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Quality assessment of promising garlic (*Allium sativum* L.) Varieties based on principal component analysis

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Abstract

Physicochemical properties, pungency, anti-nutritional factors, cutting strength, and colour attributes of seven promising garlic varieties were assessed for their potential application. The garlic varieties were found to be slightly acidic (pH 6.08 - 6.77), and contained varying amounts of crude protein, carbohydrate, crude fat, ash, crude fibre, acidity, and total soluble solids (TSS). The pungency factor as pyruvic acid was found to be in the range of 34.84 - 86.69 µmol/mL, whereas anti-nutritional factors such as saponin (6.63 - 13.98 g), phytic acid (0.03 - 0.6 g), and tannin (0.18 - 0.39 gCE) per 100 g on a fresh weight basis were present. The Bhima purple (BP) variety with a purple tinge showed higher saponin content than the other varieties with a whitish tinge. The cutting strength of garlic cloves varied between 17.20 and 104.61 N. Physical and gravimetric properties were estimated and found to be variety-dependent ($p \leq 0.05$). Colour attributes like L* (lightness), a* (redness), b* (yellowness), chroma, hue, and browning index were significantly different ($p \leq 0.05$) for all the garlic varieties. The minimum hue value, and maximum a* and b* values, browning index (BI), and chroma were found in the BP variety. Principal component analysis as a significant multivariate analysis tool was applied to assess the existence of correlation among the estimated parameters. It was found to be 75.41% of the total variance when considering the first three principals. Haryana garlic-17 (HG-17) variety showed significant quality as it yielded positive correlation with the maximum number of quality attributes.

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Introduction

Garlic (*Allium sativum* L.), a small bulbous plant cultivated underground, belongs to the family Alliaceae or Liliaceae. It is occasionally called a "stink rose" due to its odoriferous character. Central Asia is supposed to be the native land of garlic, which later spreads to Mediterranean regions (Hosein *et al.*, 2019). India is the second-largest garlic-producing country in the world, after China, with a contribution of 10.4% (FAO, 2021). In India, garlic is mostly used as wet seasoning and as the source of important nutraceuticals used to cure various ailments (Prasad *et al.*, 2002). Garlic has a flavouring property; so, it is used in the preparation of traditional products such as stews, mayonnaises, sausages, ketchups, and salads. Medicinally, it is used to reduce the arterial pressure, cholesterol, and triglyceride levels in the blood; to control platelet aggregation; to inhibit cancer cells; and as an antimicrobial agent (Pardo *et al.*, 2007).

Garlic does not produce seeds; hence, it is vegetatively cultivated using garlic cloves as a planting material. The quality and quantity of garlic yield are affected by the planting parameters, *i.e.*, clove quality, growth rate, and planting method. In India, the improvement of garlic seed production is carried out through breeding programs (clonal selection and mutagenesis) or biotechnological approaches (soma clonal variation) to fulfil the local farmer's requirements (Lawande *et al.*, 2009). The lack of basic information on the physicochemical, mechanical, colour, and anti-nutritional properties of the garlic varieties is a problem to be identified for the development of new processing equipment and

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control strategies for storage. The image analysis technique has been used to measure the dimensions and projected area. Further, mass, volume, density, and porosity of white and pink garlic cloves have been explored (Masoumi *et al.*, 2006). Dimensions, shape index, surface area, volume, density, frictional angle, crushing load, and coefficient of static friction have also been determined for the Egyptian Baladi garlic variety (Bahnasawy, 2007). Weight loss during storage of garlic bulbs at different temperatures and the use of packaging materials have also been studied (Ngo *et al.*, 2021). The cutting strength of solar-dried garlic cloves was found to be the highest (56.41 N) as compared to other dried methods and raw garlic cloves (Patel *et al.*, 2020).

The health benefits of garlic may be due to the presence of volatile and non-volatile components. Volatile components are involved in imparting flavour, whereas non-volatile components such as proteins, minerals, antioxidants, and other phytochemicals are well known for their medicinal and therapeutic properties (Rekowska and Skupień, 2009). Whole garlic bulbs contain moisture content (62 - 68%), carbohydrate (26 - 30%), crude protein (2 - 9.2%), crude fat (0.34%), ash (2.34%), and crude fibre (1.5 - 2.17%) (Rahman, 2003; Hacıseferoğulları *et al.*, 2005; Brewster, 2008). The quality and chemical differences in garlic may be associated with the peel of the garlic. Among the six genotypes of garlic studied, significant differences in total fractioned oil content were found, with a maximum quantity in purple genotypes (Gadel-Hak *et al.*, 2011). The acidity (0.172%) and pH (6.05) of garlic have been estimated elsewhere (Hacıseferoğulları *et al.*, 2005).

Garlic's pungency and flavour can vary depending on the garlic varieties and climatic conditions. A boost in temperature before harvesting may increase the pungency of the garlic (Dickerson and Wall, 1997). Numerous flavour precursor compounds are formed, and undergo a series of chemical reactions when tissues are damaged. These reactions are first catalysed by the alliinase enzyme, and form garlic flavouring substances and pungent compounds. The developed pungency is directly correlated with pyruvic acid content, and measured using a UV-Vis spectrophotometer (Wall and Corgan, 1992). Pungency of Argentine garlic after six months of harvest reached 96.4 μmol/g pyruvate as compared to control (80.1 μmol/g) (Natale *et al.*, 2004).

Although garlic has high culinary and medicinal applications, it contains a small amount of anti-nutritional factors, *i.e.*, saponin, alkaloids, flavonoids, tannin, steroids, and hydrocyanide. Flavonoids (0.04 - 0.36%), saponin (0.14 - 19.0%), and tannin (0.06 - 6.10%) present in garlic are within the limit (Friday *et al.*, 2011). Anti-nutritional factors were assessed and reported as alkaloids (4.21 mg), tannins (3.54 mg), saponin (0.80 mg), flavonoids (5.56 mg), and steroids (0.04 mg) per 100 g of garlic powder (Yusuf *et al.*, 2018). Most of the studies have been carried out on common garlic varieties with limited parameters. Very few research papers are available, with limited information on specific varieties of garlic. Therefore, the primary objective of the present work was to conduct a thorough investigation of various quality traits, such as physicochemical properties, pungency, anti-nutritional factors, cutting strength, and colour attributes of seven promising garlic varieties grown in different parts of India. Furthermore, principal component analysis (PCA) was applied to identify the varieties' quality performance with respect to the measured parameters.

Materials and methods

Seven promising varieties, namely Punjab garlic-17 (PG-17), Punjab garlic-18 (PG-18), Bhima purple (BP), Haryana garlic-17 (HG-17), Yamuna safed-1 (YS-1), Solo garlic (SG), and Elephant garlic (EG) were obtained from Punjab Agricultural University, Ludhiana; Choudhary Charan Singh Haryana Agricultural University, Hisar; farmer's field, Nashik; and Sangrur local market. Bulbs of garlic varieties were kept in a dry, cool, and dark place. 2,4-dinitrophenylhydrazine and sodium pyruvate were purchased from Nice Chemicals Pvt. Ltd., Mumbai, India. Ammonium thiocyanate, vanillin, and trichloroacetic acid were purchased from Loba Chemie Pvt. Ltd., Mumbai, India. All chemicals used in the present work were of analytical grade.

Physical properties

The polar diameter (Dp), equatorial diameter (De), and thickness (T) of garlic bulbs were measured individually using a digital Vernier calliper. The geometric mean diameter (GMD), arithmetic mean diameter (AMD), surface area (SA), and cross-sectional area (CSA) of garlic bulbs were measured using the following equations (Mohsenin, 1971):

$$GMD = \sqrt[3]{D_p \times D_e \times T}, \text{ cm} \quad \text{(Eq. 1)}$$

$$AMD = \frac{(D_p + D_e + T)}{3}, \text{ cm} \quad \text{(Eq. 2)}$$

$$SA = \frac{\pi}{4} \times D_p \times D_e, \text{ cm}^2 \quad \text{(Eq. 3)}$$

$$CSA = \frac{\pi}{4} \times \frac{(D_p + D_e + T)^2}{3}, \text{ cm}^2 \quad \text{(Eq. 4)}$$

The shape index (SI) of garlic bulbs was measured using Eq. 5 (Abd-Alla, 1993):

$$SI = \frac{D_e}{\sqrt{D_p \times T}} \quad \text{(Eq. 5)}$$

The weight of garlic bulbs was measured using a precision digital electronic weighing balance. The true density (TD) of garlic bulbs was measured by volume using the solid displacement technique. The increase in the volume of fine solids after inserting the garlic bulbs was indicated as true volume (TV). The bulk density (BD) of garlic bulbs was estimated using the relationship mentioned (Masoumi *et al.*, 2006). The porosity of garlic bulbs was measured using Eq. 6:

$$Porosity\ (\%) = \left(1 - \frac{B.D.}{T.D.}\right) \times 100 \quad \text{(Eq. 6)}$$

Gravimetric properties

The angle of repose (AOR) and static coefficient of friction (SCOF) of garlic bulbs were measured according to Kaur *et al.* (2021). The SCOF was measured on three surfaces, namely plywood, galvanised iron sheet, and glass surfaces, in the vertical and horizontal directions of garlic bulbs.

Chemical properties

The moisture content of garlic bulbs was measured using the hot air oven drying method (AOAC, 2006). The nitrogen content of garlic bulbs was measured using the Kjeldahl method (AOAC, 2006), and a factor of 6.25 was used to calculate the crude protein content of garlic bulbs. The Soxhlet apparatus was used to measure the crude fat content of garlic bulbs as per the standard method (AOAC, 2006). The ash content of garlic bulbs was measured using a muffle furnace maintained at 550 ± 10°C for 8 h (AOAC, 2006). The total carbohydrate content of garlic bulbs was measured by the difference method. The dried and fat-free garlic sample was used to measure the crude fibre content as per the standard method (AOAC, 2006). The pH of the extracted garlic juice was measured at 20°C using a pH meter. The total soluble solids (TSS) of garlic bulbs were measured at 20°C using a hand refractometer. The acidity of garlic bulbs was measured using the titration method, and results were expressed as a percentage of anhydrous citric acid on a fresh weight basis (AOAC, 2006). All the analytical work was run at least in triplicate, and the results were represented on a fresh weight basis.

Pungency

Pungency is one of the key factors in assessing the garlic varieties as a concentration of pyruvic acid content. It was analysed using the colorimetric technique according to Lucena *et al.* (2016), with slight modifications. Garlic cloves were weighed (approx. 10 g), and the peel was removed manually. It was then crushed using a pestle and mortar without the addition of distilled water. The extract was obtained after filtering (Whatman No. 2), and then stored at a refrigerated temperature. Garlic extract (0.2 mL), 5% trichloroacetic acid (1.5 mL), and distilled water (18.3 mL) were added into a test tube, and mixed thoroughly with a vortex mixer. Further, 1.0 mL of the prepared sample, 1.0 mL of 0.0125% 2,4 dinitrophenylhydrazine (DNPH), and 1.0 mL of distilled water were added step-by-step into the test tube, and mixed thoroughly. The test tubes were heated in a water bath for 10 min at 37°C, and immediately cooled down. Then, 5.0 mL of 0.6N NaOH was added and left for 5 min to develop a yellow colour. The absorbance was recorded at 420 nm using a spectrophotometer. The results were expressed in µmol/mL of pyruvic acid.

Anti-nutritional properties

Saponin

Saponin content in the garlic samples was estimated according to Obadoni and Ochuko (2002). Briefly, 44.0 mL of 20% aqueous ethanol was mixed with 2.0 g of garlic paste. The samples were heated with continuous agitation at 55°C in a water bath for 4 h. The solution was filtered with Whatman No. 2 filter paper, and the filtrated mixture was again mixed with 44.0 mL of 20% aqueous ethanol. The mixed solutions were heated at approximately 90°C in a water bath until the extract remained at 40.0 mL. The concentrated extract was transferred into a 100-mL separating funnel. Then, 8.0 mL of diethyl ether was added and shaken vigorously, and the aqueous layer separated from the ether layer. This process was repeated for purification. Furthermore, 6.0 mL of *n*-butanol was added to the aqueous layer, and pooled extracts were washed twice using 2.0 mL of 5% aqueous sodium chloride solution. The left-over solution was heated in a water bath, and further dried in a hot air oven to a constant weight. Saponin content was calculated as a percentage, and reported as the mean of three individual measurements.

Phytic acid

Phytic acid content in the garlic samples was estimated using the titration method (Ovuakporie-Uvo *et al.*, 2019). Garlic extract was prepared using 0.2 g of garlic in 100 mL of 2% hydrochloric acid for 3 h. The extracted solution was filtered through Whatman No. 2 filter paper. Then, 50 mL of filtered extract was added to 10 mL of distilled water and 10 mL of 0.3% ammonium thiocyanate solution. The mixed solution was titrated against ferric chloride solution (0.00195 g iron/mL). Endpoint was noted with the appearance of yellow colour persisting for 5 min. PHA content was calculated using Eq. 7:

$$PHA\ (\%) = \frac{TV \times 0.00195 \times 1.19}{2} \times 100 \quad \text{(Eq. 7)}$$

Tannin

Tannin content in the garlic samples was estimated using the spectrophotometric method (Bai *et al.*, 2018). Garlic extract was prepared from 0.2 g of garlic in 10 mL of 80% methanol containing 1% HCl. After 20 min, the extract solution was centrifuged at 3,000 rpm for 20 min, and the obtained supernatant was stored for tannin estimation. Next, 1.0 mL of supernatant was mixed with 5.0 mL of vanillin-hydrochloride reagent (1% vanillin and 8% hydrochloride in a 1:1 ratio). After 30 min incubation, absorbance was measured at 500 nm using a UV-Vis spectrophotometer. Catechin was used for the preparation of a standard curve, and the result was reported as g CE/100 g of garlic.

Colour property

The colour of whole garlic bulbs was analysed using a colorimeter (CR-10 model, Konica Minolta Sensing, Inc., Japan) attached with D65 illumination. It was measured ten times for each garlic variety, and the mean value was noted in terms of L* (lightness), a* (redness), and b* (yellowness). The browning index (BI), hue (H), and chroma (C) values were calculated using Eqs. 8 to 10, respectively:

$$BI = \frac{(X - 0.31) \times 100}{0.17} \quad \text{(Eq. 8)}$$

where $X = \frac{(a^* + 1.75L^*)}{(5.645L^* + a^* - 3.012b^*)}$

$$H = tan^{-1}\left(\frac{b}{a}\right) \quad \text{(Eq. 9)}$$

$$C = \sqrt{a^2 + b^2} \quad \text{(Eq. 10)}$$

Cutting strength

The cutting strength of garlic cloves was analysed using a texture analyser (TA-XT 2i, Stable Micro System, UK) according to Patel *et al.* (2020) with slight modifications. It was estimated by the application of a knife blade probe with a test speed of 0.5 mm/s from a 50 mm distance, and a load cell of 50 kg. The result was recorded as the peak force (N) achieved to spontaneously cut the garlic cloves through the probe.

Statistical analysis

All results were represented as an arithmetic mean (AM) ± standard deviation (SD). The experimental data were evaluated for ANOVA followed by Duncan's test to observe for homogeneity at a significant level of $p \leq 0.05$. Furthermore, principal component analysis (PCA) was performed to summarise the correlation between the parameters of seven garlic varieties.

Results and discussion

Physical and gravimetric properties

Physical properties comprised of dimensional and gravimetric properties for the seven garlic varieties are presented in Table 1. The garlic bulbs contained numbers of cloves ranging from 1 to 26, and weighed from 10.33 to 76.99 g. This indicated variation in per-unit clove weight as variety-dependent. Therefore, the requirement of sorting and grading unit operations is a justified step in the processing line for uniformity in the quality of processed products. The polar diameter (Dp), equatorial diameter (De), and thickness (T) of garlic varieties ranged from 3.31 - 5.04, 3.08 - 6.93, and 2.89 - 6.60 cm, respectively. The maximum coefficients of variation (CV) were 4.81% (BP),

Table 1. Physical and gravimetric properties of whole bulb garlic varieties.

Physical property	Garlic variety						
	HG-17	PG-17	PG-18	YS-1	BP	SG	EG
No. of clove	23.67 ± 1.05^{b}	16.07 ± 0.80^{d}	25.80 ± 1.21^{a}	24.20 ± 1.01^{b}	20.20 ± 0.94^{c}	1.00 ± 0.00^{f}	12.47 ± 0.52^{e}
Weight of bulb (g)	21.14 ± 1.05^{c}	10.33 ± 0.50^{e}	38.13 ± 1.14^{b}	37.45 ± 1.81^{b}	21.06 ± 1.05^{c}	19.32 ± 0.89^{d}	76.99 ± 3.55^{a}
Polar diameter (cm)	3.98 ± 0.10^{e}	3.31 ± 0.15^{g}	3.53 ± 0.07^{f}	4.52 ± 0.16^{b}	4.36 ± 0.21^{c}	4.21 ± 0.15^{d}	5.04 ± 0.11^{a}
Equatorial diameter (cm)	3.98 ± 0.09^{d}	3.08 ± 0.14^{g}	5.34 ± 0.18^{b}	4.55 ± 0.12^{c}	3.78 ± 0.11^{e}	3.39 ± 0.13^{f}	6.93 ± 0.28^{a}
Thickness (cm)	3.74 ± 0.18^{d}	2.89 ± 0.11^{g}	5.00 ± 0.17^{b}	4.37 ± 0.20^{c}	3.41 ± 0.14^{e}	3.22 ± 0.14^{f}	6.60 ± 0.13^{a}
Arithmetic mean diameter (cm)	3.90 ± 0.10^{d}	3.09 ± 0.07^{f}	4.62 ± 0.11^{b}	4.48 ± 0.11^{c}	3.85 ± 0.10^{d}	3.61 ± 0.09^{e}	6.19 ± 0.12^{a}
Geometric mean diameter (cm)	3.90 ± 0.10^{c}	3.09 ± 0.07^{e}	4.55 ± 0.11^{b}	4.48 ± 0.11^{b}	3.83 ± 0.09^{c}	3.58 ± 0.09^{d}	6.13 ± 0.12^{a}
Surface area (cm^2)	49.70 ± 1.58^{d}	32.00 ± 1.57^{f}	59.21 ± 2.87^{c}	64.70 ± 3.05^{b}	51.76 ± 2.58^{d}	44.83 ± 2.10^{e}	109.76 ± 5.39^{a}
Cross-sectional area (cm^2)	35.82 ± 1.76^{d}	22.56 ± 1.08^{f}	50.38 ± 2.48^{b}	47.33 ± 2.36^{c}	34.96 ± 1.74^{d}	30.66 ± 1.52^{e}	90.31 ± 3.65^{a}
Shape index	1.03 ± 0.03^{c}	1.00 ± 0.05^{d}	1.27 ± 0.03^{a}	1.03 ± 0.02^{c}	0.98 ± 0.04^{d}	0.92 ± 0.04^{e}	1.20 ± 0.05^{b}
True volume (mL)	30.37 ± 1.31^{d}	10.65 ± 0.31^{f}	35.35 ± 1.57^{c}	37.56 ± 1.37^{b}	29.85 ± 1.41^{d}	20.47 ± 0.68^{e}	91.58 ± 4.00^{a}
True density (g/mL)	0.69 ± 0.02^{d}	0.97 ± 0.05^{ab}	1.08 ± 0.06^{a}	1.00 ± 0.05^{abc}	0.71 ± 0.03^{e}	0.94 ± 0.05^{bc}	0.84 ± 0.05^{c}
Bulk volume (mL)	60.55 ± 1.60^{d}	22.22 ± 0.97^{f}	81.53 ± 2.92^{b}	82.33 ± 2.57^{b}	73.61 ± 2.92^{c}	42.81 ± 1.34^{e}	173.23 ± 8.47^{a}
Bulk density (g/mL)	0.34 ± 0.01^{e}	0.47 ± 0.02^{bc}	0.47 ± 0.02^{a}	0.46 ± 0.02^{b}	0.29 ± 0.01^{e}	0.45 ± 0.02^{c}	0.45 ± 0.02^{d}
Porosity (%)	49.85 ± 1.29^{e}	51.97 ± 2.47^{d}	56.63 ± 1.46^{b}	54.34 ± 2.08^{c}	59.37 ± 2.70^{a}	52.18 ± 1.09^{d}	47.08 ± 2.05^{f}

Gravimetric property								
Angle of repose		53.86 ± 0.96^{ab}	46.82 ± 0.43^{d}	46.60 ± 0.81^{d}	47.19 ± 0.86^{d}	52.37 ± 1.12^{b}	50.07 ± 2.42^{c}	54.99 ± 2.37^{a}
Coefficient of static friction (horizontal side)	Plywood	0.47 ± 0.02^{a}	0.28 ± 0.01^{d}	0.38 ± 0.01^{c}	0.38 ± 0.01^{c}	0.38 ± 0.01^{c}	0.22 ± 0.01^{e}	0.43 ± 0.02^{b}
	Galvanised sheet	0.34 ± 0.02^{a}	0.22 ± 0.01^{d}	0.33 ± 0.01^{a}	0.34 ± 0.01^{a}	0.29 ± 0.01^{b}	0.18 ± 0.01^{e}	0.26 ± 0.01^{c}
	Glass surface	0.25 ± 0.01^{b}	0.20 ± 0.01^{d}	0.28 ± 0.01^{a}	0.28 ± 0.01^{a}	0.25 ± 0.01^{b}	0.16 ± 0.01^{e}	0.22 ± 0.01^{c}
Coefficient of static friction (vertical side)	Plywood	0.21 ± 0.01^{d}	0.22 ± 0.01^{c}	0.19 ± 0.01^{e}	0.19 ± 0.01^{e}	0.24 ± 0.01^{b}	0.16 ± 0.01^{f}	0.29 ± 0.01^{a}
	Galvanised sheet	0.18 ± 0.01^{c}	0.16 ± 0.01^{d}	0.18 ± 0.01^{cd}	0.17 ± 0.01^{d}	0.23 ± 0.01^{a}	0.14 ± 0.01^{e}	0.20 ± 0.01^{b}
	Glass surface	0.17 ± 0.01^{c}	0.16 ± 0.01^{c}	0.18 ± 0.01^{b}	0.17 ± 0.01^{bc}	0.22 ± 0.01^{a}	0.13 ± 0.01^{d}	0.18 ± 0.01^{b}

Values are mean ± S.D. Means followed by different lowercase superscripts in the same column are significantly different ($p \leq 0.05$).

4.43% (PG-17), and 4.78% (HG-17), while the minimum CV were 2.08% (PG-18), 2.33% (HG-17), and 1.90% (EG) for the Dp, De, and T in the garlic varieties. The mean values of arithmetic mean diameter (AMD), geometric mean diameter (GMD), surface area (SA), and cross-sectional area (CSA) of garlic varieties ranged from 3.09 - 6.19 cm, 3.09 - 6.13 cm, 32.00 - 109.76 cm^2, and 30.66 - 90.31 cm^2, respectively. SA and CSA are useful to estimate the garlic respiration rate during storage, in the determination of heat transfer (Bahnasawy, 2007), and the requirement of chemicals during the application of lye peeling. The mean shape index (SI) value of garlic varieties ranged from 0.92 - 1.27. These values indicated that all garlic varieties' bulbs were spherical in shape (Abd-Alla, 1993). These parameters are the most important for designing the mechanical shortener and grader. It is also helpful in designing the mechanical peeler for efficient peeling. The average values of true volume, true density, bulk volume, and bulk density of the garlic bulbs ranged from 10.65 - 91.58 mL, 0.69 - 1.08 g/mL, 22.22 - 173.23 mL, and 0.29 - 0.47 g/mL, respectively. These parameters are useful in designing the room for storage and transportation requirements. The maximum porosity was observed in the BP variety (59.37%), and lower in the EG (47.08%) and HG (49.85%) varieties. Hence, BP variety required more space for storage and transportation than the other garlic varieties.

Table 1 shows the mean value of five independent experiments of gravimetric properties, *viz*., angle of repose and coefficient of static friction at different surfaces (plywood, galvanised iron sheet, and glass), for garlic varieties at a significant level of $p \leq 0.05$. An angle of repose was observed in the range of 46.82 - 54.99 for different garlic varieties. This correlated with other physical parameters, *viz*., density, surface area, and coefficient of friction. This property is helpful in designing the handling (conveyor belt) and processing equipment. The observed values were in agreement with the reported data (Bahnasawy, 2007). The coefficient of static friction measured for different garlic varieties yielded larger horizontal side than the vertical side on all the surfaces (plywood, galvanised sheet, and glass surface). This could have been due to differences in the contact surface area of the material with the measured surface area. At the same time, the coefficient of static friction was larger on the plywood surface as compared to galvanised iron sheet and glass surfaces on the horizontal and vertical sides. The measured values were similar to those reported earlier (Bahnasawy, 2007) for the contact surfaces, namely plywood and galvanised sheet on the horizontal side of the garlic bulb.

Chemical properties

Table 2 shows the chemical properties of seven garlic varieties at significant level of $p \leq 0.05$. Maximum moisture content of 74.57% and the minimum TSS of 28.93°Brix were observed in the SG variety, followed by the EG variety, which had 71.60% moisture content with a TSS of 29.13°Brix. This means that these varieties had high respiration rate during storage and are, therefore, susceptible to rotting and sprouting (Abhayawick *et al.*, 2002). The minimum moisture content was observed in the BP variety (61.64%), and the maximum TSS content was observed in the PG-17 variety (37.93%). This parameter is directly correlated to the recovery of the processed product, hence is useful for the preparation of garlic-processed products with high throughput. The crude protein and carbohydrate contents were present in the range of 4.23 - 7.39 and 18.94 - 29.18%, respectively. Therefore, garlic could be a good source of crude protein and carbohydrate. The presence of a high amount of crude protein in garlic is due to the occurrence of active proteinaceous metabolites, particularly allicin, capsaicin, and ajoene (Dashak *et al.*, 2001). Crude fat content was estimated in the range of 0.15 - 0.91% in the garlic varieties. The garlic varieties, which have high oil content, can be used for the extraction of oil and further utilised in the formation of flavouring compounds (Okwu and Nnamdi, 2008). The garlic varieties contained a lower amount of ash (0.92 - 1.77%) and crude fibre (0.58 - 0.84%). These results were supported by the study of the proximate composition of garlic (Hacıseferoğulları *et al.*, 2005). The pH value of different varieties of garlic was measured between 6.08 and 6.77. These results were consistent with Lucena *et al.*, 2016 for raw garlic. Titratable acidity is one of the key factors in the development of flavour in food items. Garlic varieties showed an acidity of between 0.73 and 1.24%. A similar result was also reported for garlic powder (Yusuf *et al.*, 2018).

Pungency

From Table 3, it was noticed that the pyruvic acid content was significantly different in all the garlic varieties ($p \leq 0.05$), and ranged between 34.84

Table 2. Chemical properties of different garlic varieties.

Chemical parameter	Garlic variety						
	HG-17	PG-17	PG-18	YS-1	BP	SG	EG
Moisture (%)	64.52 ± 0.64^{c}	64.41 ± 0.74^{c}	64.98 ± 0.75^{c}	64.16 ± 0.19^{c}	61.64 ± 0.82^{d}	74.57 ± 0.57^{a}	71.60 ± 0.92^{b}
Crude protein (%)	6.77 ± 0.18^{b}	4.23 ± 0.14^{d}	5.17 ± 0.11^{c}	7.26 ± 0.22^{a}	7.39 ± 0.38^{a}	5.42 ± 0.06^{c}	6.71 ± 0.17^{b}
Crude fat (%)	0.18 ± 0.02^{e}	0.47 ± 0.05^{c}	0.91 ± 0.03^{a}	0.32 ± 0.05^{d}	0.72 ± 0.02^{b}	0.15 ± 0.04^{e}	0.51 ± 0.05^{c}
Ash (%)	1.77 ± 0.12^{a}	1.71 ± 0.12^{ab}	1.22 ± 0.06^{e}	1.38 ± 0.11^{de}	1.47 ± 0.09^{cd}	0.92 ± 0.06^{f}	1.56 ± 0.03^{bc}
Carbohydrate (%)	26.76 ± 0.81^{c}	29.18 ± 0.92^{a}	27.72 ± 0.89^{bc}	26.89 ± 0.33^{c}	28.77 ± 0.43^{ab}	18.94 ± 0.60^{d}	19.62 ± 0.88^{d}
Crude fibre (%)	0.84 ± 0.06^{a}	0.81 ± 0.04^{ab}	0.76 ± 0.04^{b}	0.63 ± 0.02^{cd}	0.58 ± 0.04^{d}	0.67 ± 0.02^{c}	0.77 ± 0.04^{b}
TSS (°Brix)	35.17 ± 0.29^{c}	37.93 ± 0.12^{a}	34.93 ± 0.12^{cd}	34.80 ± 0.20^{d}	36.33 ± 0.31^{b}	28.93 ± 0.12^{e}	29.13 ± 0.12^{e}
pH	6.20 ± 0.03^{cd}	6.77 ± 0.04^{a}	6.41 ± 0.03^{b}	6.25 ± 0.03^{c}	6.16 ± 0.03^{de}	6.08 ± 0.02^{f}	6.14 ± 0.02^{e}
Acidity (%)	1.24 ± 0.07^{a}	0.87 ± 0.07^{cd}	0.81 ± 0.09^{d}	1.00 ± 0.07^{bc}	1.03 ± 0.13^{b}	0.73 ± 0.10^{d}	1.00 ± 0.05^{bc}

Values are mean ± S.D. Means followed by different lowercase superscripts in the same column are significantly different ($p \leq 0.05$).

Table 3. Pungency, anti-nutritional factors, and cutting strength of different garlic varieties.

Garlic variety	Pungency	Anti-nutritient			Cutting strength (clove) (N)
	Pyruvic acid (µmol/mL)	Saponin (g/100 g)	Phytic acid (g/100 g)	Tannin (g CE/100 g)	
HG-17	71.36 ± 2.40[c]	12.50 ± 0.35[c]	0.05 ± 0.01[ab]	0.33 ± 0.01[b]	26.83 ± 0.77[cd]
PG-17	86.69 ± 3.69[a]	11.10 ± 0.35[d]	0.05 ± 0.01[ab]	0.25 ± 0.02[d]	26.28 ± 0.94[cd]
PG-18	34.84 ± 0.94[f]	13.42 ± 0.13[b]	0.05 ± 0.01[a]	0.29 ± 0.01[c]	17.20 ± 0.57[e]
YS-1	63.51 ± 1.42[d]	6.63 ± 0.10[f]	0.04 ± 0.01[ab]	0.31 ± 0.01[bc]	30.12 ± 0.60[c]
BP	55.03 ± 2.43[e]	13.98 ± 0.25[a]	0.03 ± 0.01[b]	0.18 ± 0.01[f]	25.93 ± 1.45[d]
SG	37.21 ± 1.30[f]	7.45 ± 0.18[e]	0.05 ± 0.01[a]	0.21 ± 0.01[e]	104.61 ± 4.25[a]
EG	78.21 ± 1.77[b]	13.92 ± 0.24[a]	0.06 ± 0.01[a]	0.39 ± 0.02[a]	81.35 ± 3.00[b]

Values are mean ± S.D. Means followed by different lowercase superscripts in the same row are significantly different ($p \leq 0.05$).

and 86.68 µmol/mL. The maximum concentration of pyruvic acid was present in the PG-17 variety, followed by the EG, HG-17, YS-1, BP, SG, and PG-18 varieties. The amount of pyruvic acid was used to correlate the flavouring component and pungency of the garlic. These results were in concurrence with the results reported by other studies (Abd-Alla, 1993; Lucena *et al.*, 2016, Prakash and Prasad, 2023). All the tabulated data and previous results mentioned by researchers indicated that garlic may be categorised into three groups on the basis of pyruvic acid content, namely low-pungent garlic (< 40 µmol/mL), medium-pungent garlic (40 - 70 µmol/mL), and high-pungent garlic (> 70 µmol/mL).

Anti-nutritional properties

Anti-nutritional factors, namely saponin, phytic acid, and tannin contents present in different garlic varieties are reported in Table 3 ($p \leq 0.05$). Saponin, phytic acid, and tannin were found in the range of 6.63 - 13.92 g, 0.03 - 0.06 g, and 0.18 - 0.39 g CE per 100 g, respectively. The lowest amount of saponin content was found in the YS-1 variety (6.63 g), followed by the SG (7.45 g), PG-17 (11.10 g), HG-17 (12.50 g), PG-18 (13.42 g), EG (13.92 g), and BP (13.98 g) varieties per 100 g. Marginal differences in phytic acid content were found. Tannin content was observed to be lower in the BP variety (0.18 gCE) than in the SG (0.21 gCE), PG-17 (0.25 gCE), PG-18 (0.29 gCE), YS-1 (0.31 gCE), HG-17 (0.33 gCE), and EG (0.39 gCE) varieties per 100 g. From Table 3, it was also noticed that the BP variety had the highest amount of saponins, but the lowest amount of phytic acid and tannin content. It may be due to the presence of a maximum amount of reddish colour in the BP variety (Figure 1). The highest amounts of saponin, phytic acid, and tannin were present in the EG variety, which may be correlated with size dependency (Table 1). The results of saponin and phytic acid contents in the garlic varieties were higher, whereas tannins were lower (Onyeneke, 2018).

Colour analysis

The L*, a*, b*, BI, H, and C values of garlic varieties ranged between 76.20 - 86.00, 1.40 - 8.70, 6.60 - 9.50, 9.52 - 17.15, 40.38 - 81.53, and 7.10 - 11.44, respectively. The variation in colour of garlic varieties may be due to their inherent characteristics associated with pulp and peel. From Figure 1, it was observed that the BP variety was low in lightness and hue value, and high in redness, yellowness, and chroma value. This indicated that the BP variety contained anthocyanin pigment. Earlier research found that sprouted onions had lower lightness, and higher redness and yellowness due to an increase in anthocyanin content (Majid *et al.*, 2016). The variation in colour may also be attributed to preharvest factors, namely soil condition, growing temperature, types of fertiliser application and their concentration, water supply, harvesting stage, and postharvest factors, namely storage condition and temperature. Postharvest conditions, *viz.*, temperature and storage conditions, affect the colour attributes of fruits and vegetables (Dobrzański and Rybczyński, 2002). Colour attributes may be helpful in identifying the maturity indices, thus assisting in the marketability of garlic. Colour has been used as one of the non-destructive maturity indices for the assessment of vegetables (Paul *et al.*, 2017).

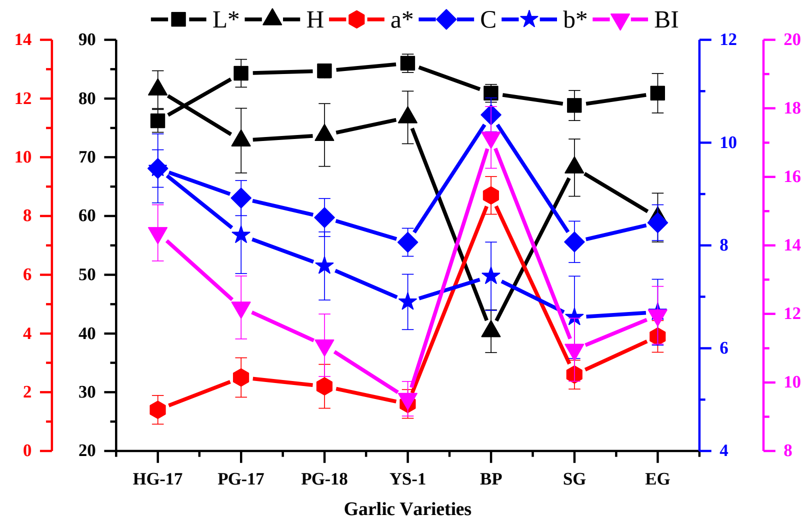

Figure 1. Frequency distribution curves of colour attributes (L*, a*, b*, BI, C, and H) of garlic varieties.

Cutting strength

The PG-18 variety recorded the lowest cutting strength (17.20 N), followed by the BP (25.93 N), PG-17 (26.28 N), HG-17 (26.83 N), YS-1 (30.12 N), EG (81.35 N), and SG (104.61 N) varieties (Table 3). The De of the SG variety's garlic cloves was higher than the other varieties; hence, it required higher cutting strength force. Furthermore, the EG variety contained 12 cloves, hence per clove, De and clove weight (6.17 g) was lower than SG, so it required lower cutting strength force. The cutting strength showed a direct correlation with the number of cloves present in the bulb, or average per clove weight, and the De of the garlic. This information is useful for designing processing equipment, particularly automatic cutters. The experimental cutting strength values of all the varieties were higher than the value of 7.25 N for the G-282 variety (Patel *et al.*, 2020).

Principal component analysis (PCA)

PCA was applied to envision the correlation between the parameters (physicochemical, pungency, anti-nutritional factors, colour attributes, and cutting strength) of seven garlic varieties. The evaluated results showed that the magnitude of eigenvalues of the correlation matrix for the first three principal components was 32.89, 25.01, and 17.51%. From the correlation matrix, it was found that the first two principal components provided 57.90% of total variance, and 75.41% of total variance was observed after the addition of the third principal component. Red points represent the garlic varieties, and vectors represent the parameters in biplot representation (Figures 2A, 2B, and 2C). In Figure 2D, red vectors show the parameters' interaction in a 3-D plot, and blue vectors represent the parameters in a biplot on different axis.

From Figure 2A (PC-1 *vs*. PC-2), it was noticed that the measured parameters, *viz*., NoC, porosity, CSF-11, CSF-21, and CSF-31. CSF-12, CSF-22, CSF-32, crude protein, crude fat, ash, CHO, TSS, acidity, a*, b*, BI, C, PYA, and SAP were positively correlated with the HG-17 and BP varieties. The PG-18, YS-1, and SG varieties were found in a cluster with the following parameters: TD, BD, MC, CF, L*, H, CS, and SAP. The EG variety was present in a separate cluster, which was positively correlated with the parameters, *i.e*., BW, Dp, De, AMD, GMD, SA, CSA, SI, BV, AoR, and TAN. It means that the EG variety was highly correlated with physical parameters. In Figure 2B (PC-1 *vs*. PC-13), the PG-18, YS-1, and HG-17 varieties were found in a cluster, which were positively correlated with the parameters *viz*. NoC, SI, TD, CSF-11, CSF-21, CSF-31, crude protein, crude fat, ash, CF, pH, acidity, L*, b*, H, PYA, PHA, and TAN. The EG variety was positively correlated with the characteristics of BW, De, T, AMD, GMD, SA, CSA, TV, BV, CSF-12, and SAP, whereas the BP and SG varieties were positively correlated with CSF-22, a*, BI, C, and CS. In Figure 2C (PC-2 and PC-3), the HG-17 variety was found in a cluster, having a positive correlation with NoC, SA, TV, TD, BV, CSF-11, CSF-21, CSF-31, crude fat, ash, CHO, TSS, acidity, b*, PYA, and SAP. The parameters, *i.e*., BW, De, T, AMD, GMD, CSA, SI, TD, BD, CF, pH, L*, H, PHA, and TAN were positively correlated with the PG-17, PG-18, and YS-1 varieties. The BP variety was noticed in a separate

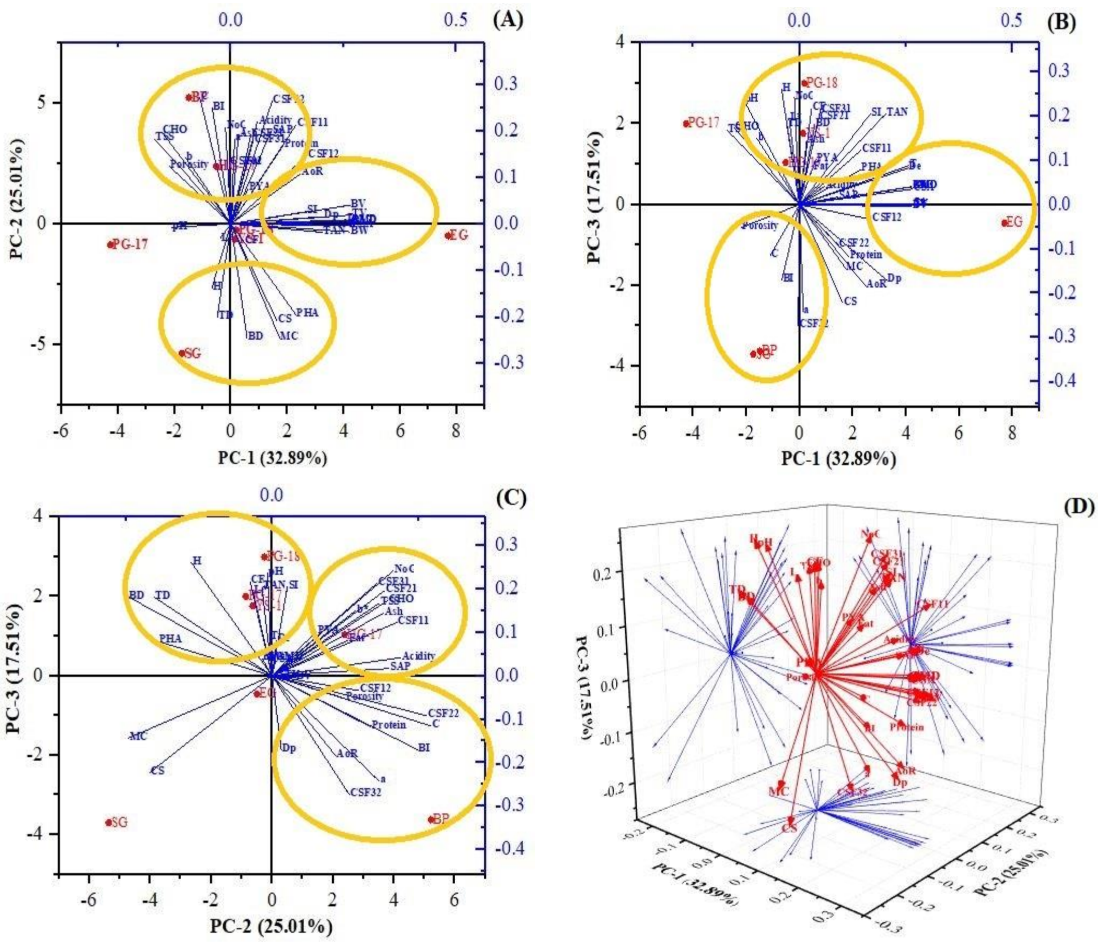

Figure 2. Biplot **(A**, **B**, and **C)** and 3-D plot **(D)** of principal component analysis of garlic varieties. NoC: no. of clove; BW: bulb weight; D_p: polar diameter; De: equatorial diameter; T: thickness; AMD: Arithmetic mean diameter; GMD: geometric mean diameter; SA: surface area; CSA: cross-sectional area; SI: shape index; TV: true volume; TD: true density; BV: bulk volume; BD: bulk density; AoR: angle of repose; CSF-11: coefficient of static friction on plywood horizontal side; CSF-21: coefficient of static friction on galvanised sheet horizontal side; CSF-31: coefficient of static friction on glass surface horizontal side; CSF-12: coefficient of static friction on plywood vertical side; CSF-22: coefficient of static friction on galvanised sheet vertical side; CSF-32: coefficient of static friction on glass surface vertical side; MC: moisture content; CHO: carbohydrate content; CF: crude fibre; TSS: total soluble solid; L*: lightness; a*: redness; b*: yellowness; BI: browning index; H: hue; C: chroma; CS: cutting strength; PYA: pyruvic acid; SAP: saponins; PHA: phytic acid; and TAN: tannins.

cluster with parameters of Dp, porosity, AoR, CSF-12, CSF-22, CSF-32, crude protein, a*, BI, and C.

A combined correlation was found between principal components (PC-1, PC-2, and PC-3) and parameters, which was represented in the 3-D plot (Figure 2D). The collective results showed that the HG-17 variety was positively correlated with NoC, CSF-11, CSF-21, CSF-31, crude fat, ash, acidity, b*, and PYA, whereas the PG-18 and YS-1 varieties were positively correlated with the parameters TD, CF, L*, H, and PHA. The BP variety showed positive correlations with the colour parameters, namely a*, BI, and C. From these data, it was concluded that among the seven garlic varieties, HG-17, a highly pungent garlic, showed positive correlations with the maximum number of measured quality attributes.

Conclusion

Seven garlic varieties were assessed and found to have significant differences ($p \leq 0.05$) in the quality traits, namely physicochemical, pungency, anti-nutritional factors, colour attributes, and cutting strength. The porosity of the BP variety was found to be higher; hence, it took up more storage space than the other garlic varieties. The pungency was found to be higher in the PG-17 variety (86.69 μmol/mL) and lower in the PG-18 variety (34.84 μmol/mL) in terms of pyruvic acid content. The BP variety was found to be lower in L and H values, but higher in a, b, and C values than the other varieties. This indicated that the BP variety may contain anthocyanin pigment. The cutting strength of garlic mainly depends on the De of the garlic clove and/or the number of cloves present in the whole bulb. TSS was found more in the PG-17, PG-18, HG-17, BP, and YS-1 varieties; so, these varieties may be useful for the preparation of garlic processed products, *i.e.*, garlic paste and powder. The measured parameters may be useful to growers in selecting varieties based on the market demand. The results obtained may also be useful for the design of the handling and processing equipment. The measured parameters were classified using PCA, and showed positive correlation with the HG-17 variety, which was loaded with the maximum number of measured quality traits.

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