Ethiopian genetic resources, as well as for local and international garlic-based food processors. It guides the selection of garlic varieties and the design of effective and efficient agricultural processing equipment for products like garlic paste, flakes and powder. By understanding the characteristics of different garlic varieties, stakeholders can improve the quality and marketability of garlic products, benefiting both producers and consumers and contributing to the industry's growth and sustainability.

SIGNIFICANCE STATEMENT

Garlic, a popular ingredient in both global and Ethiopian cuisine, has different physical properties depending on the variety and location where it is grown. Using a randomized complete block design, this study evaluated eleven garlic varieties grown in Chefe Donsa and Debre Zeit. The findings revealed significant variations in bulb and clove dimensions between locations, including width, arithmetic mean diameter and other parameters. While some properties were relatively unaffected by location, others, such as bulb width and bulk density, varied significantly. Understanding these variations is crucial for optimizing garlic processing equipment and tailoring production methods to enhance product quality and consistency.

ACKNOWLEDGMENT

The authors extend their gratitude to the Ethiopian Institute of Agricultural Research (EIAR) for their invaluable support and provision of facilities essential for the successful completion of this research

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