International Journal of Horticultural Science 2024, 30: 74-83.
https://doi.org/10.31421/ijhs/30/2024/13228

Morphological characterization of shallot (*Allium cepa* L. var. *aggregatum*) segregating populations obtained from natural-outcrossing in Ethiopia

Tabor, G., Mengistu, F. G. & Atinafu, G.

Ethiopian Institute of Agricultural Research, Debre Zeit Agricultural Research Center, P.Box 32, Debre Zeit, Ethiopia
Author for correspondence: gebretensay.fekadu@gmail.com

Summary: Shallot is a vegetable and condiment crop widely used in Ethiopia and globally. However, absence of improved and adaptable varieties has been the major cause of low productivity. Narrow genetic base of local shallot germplasm owing to vegetative reproduction of the crop, among others, has been the root cause of low productivity. Nevertheless, some plants within the germplasm were observed bolting and producing viable seeds, presenting an opportunity for genetic diversification. Consequently, a germplasm enhancement program was initiated using these naturally outcrossing genotypes where about eighty-one genotypes were generated. The present study was thus undertaken with the objective of characterizing, classifying, and selecting the eighty-one genotypes for future breeding activities. The genotypes were planted in 9x9 simple lattice design with two replications at Debre Zeit Agricultural Research Center (Ethiopia) during the dry (irrigated) season of 2021. The genotypes were evaluated for fifteen growth, yield, and quality traits. Significant variations were observed among the genotypes in terms of bulb yield, bulb height and diameter, total soluble solids, bolting percentage, and bulb skin color. Bulb yield of the genotypes ranged from 31.33 t/ha in DZSHT-79-1A to 9.63 t//ha in DZSHT-45-1A-1. DZSHT-51-2 (207.93 g) was the highest yielder per plant whereas DZSHT-065-6/90 (74.51 g) was the lowest yielder. DZSHT-14-2-1/90 had the thickest bulb (44.69 mm) significantly thicker than twenty two genotypes which had bulb diameter ranging from 28.92 mm to 20.29 mm. DZSHT-81-1/90 was a genotype with the longest bulb height (52.33 mm) while DZSHT-147-1C was a genotype with the shortest bulb (33.12 mm). DZSHT-307-1/90 had the highest TSS (16.78°Brix) significantly differing from DZSHT-002/07 which had the lowest TSS (11.17 °Brix). Dry matter of the genotypes ranged from 12.00% to 22.79%. DZSHT-004/07, DZSHT-111-2-1, DZSHT-41-2B and DZSHT-72-2 had DM% greater than 20% which coupled with greater than 14 °Brix could make them suitable for dehydrated shallots. Among the 81 genotypes characterized 4 (4.9%), 7 (8.6%), 13 (16.1%), 28 (34.6%) and 29 (35.8%) were yellow, golden, light red, red and dark red in colour, respectively. Fifteen of the genotypes had at least 50% bolting plants whereas twenty nine of the genotypes had less than 25% bolting. The results revealed that seven principal components explained approximately 76% of the observed variation. Cluster analysis grouped the genotypes into seven clusters, with the majority falling into three clusters. The study successfully identified genotypes with diverse and important traits and availed both the genotypes and the information for future breeding programs. These genotypes could be used for the development of improved hybrid and open pollinated shallot varieties with higher yield, quality and pest resistance/tolerance attributes.

Tabor, G., Mengistu, F. G. & Atinafu, G. (2024): Morphological characterization of shallot (*Allium cepa* L. var. *aggregatum*) segregating populations obtained from natural-outcrossing in Ethiopia. International Journal of Horticultural Science 30: 74-83. https://doi.org/10.31421/ijhs/30/2024/13228

Key words: characterization, cluster analysis, germplasm, morphological traits, principal component analysis

Introduction

Shallot (*Allium cepa* L. var. *aggregatum*) is an important vegetable and condiment crop used for seasoning of various cuisines in Ethiopia and worldwide. It is a close relative of onion (*Allium cepa* L. var. *cepa*) and both belong to the same species (Fritsch & Friesen, 2002; Rabinowitch & Kamenetsky, 2002; Brickell et al., 2016). The largest producers of shallots are China and Japan, with more than five hundred tons of shallot bulbs produced annually, followed by New Zealand, Mexico, Iran, Iraq, Cambodia and Cameroon (FAOSTAT, 2018). Ethiopia produces about 262 thousand tons of onion and shallot on 28.2 thousand hectares of land (CSA, 2018).

Shallot is mainly propagated by vegetative bulbs and hence earlier breeding endeavours of shallot in Ethiopia has been limited to clonal selection of genotypes or populations collected from different parts of the country. Clonal selection utilized the naturally existing diversity of germplasm pool (Awale et al., 2011; Ita et al., 2016). Getachew & Asfaw (2000) observed wide diversity among Ethiopian shallot accessions in vegetative growth, bulb characteristics, maturity and yield. Getachew et al. (2022) confirmed that natural-outcrossing gave rise to diverse groups of shallot segregating populations which vary in vegetative and reproductive traits. Fasika et al. (2008) previously, studied forty-nine accessions collected from northern provinces of Ethiopia and reported highly significant phenotypic (7.6-41.6%) and genotypic (4.4-27.9%) coefficients of variances. The genotypes varied in plant height, number of leaves and bulblets/plant; bulb size, yield and dry weight as well as in quality traits such as harvest index, total soluble solids and pungency. Similarly, Awale et al. (2011) reported high phenotypic and genetic variances among forty-nine accessions collected from Shewa, Hararghe and Kefa provinces of Ethiopia for major growth traits, maturity and postharvest sprouting of bulbs. Similar studies in Indonesia indicated high genetic diversity among shallot genotypes and clustered them into two with dissimilarity coefficient of 76 (Hasanah et al., 2022). The presence of significant genetic variability for important agronomic and morphological traits in Indonesian shallot was further confirmed by Farid et al. (2012). Josipa et al. (2021) morphologically characterized Croatian shallot genotypes and found phenotypic diversity in vegetative and reproductive traits. Similarly, Major et al. (2018) used vegetative and bulb morphological traits to discriminate among shallot landraces of Croatian coast.

Shallot variety improvement program in Ethiopia began in 1986 at Debre Zeit Agricultural Research Centre (DZARC) using shallot genotypes collected from major growing regions (Getachew & Asfaw, 2000). The genotypes were characterized for morphological traits revealing high level of variability. Initially, the program focused on developing vegetatively propagated varieties with high yield and quality and succeeded in releasing four varieties. However, a large quantity of bulbs required for propagation, bulkiness to transport the bulbs and bulb transmitted diseases reduced the acceptance of shallot varieties as compared to that of onions. In order to alleviate the aforementioned constraints, the program was led to focus on developing seed propagated varieties from local as well as foreign germplasm sources that can bolt and produce viable seeds. Consequently, the DZARC released two seed propagated varieties while Melkassa Agricultural Research Centre (MARC) introduced and registered two other seed propagated varieties. A selection from a vegetatively propagated variety (“Huruta”) was also released from Haramaya University, Ethiopia (MoANR, 2019).

Currently, there are about 168 shallot genotypes that can bolt, flower and produce viable seeds within the germplasm holding of the DZARC. The possibility of out-crossing of the shallot genotypes provided an opportunity of genetic recombination and development of new genotypes thus further broadening the germplasm base and providing breeders with diverse genotypes from which high yielding, good quality and pest resistant/tolerant varieties could be selected.

However, the utilization of the diversity created, requires well evaluated, characterized, and documented information about the genotypes that could be readily available to the breeder for which none was available. Thus, the present study was initiated with the objective of characterizing, classifying and documenting information for the eighty-one recently developed germplasm so that it could be used for future breeding activities.

Materials and methods

The experiment was undertaken at DZARC, East Shewa zone, Ethiopia during the 2021 irrigated season. The DZARC is located 47 km southeast of Addis Ababa at 08°44'N latitude and 38°58'E longitude. It has a medium altitude of 1860 m.a.s.l, annual min. and max. temperature of 8.9 °C and 24.3 °C. It receives an annual rainfall of 851 mm (DZARC, 2008). The experiment was planted on Vertisol soils of the Centre. The soil has sandy-clay-loam texture and pH 7.2 (Diria et al., 2013).

Plant material and experimental design

Genotypes for the experiment were developed by planting shallot accessions collected from different parts of Ethiopia at Kulumsa Agricultural Research Centre (KARC). KARC has higher altitude (2200 m.a.s.l.) and cooler environment than DZARC, and favoured shallots to bolt, flower and out-cross naturally. Seeds of these accessions were collected and sown at DZARC to produce bulbs. The bulbs were selected for size, color and shape uniformity. The bulb-seed-bulb planting and selection process was undertaken for three consecutive cycles and finally uniform bulbs were maintained by vegetative propagation.

The experiment comprised of a total of eighty-one genotypes, seventy-nine genotypes developed as described above and two released varieties used as controls. The experiment was laid-out using 9x9 simple lattice design with two replications. Twenty uniform bulbs of each genotype were planted on a ridge comprising of two rows. All agronomic practices were undertaken as recommended by Getachew et al. (2008).

Data collection

The genotypes were characterized based on the descriptors for allium developed by International Plant Genetic Resources Institute (IPGRI, 2001). Data on vegetative growth such as plant height, number of leaves and number of shoots were collected from five randomly selected and tagged plants whereas sheath length and diameter were recorded from one shoot of each of the sample plants about 90 days after planting, when the plants were considered fully grown. Data on diameter, height and weight of bulbs were collected from three bulbs of each of three randomly selected plants after harvesting and curing for one week. Bulb height to diameter ratio was calculated from the two parameters. Yield/plant was the mean yield of the five randomly selected plants. Yield data was the yield of cured bulbs of the plants in the plot converted into ha. Total Soluble Solids (TSS) was recorded by pressing a drop of juice of bulbs on sample well of a digital refractometer (DRBO-45, Nanjing T-Bota Scietech Instruments and Equipment Co., Ltd). Dry matter of bulbs was measured after the bulbs were chopped and sample was drawn, weighed and dried in an oven at 70°C until a constant weight was achieved. Percent bolting was recorded as the proportion of bolted plants to the total number of plants/plot whereas the number of flower stalks/plant was a mean of flower stalks/bolted plants. Bulb skin color was recorded based on the color descriptors of IPGRI (2001).

Data analysis

Analysis of variance was done using Minitab Statistical Software (Minitab LLC 2020) while means were separated at probability of 5% whenever the analysis was significant.

In contrast to previous diversity studies on shallots, the present study used multivariate analysis that could capture the actual variability that existed within the germplasm and quantify genetic diversity between individuals based on morphological traits (Cabral et al., 2010; Singh et al., 2013). Principal Component Analysis (PCA) was done on standardized data using complete linkage method and Euclidean distance. It was used to identify representative traits for phenotypic characterization and identification of superior clones of sweet potato (Placide et al., 2015). The bi-plot and scree plot generated from PCA show inter-unit distances and indicate clustering of genotypes and displaying variances and correlations of the variables (Gabriel, 1971). Hanci & Gokce (2016) used PCA for data reduction and estimation of genetic diversity of onion breeding materials. Cluster analysis was used to group genotypes based on their similarities (Blashfield & Aldenderfer, 1988; Levenstien et al., 2003). Graphical representation of the cluster analysis (dendrogram) was generated to elucidate the relation among the genotypes.

Results and discussion

Mean performance of quantitative traits

Significant differences in bulb yield, yield/plant, TSS, bulb height and diameter, plant height, sheath diameter, number of leaves, and percent bolting were observed among the genotypes (***Table 1***). Similarly, Awale et al. (2011) and Fasika et al. (2008) reported the presence of notable genetic variability in morphological and yield parameters among shallot genotype collected from different parts of Ethiopia. According to Getachew et al. (2022), shallot genotypes obtained by open pollination significantly differed in yield/plant, number of bolting plants and number of flower stalks/plant. However, differences among the genotypes in bulb height to diameter ratio, sheath length, number of shoots and number of inflorescence/plant were not significant. The bulb yield of the genotypes ranged from the highest 31.33 t/ha in DZSHT-79-1A to the lowest 9.63 t//ha in DZSHT-45-1A-1 indicating a three-fold difference. However, seventy nine of the eighty-one genotypes had statistically similar bulb yields; they also did not differ from that of the popular released shallot variety (Minjar) that produced 16.77 t/ha yield and 117.63 g yield/ plant.

The highest yield/plant (207.93 g) was recorded in DZSHT-51-2 whereas the lowest 74.51 g was recorded in DZSHT-065-6/90, which is more than two and half folds smaller than that of DZSHT-51-2. The yield/plant of DZSHT-51-2, however, was not significantly different from most (79) of the genotypes. DZSHT-307-1/90 and DZSHT-47-1B-1 had the highest TSS of 16.78 and 16.20 °Brix but only significantly differing from DZSHT-002/07 which had the lowest TSS of 11.17 °Brix. The result is in agreements with Getahun et al. (2003) who reported that shallot cultivar DZSHT-OPS-13 had the highest TSS (16.7%) while DZSHT-OPS-14 had the lowest (10.15%). Genotypes with high TSS are known to have high pungency (Simon 1995) in onions. Dry matter of the genotypes ranged from 12.4% to 21.6%. Genotypes DZSHT-OP-14-2-1/90, DZSHT-OP-21-2/07, DZSHT-OP-OP-54-2-1, DZSHT-OP-114-2/90 and DZSHT-OP-65-6/90 had high DM% above 19.6% whereas DZSHT-OP-34A/90, DZSHT-OP-41-1-2/90 and DZSHT-OP-21-4/07 had the lowest percent dry matter, below 12.4%.

DZSHT-14-2-1/90 had the thickest bulb diameter of 44.69 mm differing from twenty two of the genotypes which had bulb diameter ranging from 28.92 mm to 20.29 mm. DZSHT-81-1/90 had the longest bulb height (52.33 mm) followed by DZSHT-14-2-1/90 (51.96 mm) differing from five of the genotypes (DZSHT- 307-1/90, DZSHT-85-2-3, DZSHT-224 , DZSHT-242-1-2 and DZSHT-147-1C) which had short bulb height ranging from 35.39 to 33.12 mm. The highest plant height (52.63 cm) was recorded in DZSHT-009-2 which only significantly differed from DZSHT-002/07 which had 32.85 cm. DZSHT-34-1B had the thickest sheath diameter (19.21 mm) which only differed from DZSHT-101-1B (10.72 mm). Genotypes with thick sheath diameter are likely to have bulbs with thick neck which might reduce storage life. DZSHT-147-1C had the highest number of leaves/plant (67.85) significantly more than thirty three of the genotypes which had leaf numbers ranging from 33.93 to 20.89. The vegetative vigor owing to leaf number, however, was not translated into better yield than in other genotypes which had fewer leaves. DZSHT-111-2-1 (82.79%), DZSHT-OP-13-3-4/94 (72.26%), DZSHT-OP-45-1A-1 (66.65%), DZSHT-OP-OP-47-1c-1 (64.35%) DZSHT-OP-34A/90 (63.18%) and other ten genotypes had high percent of bolting plants, while DZSHT-65-6/90 DZSHT-305-2-3/90, DZSHT-21-2/07 and DZSHT-114-1-2/90 had less than 2% bolting. Likewise, Getachew et al. (2022) and Josipa et al. (2021) found that shallot genotypes from Ethiopia and Croatia, respectively, had bolting percentage ranging from 0 to 100%. Wassu et al. (2018) and Getachew (2018) also indicated that shallot genotypes had a potential of attaining 95% and 98% bolting, respectively. Such a complete bolting was attained in some shallot genotypes that received verenalization temperature of 8 or 12ºC for 60 days (Getachew, 2004). High bolting percent of plants during bulb production is not a desired characteristic of shallot because inflorescences compete with developing bulbs for photosynthates thus limiting bulb growth and reducing yield. Selection for low bolting genotypes at this phase is often a key criterion for better yield and reduces the otherwise expensive deflowering practice.

Bulb height to diameter ratio ranged from 1.66 in DZSHT-147-1C to 1.11 in DZSHT-35-1B, sheath length from 3.79 cm in DZSHT- 285-2-1 to 7.37 cm in DZSHT-41-2B while the number of shoots ranged from 3.1 in DZSHT-224 to 8.1 in DZSHT-93-1A-1. The genotypes DZSHT-OP-057-1/90 and DZSHT-OP-242-1-2 produced the highest (8.9) and the lowest (1.9) number of inflorescence/ plant. Although higher number of inflorescence are required in bulb to seed production phase for better seed production, genotypes with no or low number of inflorescence per plant are required for better bulb yield.

Various bulb skin colors were observed among the genotypes. Among the 81 genotypes characterized 4 (4.9%), 7 (8.6%), 13 (16.1%), 28 (34.6%) and 29 (35.8%) were yellow, golden, light red, red and dark red (***Table 1***, ***Figure 4***) in agreement with the findings Arifin et al. (1999), Josipa et al. (2021) and Getahun et al. (2003). However, no clear relation was observed between bulb skin color and dry matter percent or TSS of the genotypes; low and high percent dry matter and TSS were observed in each of the skin color categories. The results disagree with the local established belief that red and dark red genotypes have high dry matter and TSS contents and hence are considered as pungent. As a result, the red and dark red genotypes enjoyed high local demand and breeders favored genotypes with these bulb colors to win the acceptance of consumers for their varieties. On the other hand, yellow and golden varieties have been disfavored in the local breeding works despite of their merits such as high yield and favorable bulb related traits. Based on the aforementioned facts, it is thus imperative to gradually convince consumers to use these genotypes alike the red and dark red genotypes.

Principal Component Analysis

The principal component analysis (PCA) for fifteen traits was computed to identify traits that explained most of the variations and hence are important for the improvement of shallot (***Table 2***). As a result, six principal components with eigen values of greater than /close to unity, which accounted for 76% of the total variation among the genotypes were identified. The results are in agreement with that of Getachew et al. (2022) who examined genetic diversity of 63 shallot genotypes in seven components, five of which contributed to 83.1%. Hanci & Gokce (2016) indicated that 71.8% of the variations were accounted for nine principal components in 87 onion genotypes. Similarly, Ravindra et al. (2018) reported five principal components with 78.5% variability in 58 onion accessions. Accordingly, Principal Component one (PC1) had an eigen value of 2.94 and accounted for 21% of the total variation. Yield, yield/plant, bulb height and diameter were associated with PC1 with high loading effect. PC2 had an eigenvalue of 2.38 and accounted for 17% of the total variation mainly due to yield, bulb height: diameter, number of shoots, number of leaves and sheath diameter. PCA3 had an eigenvalue of 1.64 and contributed to 12% of the variation due to plant height, sheath length and diameter and percent bolting. PC4, PC5 and PC6 had eigenvalues of 1.51, 1.17, 0.95 and contributed to 11, 8 and 7% of the variation, respectively. TSS, DM, sheath length and bolting percent exerted high loading and great effect on PC4. Traits such as TSS, sheath diameter, percent bolting and number of flowers talks/plant had high loading values on PC5 whereas only DM and sheath diameter had high values on PC6.

The loading plot of the PCA (***Figure 2***) revealed the relations among the different parameters along the values of the first two principal components which explained 38% of the variation. Yield, yield/plant, bulb height and bulb diameter were positively correlated with PC1 and to each other. On the other hand, sheath length, plant height, percent bolting and number flower stalks/plant had low loadings to PCA1 and are not well explained by it. They are positively correlated to each other and positively but weakly correlated to yield related traits. Number of leaves, number of shoots, bulb height and diameters are correlated to each other and to PCA 1 with high loadings; however, they are negatively correlated or not at all related to the other parameters. TSS and dry matter are neither related to the vegetative nor yield traits and are weakly correlated to each other. Variables DM%, percent bolting, plant height, sheath length and number of flower stalks/plant are not well explained by the PCA.

The score plot of the principal component (***Figure 1***) showed the values of the genotypes on the first two principal components. It indicated that genotypes DZSHT-OP-81-1/90(14), DZSHT-OP-51-2 (17), DZSHT-OP-14-2-1/90 (18) and DZSHT-OP-009-2 (36) have high values of yield, yield/plant, bulb height and bulb diameter. On the other hand, genotypes DZSHT-147-1C (35) had high number of shoots, number of leaves, bulb height: diameter ratio but poor yield, yield/plant, bulb diameter and bulb height.

Cluster analysis

Cluster analysis of the eighty-one genotypes based on fourteen quantitative traits grouped the genotypes into six clusters (***Tables 3-4***). Cluster I comprised of 22 genotypes which makes 27.2% whereas Cluster II contains most (30) of the genotypes constitueting 30.7% of the genotypes. Cluster IV has 20 geotypes that made 24.5%. Clusters III, V and VI contained 2, 8, and 9 genotypes which is 2.5, 9.9, and 11.1% of the genotypes. Cluster I is characterized by genotypes with high bulb yield, yield/plant, bulb diameter, bulb height and plant height. High yielding genotypes such as DZSHT-OP-79-1A, DZSHT-OP-21-2/07, DZSHT-OP-305-2/90 DZSHT-OP-24-1-2 and DZSHT-OP-155-2-2/90 belong to this cluster. Genotypes in Cluster II are characterized by high TSS, dry matter and bulb height to diameter ratio indicating that genotypes in this cluster have good quality for use as dehydrated products. Among the genotypes that belong to this cluster is the widely grown shallot variety (Minjar). Genotypes in Cluster III (DZSHT-OP-83-2-3 and DZSHT-OP-147-1C) are characterized by high yield, yield/plant, bulb height to bulb diameter ratio, number of leaves, number of shoots and number of flower stalks/plant. These genotypes are vegetatively vigorous, high yielders and high bolters. Consequently, these genotypes could be sensitive to cool temperature growing conditions that may lead them to high bolting. The twenty genotypes in Cluster IV had high yield and number of shoots. The recently released shallot variety DZSHT-005/02 belongs to this cluster. Genotypes in Cluster VI are low in most parameters except for bulb height to bulb diameter ratio. Simiarity within and between clusters is depicted by the dendrogram (***Figure 3***). Genotypes within clusters I, II, III, IV and VI had atleast 39.4, 42.3, 57.2, 47.1, 47.2 and 49.3% similarities, respectively. High cluster distances were observed between Cluster III and all other clusters, and Cluster VI and clusters I and V (***Table 5***). Genotypes within distant clusters, have high dissimilarity, are expected to make good hybrids.

Conclusions

Shallot is one of the important vegetable and condiment crops used to flavor different cuisines in different countries. In Ethiopia, shallot had been the sole traditionally used condiment crop reputed for its culinary values until common onion was introduced in 1980s. It is still preferred for its special flavor and keeping quality of “doro wot”, the traditional chicken stew, in which shallot is the major ingredient. Despite its importance, the production of shallot in Ethiopia has been decreasing owing to its low productivity and reproduction through vegetative bulbs; bulbs as planting material are expensive, bulky to transport and transmit diseases. In order to mitigate aforementioned problems, current research attempts in Ethiopia have been geared towards developing varieties that are productive and can reproduce using botanical seeds. Development of such varieties with desirable agronomic traits, first and for most, needed broadening the genetic base of local shallot germplasm. In such an attempt, local shallot germplasm within the holding of DZARC were subjected to natural agro-ecology of the central highland Ethiopia (KARC) and were allowed to bolt, flower and freely open pollinate. Seeds from these genotypes were collected and sown on a seed bed in midland agro-ecology (DZARC). The process of seed-bulb-seed production and selection cycles were carried out for three cycles resulting in about 168 new genotypes. In the present study, 81 of the genotypes were characterized, evaluated and classified based on fifteen important agronomic traits. The genotypes along with information generated could be used and made available to undertake the following future breeding activities:

- Develop varieties with high bulb yield and quality,
- Develop varieties for dehydrated products with high dry matter and TSS contents,
- Develop hybrid varieties that could combine best agronomic traits,
- Develop varieties that can be easily regenerated through botanical seeds, and
- Further diversify the genetic base of shallots through open pollination.

However, as the study was undertaken for one season, further investigation could help generate more valuable information.

Table 1. Bulb yield, yield components and vegetative characteristics of ninety one shallot genotypes at Debre Zeit, Ethiopia

Genotype	**Yield (t/ha)**	**Yield/ plant (g)**	**DM%**	**TSS (°Brix)**	**Bulb diameter (mm)**	**Bulb height (mm)**	**Bulb height: diameter**	**Plant height (cm)**	**Sheath length (cm)**	**Sheath diameter (mm)**	**No. of Shoots/ plant**	**No of leaves/ plant**	**Percent bolting**	**No. of Flower stalk/plant**	**Bulb skin color****
DZSHT-79-1A	31.34a*	163.6ab	15.35ab	13.25ab	31.46abc	47.59abc	2.65ns	48.94ab	6.07	15.44ab	4.78	41.16ab	3.12ab	5.28	DR
DZSHT-34-2-1	29.93ab	130.68ab	19.45 ab	14.91b	31.08abc	40.35abc	1.49	47.98ab	6.61	13.31ab	6.8	35.08ab	54.92ab	5.16	LR
DZSHT-85-2-3	27.64abc	165.32ab	14.02 ab	13.37ab	28.189 bc	34.85 bc	1.31	45.89ab	4.86	13.04ab	6.9	44.23ab	54.75ab	7.57	LR
DZSHT-13-3-1/90	26.25abc	155.77b	15.50 ab	13.47ab	27.65bc	40.14abc	1.49	41.78ab	4.67	15.95ab	5.9	44.04ab	36.05ab	4.82	LR
DZSHT-21-2/07	26.07abc	168.18ab	19.22 ab	13.8ab	34.75abc	44.87abc	1.39	48.29ab	6.13	14.72ab	5.79	45.02ab	2.23 b	5.16	DR
DZSHT-305-2/90	25.88abc	152.57ab	17.19 ab	12.85ab	32.70abc	43.73abc	1.9	46.82ab	5.52	13.09ab	4.76	29.56 b	23.97ab	5.07	R
DZSHT-24-1-2	25.38abc	135.62ab	15.07ab	12.81ab	30.72abc	41.98abc	1.41	40.62ab	6.87	13.00ab	5.34	31.46 b	13.50ab	6.91	DR
DZSHT-285-2-1	25.36abc	167.16ab	14.90ab	12.48ab	32.93abc	45.84abc	1.42	41.60ab	4.89	13.75ab	5.62	41.96ab	20.38ab	2.57	R
DZSHT-002/07	25.18abc	171.57ab	13.73 b	11.176 b	28.92 bc	43.30abc	1.52	32.85b	4.43	12.11ab	5.75	34.19ab	18.49ab	3.76	R
DZSHT-111-2	24.94abc	150.81ab	17.94ab	14.15ab	30.52abc	37.99abc	1.27	46.96ab	6.85	14.52ab	7.42	43.56ab	37.94ab	4.15	R
DZSHT-155-2-	24.53abc	184.41ab	16.19ab	12.82ab	34.31abc	49.85abc	2.44	47.82ab	7.69	18.38ab	5.38	36.56ab	24.76ab	4.07	Y
DZSHT-122-1B	24.43abc	145.61ab	18.27ab	13.82ab	25.22 bc	38.89abc	2.62	47.71ab	6.32	15.08ab	5.61	36.44ab	16.39ab	2.68	R
DZSHT-004-1/90	24.27abc	153.92ab	16.90ab	13.73ab	33.03abc	43.02abc	1.33	45.65ab	5.43	15.31ab	7.07	42.69ab	11.11ab	5.38	DR
DZSHT-81-1/90	24.24abc	179.81ab	13.79ab	13.89ab	34.74abc	52.33a	1.55	49.93ab	5.87	15.06ab	7.65	49.70ab	49.17ab	5.99	R
DZSHT-206-2	24.15abc	180.59ab	14.96ab	13.89ab	33.64abc	44.84abc	1.38	45.76ab	5.55	15.38ab	6.49	40.48ab	60.04ab	3.80	DR
DZSHT-13-3/90	24.02abc	139.69ab	16.31ab	14.05ab	36.32abc	43.03abc	1.18	41.67ab	5.07	14.24ab	5.15	39.20ab	18.20ab	4.29	LR
DZSHT-51-2	23.88abc	207.93a	13.94ab	13.46ab	36.41ab	46.95abc	1.28	48.77ab	6.23	11.86ab	5.35	32.49 b	39.38ab	5.93	R
DZSHT-14-2-1/90	23.79abc	167.32ab	16.36ab	13.73ab	44.69a	51.96ab	1.24	50.45ab	5.95	18.52ab	3.27	23.038b	40.36ab	6.67	DR
DZSHT-66-2/95	23.59abc	177.23ab	14.73ab	13.18ab	33.79abc	49.12abc	1.48	44.06ab	6.69	14.82ab	5.17	33.08 b	37.64ab	5.08	R
DZSHT-101-1B	23.33abc	193.51ab	17.86ab	14.9ab	31.30abc	46.63abc	1.51	46.58ab	5.36	10.72b	6.72	41.83ab	27.97ab	4.04	LR
DZSHT-19-2B	22.88abc	159.95ab	14.08ab	13.19ab	35.64bc	45.93abc	1.28	51.19ab	5.22	19.02a	4.39	33.72b	7.65ab	3.45	G
DZSHT-111-2-1	22.84abc	143.05ab	21.18ab	15.34ab	32.97abc	41.03abc	1.33	46.79ab	6.20	15.2ab	4.68	21.89 b	82.79a	3.88	R
DZSHT-101-1B-3	22.78abc	176.4b	17.33ab	13.44ab	30.90abc	44.57abc	1.48	39.77ab	5.63	14.99ab	5.12	31.48 b	24.38ab	4.06	DR
DZSHT-005/02	22.75abc	148.51ab	15.42ab	14.72ab	30.38abc	41.59abc	1.41	43.50ab	6.59	13.68ab	6.34	32.18 b	25.78ab	2.86	R
DZSHT-23-2/07	22.59abc	151.92ab	16.42ab	13.67ab	32.42abc	44.20abc	1.41	40.21ab	5.16	16.24ab	4.77	31.25 b	35.65ab	6.46	R
DZSHT-41-2B	22.58abc	150.55ab	20.49ab	14.50ab	31.83abc	39.38abc	1.32	50.52ab	7.37	18.5ab	5.62	51.44ab	20.94ab	3.49	G
DZSHT-161-1C-1	22.46abc	147.83ab	16.66ab	14.50ab	32.14abc	45.86abc	1.45	47.04ab	5.59	12.44ab	6.08	35.76ab	31.61ab	4.62	G
DZSHT-102-2	22.29abc	135.78ab	17.99ab	14.87ab	34.98abc	44.97abc	1.33	48.68ab	6.13	16.56ab	3.62	34.14ab	14.75ab	3.34	DR

DZSHT-005/07	22.27abc	154.85ab	12.00 b	14.56ab	28.76 bc	38.97abc	1.42	44.76ab	6.067	13.8ab	7.68	40.39ab	32.41ab	4.70	R
DZSHT-16/07	22.23abc	146.42ab	14.49ab	15.24ab	37.32ab	48.25abc	1.30	43.06ab	5.58	15.54ab	4.15	36.11ab	15.32ab	4.02	DR
DZSHT-47-1B-1	22.17abc	163.54ab	18.43ab	16.19a	35.33ab	43.36abc	1.27	41.92ab	4.53	17.28ab	4.38	32.63b	27.79ab	4.56	G
DZSHT-251-1B-1	21.83abc	150.57ab	15.97ab	13.35ab	32.2abc	42.37abc	1.33	45.81ab	5.95	16.20ab	4.55	30.66 b	46.98ab	6.92	R
DZSHT-13-3-4/94	21.68abc	171.47ab	13.45ab	12.18ab	29.54abc	44.75abc	1.53	49.07ab	6.46	16.93ab	5.19	38.79ab	72.26ab	3.70	R
DZSHT-21-4/07	21.42abc	168.05ab	15.52ab	14.59ab	31.38abc	41.18abc	1.47	47.77ab	7.04	15.42ab	5.24	36.27ab	36.28ab	6.92	DR
DZSHT-147-1C	21.32abc	144.17ab	17.02ab	12.25ab	20.29 c	33.12 c	2.65	41.80ab	5.29	14.8ab	7.08	67.85a	39.31ab	6.15	DR
DZSHT-009-2	21.30abc	196.34ab	14.61ab	13.05ab	37.63ab	49.55abc	1.36	52.63a	6.36	14.76ab	6.25	40.81ab	47.04ab	5.49	DR
DZSHT-51-2-1	20.88abc	184.46ab	15.35ab	13.75ab	32.72abc	39.11abc	1.20	51.21ab	6.53	18.18ab	5.12	33.74b	32.43ab	4.10	R
DZSHT-155-2-	20.82abc	135.1ab	17.17ab	15.95ab	29.99abc	38.42abc	1.39	45.86ab	5.65	14.90ab	5.88	31.25b	44.08ab	3.53	Y
DZSHT-242-1C-1	20.81abc	166.99ab	17.36	12.63ab	37.94ab	48.16abc	1.29	45.81ab	6.12	16.20ab	4.14	34.95ab	20.83ab	4.96	LR
DZSHT-21-1B	20.31abc	111.52ab	17.68ab	14.29ab	27.64bc	41.09abc	2.47	48.79ab	4.88	17.98ab	5.02	45.85ab	7.91ab	2.6	DR
DZSHT-65-5/07	20.07abc	122.36ab	15.33ab	14.72ab	32.38abc	35.96abc	1.16	47.17ab	6.62	14.67ab	4.64	33.93ab	38.35ab	4.71	R
DZSHT-45-1A	19.96abc	146.53ab	13.93ab	14.16ab	30.28abc	43.52abc	1.48	40.04ab	5.49	12.23ab	5.72	32.88 b	58.80ab	3.62	R
DZSHT-47-1C-1	19.89abc	168.06ab	16.69ab	15.29ab	32.14abc	44.45abc	1.41	43.68ab	5.33	13.36ab	4.85	20.99 b	64.35ab	4.02	R
DZSHT-232-1C-1	19.98abc	136.69ab	14.29ab	13.17ab	31.41abc	43.61abc	1.42	46.96ab	5.93	16.86ab	4.93	38.73ab	49.21ab	2.84	R
DZSHT-41-1-2/90	19.88abc	134.04ab	17.59ab	15.31ab	34.03abc	40.30abc	1.38	52.38ab	5.60	17.52ab	4.52	31.48 b	21.44ab	4.58	Y
DZSHT-19-2B-4	19.68abc	155.12ab	15.47ab	15.05ab	29.36abc	39.99abc	1.43	42.66ab	5.84	17.51ab	6.02	39.26ab	24.36ab	4.10	LR
DZSHT- 307-1/90	19.65abc	125.26ab	16.32ab	16.78a	26.92 bc	35.39 bc	1.49	51.35ab	7.5	14.5ab	6.53	37.87ab	18.64ab	4.45	LR
DZSHT-004/07	19.65abc	142.50ab	22.79a	14.52ab	29.75 bc	36.58abc	1.25	38.24ab	5.85	13.4ab	5.58	30.55 b	50.12ab	5.26	LR
DZSHT-305-2-	19.51abc	102.2ab	14.76ab	14.88ab	27.69bc	36.34abc	1.34	42.46ab	6.24	15.13ab	5.37	32.16 b	1.88ab	3.77	DR
DZSHT-255-2-	19.26abc	116.53ab	16.23ab	13.94ab	27.92 bc	37.05abc	1.35	40.64ab	6.26	13.7ab	6.99	36.68 b	41.19ab	2.69	DR
DZSHT-67/90	19.22abc	147.13ab	15.71ab	13.57ab	31.67abc	40.50abc	1.28	42.81ab	6.32	17.38ab	5.01	27.34 b	54.72ab	3.86	DR
DZSHT-111-2/05	19.11abc	175.98ab	12.73 b	12.30ab	30.83abc	41.35abc	1.42	48.89ab	5.79	15.47ab	4.44	42.36ab	25.42ab	3.43	DR
DZSHT-272-1-	19.08abc	146.41ab	15.26ab	12.38ab	33.66abc	42.70abc	1.39	43.57ab	6.16	16.17ab	4.45	33.88 b	11.47ab	2.16	DR
DZSHT-34A/90	18.98abc	126.04ab	15.84ab	13.65ab	31.89abc	39.04abc	1.22	38.39ab	5.26	15.55ab	5.24	30.95 b	63.18ab	6.35	R
DZSHT-057-1/90	18.98abc	130.37ab	18.41ab	14.075ab	30.42abc	42.90abc	1.45	40.16ab	5.19	15.56ab	3.55	28.49 b	40.45ab	8.93	Y
DZSHT-47-1B	18.88abc	147.96ab	16.19ab	14.07ab	27.82 bc	39.04abc	1.45	46.38ab	5.68	18.15ab	5.08	33.03 b	31.94ab	3.81	R
DZSHT-93-1A-1	18.62abc	146.42ab	17.25ab	14.44ab	26.06bc	36.50abc	1.43	40.89ab	6.99	13.17ab	8.14	41.16ab	27.55ab	3.24	DR
DZSHT-72-2-3	18.36abc	134.04ab	16.04ab	14.04ab	31.25abc	37.79abc	1.31	44.07ab	6.12	13.19ab	5.04	32.33 b	60.15ab	5.90	LR
DZSHT-224	17.97abc	117.00ab	17.36ab	14.53ab	28.49 bc	34.23 bc	1.29	43.86ab	5.14	18.42ab	3.14	36.07ab	50.64ab	4.08	R

DZSHT-42-2A-1	17.86abc	159.98ab	16.49ab	14.58ab	34.19abc	40.19abc	1.25	48.38ab	6.30	16.02ab	4.12	34.88ab	43.67ab	5.57	R
DZSHT-009-2-1	17.73abc	143.61ab	17.64ab	15.13ab	25.75 bc	40.08abc	1.65	37.86ab	5.46	13.65ab	5.45	27.39b	22.14ab	5.64	R
DZSHT-72-2	17.65abc	139.12ab	20.31ab	14.92ab	32.19abc	35.68abc	1.15	42.10ab	6.16	12.12ab	5.32	29.33 b	38.48ab	5.05	DR
DZSHT-35-1B	17.44abc	139.78ab	14.01ab	15.36ab	34.8abc	36.36abc	1.11	44.91ab	4.44	15.65ab	4.60	35.29ab	44.41ab	4.72	Y
DZSHT-206-1	17.14abc	124.46ab	15.90ab	13.69ab	33.59abc	45.06abc	1.37	37.70ab	5.58	16.85ab	5.22	37.85ab	29.39ab	4.92	LR
DZSHT-251-	17.11abc	137.15ab	14.23ab	13.82ab	31.89abc	43.36abc	1.43	42.59ab	5.69	14.47ab	5.55	34.11ab	42.36ab	5.71	R
DZSHT-54-2-1	17.19abc	146.03ab	14.40ab	14.12ab	35.52abc	41.50abc	1.19	43.08ab	5.53	13.86ab	4.94	24.09 b	48.39ab	5.04	R
DZSHT-35-1B-2	16.96abc	116.57ab	18.86ab	15.10ab	27.78bc	38.66abc	1.45	43.82ab	6.37	17.22ab	5.13	35.24ab	39.28ab	3.43	LR
DZSHT-009-2-	16.79abc	166.88ab	17.02ab	15.84ab	30.98abc	45.70abc	1.50	40.69ab	5.37	14.92ab	5.77	27.85 b	38.27ab	3.71	DR
Minjar	16.79abc	117.63ab	15.53ab	13.57ab	31.73abc	42.31abc	1.34	41.79ab	5.96	14.86ab	6.79	36.36ab	26.72ab	3.64	DR
DZSHT-34-1B	16.05abc	120.67ab	14.10ab	15.33ab	29.60abc	35.94abc	1.29	45.12ab	5.67	19.21a	4.43	37.04ab	31.77ab	3.87	G
DZSHT-161-1C	15.93abc	117.14ab	16.31ab	13.80ab	26.57 bc	39.78abc	1.55	38.71ab	6.67	12.98ab	6.21	35.19ab	4.84ab	3.65	DR
DZSHT-100-2	15.91abc	135.72ab	16.09ab	14.97ab	25.75 bc	39.83abc	1.64	48.14ab	6.26	17.06ab	6.65	49.16ab	42.52ab	3.45	G
DZSHT-25-2-1/90	14.61abc	90.89ab	18.75ab	14.45ab	25.30 bc	38.49abc	1.56	41.93ab	6.65	14.06ab	5.76	38.26ab	28.94ab	4.12	DR
DZSHT-45-1A-3	14.54abc	136.01ab	14.67ab	15.27ab	31.19abc	39.77abc	1.45	43.36ab	6.5	17.79ab	4.03	26.13b	55.89ab	4.02	G
DZSHT-114-2/90	14.37abc	147.65ab	15.32ab	12.65ab	35.20abc	46.19abc	1.31	44.57ab	4.95	13.85ab	5.15	37.90ab	22.78ab	3.26	DR
DZSHT-10/07	13.88abc	115.37ab	15.36ab	13.59ab	24.47 bc	35.79abc	1.51	41.32ab	5.29	12.88ab	5.48	32.45 b	40.15ab	5.70	LR
DZSHT-111-2-3	13.34abc	159.01ab	15.09ab	11.96ab	27.69 bc	38.75abc	1.47	47.51ab	6.53	18.05ab	4.47	38.41ab	60.88ab	6.69	R
DZSHT-242-1-2	12.55abc	79.21b	13.33ab	14.42ab	23.47 bc	34.10bc	1.5	35.35ab	5.44	13.55ab	4.03	29.66 b	5.62ab	1.87	DR
DZSHT-114-1-	12.05bc	107.12ab	18.73ab	13.11ab	29.48abc	40.73abc	1.44	50.89ab	5.16	16.38ab	4.49	40.72ab	-5.14ab	3.23	DR
DZSHT-65-6/90	99.72bc	74.51b	14.99ab	13.95ab	26.67 bc	39.89abc	1.53	46.34ab	5.65	16.04ab	4.19	28.66 b	0.78ab	2.78	DR
DZSHT-45-1A-1	9.63c	116.05ab	12.28b	13.70ab	30.61abc	40.00abc	1.38	42.89ab	5.09	17.67ab	4.54	36.76ab	66.66ab	6.79	R
Mean	20.35	145.79	16.15	13.98	31.14	41.59	1.39	44.68	5.79	10.32	5.30	35.76	33.87	4.53	
LSD 0.05	17.53	115.11	11.42	4.58	13.91	15.84	0.66	16.72	3.29	6.99	4.60	30.09	87.15	6.99	
CV (%)	19.38	17.75	15.90	7.37	10.05	8.56	10.67	8.41	12.77	15.23	19.51	18.92	57.98	34.67	

*Means followed by the same letter are not significantly different from each other at 5% level of probability

**Y = yellow, G = golden, LR = light red, R = red, DR = dark red

Table 2. The first six principal components that explain the variation of fourteen measured traits of 81 shallot genotypes.

Variable	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**
Yield (Q/ha)	**0.35**	**0.30**	-0.06	0.14	0.25	-0.05
Yield/ plant (g)	**0.47**	0.20	-0.09	0.07	-0.03	0.01
DM%	-0.06	0.02	-0.05	**0.35**	0.28	**-0.81**
TSS	-0.18	-0.27	0.05	**0.39**	**0.39**	0.03
Bulb height: diameter	-0.17	**0.40**	0.12	-0.25	-0.12	-0.23
Bulb diameter	**0.49**	-0.25	-0.05	-0.05	0.19	0.04
Bulb Height	**0.46**	0.07	-0.00	-0.28	0.17	-0.10
Plant height	0.29	-0.03	**0.53**	0.24	-0.10	0.02
Sheath length	0.04	-0.00	**0.40**	**0.44**	-0.04	0.31
Sheath diameter	0.08	**-0.30**	**0.45**	-0.11	**-0.32**	**-0.34**
No. Shoots	-0.06	**0.51**	-0.06	0.31	0.11	0.19
No Leaves	-0.02	**0.45**	0.29	0.02	-0.24	-0.12
Percent Bolting	0.07	-0.12	**-0.33**	**0.39**	**-0.47**	-0.03
No. Flower stalk	0.18	-0.02	-0.36	0.20	**-0.47**	-0.10
Eigenvalue	2.94	2.38	1.64	1.51	1.17	0.95
Proportion	0.21	0.17	0.12	0.11	0.08	0.07
Cumulative	0.21	0.38	0.50	0.61	0.69	0.76

Table 3. Distribution of eighty-one genotypes into seven clusters based on Euclidean distance.

Cluster number	**No. of genotypes**	**Percentage**	**Genotypes**
I	22	27.2	DZSHT-OP-79-1A, DZSHT-OP-21-2/07, DZSHT-OP-305-2/90, DZSHT-OP-24-1-2, DZSHT-OP-155-2-2/90, DZSHT-OP-004-1/90, DZSHT-OP-81-1/90, DZSHT-OP-206-2, DZSHT-OP-OP-51-2, DZSHT-OP-14-2-1/90, DZSHT-OP-66-2/95,DZSHT-OP-19-2B,DZSHT-OP-101-1B-3, DZSHT-OP-13-3-4/94, DZSHT-OP-21-4/07, DZSHT-OP-009-2, DZSHT-OP-51-2-1, DZSHT-242-1C-1, DZSHT-OP-232-1C-1, DZSHT-OP-111-2/05, DZSHT-OP-272-1-2/90, DZSHT-OP-114-2/90
II	30	30.7	DZSHT-OP-34-2-1, DZSHT-OP-111-2,DZSHT-OP-122-1B, DZSHT-OP-13-3/90, DZSHT-OP-111-2-1, DZSHT-OP-41-2B, DZSHT-OP-102-2, DZSHT-OP-16/07, DZSHT-OP-47-1B-1, DZSHT-OP-155-2-1/90, DZSHT-OP-65-5/07, DZSHT-OP-41-1-2/90, DZSHT-OP-19-2B-4, DZSHT-OP- 307-1/90, DZSHT-OP-004/07, DZSHT-OP-255-2-1/90, DZSHT-OP-67/90, DZSHT-OP-47-1B, DZSHT-OP-93-1A-1, DZSHT-OP-224, DZSHT-OP-42-2A-1, DZSHT-OP-72-2, DZSHT-OP-35-1B, DZSHT-OP-206-1, DZSHT-OP-54-2-1, DZSHT-OP-35-1B-2, Minjar, DZSHT-OP-34-1B, DZSHT-OP-100-2, DZSHT-OP-45-1A-3
III	2	2.5	DZSHT-OP-85-2-3, DZSHT-OP-147-1C
IV	20	24.5	DZSHT-OP-13-3-1/90, DZSHT-OP-285-2-1, DZSHT-OP-002/07, DZSHT-OP-101-1B, DZSHT-OP-005/02, DZSHT-OP-161-1C-1, DZSHT-OP-005/07, DZSHT-OP-45-1A, DZSHT-OP-47-1c-1, DZSHT-OP-009-2-2/07
V	8	9.9	DZSHT-OP-23-2/07, DZSHT-OP-251-1B-1, DZSHT-OP-34A/90, DZSHT-OP-057-1/90, DZSHT-OP-72-2-3, DZSHT-OP-251-1B/95, DZSHT-OP-111-2-3, DZSHT-OP-45-1A-1
VI	9	11.1	DZSHT-OP-21-1B, DZSHT-OP-305-2-3/90, DZSHT-OP-009-2-1, DZSHT-OP-161-1C, DZSHT-OP-25-2-1/90, DZSHT-OP-10/07, DZSHT-OP-242-1-2, DZSHT-OP-114-1-2/90, DZSHT-OP-65-6/90

Table 4. Cluster means (centroids) of fourteen parameters∗ in six clusters.

Variable	**I**	**II**	**III**	**IV**	**V**	**VI**
Yield (q/ha)	**0.59**	-0.11	**0.99**	**0.50**	-0.66	-1.24
Yield/ plant (g)	**0.89**	-0.32	0.36	**0.65**	-0.30	-1.64
Dry matter (%)	-0.30	0.37	-0.36	-0.33	-0.05	-0.00
TSS	-0.87	**0.73**	-1.13	0.13	-0.43	0.19
Bulb height: diameter	0.02	-0.55	**0.77**	**0.59**	-0.11	**1.04**
Bulb diameter	**0.75**	0.02	-1.84	-0.16	-0.03	-1.28
Bulb height	**0.94**	-0.48	-1.79	0.47	-0.13	-0.73
Plant height	0.62	0.04	-0.21	-0.60	-0.49	-0.50
Sheath length	0.31	0.20	-1.17	-0.76	-0.23	-0.11
Sheath diameter	0.18	0.28	-0.93	-1.02	0.33	-0.32
No. shoots	-0.06	-0.06	**1.68**	**0.63**	-0.58	-0.19
No Leaves	0.13	-0.10	**2.88**	-0.08	-0.41	-0.18
Bolting (%)	-0.21	0.16	0.73	0.10	**1.00**	-1.17
No. flower stalk/plant	0.14	-0.31	**1.73**	-0.49	**1.63**	-0.61

*standardized data

Table 5. Inter cluster distances between cluster centroids.

Cluster	I	II	III	IV	V
I					
II	2.93				
III	5.78	5.68			
IV	2.75	2.82	5.04		
V	3.29	2.73	5.40	3.54	
VI	4.71	3.22	5.99	3.81	4.02

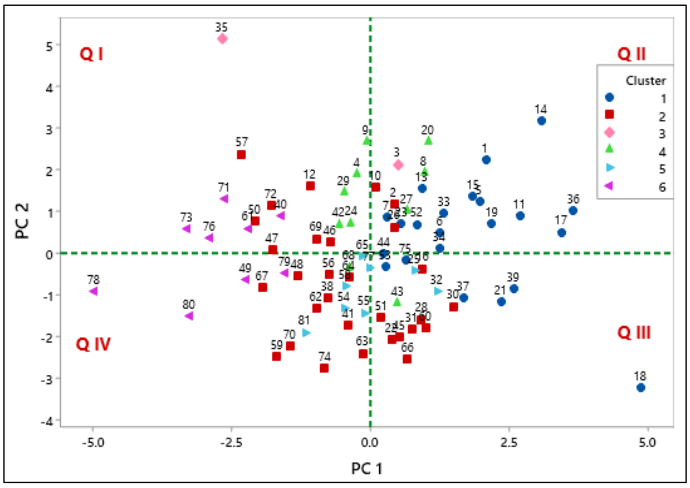

Figure 1. Principal component analysis score-plot of PC1 and PC2 describing overall variation among shallot genotypes. Numbers on the scatter plot indicate shallot genotypes as shown in ***Table 1.***

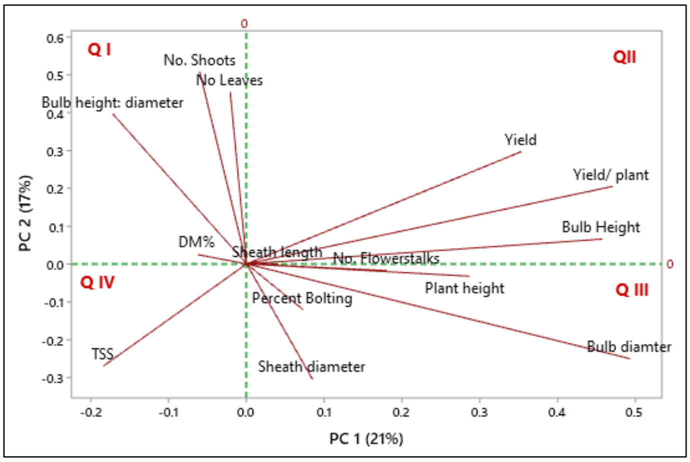

Figure 2. Principal component analysis loading-plot for 15 quantitative traits of 81 shallot genotypes.

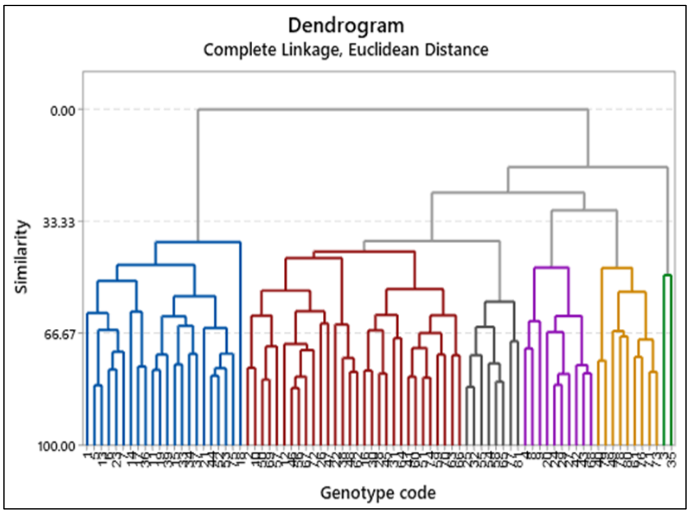

Figure 3. Dendrogram showing eighty-one genotypes into seven clusters.

Figure 4. Samples of the shallot genotypes that differ in bulb characters.

Acknowledgements

The authors acknowledge the Ethiopian Institute of Agricultural Research for funding the research. Staff of the Cool Season Vegetables Program of Debre Zeit and Kulumsa agricultural research centres are also acknowledged for handling the research fields and data collection.

References

Arifin, N. S., Miyajima, I., Okubo, H. (1999): Variation of pigments in the bulbs of shallot (*Allium cepa* L. var. *ascalonicum*) and *Allium* × *wakegi*. Journal of Faculty of Agriculture. 43(3-4): 303–308.

Awale, D., Sentayehu, A., Getachew, T. (2011): Genetic variability and association of bulb yield and related traits in shallots (*Allium cepa* L. var. *aggregatum*) in Ethiopia. International Journal of Agricultural Research. 6(7): 517–536. https://doi.org/10.3923/ijar.2011.

Blashfield, R. K, Aldenderfer, M. S. (1988): The methods and problems of cluster analysis. In: Nesselroade JR, Cattell RB, eds. Handbook of Multivariate Experimental Psychology. Boston, MA: Springer. 447-473. http://doi.org/10.1007/978-1-4613-0893-5-14.

Brickell, C. D., Alexander, C., Cubey, J. J., David, J. C., Hoffman, M. H., Malécot, A. (2016): International code of nomenclature for cultivated plants (ICNCP or Cultivated Plant

Code). Leuven International Society for Horticultural Science. 9th edn. Scripta Horticulture. Number 18.

Cabral, P. D. S., Soares, T. C. B., Goncalves, L. S. A., Amaral, A. T., Jr, Lima, A. B. P., Rodrigues, R., Mata, F. P. (2010): Quantification of the diversity among common bean accessions using Ward MLM strategy. Brazilian Journal of Agricultural Research. 45(10): 1124–1132. https://doi.org/ 10.1590/S0100-204X2010001000011.

Central Statistical Agency (CSA) (2018): Agricultural Sample Survey. The Federal Democratic Republic of Ethiopia. Addis Ababa, Ethiopia.

Debre Zeit Agricultural Research Centre (DZARC) (2008): Annual Research Report, Debre Zeit, Ethiopia.

Diriba, S. G., Nigussie, D. R., Kebede, W., Getachew, T., Sharma, J. J. (2013): Growth and nutrients content and uptake of garlic (*Allium sativum* L.) as influenced by different types of fertilizers and soils. Science, Technology and Arts Research Journal 2(3): 35-50. http://dx.doi.org/10.4314%2Fstar. v2i3.98727.

Farid, N., Sugiharto, A. N., Herison, C., Purwito, A., Sutjahjo, S. H. (2012): Analysis of combining ability, heterosis effect and heritability estimate of yield-related characters in shallot (*Alium cepa* L. var. *ascalonicum* Baker). Agrivita. 34 (1): 36-43.

Fasika, S., Hailu, T., Kebede, W.T. (2008): Genetic variability studies in Ethiopian shallot (*Allium cepa* L. var. *ascalonicum* Backer) genotypes. East African Journal of Sciences. 2 (2): 130-134.

Food and Agriculture Organization (FAOSTAT) 2018: Corporate Statistical Database. http://www.fao.org/faostat/en/ #data/QC/visualize

Fritsch, R. M., Friesen, N. (2002): Evolution, domestication and taxonomy. In: Rabinowitch HD, & Currah L, eds. Allium crop science: recent advances. Wallingford: CABI, 5-30.

Gabriel, K. R. (1971): The biplot graphic display of matrices with application to principal componenet analysis. Biometrika. 58: 453-467.

Getachew, T. (2004): Manuplation of flowering for seed production of shallot (*Allium Cepa* L. var. *ascalonicum Backer*). Hannover, Germany: Hannover, University, PhD dissertation.

Getachew, T. (2018): Development of seed propagated shallot (*Allium cepa* L var. *aggregatum*) varieties in Ethiopia. Scientia Horticulturae. 240: 89–93.

Getachew, T., Asfaw, Z. (2000): Achievements in shallot and garlic research. Research report. Number 38, Ethiopian Agricultural Research Organization, EARO, Addis Ababa, Ethiopia.

Getachew, T., Eshetu, D., Tebikew, D. (2008): Shallot and garlic production guide (Amharic). Ethiopian Institute of Agricultural Research. Addis Ababa, Ethiopia.

Getachew, T., Gizachew, A., Fekadu, G.T., Fasil, T., Yenenesh, A., Desta, F. (2022): Genetic diversity of shallot (*Allium cepa* L. var. *aggregatum*) segregating populations from Ethiopia using multivariate analysis. Ethiopian Journal of Crop Sciences. 1(10): 67-80.

Getahun, D., Zelleke, A., Derso, E., Kiflu, E. (2003): Storability of shallot cultivars (*Allium cepa* L. var. *ascalonicum* Backer) at Dere Zeit, Ethiopia. Acta Hortic. 604, 639-646 https://doi.org/10.17660/ActaHortic. 2003.604.78.

Hanci, F., Gokce, A. F. (2016): Genetic diversity evaluations in Turkish onion (*Allium cepa* L.) genotypes: Principal component analyses (PCA) for breeding strategies. Acta Horticulture. 1143: 227-234.

Hasanah, Y., Mawarni, L., Hanum, H., Lestami, A. (2022): Genetic diversity of shallots (*Allium ascalonicum* L.) from several locations in North Sumatra, Indonesia based on RAPD markers. Biodiversitas. 23(5): 2405-2410.

International Plant Genetic Resources Institute (IPGRI) (2001): Descriptors of *Allium* spp, Rome.

Ita A, Pratiwi, EA, Awang, M., Sobir, H. H. (2016): Collection and characterization of shallot germplasm in effort to support national food security. Proceeding International Seminar on Tropical Horticulture: The Future of Tropical Horticulture. IPS International Convention Centre, Bogor, Indonesia, 28-29.

Josipa, P., Nikola, M., Dean, B., Danko, C., Smiljana, G.B. (2021): Shallot species and subtypes discrimination based on morphology descriptors. Plants. 10 (60): 1-17. https://doi.org/10.3390/plants10010060.

Levenstien, M. A., Yang, Y., Ott, J. (2003): Statistical significance for hierarchical clustering in genetic association and microarray expression studies. BMC Bioinformatics. 11 (4): 62. https://doi.org/10.1186/1471-2105-4-62

Major, N., Goreta, B. S., Urlic, B., Ban, D., Dumicic, G., Perković, J. (2018): Morphological and biological diversity of shallot landraces preserved along the Croatian coast. Frontier in Plant Sciences. 9, 1749.

Ministry of Agriculture and Natural Resource (MoANR) (2019): Plant variety release, protection and seed quality control directorate. Crop Variety Register. 22: 1-393.

Minitab, L. L. C. (2020): Minitab 19 Statistical Software. https:// www.minitab.com.

Placide, R., Shimelis, H., Laing, M., Gahakwa, D. (2015): Application of principal component analysis to yield and yield related traits to identify sweet potato breeding parents. Journal of Tropical Agriculture. 92 (1): 1-15.

Rabinowitch, H. D., Kamenetsky, R. (2002): Shallot (*Allium cepa* L *aggregatum* group). In: Rabinowitch & Currah, eds. Allium Crop Science: Recent Advances, Wallingford: CABI, 409-430.

Ravindra, D., Amrender, K., Anil, K. (2019): Genetic variability, heritability, and diversity analysis studies in short day tropical onion (*Allium cepa* L.). Indian Journal of Agricultural Science. 88(6): 948-957.

Simon, P.W. (1995): Genetic analysis of pungency and soluble solids in long-storage onions. Euphytica. 82: 1-8.

Singh, S. R., Lal, S., Ahmed, N., Srivastava, K. K., Kumar, D., Jan, N., Amin, A., Malik, A. R. (2013): Determination of genetic diversity in onion (*Allium cepa* L.) using the multivariate analysis under long day conditions. African Journal of Biotechnology. 7(20): 599-606.

Wassu, M., Kebede, W. T., Bekele, K. (2018): Registration of a new “Improved Huruta” shallot variety with true seed production potential. East African Journal of Sciences. 12: 77-82.