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QUANTITATIVE TRAIT VARIATION AND MULTIVARIATE ANALYSIS OF LOTUS (*Nelumbo nucifera* GAERTN.) GENOTYPES

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ABSTRACT

Morphological characterization and assessment of genetic variability are essential for identifying promising and diverse lotus genotypes. The present study was conducted to evaluate 48 flowering genotypes of lotus (*Nelumbo nucifera* Gaertn.) for vegetative, flowering and floral traits. Significant variation was observed among the genotypes, with flower weight, tepal number, total number of flowers, total number of aerial leaves and leaf blade length showing high GCV and PCV, indicating substantial variability. High heritability coupled with high genetic advance as per cent of mean was observed for several important vegetative and flowering traits, indicating good scope for selection. Correlation analysis revealed strong positive associations among traits, with the highest correlation observed between flower bud count and flowering duration (r = 0.952***). Principal component analysis showed that the first three components explained 69.0% of the total variation, with PC1, PC2 and PC3 contributing 39.7%, 16.9% and 12.4%, respectively. The PCA biplot indicated that flowering behaviour, flower production and morphological traits were major contributors to the observed variability. Cluster analysis grouped the 48 genotypes into four clusters, with the maximum inter-cluster distance observed between Cluster II and Cluster III (7.849). Cluster mean analysis revealed distinct variation among clusters for important vegetative and flowering traits. The identified variability and diverse genotypes provide opportunities for selection and utilization in future lotus improvement programmes.

Key words : Lotus, *Nelumbo nucifera*, Morphological characterization, Genetic variability, Heritability, Correlation, Principal component analysis, Cluster analysis, Germplasm diversity.

Introduction

Lotus (*Nelumbo nucifera* Gaertn.) is an important perennial aquatic plant of the family Nelumbonaceae, valued for its ornamental, nutritional, medicinal, cultural and economic significance. Its attractive flowers are widely used for religious offerings, garlands, floral arrangements and ornamental purposes and the plant is commonly cultivated in ponds, lakes, temple tanks and landscape water bodies (Ming *et al*., 2013; Roy *et al*., 2022; Lin *et al*., 2019). The plant is also recognized for its diverse phytochemical constituents and associated biological and health-promoting properties (Chen *et al*., 2019; Paudel and Panth, 2015).

The genus *Nelumbo* comprises two extant species, *N. nucifera* Gaertn. and *N. lutea* Willd., both with 2n = 16 chromosomes. The genome size of *N. nucifera* is approximately 929 Mb. Considerable genetic and morphological variability has been reported among lotus germplasm, providing opportunities for selection and breeding of superior types (Wang *et al*., 2019; Fu *et al*., 2021; Liu *et al*., 2022;Mekbib *et al*., 2020).

Lotus has high ornamental value due to its attractive flowers, large leaves and variation in flower colour, size, shape and petal number. This diversity provides scope for selecting desirable genotypes for landscaping and cut-flower utilisation (Hayes *et al*., 2000; Guo *et al*., 2010;

Roy *et al*., 2022). Variation in flowering behaviour and floral traits also offers opportunities for identifying early-flowering and superior ornamental genotypes (Jiang *et al.*, 2023; Fu *et al*., 2021).In addition to its ornamental and medicinal importance, lotus has potential for fibre utilisation, contributing to its broader economic value (Pandey *et al.*, 2023).

Therefore, characterisation of lotus genotypes based on morphological, flowering and floral traits is essential for identifying superior genotypes and their utilisation in breeding and ornamental cultivation. Hence, the present study was undertaken to characterise lotus genotypes and identify promising types for ornamental and cut-flower purposes (Lin *et al.*, 2019; Liu *et al.*, 2022; Ashoka and Revanna 2022).

Materials and Methods

Experimental site

The present investigation was conducted at the Division of Floriculture and Medicinal Crops, ICAR–Indian Institute of Horticultural Research (ICAR–IIHR), Bengaluru, Karnataka, India.

Plant material

A total of 48 lotus (*Nelumbo nucifera* Gaertn.) genotypes maintained at ICAR–IIHR were used for morphological characterization and assessment of diversity.

Experimental design and data collection

The genotypes were evaluated in a Completely Randomized Design (CRD) with three replications. Quantitative morphological observations were recorded at appropriate stages of vegetative growth, flowering and seed development. The observations were averaged over the three replications and used for subsequent statistical analysis.

Morphological characterization

Twenty-three quantitative morphological characters representing vegetative, flowering and reproductive traits were recorded. The characters included plant height, days taken for first coin leaf, aerial leaf, total aerial leaf, leaf blade length, leaf blade width, lamina thickness, petiole length, days taken to first bud, days taken to first flower, flower bud circumference, flower diameter, rhizome thickness, flower weight, tepal number, flower stalk length, total number of flowers, flowering duration, carpel number, receptacle diameter, seed length and seed width.

Statistical analysis

The recorded quantitative data were compiled and subjected to statistical analysis for assessing the extent and pattern of morphological variation among the lotus genotypes. Pearson's correlation coefficients were calculated to determine the magnitude and direction of association among the quantitative characters and the correlation matrix was used to identify significant relationships among traits.

Principal component analysis (PCA) was performed on the standardized quantitative data to identify the major components contributing to the total variation among the genotypes. Eigenvalues, proportion of variance and cumulative percentage of variance explained by each principal component were calculated. A PCA biplot was constructed to visualize the relationships among genotypes and morphological characters and to identify the traits contributing most to the observed variation.

For assessing overall morphological diversity, the quantitative data were standardized to eliminate differences in measurement scale. A Euclidean distance matrix was generated from the standardized data, followed by hierarchical cluster analysis using Ward's method. The resulting dendrogram was used to group the 48 lotus genotypes into distinct clusters. Intra- and inter-cluster distances were calculated to assess the extent of divergence within and between clusters. Cluster-wise means were also calculated for all the quantitative characters to identify clusters possessing desirable trait performance.

All statistical analyses and graphical presentations were carried out using R software.

Results and Discussion

Plant height

Higher plant height was recorded in genotype IIHR-NN-S-2 (89.615 cm), followed by IIHR-NN-S-13 (85.849 cm), whereas the lowest plant height was observed in IIHR-NN-S-10 (21.89 cm), followed by IIHR-NN-S-74 (25.009 cm).

Coin leaf

The lowest number of days taken for emergence of the coin leaf was recorded in genotype IIHR-NN-S-25 (65.306 days), followed by IIHR-NN-S-34 (67.652 days), whereas the highest number of days was recorded in IIHR-NN-S-49 (90.640 days), followed by IIHR-NN-S-59 (89.531 days)

Aerial leaf

The lowest number of days taken for emergence of the aerial leaf was recorded in genotype IIHR-NN-S-25 (6.025 days), followed by IIHR-NN-S-42 (7.000 days), whereas the highest number of days was recorded in IIHR-NN-S-49 (19.667 days), followed by IIHR-NN-S-59 (18.333 days).

Table 1 : Mean Performance of Lotus genotypes for Vegetative Traits.

Genotypes	Plant height (cm)	Days taken for Coin leaf (days)	Days taken for aerial leaf	Total number of aerial leaves	Leaf blade length (cm)	Leaf width (cm)	Lamina Thickness (mm)	Petiole length (cm)	Rhizome thickness (mm)
IIHR-NN-S-1	54.495	83.286	11	16.567	15.979	14.496	0.54	42.06	22
IIHR-NN-S-2	89.615	85.347	7.578	16.843	13.336	10.719	0.634	69.878	24.203
IIHR-NN-S-4	57.211	79.225	10	23.648	10.293	8.586	0.466	37.1	18.6
IIHR-NN-S-13	85.849	83.65	11	12.561	20.246	17.211	0.484	65.6	25.1
IIHR-NN-S-15	59.163	80.386	13	19.598	16.861	13.873	0.324	47.167	17.703
IIHR-NN-S-16	82.724	84.395	10	12.384	20.981	17.358	0.474	62.167	23.8
IIHR-NN-S-18	45.296	83.438	8	15.17	21.617	17.757	0.385	53.8	18
IIHR-NN-S-19	44.53	81.375	10.333	10.642	14.6	17.545	0.403	35.833	15.3
IIHR-NN-S-20	61.831	80.299	10	9.531	17.499	15.573	0.253	41.833	19.7
IIHR-NN-S-21	61.619	81.636	15	10.971	22.505	19.118	0.351	54.8	25.797
IIHR-NN-S-25	55.425	65.306	7	6.595	34.416	28.567	0.428	39.833	33.1
IIHR-NN-S-28	58.917	83.728	9	7.635	19.17	17.389	0.553	46.1	22.3
IIHR-NN-S-31	28.899	84.316	10	13.269	19.273	15.427	0.363	46.867	22.9
IIHR-NN-S-33	59.067	80.185	13	22.249	17.086	13.69	0.415	55.23	14.9
IIHR-NN-S-34	69.717	67.652	6.025	10.576	20.835	18.523	0.563	49.033	25.5
IIHR-NN-S-37	67.4	69.493	10	17.073	23.445	26.322	0.438	47.733	32.897
IIHR-NN-S-38	64.991	84.562	16	14.168	28.503	23.419	0.655	54.767	27.5
IIHR-NN-S-42	70.9	78.491	7.404	7.053	23.305	20.503	0.394	52.433	25.103
IIHR-NN-S-43	40.46	77.558	18	22.823	19.351	16.356	0.425	51.4	19.7
IIHR-NN-S-45	56.017	70.16	8.777	22.539	37.621	31.457	0.542	52.8	23.6
IIHR-NN-S-46	38.519	73.36	12	16.105	10.509	9.507	0.485	32.133	17.4
IIHR-NN-S-48	50.1	81.956	12.333	12.423	11.422	13.744	0.451	44.633	25.103
IIHR-NN-S-49	44.078	90.64	19.667	35.74	14.262	11.735	0.505	34.8	10.8
IIHR-NN-S-50	61.23	81.333	15.2	15.534	5.533	4.289	0.467	28.933	17.7
IIHR-NN-S-51	33.272	83.588	11	18.708	6.516	5.926	0.373	25.767	12.3
IIHR-NN-S-52	50.16	75.694	10	26.964	13.982	11.918	0.586	30.767	16.203
IIHR-NN-S-53	35.76	80.859	8.267	18.341	7.611	9.234	0.522	28.1	13.103
IIHR-NN-S-54	41.642	81.236	13	20.386	13.567	12.627	0.623	34.8	26.4
IIHR-NN-S-55	68.124	86.41	15	11.179	12.185	11.373	0.593	37.133	24.8
IIHR-NN-S-56	48.127	88.369	17.667	9.487	19.865	17.307	0.503	42.8	26.3
IIHR-NN-S-57	76.829	73.05	11	9.184	39.068	34.32	0.393	56.8	26.303
IIHR-NN-S-58	42.344	85.362	10	8.194	27.856	22.839	0.444	46.1	29.6
IIHR-NN-S-59	46.975	89.531	18.333	21.417	24.329	20.28	0.505	44.733	24.4
IIHR-NN-S-60	39.585	79.486	11	25.654	12.466	10.521	0.922	29.367	18.603
IIHR-NN-S-61	35.2	81.668	9.733	39.631	8.633	10.467	0.516	33.834	19.503
IIHR-NN-S-66	42.234	82.583	14.467	24.289	9.589	11.778	0.545	33.4	18.697
IIHR-NN-S-68	35.869	81.45	15	30.309	20.327	17.412	0.605	31.033	27.2
IIHR-NN-S-69	30.592	74.393	16	21.356	16.429	13.587	0.772	22.734	19.003
IIHR-NN-S-70	38.948	85.159	8	19.411	17.175	14.788	0.487	33.767	15.703
IIHR-NN-S-71	45.057	77.331	11	16.4	17.863	16.571	0.422	41.933	15.603
IIHR-NN-S-72	40.578	77.512	11.42	14.73	15.378	25.433	0.481	46.867	21.397
IIHR-NN-S-73	44.347	83.087	12.65	25.383	20.467	18.267	0.415	22.711	35

Table 1 continued...

Table 1 continued...

IIHR-NN-S-74	25.009	76.454	14.4	25.583	25.467	22.467	0.248	20.545	9.203
IIHR-NN-S-75	42.566	75.167	13.653	35.283	24.467	21.6	0.503	33.467	1.553
IIHR-NN-S-27	48.507	81.546	16.533	9.45	22.466	21.533	0.405	36.344	22.503
IIHR-NN-S-36	34.963	82.817	12.517	13.338	11.567	9.633	0.435	30.334	13.7
IIHR-NN-S-40	53.407	81.867	12.367	9.653	20.833	16.522	0.45	39.711	23.8
IIHR-NN-S-10	21.89	82.2	14.337	11.339	14.544	12.167	0.436	18.567	18.7
C.D.	2.089	0.862	0.758	0.975	0.813	0.827	0.041	1.798	1.002
SE(m)	0.743	0.306	0.27	0.347	0.289	0.294	0.015	0.639	0.356
SE(d)	1.051	0.433	0.381	0.49	0.409	0.416	0.021	0.904	0.504
C.V.	2.541	0.66	3.815	3.443	2.729	3.087	5.237	2.701	2.938

Table 2 : Mean performance of Lotus Genotypes for Flowering Traits.

Genotypes	**Days to 1st bud**	**Days 1st flower**	**Flower bud circumf-erence**	**Flower diameter**	**Flower stalk length**	**Flower weight**	**Tepal number**	**Total number of flowers**	**Flowering duration**
IIHR-NN-S-1	97.667	113.167	14.7	18.5	77.404	15.356	108	3.64	11.308
IIHR-NN-S-2	118.778	132.945	20.283	23.517	92.281	10.69	122.5	10.167	23.407
IIHR-NN-S-4	126.333	137.499	12.5	15.567	40.415	9.39	120.334	10.955	24.594
IIHR-NN-S-13	95.334	111.301	18.567	22.567	76.392	16.543	69.666	4.492	11.945
IIHR-NN-S-15	99.333	116.833	15.267	17.617	66.637	14.43	180.333	9.385	22.338
IIHR-NN-S-16	128.667	141.4	26.9	24.15	66.553	15.564	101.333	5.62	14.37
IIHR-NN-S-18	97.667	113.134	20.644	24.932	69.516	13.49	137.333	8.279	19.572
IIHR-NN-S-19	187.333	211.633	14.642	17.554	25.482	6.663	74.252	5.026	13.227
IIHR-NN-S-20	124.778	140.445	13.767	19.333	45.544	11.23	135.5	2.96	8.59
IIHR-NN-S-21	120.667	132.477	14.634	16.2	65.508	13.454	66.667	4.137	11.562
IIHR-NN-S-25	112.333	133.666	18.583	19.617	47.346	16.577	62.667	8.068	19.413
IIHR-NN-S-28	115.667	128.167	13.233	17.55	56.551	13.357	70.633	9.62	22.703
IIHR-NN-S-31	110.5	131.833	17.4	20.584	37.779	18.293	66.433	8.579	20.473
IIHR-NN-S-33	92.667	103	14.6	15.592	79.566	19.543	145.167	3.126	8.868
IIHR-NN-S-34	128.333	144.666	13.4	17.233	50.379	21.427	72.333	7.944	18.35
IIHR-NN-S-37	179.333	194.867	22.274	30.388	61.683	20.949	96.149	6.955	15.336
IIHR-NN-S-38	129.222	144.722	18.184	22.517	66.492	22.72	81.834	5.278	13.413
IIHR-NN-S-42	120.584	139.918	17.767	23.15	57.319	16.587	150.333	6.456	14.637
IIHR-NN-S-43	122.417	136.917	11.6	13.2	50.663	15.337	62.334	5.555	13.72
IIHR-NN-S-45	100.834	118.389	21.656	24.45	57.393	13.577	92.583	11.923	25.497
IIHR-NN-S-46	96	108	14.641	16.067	46.579	12.447	167.555	9.157	21.437
IIHR-NN-S-48	190	215.433	20.259	25.37	62.289	20.245	62.317	3.098	9.642
IIHR-NN-S-49	148.667	172	6.166	9.624	20.589	4.61	19.533	3.252	10.337
IIHR-NN-S-50	175.334	191.734	14.285	17.249	22.387	5.137	82.763	8.609	21.114
IIHR-NN-S-51	124.667	143	12.533	14.933	32.897	10.39	47.667	7.292	16.135
IIHR-NN-S-52	143.278	163.611	16.311	18.355	26.625	8.544	49.667	4.6	12.56
IIHR-NN-S-53	176.333	193.867	12.878	16.285	38.487	5.846	60.252	4.304	11.744
IIHR-NN-S-54	113.667	131.6	10.384	12.35	32.65	7.443	20.556	2.589	8.43
IIHR-NN-S-55	107.333	124.4	25.233	33.567	15.574	9.68	25.75	6.312	14.48
IIHR-NN-S-56	123.5	141.567	16.483	18.633	53.531	5.28	26.333	3.578	10.866
IIHR-NN-S-57	117.334	136.278	20.467	26.433	83.455	35.157	172.667	7.414	16.735

Table 2 continued...

Table 2 continued...

IIHR-NN-S-58	137.833	157.333	29.883	32.608	69.2	20.557	68.556	7.569	17.488
IIHR-NN-S-59	114.333	129.666	13.067	14.317	56.422	8.524	67.5	2.445	7.563
IIHR-NN-S-60	173.667	185.567	13.933	16.5	17.224	15.267	23.5	7.126	15.73
IIHR-NN-S-61	181.667	201.234	11.378	14.563	25.551	3.924	16.15	3.413	10.806
IIHR-NN-S-66	186.334	208.967	9.845	11.456	19.919	5.317	20.12	2.163	6.798
IIHR-NN-S-68	147.667	164.084	17.3	18.6	38.999	33.953	169.23	8.548	20.595
IIHR-NN-S-69	149.667	164	26.883	30.65	61.386	18.567	130.787	1.465	5.333
IIHR-NN-S-70	132.333	151.666	20.567	24.433	52.436	29.293	148	4.059	9.603
IIHR-NN-S-71	94.333	105.466	23.5	31.333	43.975	25.9	101.333	6.579	14.951
IIHR-NN-S-72	103.667	118.733	18.933	25.233	45.671	30.467	168.633	6.278	14.747
IIHR-NN-S-73	150.667	162.333	17.8	22.4	51.473	26.233	112.667	7.312	14.813
IIHR-NN-S-74	117.667	134.167	17.133	23.7	54.584	23.54	128.833	8.292	17.135
IIHR-NN-S-75	99.574	117.074	13.067	14.667	47.383	9.557	35.567	5.492	12.945
IIHR-NN-S-27	248.229	275.833	23.36	25.537	65.31	20.81	151.283	4.585	9.464
IIHR-NN-S-36	233.994	247.242	16.433	20.493	31.31	14.24	70.34	5.616	11.523
IIHR-NN-S-40	239	265.093	18.97	18.717	74.98	17.323	155.56	2.575	11.901
IIHR-NN-S-10	237	254.613	4.043	6.043	23.413	3.523	28.523	3.059	8.557
C.D.	1.999	6.802	1.441	0.92	2.13	0.7113	3.687	0.7494	0.9
SE(m)	0.711	2.419	0.513	0.327	0.758	0.253	1.311	0.2666	0.32
SE(d)	1.005	3.421	0.725	0.463	1.072	0.3578	1.854	0.377	0.453
C.V.	0.886	2.685	5.292	2.821	2.619	2.86	2.507	7.78	3.82

Total number of aerial leaves

The highest total number of aerial leaves was recorded in genotype IIHR-NN-S-61 (39.631), followed by IIHR-NN-S-49 (35.740), whereas the lowest total number of aerial leaves was recorded in IIHR-NN-S-25 (6.595), followed by IIHR-NN-S-42 (7.053).

Leaf blade width

Higher Leaf blade width was observed in genotype IIHR-NN-S-57(34.320) followed byIIHR-NN-S-45(31.457) while the lowest Leaf blade width was observed in genotype IIHR-NN-S-50(4.289) followed byIIHR-NN-S-51(5.926)

Leaf blade length

Higher Leaf blade width was observed in genotype IIHR-NN-S-57(39.068) followed byIIHR-NN-S-45(37.621) while the lowest Leaf blade width was observed in genotype IIHR-NN-S-50(5.533) followed byIIHR-NN-S-51(6.516)

Lamina thickness

Highest Lamina thickness was observed in genotype IIHR-NN-S-60(0.922) followed byIIHR-NN-S-69(0.772) while the lowest Lamina thickness was observed in genotype IIHR-NN-S-74(0.248) followed byIIHR-NN-S-20(0.253)

Fig. 1 : Representative floral diversity among the evaluated lotus genotypes.

Table 3 : Mean performance of Lotus Genotypes for receptacle and Seed traits.

Genotypes	Carpel number	Receptacle diameter	Receptacle height	Seed length	Seed width
IIHR-NN-S-1	13.5	29.463	40.758	3.233	2.573
IIHR-NN-S-2	9.967	26.697	29.442	7.747	7.28
IIHR-NN-S-4	6.967	17.671	28.517	2.137	2.64
IIHR-NN-S-13	5.433	26.71	33.65	2.123	3.354
IIHR-NN-S-15	5.067	18.546	27.577	0.833	0.86
IIHR-NN-S-16	11.667	24.237	33.555	0.25	0.533
IIHR-NN-S-18	8.044	35.76	39.677	2.356	3.353
IIHR-NN-S-20	6.067	22.325	30.41	2.63	3.45
IIHR-NN-S-21	5.834	23.285	29.37	1.08	1.18
IIHR-NN-S-28	6.353	30.47	34.656	1.642	2.782
IIHR-NN-S-33	9.1	18.53	29.544	0.467	0.667
IIHR-NN-S-34	10.219	19.78	31.45	0.453	0.586
IIHR-NN-S-37	10.227	31.52	39.642	7.547	4.827
IIHR-NN-S-38	12.035	30.455	38.534	3.557	3.74
IIHR-NN-S-42	12.953	41.528	47.609	3.667	3.233
IIHR-NN-S-43	10.35	20.705	25.556	6.267	6.45
IIHR-NN-S-45	11.945	27.411	36.349	0.533	0.933
IIHR-NN-S-48	12.886	25.499	34.463	5.073	5.539
IIHR-NN-S-49	5.167	15.472	22.582	0.26	0.637
IIHR-NN-S-51	6.733	18.767	30.085	8.58	8.45
IIHR-NN-S-52	8.756	20.288	26.167	0.203	0.227
IIHR-NN-S-54	7.25	13.5	18.241	2.417	2.593
IIHR-NN-S-55	14.656	19.465	26.677	2.343	2.47
IIHR-NN-S-56	7.967	26.393	33.56	2.268	2.747
IIHR-NN-S-57	7.155	33.723	37.503	1.773	1.857
IIHR-NN-S-59	9.333	36.156	41.293	0.383	1.263
IIHR-NN-S-60	8.544	17.527	27.7	1.364	1.16
IIHR-NN-S-61	4.944	11.598	15.621	4.123	4.551
IIHR-NN-S-66	5.143	16.636	23.21	2.632	2.908
IIHR-NN-S-69	6.133	28.3	31.634	1.534	1.947
IIHR-NN-S-70	8.667	22.663	29.645	0.11	0.15
IIHR-NN-S-71	6.667	29.55	36.04	0.35	0.35
IIHR-NN-S-72	10.667	22.71	36.6	3.473	2.377
IIHR-NN-S-74	11.637	34.55	25.6	0.933	0.45
IIHR-NN-S-75	5.263	17.829	19.682	0.75	0.55
IIHR-NN-S-27	7.34	15.633	18.633	0.403	0.293
IIHR-NN-S-10	2.523	13.56	15.56	1.641	1.7
C.D.	0.466	1.095	1.274	0.241	0.109
SE(m)	0.165	0.388	0.451	0.085	0.039
SE(d)	0.233	0.548	0.638	0.121	0.055
C.V.	3.375	2.807	2.566	6.273	2.729

Petiole length

Highest Petiole length was observed in genotype IIHR-NN-S-2(69.872) followed byIIHR-NN-S-13(65.600) while the lowest Petiole length was observed in genotype IIHR-NN-S-10(18.567) followed byIIHR-NN-S-74(20.545)

Rhizome thickness

Highest Rhizome thickness was observed in genotype IIHR-NN-S-73(35.00) followed byIIHR-NN-S-25(33.10) lowest Rhizome thickness was observed in genotype IIHR-NN-S-75(1.55) followed byIIHR-NN-S-74(9.20).

Days to 1st bud

The lowest number of days taken to first bud was observed in genotype IIHR-NN-S-33 (92.667), followed by IIHR-NN-S-49 (94.333), whereas the highest number of days was observed in genotype IIHR-NN-S-27 (248.229), followed by IIHR-NN-S-40 (239.000)

Days to 1st flower

The lowest number of days taken to first flower was observed in genotype IIHR-NN-S-10 (103.000), followed by IIHR-NN-S-71 (105.466), whereas the highest number of days was observed in genotype IIHR-NN-S-58 (275.833), followed by IIHR-NN-S-71 (265.093).

Tepal number

Highest Tepal number was observed in genotype IIHR-NN-S-70(172.667) followed byIIHR-NN-S-68(169.230) while the Tepal number was observed in genotype IIHR-NN-S-10(013.523)followed byIIHR-NN-S-61(18.369).

Flower weight

Highest Flower weight was observed in genotype IIHR-NN-S-70(35.157) followed byIIHR-NN-S-68(33.953), while the Flower weight was observed in genotype IIHR-NN-S-10(2.857) followed by IIHR-NN-S-61(3.924).

Flower stalk length

Highest Flower stalk length was observed in genotype IIHR-NN-S-2(92.281) followed by IIHR-NN-S-57(83.455), while the Flower stalk length was observed in genotype IIHR-NN-S-55(15.574) on par IIHR-NN-S-60(17.224) followed by IIHR-NN-S-36(19.919) on par IIHR-NN-S-23(20.589).

Flower bud circumference

Highest Flower bud circumference was observed in genotype IIHR-NN-S-58(29.883) followed by IIHR-NN-S-71(27.733), while the Flower bud circumference was observed in genotype IIHR-NN-S-10(4.043) followed byIIHR-NN-S-49(6.166).

Table 4 : Estimation of variability parameters for lotus accessions.

Character	GCV	PCV	Heritability	Genetic advance	Genetic advance as per cent of mean
Plant height	28.03	29.15	99.23	31.56	59.58
Days taken for emergence of coin leaf	6.09	7.12	85.12	11.69	14.53
Days taken for emergence of aerial leaf	30.46	33.61	86.10	8.18	68.61
Total number of aerial leaves	39.89	43.98	87.61	15.63	90.25
Leaf blade length	38.65	42.74	98.53	15.92	87.69
Leaf blade width	35.62	39.74	94.38	13.10	81.36
Lamina thickness	21.56	24.73	98.57	0.25	50.22
Petiole length	22.18	26.32	92.93	23.07	53.64
Days to 1st bud	19.52	22.54	93.80	60.73	46.34
Days to 1st flowering	18.71	21.78	98.35	7.53	44.57
Flower bud circumference	27.85	29.98	97.18	10.34	61.24
Flower diameter	25.51	29.63	99.20	12.23	60.56
Rhizome thickness	23.90	25.03	95.97	1.10	51.03
Flower weight	45.64	51.69	99.80	15.71	106.27
Tepal no	48.47	54.54	99.73	97.95	112.05
Carpel no	30.30	32.42	82.25	5.71	66.29
Receptacle diameter	26.08	29.21	83.13	14.55	59.64
Receptacle height	17.66	21.80	81.70	14.00	44.32
Seed length	20.02	23.12	65.78	4.78	191.41
Seed width	19.93	22.97	63.90	4.33	162.50
Flower stalk length	36.45	39.55	97.51	40.76	81.06
Total no flowers	41.38	44.47	99.60	5.51	91.24
Flowering duration	35.62	37.74	98.32	10.89	73.13

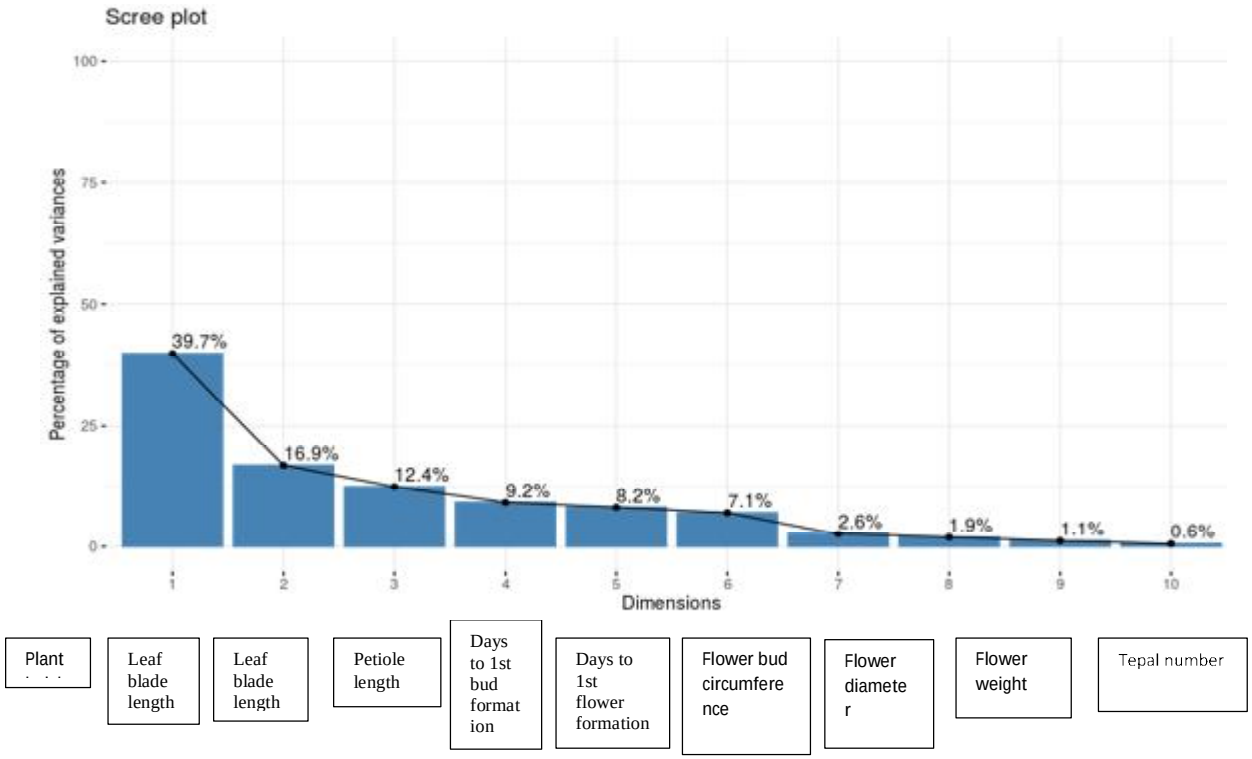

Fig. 2 : Scree plot showing the eigenvalues of different principal components and the percentage of cumulative variability explained by PCA based on quantitative morphological and flowering traits of lotus genotypes.

Table 5 : Correlation coefficients among vegetative morphological traits of lotus germplasm.

PH	CL	AL	TAL	LL	LW	LT	PT	DB	DF	FBC	FD	RT	FW	TN	FSL	TF	FD.1
1	-0.008	-0.23	-0.417**	0.316*	0.286*	0.002	0.709***	-0.247	-0.267	0.297*	0.273	0.097	0.108	0.248	0.495***	0.169	0.273
	1	0.226	-0.112	-0.145	-0.214	0.125	0.084	0.12	0.099	0.01	-0.027	0.035	-0.239	-0.269	0.042	-0.221	-0.027
		1	0.252	-0.097	-0.126	0.222	-0.285*	0.11	0.106	-0.234	-0.228	0.102	-0.095	-0.137	-0.153	-0.287*	-0.228
			1	-0.3*	-0.339*	0.312*	-0.394**	0.004	-0.015	-0.369**	-0.396**	-0.412**	-0.174	-0.19	-0.307*	-0.047	-0.396**
				1	0.923***	-0.247	0.481***	-0.253	-0.238	0.449**	0.392**	0.456**	0.531***	0.313*	0.58***	0.152	0.392**
					1	-0.24	0.464***	-0.213	-0.197	0.454**	0.445**	0.511***	0.565***	0.318*	0.494***	0.142	0.445**
						1	-0.128	0.101	0.089	-0.081	-0.127	-0.076	-0.2	-0.327*	-0.195	-0.137	-0.127
							1	-0.467***	-0.477***	0.348*	0.299*	0.124	0.279	0.257	0.675***	0.163	0.299*
								1	0.90***	-0.105	-0.086	0.224	-0.131	-0.209	-0.315*	-0.322*	-0.086
									1	-0.096	-0.073	0.227	-0.116	-0.224	-0.337*	-0.321*	-0.073
										1	0.952***	0.342*	0.637***	0.479***	0.514***	0.225	0.952***
											1	0.357*	0.652***	0.461***	0.437**	0.243	0.853
												1	0.417**	0.16	0.266	-0.003	0.357*
													1	0.614***	0.497***	0.23	0.652***
														1	0.558***	0.321*	0.461***
															1	0.068	0.437**
																1	0.243
																	1

Flower diameter

Highest Flower diameter was observed in genotype IIHR-NN-S-58(32.608) followed by IIHR-NN-S-71(31.333), while the Flower diameter was observed in genotype IIHR-NN-S-10(6.043) followed by IIHR-NN-S-49(9.624).

Total no of flowers

Highest Total no of flowers was observed in genotype IIHR-NN-S-20(11.923) followed by IIHR-NN-S-3(10.955), while the total no of flowers was observed in genotype IIHR-NN-S-69 (1.465) followed by IIHR-NN-S-66(2.163).

Flowering duration

Highest flowering duration was observed in genotype IIHR-NN-S-20(25.497) followed by IIHR-NN-S-3(24.594), while the Flowering duration was observed in genotype IIHR-NN-S-69(5.333) followed by IIHR-NN-S-66(6.798).

Carpel number

Highest Carpel number was observed in genotype IIHR-NN-S-55(14.656) followed by IIHR-NN-S-1(13.500) while the lowest Carpel number was observed in genotype IIHR-NN-S-10(2.523) followed by IIHR-NN-S-61(4.944).

Receptacle diameter

Highest Receptacle diameter was observed in genotype IIHR-NN-S-42(41.528) followed by IIHR-NN-S-59(36.156), while the lowest Receptacle diameter was observed in genotype IIHR-NN-S-10(9.560) followed by IIHR-NN-S-61(11.598).

Receptacle height

The highest receptacle height was observed in genotype IIHR-NN-S-42 (47.609), followed by IIHR-NN-S-59 (41.293), whereas the lowest receptacle height was observed in genotype IIHR-NN-S-10 (13.560), followed by IIHR-NN-S-61 (15.621).

Seed length

The highest seed length was observed in genotype IIHR-NN-S-51(8.580) followed by IIHR-NN-S-2(7.747) whereas the lowest Seed length was observed in genotype IIHR-NN-S-71(0.110) followed by IIHR-NN-S-27(0.203).

Seed width

The highest Seed length was observed in genotype IIHR-NN-S-51(8.450) followed by IIHR-NN-S-2(7.280) while the lowest Seed length was observed in genotype IIHR-NN-S-70 (0.196) on par IIHR-NN-S-52(0.227)

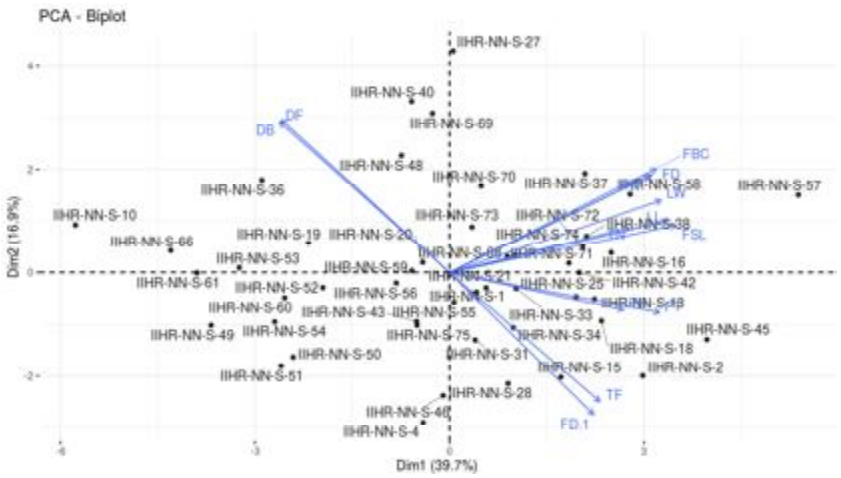

Fig. 3 : PCA biplot showing the association among vegetative and flowering traits of lotus genotypes.

leaves, leaf blade length, leaf blade width, flower weight, tepal number, flower stalk length and total number of flowers, indicating greater scope for selection and genetic improvement of these traits. The results indicated considerable genetic variability among the lotus genotypes, providing opportunities for the selection of superior genotypes for important vegetative, flowering and floral traits (Kumar *et al.*, 2024).

Principal component analysis (PCA) was used to identify the major traits contributing to the variability among the lotus genotypes and to reduce the dimensionality

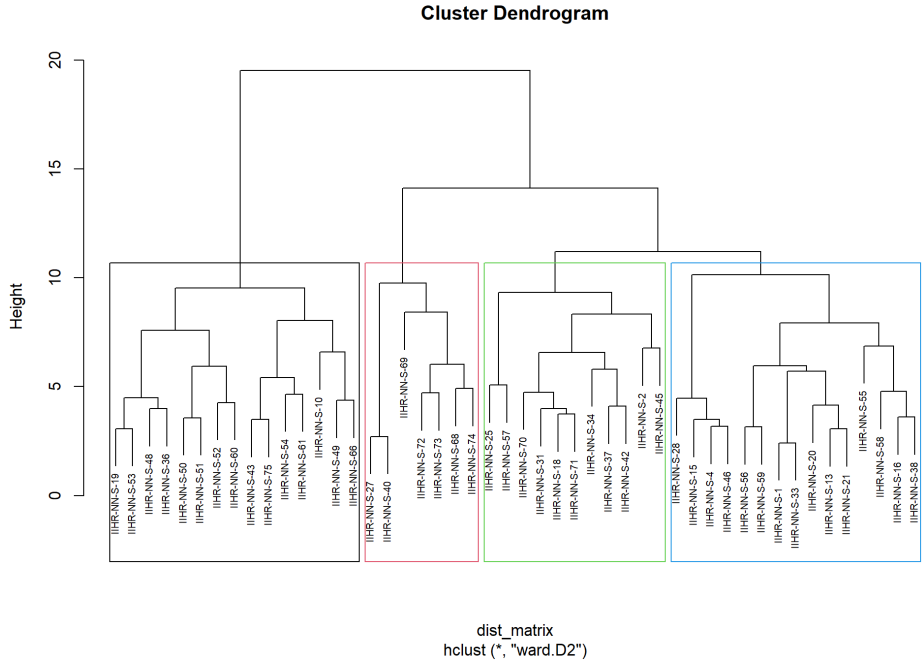

Fig. 4 : Dendrogram showing the clustering pattern of 48 lotus genotypes based on quantitative morphological characters.

followed byIIHR-NN-S-27(0.293).

The analysis of genetic variability revealed considerable variation among the lotus genotypes for the traits studied. GCV ranged from 6.09% for days taken for emergence of coin leaf to 48.47% for tepal number, while PCV ranged from 7.12% to 54.54%. High GCV and PCV were recorded for tepal number, flower weight, total number of flowers, total number of aerial leaves and leaf blade length, indicating the presence of substantial variability for these traits.

Heritability estimates ranged from 63.90% for seed width to 99.80% for flower weight. High heritability coupled with high genetic advance as a per cent of mean was observed for plant height, total number of aerial of the dataset. The scree plot showed that PC1, PC2 and PC3 accounted for 39.7, 16.9 and 12.4% of the total variation, respectively. The first three principal components together explained 69.0% of the total variation. The remaining principal components contributed comparatively less to the total variation. Thus, the first three principal components represented a major proportion of the variability observed among the lotus genotypes. Similar use of PCA to assess variability among flower crop genotypes was reported by Kumar *et al.* (2025).

The PCA biplot revealed considerable variation and association among the vegetative and flowering traits of the lotus genotypes. Days to first bud (DB) and days to first flowering (DF) were oriented in the opposite direction

Table 6 : Clustering of lotus genotypes.

Cluster	No. of genotypes	Genotypes
Cluster I	15	IIHR-NN-S-1, IIHR-NN-S-4, IIHR-NN-S-13, IIHR-NN-S-15, IIHR-NN-S-16, IIHR-NN-S-20, IIHR-NN-S-21, IIHR-NN-S-28, IIHR-NN-S-33, IIHR-NN-S-38, IIHR-NN-S-46, IIHR-NN-S-55, IIHR-NN-S-56, IIHR-NN-S-58, IIHR-NN-S-59
Cluster II	11	IIHR-NN-S-2, IIHR-NN-S-18, IIHR-NN-S-25, IIHR-NN-S-31, IIHR-NN-S-34, IIHR-NN-S-37, IIHR-NN-S-42, IIHR-NN-S-45, IIHR-NN-S-57, IIHR-NN-S-70, IIHR-NN-S-71
Cluster III	15	IIHR-NN-S-48, IIHR-NN-S-49, IIHR-NN-S-50, IIHR-NN-S-51, IIHR-NN-S-52, IIHR-NN-S-53, IIHR-NN-S-54, IIHR-NN-S-60, IIHR-NN-S-61, IIHR-NN-S-66, IIHR-NN-S-75
Cluster IV	7	IIHR-NN-S-27, IIHR-NN-S-40, IIHR-NN-S-68, IIHR-NN-S-69, IIHR-NN-S-72, IIHR-NN-S-73, IIHR-NN-S-74

Table 7 : Intra- and inter-cluster distances of 48 genotypes of lotus.

Cluster	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Cluster 1	5.243	6.233	6.529	7.185
Cluster 2	6.233	5.979	7.849	7.306
Cluster 3	6.529	7.849	5.569	7.524
Cluster 4	7.185	7.306	7.524	6.398

to the total number of flowers (TF) and Flowering duration (FD1), indicating a negative association between flowering-time traits and flower production. Thus, genotypes with earlier bud initiation and flowering tended to exhibit greater flower production in the present germplasm. A similar negative association between days to bud initiation and flower yield was reported in lotus by Nagajyothi *et al*. (2026). In contrast, flower bud circumference, flower diameter and leaf width, which were oriented in similar directions, showed positive associations. Overall, the PCA biplot indicated that flowering behaviour, flower production and morphological traits contributed substantially to the variability among the lotus genotypes.

Significant positive correlations were observed among several vegetative and floral traits. Leaf length showed a very strong positive correlation with leaf width (r = 0.923***), while days to bud initiation showed a very strong positive correlation with days to flowering (r = 0.900***). Flower bud count exhibited a very strong positive correlation with flowering duration (r = 0.952***) and significant positive associations with flowering window (r = 0.637***) and flower stalk length (r = 0.514***). Similarly, flowering duration showed a strong positive association with flowering window (r = 0.652***). These results indicate strong associations among related vegetative and flowering traits. The strong positive association between leaf length and leaf width is comparable with the findings of Kumar *et al*. (2025), who reported strong positive correlations among related morphological traits in lotus. Nagajyothi *et al*. (2026) also reported a significant positive association between the number of flowers per plant and flowering duration (r = 0.784 at the genotypic level and 0.720 at the phenotypic level), supporting the present finding of a strong positive association between flower production and flowering duration.

Cluster analysis

Cluster analysis of the 48 lotus genotypes based on quantitative morphological characters grouped the genotypes into four distinct clusters (Fig. 4, Table 6). Cluster I and Cluster III comprised 15 genotypes each, followed by Cluster II with 11 and Cluster IV with seven genotypes. The clustering pattern indicated considerable morphological diversity among the lotus germplasm. Similar clustering-based assessment of morphological diversity in lotus was reported by Roy *et al*. (2022) and Kumar *et al*. (2024).

Intra- and inter-cluster distance

The intra- and inter-cluster distances are presented in Table 7. The intra-cluster distance ranged from 5.243 in Cluster I to 6.398 in Cluster IV. The maximum inter-cluster distance was observed between Cluster II and Cluster III (7.849), followed by Cluster III and Cluster IV (7.524), whereas the minimum distance was observed between Cluster I and Cluster II (6.233). The greater distance between Cluster II and Cluster III indicated higher morphological divergence between these clusters, suggesting their potential usefulness as diverse parents in future breeding programmes. Similar observations were reported by Kumar *et al*. (2024).

Cluster mean analysis

Cluster means for the 23 quantitative morphological characters are presented in Table 8. Cluster I recorded the highest mean for plant height (59.33 cm), while Cluster II recorded the highest values for leaf blade length (24.36

Table 8 : Cluster means for 23 quantitative morphological characters of lotus genotypes.

Cluster	1	2	3	4
PH	59.33	58.56	41.18	39.76
CL	82.96	76.34	81.21	79.47
AL	12.6	8.8	13.37	14.05
TAL	14.38	14.01	22.07	19.49
LL	18.92	24.36	12.54	20.2
LW	16.13	21.36	11.97	19.32
LT	0.47	0.46	0.51	0.48
PT	47.31	49.53	32.93	31.42
DB	113.96	119.31	166.26	165.22
DF	128.67	136.62	184.97	183.46
FBC	17.44	19.69	12.52	20.05
FD	20.32	24.19	15.24	23.55
RT	2.26	2.39	3.69	16.64
FW	13.87	20.18	9.07	24.41
TN	95.68	111.12	44.9	145.28
FSL	58.82	59.41	31.79	56.06
TF	5.88	7.86	4.75	5.58
FD.1	14.77	18	12.22	13.43
CN	8.43	9.88	7.94	2.52
RD	24.37	26.85	22.01	13.56
RH	32.54	33.96	26.46	15.56
SL	1.6	4.65	1.64	1.64
SW	1.8	4.44	1.84	1.7

cm), leaf blade width (21.36 cm), petiole length (49.53 cm), flower diameter (24.19), flowering duration (18.00 days), tepal number (7.86), carpel number (9.88), receptacle diameter (26.85), seed length (4.65) and seed width (4.44). Cluster III recorded the highest values for total aerial leaf (22.07) and days taken to first flower (184.97 days), whereas Cluster IV showed the highest values for aerial leaf (14.05), flower bud circumference (20.05), flower weight (24.41) and total number of flowers (7.86). The variation in cluster means indicated considerable diversity for vegetative, flowering and reproductive characters. Genotypes with desirable cluster means combined with greater inter-cluster distance may be useful as potential parents for future lotus improvement programmes, as reported by Kumar *et al*. (2024).

Conclusion

The 48 lotus genotypes exhibited considerable variation for the morphological, vegetative, flowering and floral traits studied. High GCV and PCV, together with high heritability and genetic advance, indicated substantial genetic variability and good scope for selection of superior genotypes. Correlation analysis revealed strong associations among important traits, particularly between flower bud count and flowering duration. PCA showed that the first three components accounted for 69.0% of the total variation, with flowering behaviour, flower production and morphological traits contributing substantially to the observed diversity. Cluster analysis grouped the genotypes into four distinct clusters, with maximum divergence between Cluster II and Cluster III. The identified variability and divergent genotypes can be effectively utilized for selection of superior genotypes, identification of diverse parents and future improvement of lotus.

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