



RESEARCH ARTICLE

Morphological diversity, DUS characterisation and trait association analysis in *Celosia cristata* L. germplasm

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Abstract

Thirty-five accessions of *Celosia cristata* L. were evaluated for morphological diversity, genetic variability, floral traits and yield performance under field conditions at the Eastern Farm, Department of Floriculture and Landscape Architecture, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Periyakulam. The experiment was laid out in a randomised block design (RBD) with 3 replications. Sixteen quantitative traits, along with qualitative distinctness, uniformity and stability (DUS) descriptors, were recorded for vegetative, flowering and yield parameters. Significant variability was observed among the accessions for all the characters studied. Days to first flowering ranged from 28 to 45 days, whereas flower yield varied from 7.48 to 28.49 t ha⁻¹. High coefficient of variation was recorded for flowering branches, flower weight per plant and yield traits, indicating the presence of substantial exploitable variability and wider scope for selection. Correlation analysis revealed strong positive associations among floral and yield traits, suggesting the possibility of simultaneous improvement of flower quality and productivity through indirect selection. Hierarchical cluster analysis grouped the accessions into distinct clusters, confirming the existence of wide genetic diversity among the germplasms. Principal component analysis showed that the first two principal components accounted for a major proportion of total variability, while hierarchical cluster analysis categorised the accessions into distinct groups based on morphological and yield traits. Heatmap analysis further confirmed the existence of wide phenotypic diversity among the evaluated accessions. Among the evaluated accessions, Accession 9 exhibited superior performance with early flowering, larger inflorescence size, higher number of flowers and maximum flower yield. The identified superior accessions hold promise as valuable genetic resources for future breeding programmes and commercial cultivation of *C. cristata*.

Keywords: *Celosia cristata*; cluster analysis; correlation analysis; DUS characterisation; flower yield; genetic diversity; germplasm evaluation; morphological variability

Introduction

Floriculture is one of the fastest-growing sectors of Indian horticulture, contributing significantly to the national economy through domestic consumption, employment generation and export earnings. Among the commercially important ornamental crops cultivated in India, *Celosia cristata* L., commonly known as cockscomb or wool flower, has gained considerable importance because of its attractive and vibrant inflorescences, extended vase life and adaptability to diverse agro-climatic conditions (1, 2).

Celosia cristata belongs to the family Amaranthaceae and is one of the most popular ornamental annuals cultivated for its unique floral morphology. The genus comprises several distinct growth forms, including the crested (var. *cristata*), plumed (var. *plumosa*) and spike (var. *spicata*) types, each possessing considerable ornamental value (1). These forms exhibit

remarkable variation in inflorescence shape, colour, size and plant architecture, making them suitable for diverse horticultural applications, including cut flowers, potted plants, bedding displays, landscaping and loose flower markets (3, 4).

In Tamil Nadu and other parts of South India, *Celosia* is cultivated as an important loose-flower crop. Its flowers are widely utilised for garland making, temple offerings, festive decorations, ornamental displays and more recently as a potential natural source of betalain pigments (5). The crop performs well under tropical climatic conditions and can be cultivated throughout the year under suitable environmental conditions. Despite its commercial significance, systematic germplasm collection, characterisation and comprehensive evaluation of *Celosia* in India remain relatively limited compared with major ornamental crops such as rose, chrysanthemum and tuberose, indicating the need for further genetic resource characterisation and breeding efforts (6, 7).

In commercial flower production, *Celosia* is generally maintained with a single flowering stem and the removal of lateral buds through disbudding improves the quality and size of the terminal inflorescence (8). Owing to its distinctive floral forms and brilliant colours, the crop has become increasingly popular in the ornamental industry and continues to attract considerable attention from breeders and commercial growers (2).

Growth analysis provides valuable information on plant development and biomass accumulation by assessing changes in plant growth over time. Such analyses facilitate a better understanding of crop performance and the expression of economically important traits under different genetic backgrounds and growing conditions (9, 10).

Growth and floral diversity in *Celosia* are largely governed by the differential expression of developmental regulatory genes and plant hormone signalling pathways, resulting in considerable variation in plant architecture, inflorescence shape and flower morphology. Such variations contribute to the continuous development of novel ornamental types with improved aesthetic value and commercial potential (2, 11).

Assessment of genetic diversity forms the foundation of any successful plant breeding programme. A comprehensive understanding of morphological variability within a germplasm collection enables breeders to identify superior parental lines, select desirable genotypes and formulate effective breeding strategies for crop improvement (12). Morphological characterisation remains one of the most reliable, economical and widely adopted approaches for the preliminary evaluation of genetic diversity and is indispensable for the characterisation, conservation and utilisation of plant genetic resources (12–14).

Correlation analysis is an important statistical tool that quantifies the strength and direction of linear relationships among different quantitative traits. Identification of significant positive associations between yield and its component traits facilitates indirect selection and assists breeders in improving economically important characters. In addition, path coefficient analysis provides further insight by partitioning the observed correlations into direct and indirect effects of individual traits on yield. Analysis of variance (ANOVA) is employed to determine the existence of significant differences among genotypes for the traits under investigation.

Therefore, the present investigation was undertaken to characterise diverse *C. cristata* germplasm using distinctness, uniformity and stability (DUS) descriptors, evaluate the extent of morphological variability, assess genetic diversity and trait associations through appropriate statistical analyses and identify superior accessions for their potential utilisation in future breeding and crop improvement programmes.

Materials and Methods

Experimental site and plant material

The present investigation was carried out at Eastern Farm, Department of Floriculture and Landscape Architecture, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Periyakulam, Theni District, Tamil Nadu, India (Fig. 1). Thirty-five accessions of *Celosia cristata* L. were procured from diverse institutional and local sources, state agricultural universities, National Bureau of Plant Genetic Resources (NBPGR) regional stations and local market collections across Tamil Nadu. An experimental field view of the 35 *Celosia* accessions evaluated during the study is presented in (Fig. 2).

Experimental design and cultural practices

The experiment was laid out in a randomised block design (RBD) with 3 replications. Observations on all recorded traits were made independently across the three replications and the mean values were used for statistical analysis. Seeds were sown in pro-trays filled with a cocopeat : vermiculite : perlite mixture (3 : 1 : 1) and maintained under greenhouse conditions; subsequently, the seedlings were transplanted to the main field at 30 days after sowing at a spacing of 30 cm × 30 cm. Each plot consisted of 30 plants per accession. Recommended agronomic practices, including irrigation, fertilisation (100 : 50 : 50 kg NPK/ha), weeding, pinching and plant protection measures, were uniformly followed for all accessions as per the recommendations of the TNAU crop production guide.

Morphological characters recorded

Morphological observations were recorded on five randomly selected, tagged plants per plot. The following 16 quantitative traits were assessed: Days to first flowering (DFF), days to 50 % flowering (D50F), flower duration (days), number of flowering branches per



Fig. 1. Experimental field view of 35 accessions of *Celosia cristata*.

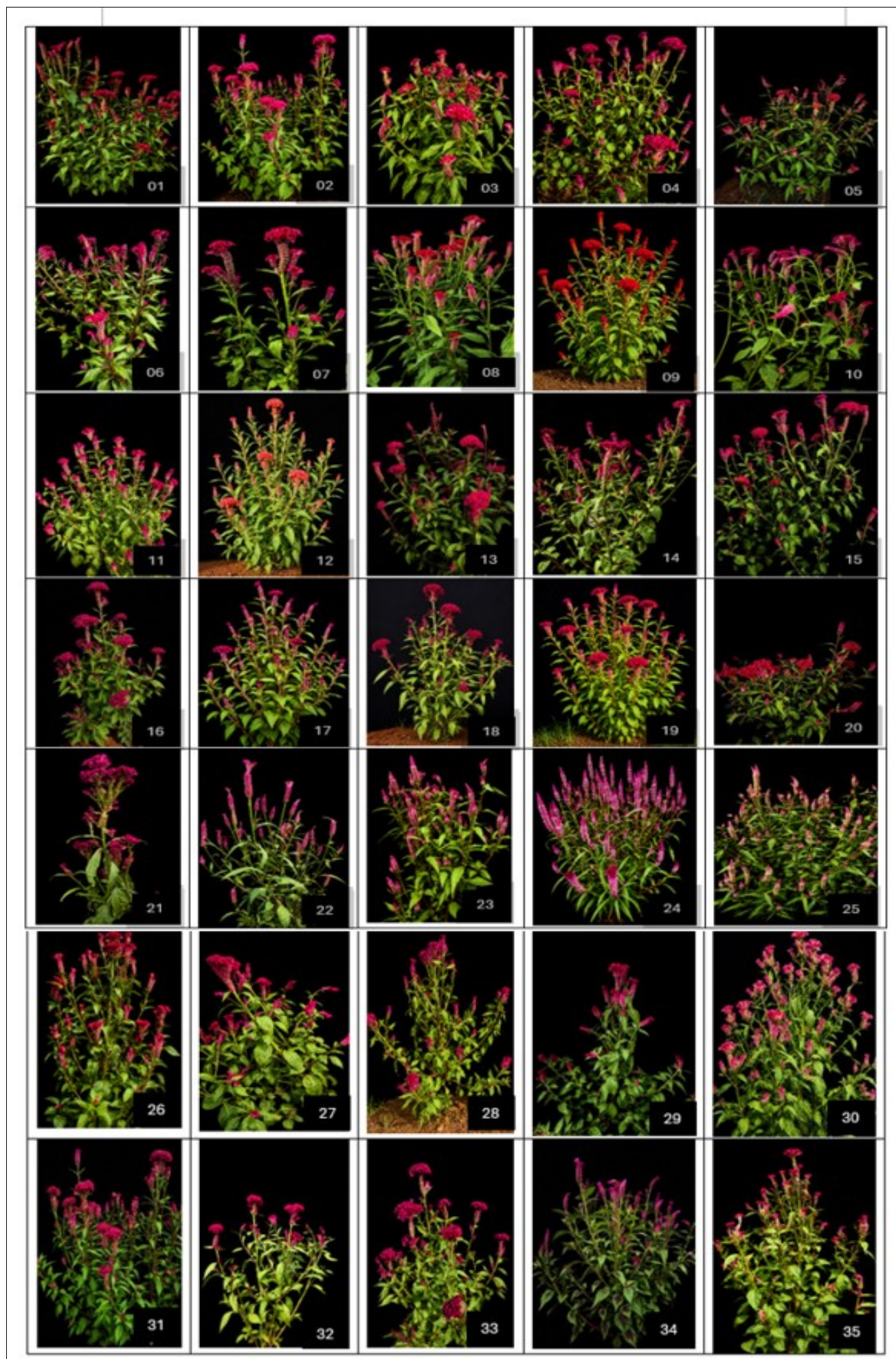


Fig. 2. Morphological diversity among 35 *Celosia cristata* accessions.

plant (FB), number of inflorescences per plant (Inflo), total number of flowers per plant, inflorescence length (IL, cm), inflorescence width (IW, cm), flower length (FL, cm), flower width (FW, cm), flower diameter (FD, cm), single flower weight (SFW, g), flower weight per plant (FW/Plant, g), yield per plant (g), yield per plot (kg) and flower yield per hectare (t/ha). Qualitative characters, including leaf shape, leaf colour, flower colour, flower shape and plant type, were recorded following DUS guidelines and standard International Plant Genetic Resources Institute (IPGRI) descriptors for *Celosia*.

Statistical analysis

Data were subjected to two-way ANOVA. Mean values were compared using the least significant difference (LSD) test at $p < 0.05$ and $p < 0.01$ levels. Descriptive statistics, including range (minimum and maximum), mean $\pm$ standard deviation (SD) and coefficient of variation (CV %), were computed for all traits. Pearson correlation coefficients among all pairs of traits were calculated. Hierarchical cluster analysis was performed using Ward's minimum variance method with Euclidean distance and all data were analysed from the mean values of 3 replications (15, 16).

Results and Discussion

Morphological characterisation of *Celosia* accessions

Morphological characterisation of the 35 *Celosia* accessions revealed extensive variability for all 16 quantitative traits evaluated (Table 1 and 2). Such wide morphological variability within *Celosia* germplasm has also been reported by several researchers (3, 4). Detailed morphological data for all 35 accessions are presented in Table 1 and 2.

Principal component analysis

Principal component analysis (PCA) revealed considerable variability among the 35 *Celosia* accessions for vegetative, flowering and yield-related characters (Fig. 3). The first two principal components explained most of the total variation among the accessions, indicating substantial genetic diversity within the germplasm. Accessions 26, 27, 28, 30 and 34 were grouped separately due to their superior performance for inflorescence size, flower number and yield traits, whereas accessions 31, 32, 33 and 35 formed a distinct cluster characterised by comparatively lower vegetative growth and yield performance. Accession 9 occupied a favourable position with balanced vegetative vigour, flowering behaviour and yield attributes, indicating its potential utility in future breeding programmes.

Heatmap analysis

The heatmap analysis revealed distinct clustering patterns among the *Celosia* accessions based on vegetative, flowering and yield traits (Fig. 4). Accessions exhibiting superior vegetative growth, larger inflorescences, higher flower production and increased yield were grouped and represented by higher intensity colour patterns. Accessions 26, 27, 28, 30 and 34 formed a high-performing cluster, while accessions 31, 32, 33 and 35 were grouped under low-performing clusters due to reduced growth and yield attributes. Accession 9 exhibited desirable performance across most of the studied parameters, confirming its superiority and suitability as a promising parent for future breeding and selection programmes.

Qualitative characterisation and DUS analysis

The DUS characterisation was carried out among the 35 accessions of *C. cristata* using important qualitative morphological

Table 1. Morphological characterisation data of 35 *Celosia cristata* accessions (Vegetative traits)

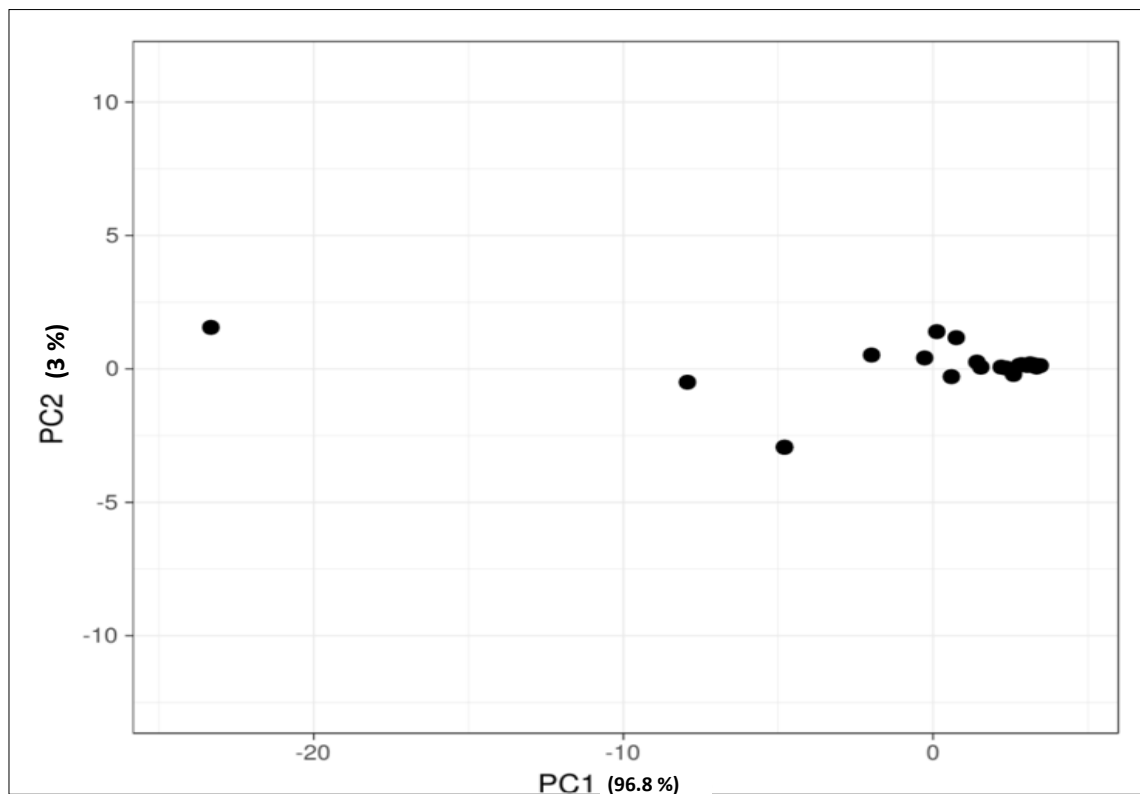
Accessions	PH (cm)	SG (cm)	PS (cm)	Leaves	Branches	LL (cm)	LB (cm)	LA (cm ²)
1	82	5.2	55	380	28	9.5	4.8	45.6
2	84	5.3	56	390	29	9.8	4.9	48.0
3	70	5.1	52	350	26	6.5	4.6	29.9
4	90	5.6	60	420	38	10.5	5.2	54.6
5	80	5.0	54	360	27	9.0	4.5	40.5
6	92	6.0	62	430	34	10.8	5.3	57.2
7	78	5.0	53	340	25	8.8	4.4	38.7
8	98	5.8	64	470	35	11.0	5.4	59.4
9	96	5.9	63	465	36	11.5	5.6	64.4
10	86	5.4	58	400	30	10.0	5.0	50.0
11	72	4.9	51	310	22	8.0	4.0	32.0
12	87	5.5	59	405	31	10.2	5.1	52.0
13	83	5.2	56	375	28	9.6	4.8	46.1
14	89	5.5	60	415	33	10.4	5.2	54.1
15	91	5.6	61	420	34	10.6	5.3	56.2
16	91	5.5	61	410	32	10.5	5.2	54.6
17	74	4.9	52	320	23	8.2	4.1	33.6
18	94	5.9	68	450	33	10.8	6.2	67.0
19	89	4.7	59	395	29	10.2	5.1	52.0
20	71	4.8	50	305	21	7.8	3.9	30.4
21	76	5.0	52	335	24	8.5	3.8	32.3
22	75	5.1	50	300	20	11.8	4.2	49.6
23	73	4.9	51	315	22	8.1	4.0	32.4
24	85	5.3	57	390	28	9.8	4.9	48.0
25	88	5.5	60	420	40	10.5	5.2	54.6
26	93	5.7	63	440	34	10.7	5.3	56.7
27	95	5.8	65	430	35	10.9	5.4	58.9
28	94	5.7	64	448	34	10.8	5.3	57.2
29	68	4.8	49	290	20	7.5	3.7	27.8
30	93	5.7	63	440	34	10.7	5.3	56.7
31	67	4.7	48	285	19	7.3	3.6	26.3
32	66	4.7	47	280	18	7.2	3.5	25.2
33	65	4.6	46	275	18	7.0	3.5	24.5
34	92	5.6	62	435	33	10.6	5.3	56.2
35	77	5.0	66	330	23	8.6	6.0	51.6

PH: plant height (cm); SG: stem girth (cm); PS: plant spread (cm); LL: leaf length (cm); LB: leaf breadth (cm); LA: leaf area (cm²).

Table 2. Morphological characterisation data of 35 *Celosia cristata* accessions (flower quality and yield traits)

Accessions	DFF	D50F	DUR	FB	INF	Flowers	IL	IW	FL	FW	FD	SFW (g)	FW/ Plant (g)	Yield/ Plant (g)	Yield/ Plot (kg)	Yield (t/ha)
1	36	44	28	15	17	180	12.0	6.2	4.0	3.0	4.8	0.85	153	153	3.06	16.83
2	35	43	29	16	18	185	12.2	6.4	4.1	3.1	4.9	0.87	161	161	3.22	17.71
3	38	46	27	13	15	160	11.5	6.0	3.0	2.6	4.2	0.75	120	120	2.40	13.20
4	31	38	35	22	24	210	13.5	8.5	4.5	3.5	5.3	0.95	200	200	4.00	22.00
5	28	35	24	14	16	170	11.8	5.8	3.8	2.8	4.5	0.80	136	136	2.72	14.96
6	32	39	34	21	23	220	14.0	7.8	4.6	3.4	5.4	0.98	216	216	4.32	23.76
7	39	48	26	13	15	165	11.2	5.2	3.7	2.7	4.4	0.78	129	129	2.58	14.19
8	33	41	32	19	21	240	14.5	7.2	4.7	3.6	5.6	1.02	245	245	4.90	26.95
9	29	36	40	25	28	235	15.5	9.2	4.8	3.7	6.0	1.10	259	259	5.18	28.49
10	33	41	31	18	20	195	13.0	7.0	4.2	3.0	5.0	0.90	176	176	3.52	19.36
11	42	51	22	11	13	145	10.5	5.0	3.4	2.4	4.0	0.70	102	102	2.04	11.22
12	32	39	32	19	21	198	13.2	7.3	4.3	3.1	5.1	0.92	182	182	3.64	20.02
13	36	44	28	15	17	182	12.1	6.2	4.0	3.0	4.8	0.85	155	155	3.10	17.05
14	31	38	33	20	22	205	13.6	7.6	4.4	3.2	5.2	0.93	191	191	3.82	21.01
15	31	38	34	21	23	210	13.8	7.8	4.5	3.3	5.3	0.95	200	200	4.00	22.00
16	30	37	35	22	24	200	9.5	8.0	4.3	3.2	5.1	0.92	184	184	3.68	20.24
17	40	49	25	12	14	150	10.8	5.5	3.5	2.5	4.1	0.72	108	108	2.16	11.88
18	37	46	27	13	15	225	14.2	8.2	5.0	3.4	5.5	0.70	158	158	3.16	17.38
19	34	42	30	17	19	190	13.2	7.0	4.3	3.1	5.0	0.88	167	167	3.34	18.37
20	43	52	21	11	13	140	10.2	4.8	3.3	2.3	3.9	0.68	95	95	1.90	10.45
21	36	44	28	14	16	150	11.0	6.0	3.6	2.7	4.3	0.75	113	113	2.26	12.43
22	37	46	27	13	15	140	10.8	5.7	3.5	2.6	4.2	0.72	101	101	2.02	11.11
23	39	48	26	12	14	145	10.6	5.4	3.4	2.5	4.0	0.70	102	102	2.04	11.22
24	37	46	27	13	15	180	12.5	6.5	4.1	2.9	4.0	0.85	153	153	3.06	16.83
25	36	44	29	28	30	230	13.8	6.8	4.4	3.0	5.2	0.95	219	219	4.38	24.09
26	31	38	36	23	25	222	14.0	8.6	4.5	3.5	5.6	0.98	218	218	4.36	23.98
27	30	37	35	22	24	228	14.3	8.8	4.6	3.5	5.5	1.00	228	228	4.56	25.08
28	30	37	36	23	25	225	14.2	8.7	4.5	3.5	5.4	0.99	223	223	4.46	24.53
29	44	53	20	10	12	130	9.8	4.5	3.2	2.2	3.8	0.65	85	85	1.70	9.35
30	30	37	37	23	25	222	14.0	8.7	4.5	3.5	5.6	0.98	218	218	4.36	23.98
31	45	55	20	9	11	125	9.5	4.2	3.1	2.1	3.7	0.62	77	77	1.54	8.47
32	45	55	20	9	11	120	9.2	4.1	3.0	2.1	3.6	0.60	72	72	1.44	7.92
33	45	55	20	8	10	118	9.0	4.0	3.0	2.0	3.5	0.58	68	68	1.36	7.48
34	31	38	36	23	25	220	13.9	8.5	4.5	3.5	5.3	0.97	213	213	4.26	23.43
35	45	55	20	8	10	155	11.5	4.0	3.7	2.7	4.5	0.78	121	121	2.42	13.31

DFF: days to first flowering (days); D50F: days to 50 per cent flowering (days); DUR: duration of flowering (days); FB: number of flowering branches per plant; INF: number of inflorescences per plant; IL: inflorescence length (cm); IW: inflorescence width (cm); FL: flower length (cm); FW: flower width (cm); FD: flower diameter (cm); SFW: single flower weight (g); FW/Plant: flower weight per plant (g); Yield/Plant: flower yield per plant (g); Yield/Plot: flower yield per plot (kg); Yield (t/ha): flower yield per hectare (tonnes).

**Fig. 3.** Principal component analysis (PCA) showing the distribution and genetic diversity among 35 *Celosia* accessions based on vegetative, flowering and yield traits.

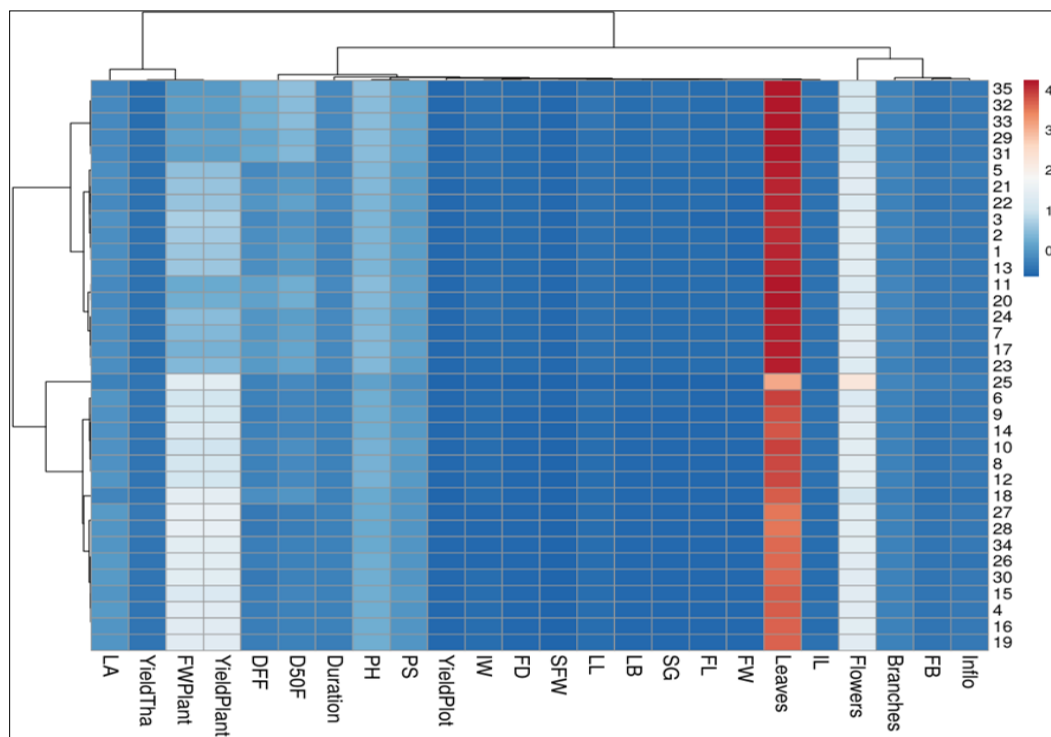


Fig.4. Heatmap with hierarchical clustering of 35 *Celosia cristata* accessions based on vegetative, flowering and yield parameters. LA: leaf area (cm^2); YieldTha: flower yield per hectare (t/ha); FWPlant: flower weight per plant (g); YieldPlant: flower yield per plant (g); DFF: days to first flowering (days); D50F: days to 50 per cent flowering (days); Duration: flower duration (days); PH: plant height (cm); PS: plant spread (cm); YieldPlot: flower yield per plot (kg); IW: inflorescence width (cm); FD: flower diameter (cm); SFW: single flower weight (g); LL: leaf length (cm); LB: leaf breadth (cm); SG: stem girth (cm); FL: flower length (cm); FW: flower width (cm); IL: inflorescence length (cm); Flowers: number of flowers per plant; Branches: number of branches per plant; FB: number of flowering branches per plant; Inflo: number of inflorescences per plant.

descriptors. Considerable variability was observed for plant growth habit, stem pigmentation, leaf morphology, inflorescence type, flower colour and flowering behaviour, indicating the existence of wide genetic diversity among the evaluated accessions (Table 3 and 4).

Among the evaluated accessions, both erect and semi-erect growth habits were recorded. Erect growth habit was predominantly observed in high-yielding accessions such as Acc. 4, 6, 8, 9, 14, 25, 27 and 30, whereas semi-erect habit was common among lower-yielding accessions. Variation in stem pigmentation ranged from light green to dark purple-green pigmentation, suggesting differential anthocyanin accumulation among genotypes.

Leaf morphology also exhibited substantial variation with narrow lanceolate, lanceolate, broad lanceolate and ovate leaf shapes observed across accessions. Accessions possessing broader leaves generally showed higher vegetative vigour and superior floral development. Leaf colour varied from light green to dark green, contributing to ornamental value and photosynthetic efficiency.

Two major inflorescence types, predominantly crest forms, were identified among the accessions. Crest-type inflorescences were mainly associated with higher flower density and superior market appeal, particularly in accessions 4, 6, 9, 14, 18, 27 and 30. Flower colour exhibited remarkable diversity, ranging from pink to deep crimson red, highlighting the ornamental significance of the germplasm. Dense and very dense flowering habits were predominantly associated with superior-yielding accessions.

The observed qualitative variability among accessions confirms the effectiveness of DUS descriptors in differentiating

Celosia genotypes and provides valuable baseline information for germplasm characterisation, varietal identification and future breeding programmes. Similar morphological diversity in *Celosia* has also been reported early (17, 18).

Descriptive statistics and variability analysis

Descriptive statistics computed for all 16 traits are presented in Table 5. The DFF ranged from 28 (Acc. 5) to 45 days (Acc. 31, 32, 33 and 35), with a mean of 36.06 ± 5.22 days and a CV of 14.48 %. Earlier flowering is desirable in commercial production as it shortens the crop cycle and reduces input costs. Days to 50 % flowering ranged from 35 to 55 days, closely paralleling DFF trends across the accessions.

Flower duration ranged from 20 to 40 days with a mean of 28.94 ± 5.67 days (CV = 19.59 %). Extended flower duration is a critical quality trait as it directly influences the marketable shelf life of cut flowers. Accession 9 recorded the maximum flower duration (40 days), which is commercially advantageous and aligns with the findings of previous researchers, who reported significant variability in flower duration among *C. cristata* genotypes (19, 20).

The number of flowering branches ranged from 8 (Acc. 33 and 35) to 28 (Acc. 25), with a mean of 16.77 ± 5.58 (CV = 33.27 %), while the number of inflorescences per plant ranged from 10 to 30, with a mean of 18.77 ± 5.63 (CV = 29.99 %). Similarly, the total number of flowers ranged from 118 to 240, with a mean of 184.97 ± 38.42 (CV = 20.77 %). High CV values for flowering branches and inflorescence number indicate substantial variability, offering good scope for selection, consistent with the findings of previous studies, which reported wide variation in inflorescence characters among *Celosia* types (20).

Table 3. Distinctness, uniformity and stability (DUS) characters of *Celosia cristata* accessions

Sl.No	Characteristics	Classification	Code / Note
1	Plant height	Very short	1
		Short	3
		Medium	5
		Tall	7
		Very tall	9
2	Stem: thickness	Thin	3
		Medium	5
		Thick	7
		Very strong	9
3	Stem: colour of basal part	Light green	1
		Medium green	2
		Dark green	3
		Yellow	4
		Orange	5
		Pinkish red	6
		Purple red	7
4	Leaves: petiole length	Short	3
		Medium	5
		Long	7
		Present	9
5	Leaf blade: length	Short	3
		Medium	5
		Long	7
6	Leaf blade: width	Narrow	3
		Medium	5
		Broad	7
7	Leaf blade: shape	Narrow elliptic	1
		Elliptic	2
		Ovate	3
		Broad ovate	4
		Present	9
8	Leaf blade: undulation of margin	Absent	1
		Present	9
9	Inflorescence: main shape	Spicate	1
		Plumose	2
		Paniculate	3
		Cristate	4
10	Inflorescence: length of main inflorescence	Short	3
		Medium	5
		Long	7
11	Inflorescence: width of main inflorescence	Narrow	3
		Medium	5
		Broad	7
12	Inflorescence: color	White	1
		Green	2
		Yellow	3
		Orange	4
		Orange pink	5
		Pink	6
		Red	7
		Purple	8

Table 4. Distinctness, uniformity and stability (DUS) characters of 35 *Celosia cristata* accessions

Accessions	Plant height	Stem thickness	Stem: Colour of the basal part	Leaves: Petiole length	Leaf blade Length	Leaf blade width	Leaf blade shape	Leaf blade: Undulation of the margin	Inflorescence shape	Inflorescence length	Inflorescence: Width of main inflorescence	Inflorescence colour
Acc. 1	Tall (7)	Medium (5)	Medium green (2)	Medium (5)	Medium (5)	Medium (5)	Ovate (3)	Present (9)	Cristate (4)	Medium (5)	Medium (5)	Red (7)
Acc. 2	Medium (5)	Medium (5)	Purple red (7)	Short (3)	Medium (5)	Short (3)	Elliptic (2)	Present (9)	Cristate (4)	Medium (5)	Medium (5)	Purple (8)
Acc. 3	Medium (5)	Medium (5)	Purple red (7)	Short (3)	Medium (5)	Short (3)	Ovate (3)	Present (9)	Cristate (4)	Medium (5)	Medium (5)	Purple (8)
Acc. 4	Medium (5)	Thick (7)	Medium green (2)	Medium (5)	Long (7)	Medium (5)	Ovate (3)	Present (9)	Cristate (4)	Long (7)	Medium (5)	Red (7)
Acc. 5	Medium (5)	Medium (5)	Purple red (7)	Short (3)	Medium (5)	Medium (5)	Ovate (3)	Present (9)	Cristate (4)	Medium (5)	Medium (5)	Red (7)
Acc. 6	Tall (7)	Thick (7)	Purple red (7)	Medium (5)	Long (7)	Medium (5)	Ovate (3)	Present (9)	Cristate (4)	Long (7)	Broad (7)	Purple (8)
Acc. 7	Medium (5)	Medium (5)	Purple red (7)	Short (3)	Medium (5)	Medium (5)	Ovate (3)	Present (9)	Cristate (4)	Medium (5)	Medium (5)	Purple (8)
Acc. 8	Tall (7)	Medium (5)	Pinkish red (6)	Medium (5)	Medium (5)	Medium (5)	Ovate (3)	Present (9)	Cristate (4)	Long (7)	Broad (7)	Red (7)
Acc. 9	Tall (7)	Medium (5)	Medium green (2)	Medium (5)	Medium (5)	Medium (5)	Ovate (3)	Present (9)	Cristate (4)	Long (7)	Broad (7)	Red (7)
Acc. 10	Medium (5)	Medium (5)	Purple red (7)	Medium (5)	Medium (5)	Medium (5)	Ovate (3)	Present (9)	Cristate (4)	Medium (5)	Broad (7)	Purple (8)
Acc. 11	Tall (7)	Medium (5)	Purple red (7)	Short (3)	Short (3)	Medium (5)	Ovate (3)	Present (9)	Cristate (4)	Short (3)	Medium (5)	Red (7)
Acc. 12	Medium (5)	Medium (5)	Purple red (7)	Medium (5)	Medium (5)	Medium (5)	Ovate (3)	Present (9)	Cristate (4)	Medium (5)	Medium (5)	Red (7)
Acc. 13	Medium (5)	Medium (5)	Purple red (7)	Short (3)	Medium (5)	Medium (5)	Ovate (3)	Present (9)	Cristate (4)	Medium (5)	Medium (5)	Red (7)
Acc. 14	Medium (5)	Medium (5)	Purple red (7)	Medium (5)	Medium (5)	Medium (5)	Ovate (3)	Present (9)	Cristate (4)	Long (7)	Medium (5)	Purple (8)
Acc. 15	Tall (7)	Medium (5)	Pinkish red (6)	Medium (5)	Long (7)	Medium (5)	Ovate (3)	Present (9)	Cristate (4)	Long (7)	Broad (7)	Red (7)
Acc. 16	Tall (7)	Thick (7)	Pinkish red (6)	Medium (5)	Long (7)	Medium (5)	Ovate (3)	Present (9)	Cristate (4)	Long (7)	Broad (7)	Red (7)
Acc. 17	Medium (5)	Medium (5)	Purple red (7)	Short (3)	Medium (5)	Short (3)	Ovate (3)	Present (9)	Cristate (4)	Medium (5)	Medium (5)	Purple (8)
Acc. 18	Medium (5)	Medium (5)	Medium green (2)	Medium (5)	Medium (5)	Medium (5)	Ovate (3)	Present (9)	Cristate (4)	Medium (5)	Medium (5)	Red (7)
Acc. 19	Medium (5)	Thick (7)	Medium green (2)	Medium (5)	Long (7)	Medium (5)	Ovate (3)	Present (9)	Cristate (4)	Long (7)	Medium (5)	Red (7)
Acc. 20	Tall (7)	Medium (5)	Purple red (7)	Short (3)	Short (3)	Medium (5)	Ovate (3)	Present (9)	Cristate (4)	Short (3)	Medium (5)	Purple (8)
Acc. 21	Short (3)	Medium (5)	Purple red (7)	Medium (5)	Medium (5)	Medium (5)	Elliptic (2)	Present (9)	Cristate (4)	Medium (5)	Medium (5)	Purple (8)
Acc. 22	Short (3)	Medium (5)	Purple red (7)	Medium (5)	Medium (5)	Medium (5)	Elliptic (2)	Present (9)	Cristate (4)	Medium (5)	Medium (5)	Purple (8)
Acc. 23	Short (3)	Medium (5)	Purple red (7)	Medium (5)	Medium (5)	Medium (5)	Elliptic (2)	Present (9)	Cristate (4)	Medium (5)	Medium (5)	Purple (8)
Acc. 24	Short (3)	Medium (5)	Purple red (7)	Short (3)	Short (3)	Narrow (3)	Narrow elliptic (1)	Present (9)	Cristate (4)	Short (3)	Narrow (3)	Purple (8)
Acc. 25	Short (3)	Medium (5)	Medium green (2)	Medium (5)	Long (7)	Medium (5)	Elliptic (2)	Present (9)	Spicate (1)	Long (7)	Medium (5)	Orange (4)
Acc. 26	Medium (5)	Thick (7)	Purple red (7)	Long (7)	Long (7)	Medium (5)	Ovate (3)	Present (9)	Cristate (4)	Long (7)	Medium (5)	Purple (8)
Acc. 27	Tall (7)	Thick (7)	Purple red (7)	Long (7)	Long (7)	Medium (5)	Ovate (3)	Present (9)	Cristate (4)	Long (7)	Broad (7)	Purple (8)
Acc. 28	Medium (5)	Thick (7)	Pinkish red (6)	Medium (5)	Long (7)	Medium (5)	Ovate (3)	Present (9)	Cristate (4)	Long (7)	Medium (5)	Red (7)
Acc. 29	Medium (5)	Medium (5)	Pinkish red (6)	Short (3)	Short (3)	Medium (5)	Ovate (3)	Present (9)	Cristate (4)	Short (3)	Medium (5)	Red (7)
Acc. 30	Tall (7)	Thick (7)	Pinkish red (6)	Medium (5)	Long (7)	Medium (5)	Ovate (3)	Present (9)	Cristate (4)	Long (7)	Medium (5)	Red (7)
Acc. 31	Tall (7)	Medium (5)	Purple red (7)	Short (3)	Short (3)	Medium (5)	Ovate (3)	Present (9)	Cristate (4)	Short (3)	Medium (5)	Purple (8)
Acc. 32	Tall (7)	Medium (5)	Purple red (7)	Short (3)	Short (3)	Medium (5)	Ovate (3)	Present (9)	Cristate (4)	Short (3)	Medium (5)	Purple (8)
Acc. 33	Tall (7)	Medium (5)	Purple red (7)	Short (3)	Short (3)	Medium (5)	Ovate (3)	Present (9)	Cristate (4)	Short (3)	Medium (5)	Purple (8)
Acc. 34	Medium (5)	Thick (7)	Purple red (7)	Medium (5)	Long (7)	Medium (5)	Ovate (3)	Present (9)	Cristate (4)	Long (7)	Medium (5)	Purple (8)
Acc. 35	Tall (7)	Medium (5)	Pinkish red (6)	Short (3)	Short (3)	Medium (5)	Ovate (3)	Present (9)	Cristate (4)	Short (3)	Medium (5)	Red (7)

Table 5. Descriptive statistics for morphological and yield traits across 35 *Celosia cristata* accessions

Trait	Minimum	Maximum	Mean $\pm$ SD	CV (%)
DFF (days)	28	45	36.06 $\pm$ 5.22	14.48
D50F (days)	35	55	44.26 $\pm$ 6.18	13.96
Flower duration (days)	20	40	28.94 $\pm$ 5.67	19.59
Flowering branches (No.)	8	28	16.77 $\pm$ 5.58	33.27
Inflorescences (No.)	10	30	18.77 $\pm$ 5.63	29.99
No. of flowers	118	240	184.97 $\pm$ 38.42	20.77
Inflorescence length (cm)	9.0	15.5	12.22 $\pm$ 1.85	15.14
Inflorescence width (cm)	4.0	9.2	6.64 $\pm$ 1.53	23.04
Flower length (cm)	3.0	5.0	4.03 $\pm$ 0.58	14.39
Flower width (cm)	2.0	3.7	2.96 $\pm$ 0.51	17.23
Flower diameter (cm)	3.5	6.0	4.79 $\pm$ 0.71	14.82
Single flower weight (g)	0.58	1.10	0.83 $\pm$ 0.15	18.07
Flower Wt./Plant (g)	68	259	167.97 $\pm$ 53.41	31.80
Yield/Plant (g)	68	259	167.97 $\pm$ 53.41	31.80
Yield/Plot (kg)	1.36	5.18	3.36 $\pm$ 1.07	31.80
Yield (t/ha)	7.48	28.49	17.95 $\pm$ 5.72	31.87

The IL varied from 9.00 to 15.50 cm (mean = 12.22 $\pm$ 1.85 cm; CV = 15.14 %) and IW ranged from 4.00 to 9.20 cm (mean = 6.64 $\pm$ 1.53 cm; CV = 23.04 %). Longer, wider inflorescences are preferred in the loose-flower market and are important selection criteria for cut-flower types. Flower diameter ranged from 3.50 to 6.00 cm (mean = 4.79 $\pm$ 0.71 cm; CV = 14.82 %), while SFW ranged from 0.58 g to 1.10 g (mean = 0.83 $\pm$ 0.15 g; CV = 18.07 %). The variability observed in single-flower weight reflects the diversity in flower size and floral mass among the evaluated accessions.

Flower yield per plant ranged from 68 g (Acc. 33) to 259 g (Acc. 9), whereas flower yield per hectare ranged from 7.48 t/ha to 28.49 t/ha with a mean of 17.95 $\pm$ 5.72 t/ha (CV = 31.87 %). The high coefficient of variation observed in yield traits indicates substantial genetic diversity among the 35 accessions and highlights the scope for effective selection and improvement.

The Venn diagram illustrates the overlap among floral and yield traits based on descriptive statistical parameters (Minimum, Maximum, Mean $\pm$ SD and CV %) to identify shared and unique variability patterns among characters (Fig. 5).

Analysis of variance

Analysis of variance for vegetative and yield traits

Analysis of variance (ANOVA) revealed significant differences among the 35 *C. cristata* accessions for vegetative traits (Table 6). The variation due to accessions (rows) was found to be significant with an *F* value of 2.848 ($p < 0.05$), indicating the existence of wide variation among the evaluated accessions for growth parameters.

Highly significant variation among accessions indicated substantial genetic diversity for vegetative traits with an *F* value of

284.69, reflecting substantial differences among the vegetative characters studied. The significant variability observed among accessions suggests the presence of broad genetic diversity within the germplasm collection, which could be effectively utilised for selection and crop improvement programmes in *C. cristata*.

The results indicated that traits such as plant height, stem girth, plant spread, leaf characters and branching pattern contributed significantly towards overall vegetative variation among the accessions. Similar variability among vegetative traits in *Celosia* germplasm has also been reported by earlier researchers (4).

Analysis of variance for flowering and yield traits

Analysis of variance revealed significant differences among the 35 *C. cristata* accessions for flowering and yield parameters (Table 7). The variation among accessions was significant with an *F* value of 2.891 ($p < 0.05$), indicating the presence of considerable diversity among the evaluated accessions.

The variation among flowering and yield traits was also highly significant, with an *F* value of 411.12, reflecting substantial differences among the floral characters studied. The significant variability observed for flowering duration, flower number, inflorescence traits and yield parameters suggests wide genetic diversity within the germplasm collection.

The results indicated the potential for effective selection of superior accessions possessing desirable flowering behaviour and enhanced flower yield in *C. cristata*. Similar variability among flowering and yield traits has also been reported by previous researchers (21).

Table 6. Analysis of variance (ANOVA) for vegetative traits in thirty-five *Celosia cristata* accessions

Source of variation	SS	df	MS	F	p-value	F crit
Rows	37522.09	34	1103.591	2.848001	1.85E-06	1.479009
Columns	1854320	7	264902.1	284.6934	9.7E-190	2.048189
Error	221540.2	238	930.4967			
Total	3948737	279				

SS: sum of squares; df: degrees of freedom; MS: mean square; *F*: *F*-statistic; *p*-value: probability value; *F* crit: critical *F*-value at the 5 % significance level.

Table 7. Analysis of variance (ANOVA) for flowering and yield traits in 35 *Celosia cristata* accessions

Source of variation	SS	df	MS	F	p-value	F crit
Rows	28034.18	34	824.5348	2.891477	3.15E-07	1.456226
Columns	1524062	13	117235.5	411.1214	2.7E-237	1.742334
Error	126040.9	442	285.1604			
Total	1678137	489				

SS: sum of squares; df: degrees of freedom; MS: mean square; *F*: *F*-statistic; *p*-value: probability value; *F* crit: critical *F*-value at the 5 % significance level.

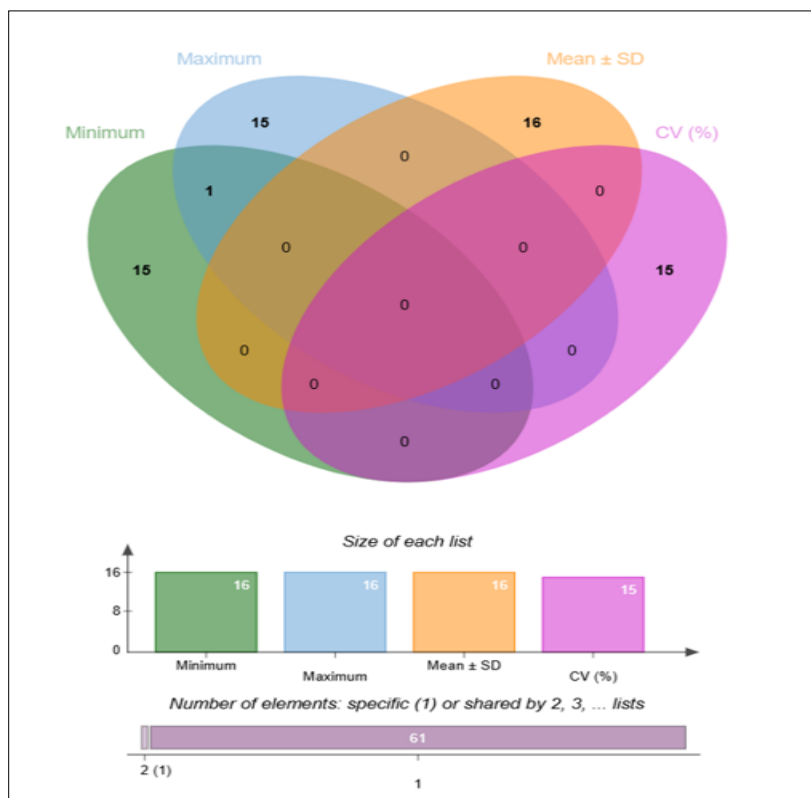


Fig. 5. Venn diagram showing the overlap among floral and yield traits based on descriptive statistical parameters such as minimum, maximum, mean $\pm$ SD and coefficient of variation (CV %).

Correlation analysis

Correlation analysis among vegetative traits

Correlation analysis among vegetative traits of 35 *C. cristata* accessions revealed wide variation among most of the characters studied (Table 8). Plant height (PH) showed positive correlation with stem girth (SG) ($r = 0.901$), plant spread (PS) ($r = 0.911$), number of leaves ($r = 0.978$), branches per plant ($r = 0.930$) and leaf area (LA) ($r = 0.952$), indicating that taller plants possessed vigorous vegetative growth.

Plant spread exhibited a strong relationship with leaf breadth (LB) ($r = 0.970$) and LA ($r = 0.934$), while the number of leaves per plant was positively correlated with branches per plant ($r = 0.955$). The LL and LB also showed a strong positive correlation with LA ($r = 0.935$), indicating their direct contribution towards photosynthetic surface area (4).

Correlation analysis among flowering and yield traits

Correlation analysis among flowering and yield parameters revealed strong positive associations among most of the traits studied (Table 9). Days to first flowering exhibited a negative correlation with flower duration, flower number and yield traits, indicating that early flowering accessions produced better yield performance.

Flower duration showed positive correlation with flowering branches ($r = 0.915$), inflorescences ($r = 0.917$), SFW ($r = 0.920$) and yield per plant ($r = 0.915$). Number of flowers per plant also exhibited a positive association with flower width (FW) ($r = 0.965$), IW ($r = 0.922$) and yield ($r = 0.861$), indicating its major contribution towards flower productivity.

Flower length, FW and FD were positively correlated with yield parameters, while SFW showed a strong relationship with FW ($r = 0.926$) and flower yield. The positive interrelationship among floral and yield traits suggests the possibility of simultaneous improvement of flower quality and productivity through selection. Overall, the study indicated that flowering and yield characters were highly interrelated and contributed collectively towards enhanced flower yield in *C. cristata*.

Cluster analysis

Hierarchical cluster analysis for vegetative traits

Hierarchical cluster analysis based on vegetative parameters grouped the 35 *C. cristata* accessions into distinct clusters, demonstrating considerable variability among the evaluated genotypes (Fig. 6). The dendrogram generated using Ward's minimum variance method revealed both closely related and highly divergent accessions based on vegetative characteristics (15).

Table 8. Correlation coefficient among vegetative traits of 35 *Celosia cristata* accessions

	PH (cm)	SG (cm)	PS (cm)	Leaves	Branches	LL (cm)	LB (cm)	LA (cm ²)
PH (cm)	1							
SG (cm)	0.901382	1						
PS (cm)	0.910728	0.849379	1					
Leaves	0.97832	0.919433	0.895493	1				
Branches	0.929921	0.887557	0.841784	0.954824	1			
LL (cm)	0.897127	0.816878	0.769578	0.824622	0.789341	1		
LB (cm)	0.871308	0.814786	0.970187	0.869889	0.821491	0.755558	1	
LA (cm ²)	0.951828	0.884478	0.933541	0.91516	0.868007	0.934773	0.934806	1

PH: plant height (cm); SG: stem girth (cm); PS: plant spread (cm); LL: leaf length (cm); LB: leaf breadth (cm); LA: leaf area (cm²).

Table 9. Correlation coefficient among flowering and yield traits of 35 *Celosia cristata* accessions

	DFF	D50F	DUR	FB	INF	FLOWERS	IL	IW	FL	FW	FD	SFW(g)	YIELD / PLANT (g)	YIELD (t/ha)
DFF	1													
D50F	0.889601	1												
DUR	-0.90271	-0.90592	1											
FB	-0.84579	-0.85441	0.914843	1										
INF	-0.84513	-0.85354	0.917113	0.842563	1									
FLOWERS	-0.82808	-0.82662	0.875279	0.890641	0.890193	1								
IL	-0.75781	-0.75473	0.802165	0.78439	0.787178	0.746564	1							
IW	-0.89354	-0.89432	0.735615	0.888264	0.889226	0.921589	0.85164	1						
FL	-0.80473	-0.79726	0.835787	0.813959	0.814103	0.781266	0.900494	0.901789	1					
FW	-0.87276	-0.86982	0.91834	0.849039	0.849799	0.964734	0.911228	0.944648	0.956904	1				
FD	-0.83873	-0.83885	0.893646	0.870431	0.872409	0.763288	0.907243	0.918292	0.949692	0.784463	1			
SFW(g)	-0.86795	-0.87172	0.919949	0.913383	0.915509	0.917843	0.86294	0.870625	0.864236	0.926147	0.910427	1		
YIELD / PLANT (g)	-0.6944	-0.8509	0.915272	0.926984	0.92869	0.861335	0.910714	0.911577	0.922621	0.955732	0.954343	0.79230 1	1	
YIELD (t/ha)	-0.8494	-0.8509	0.915272	0.926984	0.92869	0.976335	0.910714	0.911577	0.922621	0.955732	0.954343	0.97530 1	1	1

DFF: days to first flowering (days); D50F: days to 50 per cent flowering (days); DUR: duration of flowering (days); FB: number of flowering branches per plant; INF: number of inflorescences per plant; IL: inflorescence length (cm); IW: inflorescence width (cm); FL: flower length (cm); FW: flower width (cm); FD: flower diameter (cm); SFW: single flower weight (g); Yield/Plant: flower yield per plant (g); Yield (t/ha): flower yield per hectare (tonnes).

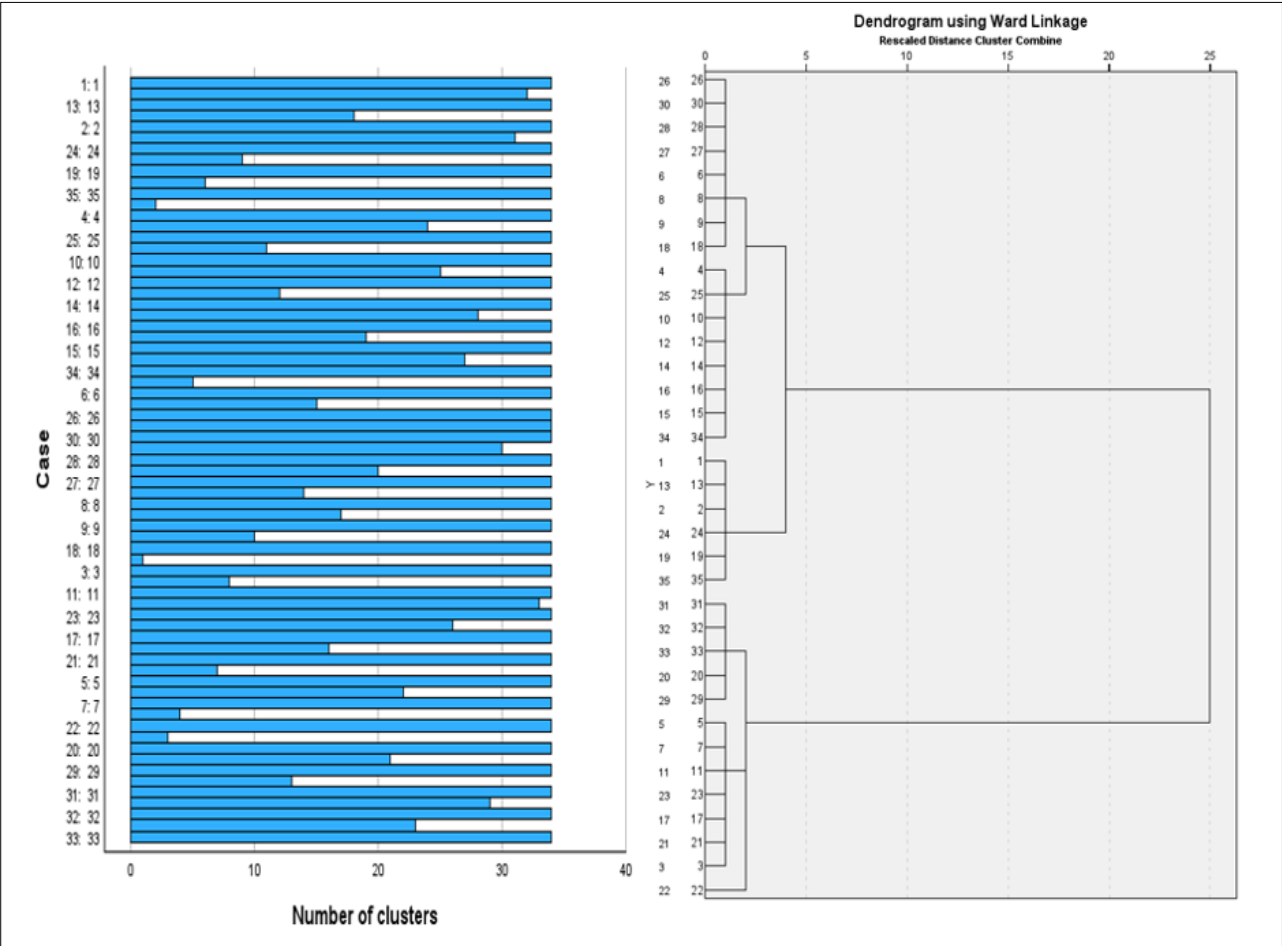


Fig. 6. Dendrogram showing hierarchical clustering of 35 *Celosia cristata* accessions based on vegetative traits using Ward's linkage method.

The agglomeration schedule indicated that accessions 26 and 30 exhibited the highest similarity, followed by accession pairs 11 and 23 and 1 and 13, indicating comparable performance for vegetative growth traits. Similarly, accessions 8 and 9, together with accessions 14, 15, 16 and 34, formed closely associated groups because of their similarity in plant height, stem girth, plant spread, leaf production, branching pattern and leaf area. A major cluster comprising accessions 4, 6, 8, 9, 10, 12, 14, 15, 16, 18, 25, 26, 27, 28, 30 and 34 was characterised by superior vegetative performance, indicating their potential as promising genetic resources for

improving vegetative vigour and overall plant architecture (3, 4).

In contrast, accessions 3, 5, 7, 11, 17, 20, 21, 22, 23, 29, 31, 32 and 33 formed separate clusters with comparatively lower vegetative performance. Similar observations of substantial morphological diversity among *Celosia* germplasm have been reported previously, suggesting that cluster analysis is an effective tool for identifying genetically diverse accessions for selection and hybridisation. The marked increase in linkage distance observed during the final stages of clustering, particularly at stage 34, further confirmed the presence of substantial divergence among the

evaluated accessions. Such genetically divergent accessions provide valuable opportunities for parent selection in breeding programmes aimed at developing improved cultivars with enhanced vegetative vigour and ornamental quality.

Hierarchical cluster analysis for flowering traits

Hierarchical cluster analysis using Ward's minimum variance method grouped the 35 *C. cristata* accessions into two major clusters based on flowering and yield traits (Fig. 7).

The clustering pattern revealed considerable diversity among the evaluated accessions. Cluster I comprised accessions 6, 8, 9, 18, 25, 27 and 28, which exhibited superior floral characteristics, including larger inflorescence size, greater flower weight, a higher number of flowers and enhanced flower yield. These accessions may therefore serve as valuable genetic resources for the improvement of flowering performance and yield in future breeding programmes (3).

In contrast, Cluster II consisted predominantly of low- to moderate-performing accessions, including 20, 22, 29, 31, 32, 33 and 35, which exhibited comparatively lower flowering performance and reduced yield attributes. Similar clustering patterns reflecting substantial diversity among *Celosia* germplasm have been reported in earlier studies, highlighting the effectiveness of cluster analysis for identifying genetically diverse accessions suitable for breeding programmes. Furthermore, the close clustering observed between accession pairs such as 26 and 30, 27 and 28 and 31 and 32 indicated a high degree of similarity for flowering and yield traits, whereas the large, rescaled distance separating the two major clusters suggested substantial genetic divergence among the evaluated accessions. Such divergent accessions could be utilised as potential parents in hybridisation programmes to combine desirable flowering characteristics with improved yield potential (4).

Identification of superior accessions

Considerable variability was observed among the 35 accessions of *C. cristata* for vegetative, flowering and yield traits (Table 10 and 11). Based on the overall performance of all evaluated characters, Accession 9 emerged as the superior genotype among all the

accessions. It exhibited vigorous vegetative growth with higher PH (96 cm), SG (5.9 cm), PS (63 cm), number of branches (36), LL (11.5 cm) and LA (64.4 cm²). In addition, the accession also recorded superior flowering and yield performance with early flowering (29 days), extended flower duration (40 days), higher number of flowers per plant (235), longest IL (15.5 cm), widest IW (9.2 cm), largest FD (6.0 cm), highest SFW (1.10 g) and maximum flower yield (28.49 t/ha).

Accessions 8, 18, 25, 26, 27, 28, 30 and 34 also exhibited superior performance for several vegetative and flowering traits, including higher plant vigour, larger inflorescence dimensions and increased flower yield, indicating their potential utility for commercial cultivation and future breeding programmes.

In contrast, accessions 20, 29, 31, 32 and 33 recorded comparatively lower values for vegetative growth, flowering behaviour and yield parameters, indicating poor overall performance.

The superior performance of accession 9 in both vegetative and flowering traits suggests its suitability as a promising parent for future crop improvement programmes aimed at developing high-yielding and ornamental *C. cristata* cultivars (Fig. 8).

Implications for breeding

The present investigation revealed substantial variability among the 35 accessions of *C. cristata* in vegetative, flowering and yield traits, indicating considerable genetic diversity within the germplasm collection. The wide variation observed for plant vigour, inflorescence characteristics and flower yield suggests good scope for selection and hybridisation in future breeding programmes.

Among all the accessions, accession 9 was identified as the most promising genotype due to its superior vegetative growth, flowering performance and highest flower yield. The accession exhibited higher plant vigour, larger inflorescence size, increased flower number and maximum yield, making it a suitable donor parent for developing superior inbred lines and high-yielding ornamental cultivars.

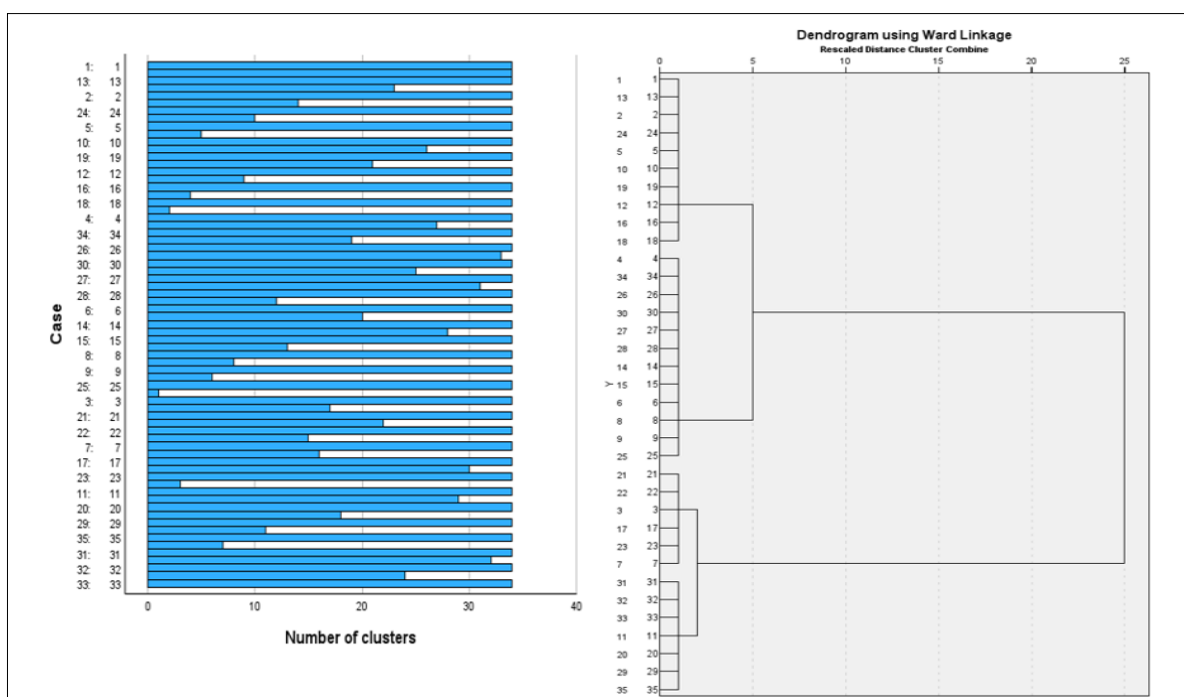


Fig. 7. Dendrogram showing hierarchical clustering of 35 *Celosia cristata* accessions based on flowering and yield traits using Ward's linkage method.

Table 10. Performance of superior *Celosia* accessions for important vegetative traits

Acc.	PH (cm)	SG (cm)	PS (cm)	Leaves	Branches	LL (cm)	LB (cm)	LA (cm ²)
9	96	5.9	63	465	36	11.5	5.6	64.4
8	98	5.8	64	470	35	11.0	5.4	59.4
18	94	5.9	68	450	33	10.8	6.2	67.0
25	88	5.5	60	420	40	10.5	5.2	54.6
27	95	5.8	65	430	35	10.9	5.4	58.9

PH: plant height; SG: stem girth; PS: plant spread; LL: leaf length; LB: leaf breadth; LA: leaf area.

Table 11. Performance of superior *Celosia* accessions for flowering and yield traits

Acc.	DFF	DUR	Flowers	IL (cm)	IW (cm)	FD (cm)	SFW (g)	Yield (t/ha)
9	29	40	235	15.5	9.2	6.0	1.10	28.49
8	33	32	240	14.5	7.2	5.6	1.02	26.95
27	30	35	228	14.3	8.8	5.5	1.00	25.08
28	30	36	225	14.2	8.7	5.4	0.99	24.53
26	31	36	222	14.0	8.6	5.6	0.98	23.98

DFF: days to first flowering; DUR: flower duration; IL: inflorescence length; IW: inflorescence width; FD: flower diameter; SFW: single flower weight.

**Fig. 8.** Superior-performing accession 9 of *Celosia cristata* under field conditions.

Accessions 8, 18, 25, 26, 27, 28, 30 and 34 also showed desirable performance in several vegetative and floral traits, including increased branching, LA, superior inflorescence dimensions and higher flower yield. These accessions may be utilised as alternate parents in hybridisation programmes to broaden the genetic base and improve ornamental quality and productivity.

The correlation analysis revealed positive correlation among vegetative vigour, inflorescence dimensions, FW and yield traits, indicating that these characters can be effectively used as indirect selection criteria during early generations of breeding programmes. The clustering pattern obtained through hierarchical cluster analysis further confirmed the existence of substantial divergence among accessions, suggesting the possibility of selecting genetically diverse parents for crop improvement in *C. cristata*.

Conclusion

The present investigation revealed significant morphological variability and genetic diversity among the thirty-five accessions of *Celosia cristata* evaluated under field conditions. Considerable variation was observed for vegetative, flowering and yield traits, indicating a broad scope for selection and crop improvement.

High coefficient of variation for flowering branches, flower weight (FW) and yield traits suggested the presence of substantial exploitable variability within the germplasm collection. Correlation analysis indicated strong positive associations among floral characters and yield parameters, suggesting the possibility of simultaneous improvement of flower quality and productivity through indirect selection. Cluster analysis further confirmed the existence of genetically diverse accessions suitable for hybridisation programmes. Among all the accessions, accession 9 emerged as the most promising genotype due to its superior vegetative vigour, early flowering, larger inflorescence size and highest flower yield (Fig. 8). The identified superior accessions may serve as valuable genetic resources for future breeding programmes and commercial cultivation of *C. cristata* for varietal development and commercial cultivation under tropical conditions.

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Authors' contributions

FRK conducted the survey, analysed the data and drafted the manuscript. RKR guided the preparation of the manuscript and approved the final version. SK contributed to the study design, reviewed the manuscript and assisted in securing research funding. KMP contributed to the review and provided additional support. JKM assisted with data collection and analysis. SG contributed to the interpretation of the results and critically reviewed the manuscript. All authors have read and approved the final manuscript.

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Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this manuscript, the authors used OpenAI solely for language editing, grammar correction, sentence refinement and improving the manuscript's overall readability. The AI tool was not used for data generation, data analysis, interpretation of results, or drawing scientific conclusions. All scientific content, analyses, interpretations and conclusions presented in this manuscript are the original work of the authors. The authors carefully reviewed, edited and verified all AI-assisted content and take full responsibility for the final version of the manuscript.

References

- Klanrit P, Thanonkeo S, Klanrit P, Klanrit P, Mueangnak K, Thanonkeo P. *Celosia argentea*: Towards a sustainable betalain source—A critical review and future prospects. *Plants*. 2025;14(13):1940. <https://doi.org/10.3390/plants14131940>
- Younis A, Muzamil Ijaz M, Ahsan M, Akram A. *Celosia* breeding: Classical and molecular approaches. In: *Breeding of ornamental crops: Annuals and cut flowers*. Cham: Springer; 2025. p. 63–75. https://doi.org/10.1007/978-3-031-78653-2_2
- Mastuti R, Arumingtyas EL, Fatimah AA. Genetic diversity of *Celosia* variants in East Java based on polyphenol oxidase (PPO) genes. *Procedia Chem*. 2015;14:361–6. <https://doi.org/10.1016/j.proche.2015.03.049>
- Oyetunde OA, Otusanya GO, Lawal IT, Oduntan AO, Olalekan OJ. Genetic diversity, discriminant and trait association analyses of *Celosia argentea* accessions. *Acta Horti Regiotect*. 2022;25(2):189–96. <https://doi.org/10.2478/ahr-2022-0023>
- Sendhilnathan R, Balaraman E, Rajkumar M, Sureshkumar R, Barathkumar T. Influence of organic nutrients and bioregulators on certain growth and flower quality attributes of *Celosia cristata* L. *Plant Arch*. 2021;21(1):2220–3. <https://doi.org/10.51470/PLANTARCHIVES.2021.v21.S1.367>
- Saha TN. Role of All India Coordinated Research Project in development of floriculture in India. *Int J Bioresour Stress Manag*. 2014. <https://doi.org/10.5958/j.0976-4038.5.1.031>
- Biswas B, Kumar PN, Bhattacharjee S. All India Coordinated Research Project on Floriculture. New Delhi: Indian Council of Agricultural Research, Division of Floriculture and Landscaping, Indian Agricultural Research Institute.

- Norman J, Ofosu-Anim J, Adjei-Frimpong P. Disbudding effects on growth analysis of *Celosia* (*Celosia cristata*). *Adv Horti Sci*. 2011;25(4):223–31. <https://doi.org/10.13128/ahs-12755>
- Pessarakli M. *Handbook of plant and crop physiology*. Boca Raton (FL): CRC Press; 2014. <https://doi.org/10.1201/b16675>
- Hunt R. *Basic growth analysis: Plant growth analysis for beginners*. Dordrecht: Springer; 2012.
- Meng LS, Sun XD, Li F, Liu HL, Feng ZH, Zhu J. Modification of flowers and leaves in cockscomb (*Celosia cristata*) ectopically expressing *Arabidopsis* ASYMMETRIC LEAVES2-LIKE38 (ASL38/LBD41) gene. *Acta Physiol Plant*. 2010;32(2):315–24. <https://doi.org/10.1007/s11738-009-0409-x>
- Govindaraj M, Vetriventhan M, Srinivasan M. Importance of genetic diversity assessment in crop plants and its recent advances: An overview of its analytical perspectives. *Genet Res Int*. 2015;2015:431487. <https://doi.org/10.1155/2015/431487>
- Mondini L, Noorani A, Pagnotta MA. Assessing plant genetic diversity by molecular tools. *Diversity*. 2009;1(1):19–35. <https://doi.org/10.3390/d1010019>
- Zaman W, Ayaz A, Park S. Integrating morphological and molecular data in plant taxonomy. *Pak J Bot*. 2025;57(4):1453–66. [https://doi.org/10.30848/PJB2025-4\(27\)](https://doi.org/10.30848/PJB2025-4(27))
- Ward JH Jr. Hierarchical grouping to optimize an objective function. *J Am Stat Assoc*. 1963;58(301):236–44. <https://doi.org/10.1080/01621459.1963.10500845>
- Everitt BS, Landau S, Leese M, Stahl D. *Cluster analysis*. 5th ed. Chichester: Wiley; 2011. <https://doi.org/10.1002/9780470977811>
- Veluru A, Bhat KV, Janakiram T, Prasad K, Panwar S, Namita SK. Phenotypic characterization and grouping of rose (*Rosa × hybrida* L.) genotypes using DUS descriptors. *Indian J Plant Genet Resour*. 2023;36(2):243–9. <https://doi.org/10.5958/0976-1926.2023.00036.2.06>
- Agnihotri R. DUS characterization and genetic studies in rose (*Rosa hybrida*) [thesis]. 2019.
- Malakar M, Gokiladevi R, Biswas S, Dutta SK. Breeding overview on ornamental youth-and-age flower (*Zinnia* spp.). In: *Breeding of ornamental crops: Annuals and cut flowers*. Cham: Springer; 2025. p. 331–80. https://doi.org/10.1007/978-3-031-78653-2_10
- Iqbal A, Mushtaq MU, Khan AHA, Nawaz I, Yousaf S, Zeshan, et al. Influence of *Pseudomonas japonica* and organic amendments on the growth and metal tolerance of *Celosia argentea* L. *Environ Sci Pollut Res*. 2020;27(20):24671–85. <https://doi.org/10.1007/s11356-019-06181-z>
- Odulana D, Salau A, Odeyemi O, Makinde E. Effects of variety, plant population and age at harvest on plant regrowth, shoot yield and nutritional composition of *Celosia argentea*. *Niger J Horti Sci*. 2023;27:74–84

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