

Assessment of genetic variability, character association and genetic diversity studies in lotus (*Nelumbo nucifera*) germplasm

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Abstract

Lotus (*Nelumbo nucifera* Gaertn.) is an important aquatic ornamental crop possessing immense ornamental, medicinal, nutritional and cultural value. The present investigation was conducted during February 2024 to October 2025 at the College of Horticulture, Mysuru, Karnataka. Fifty lotus germplasms collected from Karnataka, Kerala and Tamil Nadu were evaluated in a Completely Randomized Design (CRD) with two replications to study the extent of genetic variability, character association and genetic divergence. Significant differences were observed among the germplasm for all the characters studied, indicating considerable variability. High genotypic and phenotypic coefficients of variation were recorded for number of flowers per plant (82.81% and 84.95%), number of coin leaves per plant (64.03% and 65.31%) and duration of flowering (49.97% and 53.11%). High heritability coupled with high genetic advance as per cent mean was observed for number of flowers per plant (95.00% and 213.08%), duration of flowering (88.50% and 124.13%) and flower diameter (94.80% and 46.08%), indicating predominance of additive gene action and effectiveness of direct selection. Correlation studies revealed that number of flowers per plant showed significant positive association with duration of flowering at genotypic (0.784) and phenotypic (0.720) levels, whereas days to bud initiation exhibited negative association with flower yield (-0.597 and -0.459, respectively). Path coefficient analysis revealed high positive direct effects of number of coin leaves per plant (1.013 and 1.029) and duration of flowering (0.482 and 0.474) on flower yield at genotypic and phenotypic levels, respectively. Diversity analysis grouped the germplasm into six clusters with maximum inter-cluster distance between Cluster V and VI (20.68), indicating wide genetic divergence. Thus study highlighted diverse germplasm grouped under six clusters can be further utilized for future breeding programme and development of high-yielding ornamental lotus cultivars.

Introduction

Lotus (*Nelumbo nucifera* Gaertn.), an aquatic perennial belonging to the family Nelumbonaceae, is one of the oldest flowering plants known to mankind and possesses immense ornamental, medicinal, nutritional, ecological and cultural significance. It is widely distributed across Asian countries, particularly India, China, Japan and Southeast Asia, and is recognized as the national flower of India (Pal and Dey, 2015). In India, it is popularly known as Kamala, Padmini, Tavare, Kanwal and Suryakamal in different regional languages (Mehta et al., 2013). The crop is highly valued for its attractive flowers, edible rhizomes and seeds, therapeutic properties and adaptability to diverse aquatic ecosystems. In recent years, lotus has gained increasing importance in floriculture, landscape gardening, herbal medicine and nutraceutical industries due to its multifaceted utility and growing commercial demand.

Lotus holds immense religious, cultural, medicinal and ornamental significance and is widely used in landscaping, water gardening and traditional medicine. Globally, around 4,500 lotus cultivars are reported, including 2,080 officially documented and 142 internationally registered cultivars. India possesses rich lotus diversity from Kashmir to Kanyakumari with wide variation in plant vigour, leaf morphology, flower size, shape, colour and blooming behaviour (Bhowmik and Datta, 2012). In 2023, India exported lotus flowers to over 87 countries, with export shares of USA (33%), UAE (17%) and Germany (15%) (Volza, 2024). The global lotus products market (flowers, seeds and extracts) was valued at USD 1.8 billion in 2024, projected to reach USD 2.9 billion by 2033 with a CAGR of 5.4% (DataHorizon Research, 2024). Lotus seeds alone were valued at USD 101.5 million, driven by high demand in North America and the Middle East.

Genetic variability is the foundation of crop improvement, as effective selection depends on the extent of variation present in the germplasm. Evaluation of variability helps to identify superior lotus germplasm with desirable traits such as flower size, colour, petal number, rhizome yield, seed production and adaptability. Parameters like GCV, PCV, heritability and genetic advance provide useful information for efficient selection in breeding programmes (Bo et al., 2010). Since lotus varieties often show location-specific performance, identifying adaptable and non-seasonal genotypes capable of year-round flowering is important for ornamental use and landscaping. While, Wild lotus populations also serve as valuable genetic resources for future improvement programmes (Falconer and Mackay, 2009).

Character association studies helps to understand the relationship among yield and yield-contributing traits, while correlation and path coefficient analyses identify characters with direct and indirect effects on flower yield and ornamental value. Genetic diversity analysis further assists in grouping germplasm and selecting diverse parents for hybridization, which enhances the possibility of obtaining superior recombinants and novel ornamental types (Singh and Chaudhary, 1985).

Despite the increasing ornamental, ecological and economic importance of lotus, systematic information regarding the extent of genetic variability, character association and genetic diversity among available germplasm collections remains limited. Therefore, the present investigation entitled “Assessment of genetic variability, character association and diversity studies in lotus germplasm” was undertaken to evaluate the magnitude of genetic variability, study the association among important horticultural traits through correlation and path analysis and to assess the genetic divergence among different lotus germplasm for their effective utilization in future breeding, crop improvement and landscape development programmes.

Material and methods

The present investigation was conducted during February 2024 to October 2025 at the experimental plot of the College of Horticulture, Mysuru, Karnataka. The experiment was laid out in a Completely Randomized Design (CRD) with two replication using fifty lotus germplasm were collected from different localities of Karnataka, Kerala and Tamil Nadu for evaluation of different morphological and floral traits (Table 1). The freshly harvested lotus rhizomes weighing 180–200 g with three healthy nodes were planted at 5 cm depth in plastic tubs of 30 cm height, 35 cm bottom diameter and 45 cm top diameter. The tubs were filled halfway with a potting mixture of red soil and FYM in 2:1 ratio, while the remaining half was maintained with water at 10 cm above the soil surface throughout the crop period. Of the fifty lotus germplasm only twenty-six germplasm flowered during both the years of investigation, hence those germplasm were subjected for data analysis. The mean data obtained from various parameters *viz.*, plant height, number of leaves per plant, plant spread in N-S and E-W direction, days to flower bud initiation, flowering duration, number of flowers per plant and flower diameter were recorded from the two selected plants in each replication were pooled and subjected for statistical analysis to assess the variability and association among different morphological and floral traits. Correlation coefficients were estimated to determine the degree and direction of association among various characters as per the method suggested by Panse and Sukhatme (1967). Path coefficient analysis proposed by Wright (1921) was employed to partition the correlation coefficients into direct and indirect effects and to identify the traits contributing significantly towards flower yield and quality. Genetic diversity among the lotus germplasms was estimated using Mahalanobis D^2 statistics, and the germplasm were grouped into different clusters following Tocher's method based on minimum intra-cluster and maximum inter-cluster distances to identify genetically diverse germplasms for future breeding programmes.

Table 1
List of lotus germplasm used in the experimental study

Treatment No.	Germplasm	Location	Latitude (N)	Longitude (E)
T1	ML-TN-1	Tamil Nadu	12.11"	79.75"
T2	ML-TN-2			
T3	ML-Ke-3	Kerala	9.72"	76.72"
T4	ML-TN-4	Tamil Nadu	12.11"	79.75"
T5	ML-TN-5			
T6	ML-TN-6			
T7	ML-Ke-7	Kerala	9.72"	76.72"
T8	ML-TN-8	Tamil Nadu	12.11"	79.75"
T9	ML-Ke-9	Kerala	9.72"	76.72"
T10	ML-TN-10	Tamil Nadu	12.11"	79.75"
T11	ML-TN-11			
T12	ML-TN-12			
T13	ML-TN-13			
T14	ML-TN-14			
T15	ML-TN-15			
T16	ML-Ke-16	Kerala	9.72"	76.72"
T17	ML-TN-17	Tamil Nadu	12.11"	79.75"
T18	ML-KA-18	Isloor (Karnataka)	14.67"	74.88"
T19	ML-Ke-19	Kerala	9.72"	76.72"
T20	ML-Ke-20	Kerala	10.14"	76.70"
T21	ML-Ke-21			
T22	ML-Ke-22			
T23	ML-TN-23	Tamil Nadu	12.11"	79.75"
T24	ML-TN-24			
T25	ML-TN-25			
T26	ML-TN-26			
T27	ML-Ke-27	Kerala	9.72"	76.72"
T28	ML-TN-28	Tamil Nadu	12.11"	79.75"
T29	ML-TN-29			
T30	ML-Ke-30	Kerala	9.72"	76.72"
T31	ML-KA-31	Sakhleshpura (Karnataka)	12.89"	75.72"

Treatment No.	Germplasm	Location	Latitude (N)	Longitude (E)
T32	ML-KA-32	Tavarekere (Karnataka)	12.92"	77.60"
T33	ML-KA-33	Mugathihalli (Karnataka)	13.28"	75.75"
T34	ML-KA-34	Gavanahalli (Karnataka)	13.28"	75.75"
T35	ML-KA-35	Kavalkoppa (Karnataka)	14.62"	75.85"
T36	ML-KA-36	Mallandur (Karnataka)	14.08"	75.20"
T37	ML-KA-37	Karanji khere (Karnataka)	12.30"	76.67"
T38	ML-KA-38	Periyapatna (Karnataka)	12.33"	76.10"
T39	ML-TN-39	Tamil Nadu	12.11"	79.75"
T40	ML-TN-40			
T41	ML-Ke-41	Kerala	9.72"	76.72"
T42	ML-Ke-42		10.14"	76.70"
T43	ML-Ke-43			
T44	ML-Ke-44			
T45	ML-Ke-45	Kerala	9.72"	76.72"
T46	ML-Ke-46			
T47	ML-Ke-47			
T48	ML-Ke-48			
T49	ML-Ke-49	Kerala	10.14"	76.70"
T50	ML-TN-50	Tamil Nadu	12.11"	79.75"

Result and discussion

The estimates of genetic variability traits among the lotus germplasm revealed significant differences for all the characters, indicating the presence of considerable variability and thereby providing ample scope for selection and genetic improvement. The variability parameters such as mean, range, genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability, genetic advance and genetic advance as per cent of mean (GAM) are presented in Table 2. In general, the PCV values were slightly higher than the corresponding GCV values for most of the traits, indicating the influence of environmental factors on trait expression. However, the narrow difference between PCV and GCV for most characters suggested that environmental influence was minimal and that the majority of the observed variation was genetically controlled. This indicates that the traits are stable, highly heritable and can respond effectively to selection in breeding programmes. Similar results were reported by Sahu et al. (2021) in lotus, Kadam et al. (2014) in gladiolus and Pooja et al. (2020) in *Alpinia galanga*.

Among the vegetative traits, plant height exhibited moderate GCV (18.45%) and PCV (19.33%) along with high heritability (91.10%) and high GAM (46.49%), indicating predominance of additive gene action and suggesting that selection for this trait would be effective. Similarly, flower diameter recorded moderate GCV (17.93%) and PCV (18.41%) coupled with very high heritability (94.80%) and high GAM (46.08%), indicating that these traits are largely governed by additive gene effects and can be improved through direct selection. Similar findings were reported by Rai and Rana (2020) in *Alstroemeria*, Holkar et al. (2022) in liliun and Baranidharan et al. (2023) in canna lily.

Table 2
Genetic variability estimates of lotus germplasm for vegetative, flowering, yield and quality traits

Character	GCV (%)	PCV (%)	h ² (Broad Sense %)	Genetic Advance (%)	Genetic advance as per cent of mean (%)
Plant height (cm)	18.45	19.33	91.00	11.49	46.49
Number of coin leaves per plant	64.03	65.31	96.10	10.24	165.71
Number of floating leaves per plant	25.61	27.07	89.50	9.47	63.97
Number of aerial leaves per plant	24.87	28.53	76.00	2.37	57.26
Plant spread in N-S direction (cm)	3.79	4.58	68.40	3.23	8.26
Plant spread in E-W direction (cm)	4.12	4.80	73.70	3.74	9.35
Days to bud initiation	53.35	64.88	67.60	111.17	115.81
Duration of flowering (days)	49.97	53.11	88.50	150.09	124.13
Flower diameter (cm)	17.93	18.41	94.80	6.20	46.08
Number of flowers per plant	82.81	84.95	95.00	7.90	213.08

Traits such as number of coin leaves per plant, number of floating leaves per plant, number of aerial leaves per plant, days to bud initiation, duration of flowering and number of flowers per plant exhibited high to very high GCV and PCV along with high heritability and very high GAM, indicating the existence of substantial genetic variability and predominance of additive gene action. Number of coin leaves per plant recorded very high GCV (64.03%) and PCV (65.31%) with very high heritability (96.10%) and GAM (165.71%). Number of floating leaves per plant showed high GCV (25.61%) and PCV (27.07%) along with high heritability (89.50%) and GAM (63.97%), while number of aerial leaves per plant exhibited high GCV (24.87%) and PCV (28.53%) with heritability of 76.00 per cent and GAM of 57.26 per cent. Days to bud initiation recorded very high GCV (53.35%) and PCV (64.88%) with moderate heritability (67.60%) and high GAM (115.81%). Duration of flowering exhibited high GCV (49.97%) and PCV (53.11%) coupled with high heritability (88.50%) and very high GAM (124.13%). Number of flowers per plant showed extremely high GCV (82.81%) and PCV (84.95%) along with high heritability (95.00%) and very high GAM (213.08%), indicating excellent scope for improvement through direct selection. The close correspondence between PCV and GCV for these traits suggested minimal environmental influence and reliable transmission of superior alleles to subsequent generations. Similar findings were reported by Sahu et al. (2021) in lotus, Basavrajappa et al. (2019) in bird of paradise, Kisapotta et al. (2019) in gladiolus, Shrijitha et al. (2023) in red ginger, Pooja et al. (2020) in *Alpinia galanga* and Umachagi et al. (2023) in tuberose.

In contrast, plant spread in both N–S and E–W directions exhibited low GCV (3.79% and 4.12%) and PCV (4.58% and 4.80%) along with moderate heritability (68.40% and 73.70%) and low GAM (8.26% and 9.35%), indicating limited genetic variability and restricted scope for improvement through direct selection. The low magnitude of variability coupled with moderate heritability suggests that these traits are influenced comparatively more by environmental factors than by additive gene action. Therefore, improvement of these traits may require alternative breeding approaches such as hybridization or multi-environment selection. Similar observations were reported by Umachagi et al. (2023) in tuberose.

Genotypic and phenotypic correlation coefficients of yield and its contributing traits

The genotypic and phenotypic correlation analysis revealed both positive and negative associations among the ten characters studied, indicating the nature and extent of interrelationship among vegetative, flowering, yield and quality traits. Correlation studies provide valuable information for simultaneous improvement of characters through selection, particularly in yield improvement programmes where yield is a dependent trait influenced by several component characters and environmental conditions. The correlation coefficients at genotypic and phenotypic levels are presented in Tables 3 and 4.

The genotypic and phenotypic correlation analysis revealed both positive and negative associations among vegetative, flowering and yield traits, indicating their interrelationship and importance in flower yield improvement. Number of flowers per plant showed significant positive correlation with duration of flowering at both genotypic (0.784) and phenotypic (0.720) levels, and with number of coin leaves per plant at genotypic (0.527) and phenotypic (0.503) levels. However, it exhibited negative association with days to bud initiation at genotypic (-0.597) and phenotypic (-0.459) levels, suggesting that early flowering genotypes produced more flowers.

Plant height was positively associated with plant spread in E–W and N–S directions at both genotypic (0.554 and 0.513) and phenotypic (0.528 and 0.470) levels. Number of coin leaves per plant showed strong positive correlation with number of floating leaves per plant at genotypic (0.844) and phenotypic (0.814) levels, and with duration of flowering at genotypic (0.674) and phenotypic (0.615) levels. Negative association was observed with flower diameter at genotypic (-0.621) and phenotypic (-0.599) levels. The close similarity between genotypic and phenotypic correlations indicated lower environmental influence on trait expression. These findings suggest that duration of flowering, number of coin leaves and early bud initiation can be effectively used as selection criteria for improving flower yield in lotus. Similar relationships among flowering, vegetative and yield traits were reported by Bo et al. (2010) and Sahu et al. (2021) in lotus, Fahida et al. (2012) and Tom et al. (2015) in waterlily, Santhosh et al. (2018) in heliconia, Singh et al. (2023) in gladiolus, Pattar (2024) and Haque et al. (2023) in waterlily, Kadam et al. (2014), Naresh et al. (2015) and Singh et al. (2018) in gladiolus, and Gandhi and Bharathi (2020) and Sirohi et al. (2018) in tuberose.

Table 3
Genotypic correlation matrix of yield and yield related traits in lotus germplasm

X1	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
	1.000	-0.089	-0.026	-0.280	0.513**	0.554**	0.055	-0.019	0.001	-0.011
X2		1.000	0.844***	-0.304	-0.170	-0.160	-0.673***	0.674***	-0.621***	0.527**
X3			1.000	-0.174	-0.045	-0.073	-0.354	0.480**	-0.451*	0.222
X4				1.000	0.012	-0.182	-0.327	0.190	0.193	0.353
X5					1.000	1.032	0.160	-0.186	0.176	-0.325
X6						1.000	0.075	-0.180	0.214	-0.320
X7							1.000	-0.732	0.280	-0.597***
X8								1.000	-0.316	0.784***
X9									1.000	-0.331
X10										1.000

Table 4
Phenotypic correlation matrix of yield and yield related traits in lotus germplasm

X1	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
	1.000	-0.072	-0.028	-0.196	0.470**	0.528**	0.054	0.005	-0.008	0.005
X2		1.000	0.814***	-0.226	-0.148	-0.131	-0.535**	0.615***	-0.599***	0.503**
X3			1.000	-0.114	-0.070	-0.074	-0.340	0.429*	-0.416*	0.193
X4				1.000	-0.004	-0.121	-0.205	0.186	0.162	0.282
X5					1.000	0.946***	0.015	-0.077	0.145	-0.234
X6						1.000	-0.009	-0.059	0.167	-0.246
X7							1.000	-0.677***	0.219	-0.459**
X8								1.000	-0.311	0.720***
X9									1.000	-0.316
X10										1.000
X1-Plant height; X2-Number of coin leaves per plant; X3-Number of floating leaves per plant; X4-Number of aerial leaves per plant; X5-Plant spread in N-S direction; X6-Plant spread in E-W direction; X7-Days to bud initiation; X8: Duration of flowering; X9: Flower diameter and X10: Number of flowers per plant										

Table 5
Genotypic path matrix of lotus germplasm for yield and yield related traits

X1	X1	X2	X3	X4	X5	X6	X7	X8	X9	Correlation	Partial R ²
	0.305	-0.049	-0.041	-0.042	0.146	0.166	0.030	-0.018	0.016	0.030	0.010
X2	-0.163	1.013	0.824	-0.223	-0.150	-0.132	-0.542	0.623	-0.607	0.502	0.510
X3	0.088	-0.542	-0.666	0.076	0.047	0.049	0.226	-0.286	0.277	0.193	-0.128
X4	-0.055	-0.088	-0.044	0.393	-0.001	-0.047	-0.081	0.073	0.063	0.282	0.110
X5	-0.025	0.07	0.003	0.002	-0.053	-0.050	-0.011	0.041	-0.010	-0.234	0.012
X6	-0.116	0.027	0.015	0.025	-0.200	-0.212	0.001	0.012	-0.035	-0.242	0.051
X7	0.021	-0.115	-0.073	-0.044	0.031	-0.001	0.215	-0.145	0.047	-0.460	-0.098
X8	-0.029	0.296	0.207	0.089	-0.037	-0.028	-0.326	0.482	-0.149	0.720	0.347
X9	0.004	-0.047	-0.032	0.012	0.011	0.013	0.017	-0.024	0.079	-0.316	-0.025
R SQUARE = 0.7883 RESIDUAL EFFECT = 0.4601											

Table 6
Phenotypic path matrix yield and yield related traits in lotus germplasm

X1	X1	X2	X3	X4	X5	X6	X7	X8	X9	Correlation	Partial R ²
	0.239	-0.017	-0.007	-0.047	0.113	0.126	0.013	0.001	-0.002	0.005	0.001
X2	-0.074	1.029	0.837	-0.232	-0.153	-0.135	-0.551	0.633	-0.617	0.503	0.517
X3	0.020	-0.570	-0.700	0.080	0.049	0.052	0.238	-0.301	0.291	0.193	-0.135
X4	-0.081	-0.094	-0.047	0.414	-0.002	-0.050	-0.085	0.077	0.067	0.282	0.117
X5	-0.054	0.017	0.008	0.001	-0.115	-0.109	-0.002	0.009	-0.017	-0.234	0.027
X6	-0.059	0.015	0.008	0.013	-0.105	-0.111	0.001	0.007	-0.019	-0.243	0.027
X7	0.012	-0.123	-0.078	-0.047	0.003	-0.002	0.230	-0.156	0.051	-0.460	-0.106
X8	0.002	0.291	0.204	0.088	-0.037	-0.028	-0.321	0.474	-0.147	0.720	0.341
X9	-0.001	-0.046	-0.032	0.012	0.011	0.013	0.017	-0.024	0.076	-0.316	-0.024
R SQUARE = 0.7656 RESIDUAL EFFECT = 0.4841											
X1-Plant height; X2-Number of coin leaves per plant; X3-Number of floating leaves per plant; X4-Number of aerial leaves per plant; X5-Plant spread in N-S direction; X6-Plant spread in E-W direction; X7-Days to bud initiation; X8: Duration of flowering; X9: Flower diameter and X10: Number of flowers per plant											

Genotypic and phenotypic path analysis of yield and its contributing traits

Path coefficient analysis was carried out at both genotypic and phenotypic levels to measure the direct and indirect effects of different vegetative and flowering traits on flower yield. In the present investigation, number of flowers per plant was considered as the dependent variable, while all other vegetative, flowering and quality traits were treated as independent variables. Path analysis helps in partitioning the correlation coefficients into direct and indirect effects, thereby identifying the traits that contribute most effectively towards flower production. The genotypic and phenotypic path coefficient analyses are presented in Tables 5 and 6.

At both genotypic and phenotypic levels, flower yield exhibited positive direct effects through plant height (0.305, 0.239), coin leaves (1.013, 1.029), aerial leaves (0.393, 0.414), days to bud initiation (0.215, 0.230), flowering duration (0.482, 0.474) and flower diameter (0.079, 0.076), respectively. In contrast, floating leaves (-0.660, -0.700) and plant spread in N-S (-0.053, -0.115) and E-W (-0.212, -0.111) directions exerted negative direct effects at both genotypic and phenotypic levels. Strong positive indirect effects of coin leaves through floating leaves and flowering duration were also observed at genotypic (0.824, 0.623) and phenotypic (0.837, 0.633) levels. The consistency between genotypic and phenotypic effects indicated that plant height, coin leaves, aerial leaves, flowering duration and flower diameter are reliable selection traits for improving flower yield in lotus. Similar findings were reported by Sahu et al. (2021) in lotus, Menaie et al. (2010) in waterlily and Dhakal et al. (2021) in gladiolus.

Diversity analysis in lotus germplasm

The diversity analysis revealed the existence of high morphological divergence among the lotus germplasm for all the characters studied, indicating the presence of substantial genetic variability suitable for selection and hybridization programmes. Based on Mahalanobis D² statistics, the twenty-six lotus germplasm were grouped into six distinct clusters, reflecting their diverse genetic background and geographical origin (Table 7, Fig. 1 and Plate-1). Among the six clusters,

Cluster I was the largest comprising seventeen germplasm namely ML-TN-11, ML-Ke-19, ML-Ke-9, ML-Ke-7, ML-TN-4, ML-TN-1, ML-Ke-20, ML-Ke-21, ML-TN-14, ML-TN-13, ML-Ke-16, ML-TN-17, ML-Ke-22, ML-TN-8, ML-TN-5, ML-TN-10 and ML-TN-6, suggesting that a majority of the germplasm shared similar morphological features such as moderate vegetative growth, leaf production and flowering duration. Clusters IV and VI each consisted of three germplasm, whereas Clusters II, III and V contained single germplasm namely ML-Ke-27, ML-TN-26 and ML-TN-12, respectively. The occurrence of solitary clusters indicated the unique nature of these germplasm and their potential importance in breeding programmes for introducing novel traits and broadening the genetic base. Similar clustering patterns in lotus were reported by Roy et al. (2022) and Zhang et al. (2021), while related studies in ornamental crops were reported by Santosh et al. (2018) in *Strelitzia reginae* and Basavrajappa et al. (2019) in Bird of Paradise.

The intra- and inter-cluster distance analysis further explained the magnitude of genetic divergence among the clusters (Table 8). The intra-cluster distance ranged from 0.00 to 11.22, with the highest value observed in Cluster IV (11.22), followed by Cluster VI and Cluster I, indicating greater heterogeneity among the germplasm within these clusters. The higher intra-cluster distance suggested the presence of considerable variability in morphological and flowering traits due to diverse genetic constitution. In contrast, Clusters II, III and V exhibited minimum intra-cluster distance, indicating greater genetic similarity among the germplasm within these clusters. The inter-cluster distance was maximum between Cluster V and Cluster VI (20.68), followed by Cluster II with Cluster IV (19.11) and Cluster II with Cluster VI (18.44), indicating wider genetic divergence and contrasting trait expression among these clusters. Hence, hybridization between germplasm belonging to these clusters may result in higher heterosis and broader variability in segregating generations. On the other hand, the minimum inter-cluster distance was observed between Cluster I and Cluster III (10.52), suggesting close genetic affinity and limited scope for generating substantial variability through hybridization. Similar findings were reported by Roy et al. (2022) and Zhang et al. (2021) in lotus and Gandhi and Bharathi (2021) in tuberose.

The cluster mean analysis for vegetative, flowering, yield and quality traits revealed considerable variation among the six clusters, indicating wide genetic diversity among the lotus germplasm (Table 9). Cluster II recorded the highest mean values for plant spread in E–W direction (42.71 cm), plant spread in N–S direction (41.18 cm) and plant height (37.29 cm), indicating vigorous vegetative growth and better resource utilization, which are desirable traits for ornamental and landscape purposes. Cluster VI recorded the highest mean values for number of coin leaves (14.40), number of floating leaves (22.73) and duration of flowering (200.00 days), indicating prolonged vegetative activity and extended flowering duration. However, this cluster also recorded the lowest mean values for number of aerial leaves (2.79) and flower diameter (10.40 cm), suggesting that these germplasm may be more suitable for improving flowering duration rather than flower size. Cluster V exhibited the lowest mean values for plant height (19.22 cm), number of coin leaves (3.12) and duration of flowering (35.00 days), while it recorded the highest mean value for number of aerial leaves per plant (6.47), indicating comparatively poor vegetative growth and shorter flowering duration. Cluster IV recorded the lowest mean values for plant spread in both N–S (37.30 cm) and E–W (38.14 cm) directions, indicating compact growth habit, but exhibited the highest mean value for number of flowers per plant (10.63), suggesting its significance for commercial flower production and ornamental utilization. Similar observations were reported by Krause et al. (2023) in *Heliconia*, Sharma et al. (2017) in gladiolus and Gandhi and Bharathi (2021) in tuberose.

The relative contribution of different characters towards total genetic divergence indicated that variability among the lotus germplasm was mainly governed by a few important vegetative and flowering traits (Table 10). Among all the characters studied, number of coin leaves per plant and number of flowers per plant contributed the highest towards total genetic divergence, each accounting for 19.08 per cent and ranking first 62 times, followed by flower diameter (17.54%), duration of flowering (16.92%), plant height (14.77%) and days to bud initiation (7.08%). The high contribution of flower diameter reflected substantial variability in floral size, which is an important trait determining ornamental value and market preference. Likewise, duration of flowering contributed considerably towards divergence, indicating significant variation in flowering longevity and its importance in enhancing commercial value through extended blooming period.

Plant height also contributed appreciably, suggesting variability in plant stature and adaptability for different landscape purposes such as pond beautification and bowl lotus cultivation. Days to bud initiation showed moderate contribution, indicating variability in flowering earliness among the germplasm. In contrast, number of aerial leaves (3.38%), plant spread in N–S direction (1.85%) and number of floating leaves (0.31%) contributed relatively less towards genetic divergence, while plant spread in E–W direction exhibited no contribution (0.00%), indicating uniformity of this trait among the germplasm studied. Similar findings were reported by Basavrajappa *et al.* (2019) in Bird of Paradise, Singh *et al.* (2019) in tuberose and Rao *et al.* (2020) in gladiolus.

Table 7
Cluster composition of lotus germplasm

Cluster	Germplasm
Cluster I	ML-TN-11, ML-Ke-19, MI-Ke-9, ML-Ke-7, ML-TN-4, ML-TN-1, ML-Ke-20, ML-Ke-21, ML-TN-14, ML-TN-13, ML-Ke-16, ML-TN-17, MK-Ke-22, ML-Ke-8, ML-TN-5, ML-TN-10, ML-TN-6
Cluster II	ML-Ke-27
Cluster III	ML-TN-26
Cluster IV	ML-TN-24, ML-TN-25, ML-Ke-30
Cluster V	ML-TN-12
Cluster VI	ML-TN-15, ML-TN-28, ML-TN-2

Table 8
Average intra and inter cluster distance of lotus germplasm

Cluster I	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V	Cluster VI
	7.58	10.64	10.52	14.26	11.32	15.61
Cluster II		0	16.23	19.11	13.24	18.44
Cluster III			0	10.84	17.08	13.3
Cluster IV				8.49	18.27	13.95
Cluster V					0	20.68
Cluster VI						11.22

Table 9
Cluster means of different characters

Character	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V	Cluster VI
Plant height (cm)	24.33	37.29	22.57	24.26	19.22	25.58
Number of coin leaf	4.12	4.14	8.48	10.56	3.12	14.40
Number of floating leaf	12.84	16.74	17.29	16.76	14.10	22.73
Number of aerial leaf	4.07	3.49	5.29	5.01	6.47	2.79
Plant spread in N-S direction (cm)	39.09	41.18	40.21	37.30	39.10	39.56
Plant spread in E-W direction (cm)	40.02	42.71	40.88	38.14	39.65	40.65
Days to bud initiation	116.78	101.25	30.00	43.92	96.25	50.42
Duration of flowering (days)	100.66	57.50	177.50	187.50	35.00	200.00
Flower diameter (cm)	14.26	13.38	17.25	11.46	11.25	10.40
Number of flowers per plant	2.63	1.00	6.00	10.63	0.38	4.17

Table 10
Relative contribution of characters towards divergence

Source	Ranked 1st	Contribution %
Plant height	48	14.77
Number of coin leaf	62	19.08
Number of floating leaf	1	0.31
Number of aerial leaf	11	3.38
Plant spread in N-S direction	6	1.85
Plant spread in E-W direction	0	0.00
Days to bud initiation	23	7.08
Duration of flowering	55	16.92
Flower diameter	57	17.54
Number of flowers per plant	62	19.08

Conclusion

The present study revealed a substantial genetic variability existed among the lotus germplasm, indicating good potential for crop improvement through selection. High GCV, PCV, heritability and genetic advance were observed for number of leaves, days to bud initiation, flowering duration and number of flowers per plant, suggesting additive gene action and effectiveness of direct selection. Correlation and path analysis identified plant height, coin leaves, aerial leaves, flowering duration and flower diameter as the important contributors to flower yield. Mahalanobis D² analysis grouped the germplasm into six clusters, indicating wide genetic diversity and the possibility of utilizing diverse parents for hybridization and heterosis breeding. The findings also provide a valuable genetic base for future breeding, conservation and molecular characterization studies in lotus.

Declarations

Author Contribution

All authors helped in manuscript preparation

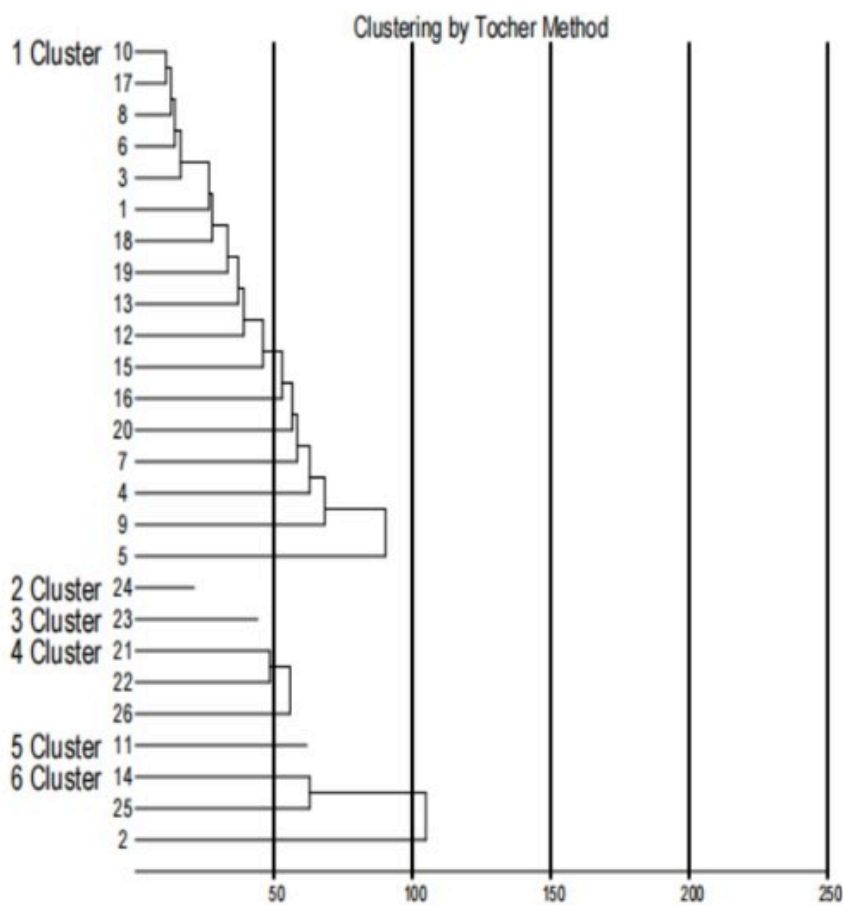
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Plate 1 is available in the Supplementary Files section.

Figures



1: ML-TN-1, 2: ML-TN-2, 3: ML-TN-4, 4: ML-TN-5, 5: ML-TN-6, 6: ML-Ke-7,
7: ML-Ke-8, 8: ML-Ke-9, 9: ML-TN-10, 10: ML-TN-11, 11: ML-TN-12, 12: ML-TN-
13, 13: ML-TN-14, 14: ML-TN-15, 15: ML-Ke-16, 16: ML-TN-17, 17: ML-Ke-19,
18: ML-Ke-20, 19: ML-Ke-21, 20: ML-Ke-22, 21: ML-TN-24, 22: ML-TN-25,
23: ML-TN-26, 24: ML-Ke-27, 25: ML-TN-28, 26: ML-Ke-30

Figure 1

Dendrogram showing clustering pattern of lotus germplasm based on morphological characters

Supplementary Files

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- [Plate1.jpg](#)