PLANT SCIENCE TODAY
Vol 13(sp1): 1-9
https://doi.org/10.14719/pst.10586

eISSN 2348-1900

RESEARCH ARTICLE

Characterization of aggregatum onion germplasm (*Allium cepa* var. *aggregatum*) by using multivariate analysis

Indu Rani C[1*], Kavitha M[2*], Pavithra P[1], Uma Devi M[3], Pugalendhi L[1], Savitha B K[1] & Vijay Mahajan[4]

[1]Department of Vegetable Science, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

[2]Horticultural Research Station, Vijayanagaram, Ooty 643 001, Tamil Nadu, India

[3]Centre for Plant Breeding and Genetics, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

[4]ICAR-Directorate of Onion and Garlic Research, Pune 410 505, Maharashtra, India

*Correspondence email - ci76@tnau.ac.in, kavitha.m@tnau.ac.in

Received: 11 July 2025; Accepted: 27 November 2025; Available online: Version 1.0: 05 March 2026

Cite this article: Indu RC, Kavitha M, Pavithra P, Uma DM, Pugalendhi L, Savitha BK, Vijay M. Characterization of aggregatum onion germplasm (*Allium cepa* var. *aggregatum*) by using multivariate analysis. Plant Science Today. 2026; 13(sp1): 1-9. https://doi.org/10.14719/pst.10586

Abstract

The present study was conducted to assess the variation among 67 aggregatum onion accessions using 15 agro-morphological characters at the Department of Vegetable Science, Tamil Nadu Agricultural University, Coimbatore during rabi 2022–23. Based on per se performance, the populations Aca 15, Aca 9 and Aca 25 were found superior to the check variety CO (On) 5 for yield and yield-contributing traits. The results revealed that the first six principal components explained about 70.39 % of the total variation among the fifteen characters in 65 onion accessions, with eigenvalues greater than 1. PC1 accounted for 18.63 % of the total variability for all the traits. The traits such as number of leaves, number of shoots, polar and equatorial diameter, number of bulbs, weight of bulbs, total soluble solids and pest and disease incidence contributed the most to the observed variability. Principal component analysis (PCA) will help researchers understand, utilize, conserve and manage the collection for a more efficient contribution to onion research and cultivation. Hence, a plant breeder must place special emphasis on these traits while conducting selection in a crop improvement programme in onion.

Keywords: aggregatum onion genotypes; genetic variation; principal component analysis

Introduction

Onion (*Allium cepa* L.) is grown as one of the important vegetable crops across the world due to its rich content of carbohydrates, proteins, minerals (Ca, P and Fe), vitamins (B and C) and dietary fibres. It also possesses anti-cholesterol, anti-inflammatory, antioxidant and anticancer properties (1). In India, two main types of onions are commercially grown, each with distinct characteristics and methods of propagation. These two types of onions cater to different culinary needs and agricultural practices in India. The common onion, propagated from seeds, produces large single bulbs suitable for a wide range of dishes and long-term storage. In contrast, multiplier onions, propagated vegetatively through clusters of small bulbs, offer convenience and ease of cultivation in regions where such varieties are preferred or traditionally grown (2). Both types contribute significantly to India's agricultural landscape and culinary diversity.

Multiplier onion, otherwise called as potato onions, scientifically known as *Allium cepa* var. *aggregatum*, is a type of onion that reproduces by forming clusters of bulbs rather than individual bulbs (3). This characteristic is why they are often referred to as "multiplier onions" or "aggregating onions." Instead of producing a single large bulb like common onions (*Allium cepa* var. *cepa*), potato onions produce several small- to medium-sized bulbs clustered together (4). The species exhibits considerable variability across various traits such as bulb characteristics (size, shape and colour), flavour profile, storage capability and the tendency to bolt (flower prematurely) or produce daughter bulbs in the first growing season. These bulbs can be separated and replanted to propagate new plants, making them an efficient and sustainable option for farmers. Propagation from seed is less common because potato onions tend to form bulbs much faster than they produce viable seeds. However, specific varieties like CO (On) 5 and CO 6 may favour seed production and propagation (5). This variation in propagation methods can sometimes lead to different local varieties or adaptations of potato onions, reflecting the diversity and adaptability of this versatile crop. They are valued for their ease of propagation and are often grown for their reliable production of multiple bulbs per plant.

In Tamil Nadu, multiplier onion is extensively grown in 46.54 thousand hectares with a yield of 564.57 thousand metric tonnes. The major onion-growing districts are Perambalur, Tiruchirapalli, Namakkal, Dindigul, Thoothukudi, Tiruppur and Virudhunagar (6). From Tamil Nadu, small onion is exported to Sri Lanka, Indonesia, Thailand, Singapore and Malaysia.

Genetic diversity refers to the variety of genetic characteristics within a species or population. Vegetative propagation typically maintains genetic uniformity because it involves cloning individuals from the same parent plant, leading to limited genetic diversity within the propagated material (7). In contrast, sexual propagation (from seed) introduces genetic variability due to genetic recombination during reproduction. In the case of multiplier onions, despite their usual mode of propagation being vegetative, the genetic diversity found in accessions propagated from seed was comparable to that found in vegetatively propagated accessions. This suggests that sexually propagated potato onions have accumulated a level of genetic diversity similar to that present among vegetatively propagated accessions. This could be due to various factors such as the selection of diverse parents for seed production or natural genetic variability within the seed-produced individuals (8).

Genetic improvement is a continuous process and its success depends on the variability present in the germplasm (9). Principal component analysis (PCA) is a valuable tool in plant breeding and germplasm characterization studies, including those involving onion germplasm. It helps in identifying key traits driving variation, recognizing patterns within the germplasm and facilitating informed breeding decisions aimed at enhancing desirable traits in onion cultivars. PCA identifies the principal components (PCs), which are linear combinations of the original variables (traits) that capture the maximum variance in the data. Traits that contribute more to the PCs are considered more influential in shaping the overall variation among genotypes. It can also reveal groups or clusters of genotypes that share similar trait profiles, indicating potential relationships or distinctions based on agro-morphological characteristics. PCA results can guide cluster analysis, where genotypes with similar trait profiles are grouped together (10). This clustering helps in identifying distinct groups or classes of onion germplasm based on their agro-morphological traits. Characterizing aggregatum onion genotypes based on agro-morphological traits using multivariate statistical analysis is a comprehensive approach that facilitates understanding of genetic diversity and trait correlations and supports breeding efforts aimed at developing improved cultivars with superior agronomic performance. PCA serves as a powerful tool in dissecting the complexity of germplasm variation within aggregatum onions. By analyzing multiple characteristics simultaneously and revealing underlying patterns of trait relationships, PCA enables informed decisions regarding the classification and utilization of onion germplasm for breeding programmes or agricultural improvement.

Materials and Methods

The present investigation was carried out using 67 multiplier onion germplasms collected from different onion-growing regions of Tamil Nadu (46 types) and Odisha University of Agriculture and Technology (OUAT), Odisha (21 types). Each accession was named from Aca 1 to Aca 67, providing a systematic and organized approach to identify and retrieve specific germplasm samples within the research conducted on aggregatum onion germplasm (Table 1).

The assembled germplasms (67 nos.) were grown in the college orchard, Department of Vegetable Science, Horticultural College and Research Institute, Tamil Nadu Agricultural University (TNAU), Coimbatore, India during rabi (Oct–Dec) 2022–23 in a Randomized block design. Fifteen quantitative characters were measured according to the descriptors for aggregatum onion provided by Directorate of Onion and Garlic Research (DOGR), Pune. Data on different agronomic characters were recorded on individual plant basis from 30 plants randomly selected in each plot. Variables considered in the descriptive and multivariate

Table 1. Details of aggregatum onion germplasm used in the present study

Code	Name	Source	Code	Name	Source
Aca 1	Coimbatore Local White	TNAU, Tamil Nadu	Aca 35	Balasore local 02	OUAT, Odisha
Aca 2	Oddanchatram	TNAU, Tamil Nadu	Aca 36	Keonjhar local 04	OUAT, Odisha
Aca 3	Dindigul type-1	TNAU, Tamil Nadu	Aca 37	Keonjhar local 06	OUAT, Odisha
Aca 4	Coimbatore Local Pink	TNAU, Tamil Nadu	Aca 38	Natagarh local 03	OUAT, Odisha
Aca 5	Dindigul type-2	TNAU, Tamil Nadu	Aca 39	Keonjhar local 05	OUAT, Odisha
Aca 6	Rasipuram	TNAU, Tamil Nadu	Aca 40	Ganjan local 01	OUAT, Odisha
Aca 7	Salem	TNAU, Tamil Nadu	Aca 41	Anugul local 08	OUAT, Odisha
Aca 8	Gnanamedu Pink type-1	TNAU, Tamil Nadu	Aca 42	Natagarh local 04	OUAT, Odisha
Aca 9	Gnanamedu type-1	TNAU, Tamil Nadu	Aca 43	Keonjhar local 01	OUAT, Odisha
Aca 10	Gnanamedu type-2	TNAU, Tamil Nadu	Aca 44	Keonjhar local 02	OUAT, Odisha
Aca 11	Gnanamedu type-3	TNAU, Tamil Nadu	Aca 45	Keonjhar local 03	OUAT, Odisha
Aca 12	Sulur Pink type-1	TNAU, Tamil Nadu	Aca 46	Mayurbhanji local 01	OUAT, Odisha
Aca 13	Gnanamedu type-4	TNAU, Tamil Nadu	Aca 47	Khurda local 01	OUAT, Odisha
Aca 14	Mettukadai	TNAU, Tamil Nadu	Aca 48	Khurda local 02	OUAT, Odisha
Aca 15	Puttarsal	TNAU, Tamil Nadu	Aca 49	Nayagarh local 01	OUAT, Odisha
Aca 16	Sandhaipadugai Pink type-3	TNAU, Tamil Nadu	Aca 50	Balasore local 01	OUAT, Odisha
Aca 17	CO (On)-5	TNAU, Tamil Nadu	Aca 51	Mettupatti local	TNAU, Tamil Nadu
Aca 18	Sandhaipadugai Pink type-2	TNAU, Tamil Nadu	Aca 52	Sudalaimalai local	TNAU, Tamil Nadu
Aca 19	Gnanamedu Pink type-2	TNAU, Tamil Nadu	Aca 53	Gounguselvanur local	TNAU, Tamil Nadu
Aca 20	Sandhaipadugai Pink type-4	TNAU, Tamil Nadu	Aca 54	Thintankulam local	TNAU, Tamil Nadu
Aca 21	Sandhaipadugai Pink type-5	TNAU, Tamil Nadu	Aca 55	Vilathikulam local	TNAU, Tamil Nadu
Aca 22	C. Mutlur	TNAU, Tamil Nadu	Aca 56	Silanaikan patti local	TNAU, Tamil Nadu
Aca 23	Sultanpet Pink	TNAU, Tamil Nadu	Aca 57	Sipalaikottai type	TNAU, Tamil Nadu
Aca 24	Thottapadi Pink	TNAU, Tamil Nadu	Aca 58	Muthukrishnapuram type	TNAU, Tamil Nadu
Aca 25	Gnanamedu Pink type-3	TNAU, Tamil Nadu	Aca 59	Vadaipatti type	TNAU, Tamil Nadu
Aca 26	Sandhaipadugai Pink type-1	TNAU, Tamil Nadu	Aca 60	Sokkikulam local	TNAU, Tamil Nadu
Aca 27	Sandhaipadugai White type-2	TNAU, Tamil Nadu	Aca 61	Poomalaikundu local	TNAU, Tamil Nadu
Aca 28	Gnanamedu White type-1	TNAU, Tamil Nadu	Aca 62	Dhaarmaapuri local	TNAU, Tamil Nadu
Aca 29	Sandhaipadugai White type-1	TNAU, Tamil Nadu	Aca 63	Kamatchipuram type	TNAU, Tamil Nadu
Aca 30	Dhenkanal local 02	OUAT, Odisha	Aca 64	Rayakkottai local	TNAU, Tamil Nadu
Aca 31	Anugul local 09	OUAT, Odisha	Aca 65	Marandahalli	TNAU, Tamil Nadu
Aca 32	Keonjhar local 07	OUAT, Odisha	Aca 66	Kauverypattinam local	TNAU, Tamil Nadu
Aca 33	Anugul local 06	OUAT, Odisha	Aca 67	Vedachanthur local	TNAU, Tamil Nadu
Aca 34	Dhenkanal local 01	OUAT, Odisha			

analyses included morphological traits such as plant height, number of leaves, number of shoots, polar diameter and equatorial diameter, yield traits such as number of bulbs per cluster, bulb weight, average clump weight, days to harvesting, total yield and marketable yield; quality traits such as total soluble solids and pest and disease incidence, including thrips, purple blotch and Stemphylium blight.

Data were statistically analyzed to identify groups among the germplasm that were genetically different or similar based on the fifteen traits measured. To identify the patterns of variation, PCA was conducted. PCs with eigenvalues greater than one were considered for further breeding work (11). Correlations between the original traits and the respective PCs were calculated and the PCA was performed using SAS PC version 8 (12). The collected data were processed using the Statistical Analysis System. The analyzed PC values were computed using the following equation:

$$PC1 = \sum_{j=1}^{p} ajXj \qquad \text{(Eqn.1)}$$

Where, PC = Principal component, aj = Linear coefficient – Eigen vectors

Results and Discussion

Mean performance

The summary of descriptive statistics and mean performance for all the traits is given in Table 2 and 3. There were significant differences ($p < 0.05$) among the aggregatum onion accessions for morphological traits, as some exhibited broad variability. The germplasm Aca 15 (Puttarasal local) recorded the highest plant height (52.73 cm), number of leaves (44.48), number of bulbs per cluster (12.32), average clump weight (100.08 g), total yield (23.49 t/ha) and marketable yield (22.59 t/ha). Aca 3 recorded the lowest plant height and Aca 5 recorded the lowest number of leaves. The maximum number of shoots was observed in Aca 56 (13.26), whereas Aca 12 (4.98) recorded the minimum number of shoots per cluster. The maximum polar and equatorial diameters were recorded in Aca 12 and Aca 30, with 41.61 mm and 38.73 mm respectively, whereas Aca 49 recorded the minimum polar diameter (12.31 mm) and Aca 1 recorded the minimum equatorial diameter (20.10 mm). Aca 44 recorded the highest total soluble solids (20.08 °Brix), while Aca 40 recorded the lowest (11.57 °Brix). Early harvest was observed in Aca 20 (63 DAP) while late harvest was observed in Aca 1 (72 DAP). In the resistant trait, Aca 28 (1.00) recorded the lowest thrips infestation, whereas Aca 6 recorded more infestation (2.29). For diseases, purple blotch and Stemphylium blight, Aca 1 (8.31) and Aca 21 (1.75) showed higher resistance, while Aca 8 and Aca 35 showed lower resistance, with scores of 24.35 and 6.00 respectively. A similar range of observations was noted in a previous study (13).

Principal component analysis (PCA)

PCA can reveal patterns and relationships between different traits by highlighting the most significant sources of variation (14). A multi-trait approach reveals the structure and the relative importance of intra- vs interspecific variability in plant traits. By examining the PCs and their associated loadings, we can identify which traits contribute most to genetic diversity and how these traits are related to each other. This understanding can guide breeding programmes and further research in optimizing and selecting desirable traits in aggregatum onion cultivation. The PCA resulted in fifteen independent PCs with a cumulative explained variance of 100 %.

In this study, we adopted the criterion established by previous studies and supported by earlier researchers (15, 16). They proposed that the first six PCs are typically the most significant in capturing the variation patterns among accessions. The characters associated with these PCs are particularly valuable for differentiating between accessions. The first six PCs with eigenvalues >1 contributed 70.39 % of the total genotypic variability for fifteen quantitative characters of 67 genotypes, as presented in Table 4 and Fig. 1, giving a clear understanding of the structure underlying the analyzed variables. A previous study reported that nine PCs with eigenvalues greater than 1 accounted for 71.84 % of the variability among 96 Turkish onion accessions (17). Another study assessing the variation among 125 grain amaranth accessions using six morphological characters through multivariate analysis revealed that the first three PCs contributed 72.74 % of the observed variability, with eigenvalues >1 and PC1 alone accounted for 35.84 % of the total morphological variation (18). According to Kaiser's criterion, also known as Guttman's lower bound principle, PCs with eigenvalues less than 1 are typically ignored (19). Based on the PCA results of the present study, eigenvalue was maximum in PC1 (2.74) followed by PC2 (2.51) and PC3 (1.68). A previous study also observed that PC1 had a maximum eigenvalue (17). Total variance percentage was maximum in PC1 (18.63 %) followed by PC2 (16.80 %), PC3 (11.20 %), PC4 (8.60 %), PC5 (7.88 %) and PC6 (7.27 %) respectively. PC7 to PC15, with eigenvalues < 1 contributed less than 30 % to the total genotypic variability.

Scree plot

The scree plot illustrates the percentage of variance explained by each PC. It is created by plotting the eigenvalues of the PCs against their corresponding component numbers. This graphical representation helps determine the number of PCs to retain for further analysis by showing the point at which the eigenvalues begin to level off, indicating diminishing returns in the variance explained by additional components. PC1 showed 18.63 % variability with an eigenvalue of 2.74, after which the values declined gradually. A previous study also reported that PC1 had the highest variability with an eigenvalue greater than 1 (20). The observation that PC1 explains the maximum variation compared to other PCs indicates that it captures the most significant patterns or features within the dataset. Therefore, focusing on the lines (or variables) that significantly contribute to PC1 will be useful (Fig. 2). Each PC has an associated eigenvalue that represents the amount of variance captured by that component. These values indicate the amount of variance that each PC accounts for. Larger eigenvalues correspond to components that capture more variance among the aggregatum onion germplasm genotypes, aiding in the selection of diverse parents.

The contributions of different morphological traits to the total variation were calculated for each component. The first PC accounted for more than 15 % of the total variance. The variables highly and positively correlated were plant height with loading of 0.40, number of leaves (0.39), average clump weight and marketable yield (0.30). Except for days to harvest, thrips

Table 2. Mean performance of aggregatum onion germplasm for 15 traits

Code	PH (cm)	NOL	NOS	BP (mm)	BE (mm)	NOB	WOB (g)	ACW (g)	TSS (%)	TY (t/ha)	MY (t/ha)	DTH	Thrips (%)	PB (PDI)	SB (PDI)
Aca 1	32.66	21.02	11.60	14.20	20.10	7.56	14.51	55.98	15.13	20.68	16.54	72	1.29	8.31	2.48
Aca 2	32.53	24.49	7.66	20.14	21.67	5.77	12.47	73.31	16.52	18.97	15.87	66	1.37	21.73	3.48
Aca 3	21.85	23.98	6.83	16.38	20.95	8.88	9.53	70.13	16.21	15.78	12.76	66	1.52	15.29	3.16
Aca 4	23.93	32.47	5.60	21.13	25.81	6.23	9.56	74.22	14.71	18.63	15.93	68	1.45	18.43	2.44
Aca 5	30.77	17.44	7.43	25.40	27.43	7.68	11.77	77.41	16.68	18.56	15.57	66	1.39	10.83	2.34
Aca 6	39.28	20.02	5.69	16.28	20.20	6.40	10.52	67.43	16.76	10.94	9.32	66	2.29	17.29	4.56
Aca 7	33.28	30.29	8.53	13.87	21.90	7.95	12.47	63.48	16.34	19.06	16.53	70	1.05	13.30	2.74
Aca 8	41.53	28.13	6.04	23.48	30.01	6.46	13.45	80.92	17.65	18.92	13.33	69	1.03	24.35	3.08
Aca 9	31.88	22.92	7.47	16.53	24.59	8.41	11.43	91.58	17.92	20.10	17.74	68	1.05	11.89	2.11
Aca 10	27.89	23.12	6.40	26.55	23.82	5.88	11.02	64.14	16.58	20.32	15.93	70	1.14	16.58	2.81
Aca 11	34.34	33.38	7.23	32.07	27.95	7.29	12.57	68.40	15.90	19.49	16.60	65	1.02	11.23	4.77
Aca 12	40.35	31.17	4.98	41.61	32.52	6.68	7.72	70.86	18.68	17.33	14.88	69	1.01	14.43	3.22
Aca 13	35.72	32.97	6.64	30.02	27.14	6.10	13.71	79.28	16.85	19.56	16.14	67	1.04	14.29	2.64
Aca 14	40.95	29.73	7.35	37.91	29.49	6.51	13.88	75.07	17.66	17.67	14.64	70	1.33	13.28	5.47
Aca 15	52.73	44.48	8.41	28.15	26.61	12.32	11.13	100.08	18.79	23.49	22.59	65	1.02	10.47	4.92
Aca 16	34.03	21.76	7.47	30.99	32.19	6.90	14.87	72.31	17.97	20.09	16.44	68	1.18	15.64	2.94
Aca 17	39.27	37.74	11.22	35.98	32.99	6.10	12.47	82.11	16.25	17.37	13.51	63	1.10	15.26	3.18
Aca 18	38.09	38.11	6.04	28.41	26.15	5.56	15.93	68.31	17.17	17.28	14.04	64	1.13	12.95	5.21
Aca 19	34.98	40.47	7.84	29.66	30.45	6.89	12.13	59.71	16.66	19.09	15.98	68	1.29	20.59	3.18
Aca 20	33.05	31.57	7.23	35.88	32.17	5.68	11.24	79.78	17.09	18.18	15.67	63	1.45	22.56	3.03
Aca 21	36.83	38.91	8.16	28.01	27.20	7.31	12.33	78.40	16.46	14.75	14.28	67	1.35	11.13	1.75
Aca 22	31.99	34.72	8.41	27.94	24.05	6.51	15.20	71.92	15.51	18.24	14.64	72	1.10	12.80	3.49
Aca 23	30.03	28.43	12.34	31.24	33.09	7.02	16.06	73.66	17.19	19.49	15.71	64	1.25	12.76	3.64
Aca 24	27.85	33.39	6.91	30.33	34.39	6.90	12.01	84.59	18.28	18.70	16.47	69	1.30	12.41	3.20
Aca 25	32.85	33.03	9.52	31.03	23.11	6.22	9.31	80.67	17.32	20.80	18.03	66	1.33	14.79	2.87
Aca 26	36.56	37.26	11.22	40.37	35.82	7.14	17.29	82.57	17.89	19.49	16.51	67	1.27	14.58	3.03
Aca 27	31.62	30.62	10.78	28.41	32.65	9.94	16.03	82.81	13.63	16.30	15.22	66	1.17	16.29	4.76
Aca 28	27.22	27.33	9.20	24.71	28.70	9.13	12.40	64.32	13.69	14.19	11.46	68	1.00	12.54	3.72
Aca 29	34.08	30.85	9.47	31.24	32.69	8.90	12.25	73.39	15.33	16.28	13.60	66	1.04	11.36	3.13
Aca 30	29.62	31.06	6.41	27.24	38.73	6.61	13.27	72.51	16.30	11.74	9.19	67	1.22	13.59	1.99
Aca 31	33.21	35.87	6.65	28.27	26.81	6.89	12.09	63.01	16.15	18.14	14.54	70	1.04	12.49	3.70
Aca 32	30.90	32.37	7.70	32.63	33.85	7.79	14.73	65.78	16.12	11.26	8.92	65	1.28	18.17	4.77
Aca 33	37.24	39.45	6.16	36.88	35.31	8.78	18.67	67.73	17.87	17.52	14.57	65	1.07	17.57	3.10
Aca 34	31.21	35.13	8.67	31.97	33.83	7.66	17.73	67.30	17.83	17.80	15.57	71	1.05	14.08	2.19
Aca 35	40.16	40.32	7.35	39.78	37.88	9.54	14.55	85.40	18.85	19.44	16.41	68	1.27	16.23	6.00

Aca 36	38.97	39.99	8.80	36.84	26.11	7.79	13.54	74.19	16.58	15.69	13.63	68	1.42	18.29	5.40
Aca 37	35.07	37.69	8.06	35.71	26.85	9.75	9.15	61.22	13.99	16.67	14.17	69	1.36	20.65	2.93
Aca 38	32.66	29.32	10.41	29.96	32.11	6.61	17.36	59.89	17.14	10.42	8.77	64	1.08	19.03	2.92
Aca 39	31.47	29.04	7.47	27.34	22.82	8.61	16.21	58.39	17.62	9.99	8.14	67	1.28	19.07	4.26
Aca 40	27.98	37.32	9.84	31.99	22.42	6.90	11.24	62.49	11.57	10.88	8.96	68	1.42	17.99	3.93
Aca 41	32.97	30.44	10.53	32.33	29.94	8.65	13.54	78.28	15.14	17.91	16.60	65	1.17	16.76	2.51
Aca 42	33.23	33.17	10.90	28.22	28.49	6.82	16.87	76.18	13.83	17.53	14.62	65	1.10	16.20	2.39
Aca 43	29.99	35.00	8.41	28.65	26.86	9.54	19.45	74.39	12.66	19.19	15.86	67	1.08	17.64	4.01
Aca 44	31.92	31.49	12.34	32.84	33.10	6.79	17.03	61.42	20.08	13.60	10.75	67	1.56	24.20	2.91
Aca 45	26.48	30.74	8.89	25.61	33.98	8.53	13.16	73.60	17.47	15.27	13.78	68	1.10	15.46	3.09
Aca 46	30.30	32.29	7.94	29.14	30.34	7.35	14.75	51.73	17.48	9.89	7.26	71	1.08	12.72	2.38
Aca 47	33.71	32.65	9.72	14.45	34.30	6.76	16.87	60.84	17.65	10.53	8.53	64	1.21	16.77	3.29
Aca 48	37.72	38.57	7.80	14.20	31.68	8.01	19.84	57.45	17.82	11.46	9.34	68	1.03	17.14	5.48
Aca 49	32.95	38.19	11.17	12.31	27.94	9.87	15.63	73.99	14.79	18.74	15.76	67	1.13	15.93	4.14
Aca 50	31.19	28.94	6.16	16.64	31.12	6.30	11.13	73.07	16.16	19.75	15.13	71	1.12	14.02	2.82
Aca 51	32.73	36.27	6.28	30.43	29.66	10.87	11.24	73.52	15.54	17.38	15.31	65	1.23	16.22	1.94
Aca 52	29.61	29.81	10.21	22.29	28.77	8.12	16.51	67.25	16.47	18.77	16.96	67	1.13	17.96	3.73
Aca 53	41.23	41.39	9.84	30.14	30.09	8.90	18.67	62.89	15.41	17.73	14.98	65	1.01	16.70	4.72
Aca 54	39.51	41.90	9.72	29.22	32.32	8.50	18.08	87.01	17.01	18.50	16.13	68	1.15	20.52	4.30
Aca 55	39.01	41.02	7.91	26.78	31.42	10.60	14.23	60.40	14.31	18.15	15.01	66	1.07	15.32	2.14
Aca 56	32.15	31.36	13.26	30.348	22.84	9.46	15.84	69.61	16.37	20.31	14.00	69	1.01	20.51	3.09
Aca 57	28.23	29.53	8.61	32.255	21.37	9.75	11.64	82.51	15.53	16.47	13.89	65	1.11	19.11	4.01
Aca 58	35.29	30.93	7.58	28.52	31.85	6.82	19.06	69.96	15.85	21.15	11.49	67	1.05	21.57	3.71
Aca 59	34.67	32.09	10.62	28.35	31.72	9.28	16.68	56.31	17.73	18.64	20.79	66	1.13	16.34	3.56
Aca 60	29.82	28.51	10.90	32.05	31.09	9.46	11.34	80.18	16.80	16.37	15.38	69	1.11	15.86	3.18
Aca 61	32.50	39.51	10.97	33.4	35.19	11.09	16.08	77.90	18.01	15.88	12.31	67	1.35	18.55	4.70
Aca 62	29.40	30.87	9.48	28.21	25.71	8.61	17.82	66.92	18.19	19.34	11.98	71	1.39	20.89	3.04
Aca 63	27.74	31.66	11.99	29.19	35.11	10.73	17.62	56.76	16.57	16.28	15.93	67	1.55	23.70	3.18
Aca 64	30.32	27.16	9.82	16.082	32.97	9.46	14.23	65.44	14.95	15.65	16.27	66	1.01	17.81	2.37
Aca 65	38.08	35.46	10.03	15.38	26.00	10.42	12.31	74.37	16.87	19.19	14.63	69	1.15	14.97	3.51
Aca 66	34.36	35.99	11.26	31.08	31.78	9.56	18.51	60.32	16.01	20.99	8.55	67	1.33	21.07	4.35
Aca 67	40.92	32.12	8.64	33.02	30.22	9.42	16.35	71.51	15.89	15.65	16.06	65	1.07	17.74	3.28
Mean	33.62	32.45	8.69	27.88	29.23	8.01	14.15	71.17	16.47	17.16	14.27	67.09	1.21	16.36	3.44
CD (0.05)	3.54	3.85	2.66	2.95	2.95	0.65	0.55	4.43	1.8	2.29	2.11	5.68	0.44	3.16	1.53
CV	5.29	5.95	15.34	5.31	5.07	4.12	1.95	3.12	5.49	6.7	7.43	4.24	18.67	9.67	44.22

Table 3. Assessment of phenotypic means and variability among 67 onion germplasm accessions

Sl. No.	Characters	Germplasm code	Minimum	Germplasm code	Maximum	Mean	SD
1.	Plant height	Aca 3	21.85	Aca 15	52.73	33.62	4.91
2.	No. of leaves	Aca 5	17.44	Aca 15	44.48	32.45	5.66
3.	No. of shoots	Aca 12	4.98	Aca 56	13.26	8.69	1.93
4.	Polar diameter	Aca 49	12.31	Aca 12	41.61	27.88	7.00
5.	Equatorial diameter	Aca 1	20.10	Aca 30	38.73	29.23	4.52
6.	Number of bulb per cluster	Aca 18	5.56	Aca 15	12.32	8.01	1.56
7.	Weight of bulb	Aca 12	7.72	Aca 15	19.84	14.15	2.89
8.	Average clump weight	Aca 46	51.73	Aca 15	100.08	71.17	9.39
9.	Total soluble solids	Aca 40	11.57	Aca 44	20.08	16.47	1.52
10.	Total yield	Aca 46	9.89	Aca 15	23.49	17.16	3.09
11.	Marketable yield	Aca 46	7.26	Aca 15	22.59	14.27	2.98
12.	Days to harvesting	Aca 20	63.00	Aca 1	72.00	67.19	2.15
13.	Thrips	Aca 28	1.00	Aca 6	2.29	1.21	0.20
14.	Purple blotch incidence	Aca 1	8.31	Aca 8	24.35	16.36	3.53
15.	Stemphylium blight	Aca 21	1.75	Aca 35	6.00	3.44	0.97

Table 4. Computed eigenvalues of the PCs along with the corresponding proportion and cumulative explained variance

Components	Eigenvalues	Explained variance	
		Percent	Cumulative
PC1	2.79	18.63	18.63
PC2	2.51	16.80	35.43
PC3	1.68	11.20	46.62
PC4	1.29	8.61	55.24
PC5	1.18	7.88	63.12
PC6	1.08	7.27	70.39
PC7	0.86	5.76	76.15
PC8	0.74	5.00	81.15
PC9	0.66	4.41	85.56
PC10	0.55	3.73	89.28
PC11	0.44	2.94	92.22
PC12	0.41	2.79	95.01
PC13	0.31	2.12	97.13
PC14	0.26	1.76	98.89
PC15	0.16	1.11	100.00

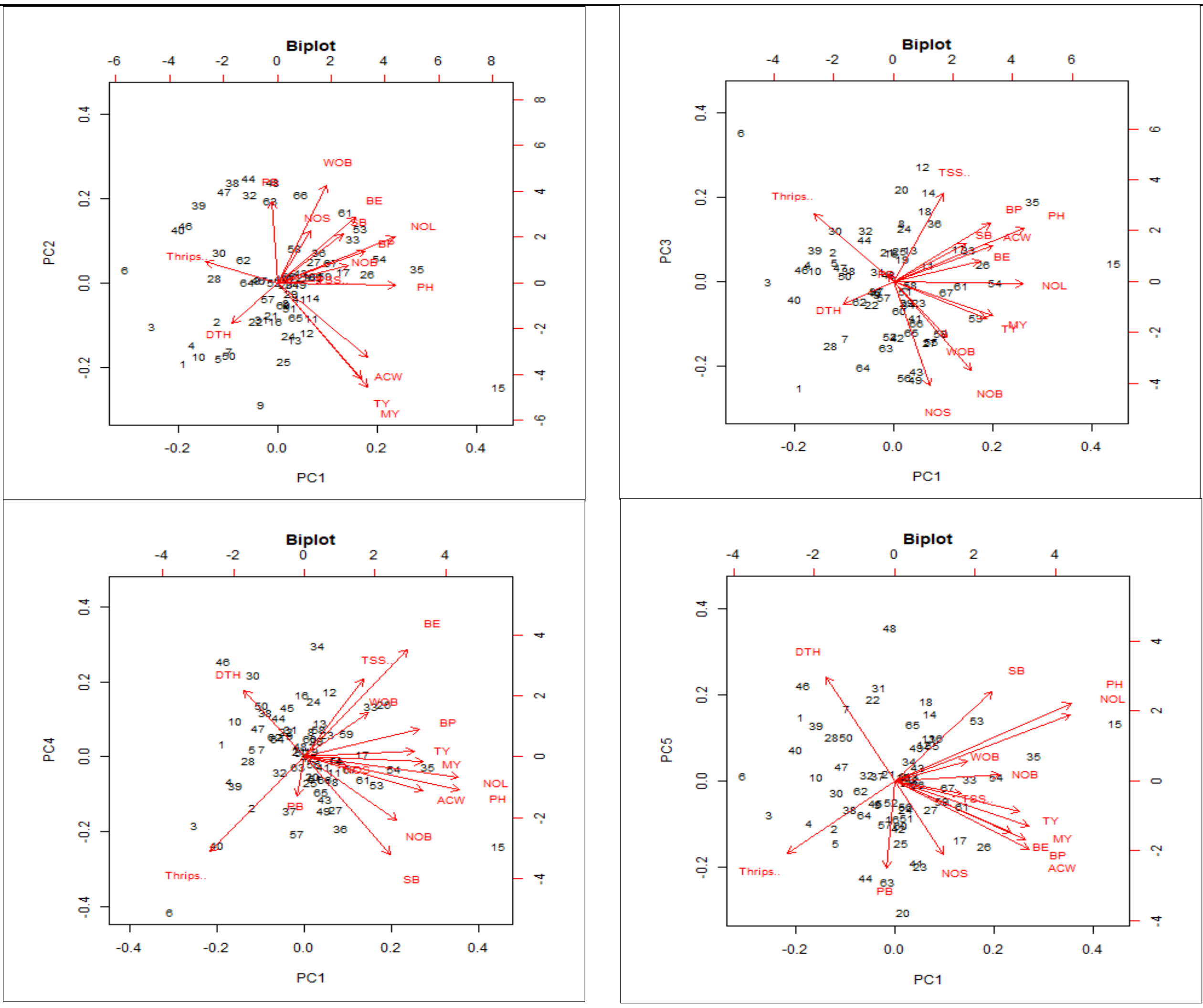

Fig. 1. PCA biplots showing the distribution of genotypes across 5 components.

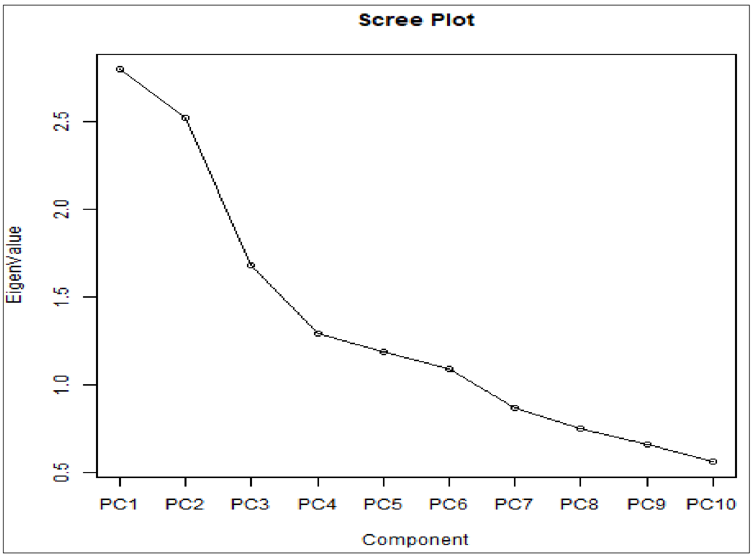

Fig. 2. Scree plot showing eigenvalue variation.

incidence and purple blotch incidence, all other traits showed positive contributions in PC1. In PC1, all traits except days to maturity and polar diameter contributed positively towards yield. Sometimes, negative selection can be a useful strategy in genetic improvement, particularly when dealing with traits that have a negative impact on yield or other desired traits (21). The PC2 accounted for more than 16 % of the variation and identified yield component variables such as average clump weight, total and marketable yield presenting negative contributions.

The PC2 accounted for 16.80 % of the variation and was associated with bulb weight (0.40) and purple blotch incidence (0.34). PC3 was related to total soluble solids (0.40) and thrips incidence (0.31), while PC4 was associated with equatorial diameter (0.47) and total soluble solid (0.34). The traits that contributed more positively to PC3 were numbers of leaves, equatorial diameter, average bulb weight and total soluble solids (22). PC5 was more related to days to harvesting (0.41), Stemphyllium blight incidence (0.35) and plant height (0.31). PC6 was related to number of leaves (0.18) and equatorial diameter (0.18). PC7 was related to total soluble solid (0.33).

PC8 was highly related to number of bulbs (0.61) and days to harvesting (0.35), while PC9 was related to purple blotch incidence (0.48) and number of bulbs (0.35). PC10 was related to Stemphyllium blight (0.47) and average clump weight (0.39), whereas PC11 was associated with average clump weight (0.63) and number of leaves (0.36).PC12 was highly related to thrips incidence (0.51), equatorial diameter (0.42) and number of leaves (0.35). Similar correlations between leaf architecture and pest incidence were reported by researchers who noted that higher leaf numbers and canopy density often lead to increased thrips infestation in onion cultivars (23). PC13 was related to plant height (0.50) and bulb weight (0.25). This indicates a possible linkage between plant stature and biomass accumulation, which is consistent with findings of an earlier study which observed that taller onion plants tend to support larger bulbs under optimal growing conditions (24). PC14 showed moderate contributions from equatorial bulb diameter (0.43) and number of shoots (0.32), pointing towards variation in bulb morphology and vegetative propagation potential. These observations align with a previous study which highlighted the importance of equatorial diameter as a selection trait in onion breeding programmes aimed at improving marketable yield (25). PC15 was highly related to total yield (0.66), indicating that this component is primarily governed by productivity traits. This agrees with previous studies which emphasized total yield as a comprehensive trait integrating multiple agronomic factors, making it a key determinant for germplasm selection (26) (Table 5).

Biplot

The PCA biplot effectively summarizes the relationships among different plant traits and the distribution of genotypes based on those traits. The first quadrant (top right) contains traits such as total yield (TY), marketable yield (MY), average bulblet weight (ACW), plant height (PH), number of leaves (NOL), number of shoots (NOS), bulblet equatorial diameter (BE), number of

Table 5. PCA of 15 morphological characters for 67 aggregatum onion germplasms (Correlations between initial variables and PC: component loading)

Variables	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13	PC14	PC15
Plant height	0.40	−0.01	0.24	−0.14	0.31	−0.08	0.15	−0.15	0.16	−0.47	0.05	−0.21	0.50	0.21	−0.03
No. of leaves	0.39	0.19	−0.01	−0.08	0.26	0.18	−0.32	0.04	0.15	−0.25	0.36	0.35	−0.45	−0.14	0.04
No. of shoots	0.11	0.21	−0.48	−0.04	−0.29	−0.19	0.13	0.11	−0.46	−0.34	0.25	−0.16	−0.11	0.32	0.03
Polar diameter	0.29	0.13	0.27	0.12	−0.23	0.17	−0.53	0.10	−0.40	−0.07	−0.31	−0.29	0.10	−0.23	−0.04
Equatorial diameter	0.26	0.27	0.09	0.47	−0.20	0.18	0.09	0.20	0.10	0.20	−0.04	0.42	0.24	0.43	0.09
Number of bulb per cluster	0.23	0.07	−0.41	−0.27	0.02	0.02	0.06	0.61	0.35	0.11	−0.27	−0.17	0.12	−0.19	0.09
Weight of bulb	0.16	0.40	−0.25	0.19	0.07	−0.27	0.18	−0.31	−0.09	0.12	0.00	0.17	0.25	−0.56	−0.19
Average clump weight	0.30	−0.31	0.16	−0.14	−0.27	0.08	0.14	0.11	−0.09	0.39	0.63	−0.10	0.16	−0.17	−0.10
Total soluble solids	0.15	0.01	0.40	0.34	−0.05	−0.48	0.33	0.26	0.11	−0.09	−0.05	−0.20	−0.43	−0.14	0.06
Total yield	0.28	−0.40	−0.17	0.02	−0.12	−0.32	−0.19	−0.26	−0.00	0.05	−0.12	0.16	0.04	−0.02	0.66
Marketable yield	0.30	−0.43	−0.15	−0.02	−0.18	−0.12	−0.00	−0.07	0.04	−0.08	−0.30	0.25	−0.15	0.11	−0.65
Days to harvesting	−0.15	−0.16	−0.10	0.29	0.41	−0.42	−0.44	0.35	−0.10	0.09	0.23	0.02	0.22	0.10	−0.17
Thrips	−0.24	0.08	0.31	−0.41	−0.29	−0.28	−0.03	0.27	−0.09	−0.25	−0.01	0.51	0.22	−0.15	0.02
Purple blotch incidence	−0.01	0.34	0.03	−0.17	−0.35	−0.3	−0.38	−0.25	0.48	0.18	0.12	−0.22	−0.03	0.21	−0.13
Stemphylium blight	0.22	0.20	0.17	−0.42	0.35	−0.19	0.08	−0.02	−0.36	0.47	−0.20	0.05	−0.17	0.28	0.00

bulblets (NOB) and weight of bulblets per plant (WOB). Genotypes located in this quadrant such as Aca 15, 18, 34 and 35, are associated with vigorous growth and high productivity. These genotypes show strong positive correlations with yield and bulb traits, indicating their potential as promising candidates for breeding programmes aimed at improving marketable yield and bulb quality.

In contrast, the second quadrant (top left) is associated with pest and disease incidence, including thrips, purple blotch (PB) and Stemphylium blight (SB). Genotypes falling in this quadrant, such as samples 38, 39, 44 and 46, are likely to be more susceptible to these biotic stresses and may require focused management strategies or breeding for resistance. Their placement opposite yield-related traits further suggests a negative correlation between pest/disease pressure and productivity.

The third quadrant (bottom left) is characterized by the variable days to harvest (DTH), representing late-maturing genotypes. Samples such as 1, 2, 10 and 11 are located here and may not be ideal in systems that prioritize early harvest. Moreover, their distance from yield- and growth-related traits indicates that these genotypes may be less productive or slower growing, although they could still be useful in environments where longer growth duration is beneficial.

The fourth quadrant (bottom right) contains samples such as 4, 50 and 60, which show more balanced or intermediate performance. These genotypes are not strongly associated with any single trait but may exhibit moderate yields, acceptable bulb traits and average disease resistance. Such genotypes could serve as stable performers across varied environments. The biplot highlights a clear separation between high-yielding, vigorous genotypes and those prone to disease or delayed maturity. Genotypes in the first quadrant stand out as ideal selections for breeding and cultivation due to their strong association with multiple desirable traits, whereas those in the second and third quadrants may need to be avoided or improved through targeted breeding strategies.

Conclusion

The PCA identified 15 key quantitative traits that significantly contribute to the genetic variation among the evaluated cultivars, with the first six components accounting for 70.39 % of the total variability. This substantial variation underscores the presence of diverse agro-morphological characteristics within the germplasm, providing a valuable resource for targeted breeding. Notably, genotypes such as Aca 9, Aca 15 and Aca 25 emerged as superior germplasm due to their strong association with high yield, vigorous growth traits and desirable bulb characteristics. These genotypes demonstrate excellent potential for enhancing marketable yield and bulb quality, making them prime candidates for inclusion in breeding programmes.

However, certain genotypes showed susceptibility to pest and disease pressures, indicating the need for careful selection and potential resistance breeding. The identified germplasm with favourable trait combinations can be strategically crossed to combine desirable traits, thereby maximizing productivity while maintaining genetic diversity. The utilization of these superior genotypes in crop improvement programmes will accelerate the development of robust, high-yielding and well-adapted varieties, ultimately contributing to sustainable agricultural production and enhanced food security.

Acknowledgements

Authors sincerely acknowledge the Co-Principal Investigators and Young Professional for successfully conducting this research at the college orchard, Department of Vegetable Science, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore.

Authors' contributions

IRC, KM and PP conducted the trial and PP recorded the observations. UDM analysed the data using different software. SBK and KM corrected and finalized the drafted manuscript. PL and VM assisted in recording various laboratory observations. All authors have read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

References

1. Bal S, Maity TK, Sharangi AB, Majumdar A. Quality assessment in association with yield attributes contributing improved yield in onion (*Allium cepa* L.). J Crop Weed. 2019;15(3):107–15. https://doi.org/10.22271/09746315.2019.v15.i3.1245
2. Choudhary DR. Phytochemistry of fruits and vegetables. New Delhi: Brillion Publishing; 2018.
3. Pandey UB. Handbook of herbs and spices. Woodhead Publ Ser Food Sci Technol Nutr. 2006;3:495–501. https://doi.org/10.1016/B978-0-85709-039-3.50033-5
4. Coonse M. Onions, leeks and garlic: a handbook for gardeners. College Station: Texas A & M Univ Press; 1995.
5. Geethanjali S, Jeyaprakash P, Masilamani P, Nithya Devi A, Aravindarajan STM. Phytochemical screening of Co (On) 5 and Co (On) 6 aggregatum onion by GCMS. Pharma Innov J. 2023;12(4):348–51.
6. Tamil Nadu Horticultural and Plantation Crop Statistics. Tamil Nadu: Government of Tamil Nadu; 2022–23.
7. Bisognin DA. Breeding vegetatively propagated horticultural crops. Crop Breed Appl Biotechnol. 2011;11:35–43. https://doi.org/10.1590/S1984-70332011000500006
8. Fritsch RM, Friesen N. Evolution, domestication and taxonomy. In: *Allium* crop science: recent advances. Wallingford: CABI Publ; 2002. p. 5–30. https://doi.org/10.1079/9780851995106.0005
9. Haussmann BIG, Parzies HK, Presterl T, Susic Z, Miedaner T. Plant genetic resources in crop improvement. Plant Genet Resour. 2004;2(1):3–21. https://doi.org/10.1079/PGR200430
10. Azam MG, Sarker U, Hossain MA, Alam AKMM, Islam MR, Hossain N, et al. Phenotypic diversity in qualitative and quantitative traits for selection of high yield potential field pea genotypes. Sci Rep. 2024;14(1):18561. https://doi.org/10.1038/s41598-024-69448-7
11. Jeffers JNR. Two case studies in the application of principal component analysis. Appl Stat. 1967;16:225–36. https://doi.org/10.2307/2985919

12. SAS Institute. SAS language reference: dictionary. Version 8. Cary: SAS Institute; 1999.

13. Gupta AJ, Mahajan V, Singh M. Evaluation of multiplier onion germplasm (*Allium cepa* var. *aggregatum*) for growth, yield and quality. J Allium Res. 2018;1(1):1–6.

14. Albert CH, Thuiller W, Yoccoz NG, Douzet R, Aubert S, Lavorel S. A multi trait approach reveals the structure and the relative importance of intra- vs interspecific variability in plant traits. Funct Ecol. 2010;24(6):1192–201. https://doi.org/10.1111/j.1365-2435.2010.01727.x

15. Clifford HT, Stephenson W. An introduction to numerical classification. New York: Academic Press; 1975. p. 224. https://doi.org/10.1016/B978-0-12-176750-1.50004-X

16. Guei RG, Sanni KA, Fawole AFJ. Genetic diversity of rice (*Oryza sativa* L.). Agron Afr. 2005;5:17–28.

17. Hanci F, Gokce AF. Genetic diversity evaluations in Turkish onion (*Allium cepa* L.) genotypes: principal component analyses for breeding strategies. Acta Hortic. 2016;1143:259–64. https://doi.org/10.17660/ActaHortic.2016.1143.33

18. Umadevi M, Devanand PS, Kumaran K. Characterization of grain amaranth genetic resources for agro-morphological traits. Indian J Ecol. 2019;46(4):221–5.

19. Kaiser HF. The varimax criterion for analytic rotation in factor analysis. Psychometrika. 1958;23(3):187–200. https://doi.org/10.1007/BF02289233

20. Nachimuthu VV, Robin S, Sudhakar D, Raveendran M, Rajeswari S, Manonmani S. Evaluation of rice genetic diversity and variability in a population panel by principal component analysis. Indian J Sci Technol. 2014;7(10):1555–62. https://doi.org/10.17485/ijst/2014/v7i10.14

21. Bal S, Maity TK, Sharangi AB. Morphological and biochemical characterization of onion (*Allium cepa* L.) germplasm by principal component analysis. J Pharmacogn Phytochem. 2021;10(1):121–4. https://doi.org/10.20546/ijcmas.2020.906.383

22. Singh SR, Ahmed N, Lal S, Ganie SA, Amin M, Jan N, et al. Determination of genetic diversity in onion (*Allium cepa* L.) by multivariate analysis under long day conditions. Afr J Agric Res. 2013;8(45):5599–606. https://doi.org/10.5897/AJAR2013.7969

23. Benke AP, Khar A, Mahajan V, Gupta A, Singh M. Study on dispersion of genetic variation among Indian garlic ecotypes using agro-morphological traits. Indian J Genet Plant Breed. 2020;80(1):94–102. https://doi.org/10.31742/ijgpb.80.1.12

24. Raj Narayan RN, Singh DB, Arun Kishor AK, Mer MS. Studies on genetic variability, heritability and genetic advance in long day onion (*Allium cepa* L.) genotypes. 2019. https://doi.org/10.5958/2249-5258.2019.00015.0

25. Patel RK, Patel MM, Patel MR. Genetic variability and correlation studies in onion (*Allium cepa* L.) for yield and quality traits. Int J Curr Microbiol Appl Sci. 2017;6(11):3300–4. https://doi.org/10.20546/ijcmas.2017.611.391

26. Manjunathagowda DC, Anjanappa M. Genetic variability studies for yield and yield contributing traits in onion (*Allium cepa* L.). Vegetos. 2021;34(1):174–82. https://doi.org/10.1007/s42535-020-00170-1

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

Publisher information: Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.