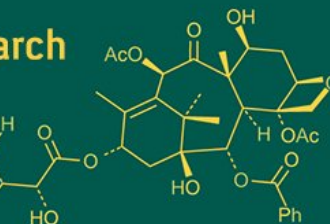
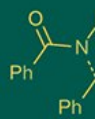


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Effect of the photoperiod response on growth and physiological traits in cut *Chrysanthemum*

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Abstract

Chrysanthemum (*Chrysanthemum morifolium* Ramat.) is one of the world's most commercially important ornamental crops and its growth and flowering are strongly regulated by photoperiod and temperature. The present investigation, conducted during 2024-25 at the College of Horticulture, Bagalkot, evaluated five cut *Chrysanthemum* varieties i.e Champagne Yellow (V₁), Artic Queen White (V₂), Lollipop Pink (V₃), Bright Orange (V₄) and Bright White (V₅) planted across five months (August through December) under a Factorial Randomized Complete Block Design. Growth parameters including plant height, plant spread (N-S and E-W), stem girth, number of primary branches and intermodal length were recorded at 30, 60, 90 and 120 DAT, while physiological parameters such as leaf area, leaf area index, crop growth rate and relative growth rate were also assessed. Results consistently demonstrated that Bright Orange (V₄) outperformed all other varieties across all measured traits, while August planting (M₁) produced the most vigorous vegetative growth. The interaction treatment M₁V₄ (August × Bright Orange) recorded the best performance across all parameters, indicating that matching a genetically vigorous variety with a favourable photoperiodic window significantly enhances crop growth and physiological efficiency.

Keywords: *Chrysanthemum*, photoperiod, planting month, cut flower, growth parameters, physiological traits, genotype × environment interaction

Introduction

Chrysanthemum (*Chrysanthemum morifolium* Ramat.), a member of the Asteraceae family (2n = 36), ranks as one of the world's most important ornamental crops. Popularly called the Queen of the East, its name derives from the Greek *Chrysies* (gold) and *anthers* (flower). In India, it holds special cultural significance in garlands, *vein*, floral jewellery and religious rituals, with an extensive range of varieties developed across numerous colours, shapes and textures (Winogrand, 1999) [48].

Flowers have held a close association with human life since time immemorial, forming an integral part of cultural and spiritual practices across history. They accompany a person's life journey from birth through life's milestones to the final farewell, in worship, adornment, celebrations and rituals (Segar *et al.*, 2010) [31]. *Chrysanthemum* is sensitive to day length, requiring longer daylight for vegetative growth and shorter days for flowering. Its growth and blooming are largely governed by light and temperature, which cause variations in cultivar performance across regions, seasons and environments. Differences among cultivars result from their specific responses to photoperiod and temperature (Pole and Heuvelink, 2006). *C. morifolium* performs optimally under tropical and subtropical conditions with day temperatures of 20-28°C and night temperatures of 15-20 °C.

Chrysanthemum cultivation in Northern Karnataka is dominated by traditional yellow and white cultivars grown for loose flower marketing, which lack the qualitative traits of cut *Chrysanthemum* types. Environmental factors such as light intensity, temperature and relative humidity profoundly influence growth, flowering and yield potential (Kulkarni and Reddy, 2010) [13]. Flowering generally occurs between August and December. Earlier findings indicated variability in the ideal planting window: Raman *et al.* (1969) [26] reported peak yields from May planting, whereas Shanmugam and Muthuswamy (1973) [32] found July planting more suitable.

Under natural cycles, *Chrysanthemums* exhibit vegetative growth during extended summer daylight, while reduced day length in late summer to early autumn triggers bud initiation and flowering (Prasad and Kumar, 2005) [24]. The present investigation was therefore undertaken to evaluate cut *Chrysanthemum* varieties planted across different months for their photoperiodic response with respect to growth and physiological parameters under open field conditions in the Northern Dry Zone of Karnataka.

Material and Methods

A field experiment was conducted during 2024-25 at the research block of the Department of Floriculture and Landscape Architecture, College of Horticulture, University of Horticultural Sciences, Bagalkot, Karnataka, India. The experimental site experienced maximum monthly rainfall in October (109.7 mm) followed by August (89.9 mm). The mean minimum temperature ranged from 17.72°C to 21.18°C, with relative humidity fluctuating from 23.00 to 86.90 per cent. The soil was prepared by thorough ploughing up to 30 cm depth followed by harrowing and raised beds of 30 cm height, 80 cm width and 30 m length were formed with 45 cm pathways between beds.

The experiment was laid out in a Factorial Randomized Complete Block Design (FRCBD) with 25 treatment combinations and two replications, comprising five

Chrysanthemum varieties (Champagne Yellow, Artic Queen White, Lollipop Pink, Bright Orange and Bright White) and five planting months (August, September, October, November and December). Rooted cuttings (25-30 days old) were transplanted from August to December 2024 at a spacing of 45 cm × 30 cm, accommodating 40 plants per treatment. Standard plant protection measures were followed to control pests and diseases using appropriate chemical and biological agents. Pinching was carried out at 30 and 45 days after planting to promote lateral branching, and staking was done using bamboo stakes and jute twine to support plant growth. Flowers were harvested at full bloom stage using sharp tools.

Observations were recorded on five randomly selected and tagged plants from each treatment in both replications. Growth parameters such as plant height, plant spread, stem girth, number of primary branches and internodal length were measured at 30, 60, 90 and 120 days after transplanting. Physiological parameters including leaf area and leaf area index were recorded at 70 days after planting, while crop growth rate (CGR) and relative growth rate (RGR) were computed using dry matter accumulation at 45 and 75 days after planting. The data obtained were subjected to statistical analysis using the critical difference (CD) at 5 per cent level of significance.



Fig 1: Cut *Chrysanthemum* varieties used in the experiment

Results and Discussion

The experimental results obtained from the evaluation of cut *Chrysanthemum* varieties for photoperiodic response under open conditions in the Northern Dry Zone of Karnataka during 2024-25 are presented and discussed below.

Growth Parameters

Plant performance in terms of growth was significantly and directly affected by day length and the intensity of light received. Planting *Chrysanthemum* during different months led to marked variations in vegetative growth parameters at 30, 60, 90 and 120 DAT. These differences can be attributed

to variation in photoperiod across planting months, which created distinct environmental conditions influencing vegetative development.

Plant Height (cm)

Plant height differed significantly among varieties at all growth stages, indicating strong genetic control over vegetative growth. The data at 30 and 60 DAT are presented in Table 1a and at 90 and 120 DAT in Table 1b.

Among the varieties, Bright Orange (V_4) consistently recorded the maximum plant height with mean values of 19.81, 40.56, 54.38 and 62.82 cm at 30, 60, 90 and 120

DAT, respectively, followed by Artic Queen White (V₂) with 19.31, 39.87, 52.13 and 61.00 cm. The minimum plant height was recorded in Bright White (V₅) with mean values of 16.15, 35.68, 46.41 and 57.96 cm. These differences can be attributed to the superior photosynthetic efficiency, enhanced cell division and effective translocation of assimilates towards stem elongation in the Bright Orange variety. Artic Queen White also exhibited vigorous growth, as earlier reported by Negi *et al.* (2020) [20]. Bright White recorded minimum height due to its compact growth habit and restricted internodal elongation, in line with Thiripurasundari *et al.* (2021) [44]. Similar varietal differences in plant height have been reported by Swaroop *et al.* (2008) [41] and Banerji *et al.* (2012) [3]. Different months of planting significantly influenced plant height at all stages. August planting (M₁) produced the tallest plants 22.43, 46.02, 57.17 and 71.92 cm at 30, 60, 90 and 120 DAT which may be attributed to higher light intensity and

longer photoperiod that enhanced photosynthetic activity and metabolic processes (Bose *et al.*, 2003; Bhattacharjee and De, 2003; Kumar *et al.*, 2011) [5, 6, 14]. December planting (M₅) produced the shortest plants (13.49, 27.89, 42.15 and 45.19 cm), attributable to reduced sunshine hours and lower temperatures suppressing vegetative growth (Jose *et al.*, 2017) [11]. The interaction between varieties and months was significant at all stages. M₁V₄ (August × Bright Orange) recorded maximum plant height with 24.10, 50.14, 61.00 and 75.26 cm at 30, 60, 90 and 120 DAT, which was on par with M₁V₂ (August × Artic Queen White) at 23.94, 48.92, 60.67 and 73.53 cm. The lowest plant height was recorded in M₅V₅ (December × Bright White) with 11.07, 26.43, 38.26 and 43.20 cm, attributable to the combined effect of an inherently less vigorous genotype and unfavourable winter conditions (Negi *et al.*, 2020; Aashutosh *et al.*, 2019) [20] [1].

Table 1a: Plant height at 30 and 60 DAT as influenced by varieties and planting months.

Plant Height (cm)												
Varieties (V)	Month (M)											
	30 DAT						60 DAT					
	M ₁	M ₂	M ₃	M ₄	M ₅	Mean V	M ₁	M ₂	M ₃	M ₄	M ₅	Mean V
V ₁	22.97	21.26	18.61	14.68	13.9	18.28	45.43	43.11	39.49	32.79	28.01	37.76
V ₂	23.94	22.06	19.05	16.66	14.87	19.31	48.92	46.50	39.94	34.83	29.15	39.87
V ₃	21.18	18.56	18.80	15.54	12.12	17.24	43.61	40.88	37.72	33.13	26.76	36.42
V ₄	24.10	22.65	20.06	16.73	15.50	19.81	50.14	47.02	40.96	35.58	29.10	40.56
V ₅	19.95	17.87	16.99	14.88	11.07	16.15	42.04	39.42	38.32	32.23	26.43	35.68
Mean M	22.43	20.48	18.70	15.70	13.49		46.02	43.38	39.28	33.71	27.89	
For comparing means of			S.Em±		C.D @ 5%		S.Em±			C.D @ 5%		
Varieties (V)			0.16		0.48		0.24			0.69		
Months (M)			0.16		0.48		0.24			0.69		
M × V			0.36		1.07		0.53			1.55		
Varieties (V): Champagne Yellow (V ₁); Artic Queen White (V ₂); Lollipop Pink (V ₃); Bright Orange (V ₄); Bright White (V ₅)												
Months (M): August (M ₁); September (M ₂); October (M ₃); November (M ₄); December (M ₅)												
DAT: Days after transplanting												

Table 1b: Plant height at 90 and 120 DAT as influenced by varieties and planting months.

Plant Height (cm)												
Varieties (V)	Month (M)											
	90 DAT						120 DAT					
	M ₁	M ₂	M ₃	M ₄	M ₅	Mean V	M ₁	M ₂	M ₃	M ₄	M ₅	Mean V
V ₁	57.36	53.24	53.05	53.40	42.22	51.85	71.99	66.32	59.55	57.45	45.18	60.09
V ₂	60.6	54.84	53.78	46.56	44.81	52.13	73.53	67.41	61.87	57.89	44.31	61.00
V ₃	53.87	52.68	50.74	53.48	38.93	49.94	71.84	62.01	60.58	55.33	45.50	59.05
V ₄	61.00	58.76	55.67	49.96	46.54	54.38	75.26	69.83	62.14	59.12	47.78	62.82
V ₅	52.97	51.89	45.59	43.37	38.26	46.41	66.99	63.13	60.77	55.75	43.20	57.96
Mean M	57.17	54.28	51.76	49.35	42.15		71.92	65.74	60.98	57.10	45.19	
For comparing means of			S.Em±		C.D @ 5%		S.Em±			C.D @ 5%		
Varieties (V)			0.41		1.20		0.45			1.32		
Months (M)			0.41		1.20		0.45			1.32		
M × V			0.92		2.69		1.01			2.96		
Varieties (V): Champagne Yellow (V ₁); Artic Queen White (V ₂); Lollipop Pink (V ₃); Bright Orange (V ₄); Bright White (V ₅)												
Months (M): August (M ₁); September (M ₂); October (M ₃); November (M ₄); December (M ₅)												
DAT: Days after transplanting												

Plant Spread (cm)

Plant Spread - North-South Direction

Plant spread (N-S) differed significantly among varieties at all growth stages.

Bright Orange (V₄) exhibited the widest spread - 8.56, 14.50, 21.67 and 27.27 cm at 30, 60, 90 and 120 DAT attributed to vigorous lateral growth and efficient

photosynthate partitioning towards canopy development (Raghava and Negi, 2015) [25]. Artic Queen White (V₂) also showed comparatively higher spread (8.01, 14.09, 20.42 and 26.14 cm), indicating inherent vegetative vigour (Singh *et al.*, 2019) [37]. Bright White (V₅) recorded the least plant spread (7.31, 12.98, 19.34 and 24.80 cm), possibly due to compact growth habit and limited lateral branching ability.

Table 2a: Plant spread (N-S) at 30 and 60 DAT as influenced by varieties and planting months.

Plant Spread (North-South)(cm)												
Varieties (V)	Month (M)											
	30 DAT						60 DAT					
	M ₁	M ₂	M ₃	M ₄	M ₅	Mean V	M ₁	M ₂	M ₃	M ₄	M ₅	Mean V
V ₁	9.34	8.96	7.74	6.86	5.48	7.67	16.86	15.97	13.74	11.90	10.89	13.87
V ₂	10.14	9.11	7.81	7.05	5.96	8.01	16.97	15.96	14.21	12.43	10.89	14.09
V ₃	9.29	8.43	7.16	6.74	5.35	7.39	16.36	15.78	13.65	11.22	10.56	13.51
V ₄	10.27	9.47	8.37	8.53	6.17	8.56	17.94	16.43	14.35	12.52	11.30	14.50
V ₅	9.31	8.16	7.19	6.70	5.19	7.31	14.62	15.26	13.97	11.03	10.01	12.98
Mean M	9.67	8.83	7.65	7.17	5.63		16.55	15.88	13.98	11.82	10.73	
For comparing means of			S.Em±		C.D @ 5%		S.Em±			C.D @ 5%		
Varieties (V)			0.06		0.17		0.13			0.38		
Months (M)			0.06		0.17		0.13			0.38		
M × V			0.13		0.38		0.29			0.85		
Varieties (V): Champagne Yellow (V ₁); Artic Queen White (V ₂); Lollipop Pink (V ₃); Bright Orange (V ₄); Bright White (V ₅)												
Months (M): August (M ₁); September (M ₂); October (M ₃); November (M ₄); December (M ₅)												
DAT: Days after transplanting												

August planting (M₁) produced the greatest plant spread (9.67, 16.55, 25.13 and 31.65 cm) due to favourable temperature and higher light availability enhancing photosynthetic activity (Singh and Arora, 2009) [35]. December planting (M₅) produced the minimum spread (5.63, 10.73, 15.80 and 19.46 cm) due to reduced sunshine hours and lower temperatures (Khan and Qureshi, 2017) [12].

The M₁V₄ combination recorded maximum values (10.27, 17.94, 27.87 and 35.04 cm), while M₅V₅ showed the lowest (5.19, 10.01, 13.61 and 17.73 cm), reflecting the role of genotype × environment interaction in shaping canopy structure (Allard and Bradshaw, 1964; Sharma *et al.*, 2018) [2, 34].

Table 2b: Plant spread (N-S) at 90 and 120 DAT as influenced by varieties and planting months.

Plant Spread (North-South)(cm)												
Varieties (V)	Month (M)											
	90 DAT						120 DAT					
	M ₁	M ₂	M ₃	M ₄	M ₅	Mean V	M ₁	M ₂	M ₃	M ₄	M ₅	Mean V
V ₁	24.74	22.07	20.48	18.32	16.01	20.32	30.89	28.63	25.02	23.80	19.91	25.65
V ₂	24.99	23.16	20.56	17.03	16.36	20.42	31.24	29.39	26.13	24.04	19.92	26.14
V ₃	24.18	22.69	20.36	18.24	15.89	20.27	30.85	27.85	25.70	23.66	19.74	25.56
V ₄	27.87	23.68	20.90	18.78	17.13	21.67	35.04	28.76	26.77	25.75	20.02	27.27
V ₅	23.88	22.28	19.74	17.20	13.61	19.34	30.23	28.13	24.47	23.44	17.73	24.80
Mean M	25.13	22.77	20.41	17.91	15.80		31.65	28.55	25.62	24.14	19.46	
For comparing means of			S.Em±		C.D @ 5%		S.Em±			C.D @ 5%		
Varieties (V)			0.20		0.59		0.19			0.54		
Months (M)			0.20		0.59		0.19			0.54		
M × V			0.45		1.33		0.41			1.21		
Varieties (V): Champagne Yellow (V ₁); Artic Queen White (V ₂); Lollipop Pink (V ₃); Bright Orange (V ₄); Bright White (V ₅)												
Months (M): August (M ₁); September (M ₂); October (M ₃); November (M ₄); December (M ₅)												
DAT: Days after transplanting												

Plant Spread - East-West Direction

Significant variation in E-W plant spread was observed across varieties at all growth stages. Bright Orange (V₄) recorded the maximum spread (9.58, 16.53, 22.70 and 28.03 cm), attributed to vigorous vegetative growth and superior branching ability (Raghava and Negi, 2015) [25]. Artic Queen White (V₂) showed good genetic vigour (9.04, 15.60, 22.09 and 27.09 cm), while Bright White (V₅) consistently recorded the lowest spread (8.00, 14.79, 20.83 and 25.90

cm) due to compact canopy structure and limited lateral branching.

August planting (M₁) resulted in the widest E-W spread (11.34, 19.68, 27.04 and 32.85 cm) due to favourable thermal regime, increased light interception and longer photoperiod supporting higher photosynthetic efficiency (Singh and Arora, 2009) [35]. A progressive reduction was observed with delayed planting, reaching the minimum in December (M₅) at 6.35, 11.46,

Table 3a: Plant spread (E-W) at 30 and 60 DAT as influenced by varieties and planting months.

Plant Spread (East-West) (cm)												
Varieties (V)	Month (M)											
	30 DAT						60 DAT					
	M ₁	M ₂	M ₃	M ₄	M ₅	Mean V	M ₁	M ₂	M ₃	M ₄	M ₅	Mean V
V ₁	11.26	9.97	8.84	7.54	6.73	8.87	18.95	17.37	15.52	13.72	11.61	15.43
V ₂	11.60	10.19	8.86	7.81	6.77	9.04	19.41	17.45	15.74	13.64	11.79	15.60
V ₃	10.82	9.89	8.65	7.44	6.72	8.70	18.68	17.20	15.70	13.42	11.77	15.35
V ₄	12.69	10.76	9.23	8.07	7.14	9.58	22.61	17.99	15.99	13.94	12.16	16.53
V ₅	10.32	9.72	8.42	7.15	4.41	8.00	18.76	17.03	15.07	13.12	9.96	14.79
Mean M	11.34	10.10	8.80	7.60	6.35		19.68	17.41	15.60	13.57	11.46	
For comparing means of			S.Em±		C.D @ 5%		S.Em±			C.D @ 5%		
Varieties (V)			0.12		0.34		0.18			0.53		
Months (M)			0.12		0.34		0.18			0.53		
M × V			0.26		0.76		0.41			1.19		
Varieties (V): Champagne Yellow (V ₁); Artic Queen White (V ₂); Lollipop Pink (V ₃); Bright Orange (V ₄); Bright White (V ₅)												
Months (M): August (M ₁); September (M ₂); October (M ₃); November (M ₄); December (M ₅)												
DAT: Days after transplanting												

Table 3b: Plant spread (E-W) at 90 and 120 DAT as influenced by varieties and planting months.

Plant Spread (East-West) (cm)												
Varieties (V)	Month (M)											
	90 DAT						120 DAT					
	M ₁	M ₂	M ₃	M ₄	M ₅	Mean V	M ₁	M ₂	M ₃	M ₄	M ₅	Mean V
V ₁	26.59	24.45	22.17	19.23	16.94	21.88	32.04	30.03	27.38	24.33	20.98	26.95
V ₂	27.54	25.15	22.03	19.11	16.96	22.09	32.47	30.25	27.34	24.60	20.79	27.09
V ₃	26.54	24.35	21.84	19.62	16.54	21.78	31.90	30.42	27.26	23.50	21.03	26.82
V ₄	29.14	25.30	22.31	19.85	16.90	22.70	36.09	30.87	27.92	24.45	20.83	28.03
V ₅	25.72	24.09	21.33	19.35	13.67	20.83	31.77	29.59	27.09	23.63	17.42	25.90
Mean M	27.04	24.67	21.93	19.43	16.20		32.85	30.23	27.39	24.10	20.21	
For comparing means of			S.Em±		C.D @ 5%		S.Em±			C.D @ 5%		
Varieties (V)			0.17		0.49		0.21			0.62		
Months (M)			0.17		0.49		0.21			0.62		
M × V			0.37		1.10		0.47			1.38		
Varieties (V): Champagne Yellow (V ₁); Artic Queen White (V ₂); Lollipop Pink (V ₃); Bright Orange (V ₄); Bright White (V ₅)												
Months (M): August (M ₁); September (M ₂); October (M ₃); November (M ₄); December (M ₅)												
DAT: Days after transplanting												

16.20 and 20.21 cm (Khan and Qureshi, 2017) ^[12]. The M₁V₄ combination was superior (12.69, 22.61, 29.14 and 36.09 cm) and M₅V₅ the lowest (4.41, 9.96, 13.67 and 17.42 cm), confirming that the expression of varietal potential is strongly conditioned by the prevailing environment (Allard and Bradshaw, 1964; Sharma *et al.*, 2018) ^[2, 34].

Number of primary branches

Marked differences in primary branch number were observed among varieties, reflecting the influence of genetic makeup on branching behaviour. Bright Orange (V₄) produced the highest number of primary branches (5.37, 6.56 and 7.69 at 60, 90 and 120 DAT), attributed to vigorous vegetative growth and greater lateral shoot development, followed by Artic Queen White (V₂) with 4.86, 6.06 and 6.90 (Kumar *et al.*, 2016) ^[16]. Bright White (V₅) recorded the least (3.82, 4.89 and 5.73), possibly due to compact growth habit and stronger apical dominance. August planting (M₁) produced the highest number of primary branches (6.11, 7.64 and 8.88) due to favourable temperature and higher light intensity during the early growth phase, which encouraged active vegetative development and lateral bud emergence. December planting

(M₅) recorded the least (3.01, 3.74 and 4.46), as cooler temperatures and shorter sunshine duration restricted vegetative growth and branch initiation (Sharma *et al.*, 2014; Yadav and Dhatt, 2013) ^[33, 49]. The M₁V₄ combination consistently produced the highest primary branch count (7.92, 9.42 and 11.67 at 60, 90 and 120 DAT), while M₅V₅ recorded the lowest (2.02, 2.33 and 3.56), attributable to the combined influence of a less vigorous genotype and unfavourable winter conditions (Aashutosh *et al.*, 2019; Allard and Bradshaw, 1964) ^[1].

Stem Girth (cm)

Stem girth differed significantly among varieties at all growth stages. Bright Orange (V₄) recorded maximum stem girth of 0.60, 0.82, 1.15 and 1.31 cm at 30, 60, 90 and 120 DAT, reflecting superior vigour and effective channelling of dry matter into structural biomass, likely associated with rapid cambial cell division and superior vascular bundle arrangement (Eisa *et al.*, 2022) ^[8]. Artic Queen White (V₂) followed with 0.53, 0.78, 1.07 and 1.22 cm, while Bright White (V₅) recorded the minimum (0.43, 0.63, 0.93 and 1.06 cm).

Table 4: Number of primary branches at 30, 60 and 90 DAT as influenced by varieties and planting months.

Number of primary branches																		
Varieties (V)	Month (M)																	
	60 DAT						90 DAT						120 DAT					
	M ₁	M ₂	M ₃	M ₄	M ₅	Mean V	M ₁	M ₂	M ₃	M ₄	M ₅	Mean V	M ₁	M ₂	M ₃	M ₄	M ₅	Mean V
V ₁	5.86	5.10	4.64	3.86	3.08	4.51	7.20	6.56	6.06	4.80	3.89	5.70	8.26	7.59	6.67	5.33	4.52	6.47
V ₂	6.11	5.49	4.95	4.31	3.47	4.86	7.76	6.87	6.28	5.10	4.28	6.06	8.94	7.81	7.29	5.71	4.78	6.90
V ₃	5.56	4.85	4.24	3.60	2.83	4.21	7.11	6.22	5.71	4.48	3.72	5.45	8.09	7.10	6.60	5.04	4.32	6.23
V ₄	7.92	5.69	5.10	4.47	3.66	5.37	9.42	6.95	6.51	5.47	4.49	6.56	11.67	8.13	7.44	6.06	5.16	7.69
V ₅	5.13	4.66	4.00	3.30	2.02	3.82	6.72	5.98	5.31	4.12	2.33	4.89	7.43	6.72	6.14	4.80	3.56	5.73
Mean M	6.11	5.16	4.58	3.91	3.01		7.64	6.52	5.97	4.79	3.74		8.88	7.47	6.83	5.39	4.46	
For comparing the means of			S.Em±		C.D @ 5%		S.Em±			C.D @ 5%			S.Em±			C.D @ 5%		
Varieties (V)			0.07		0.20		0.06			0.18			0.08			0.22		
Months (M)			0.07		0.20		0.06			0.18			0.08			0.22		
M X V			0.15		0.45		0.13			0.39			0.17			0.50		
Varieties (V): Champagne Yellow (V ₁); Artic Queen White (V ₂); Lollipop Pink (V ₃); Bright Orange (V ₄); Bright White (V ₅)																		
Months (M): August (M ₁); September (M ₂); October (M ₃); November (M ₄); December (M ₅)																		
DAT: Days after transplanting																		

Table 5a: Stem girth at 30 and 60 DAT as influenced by varieties and planting months.

Stem girth (cm)												
Varieties (V)	Month (M)											
	30 DAT						60 DAT					
	M ₁	M ₂	M ₃	M ₄	M ₅	Mean V	M ₁	M ₂	M ₃	M ₄	M ₅	Mean V
V ₁	0.60	0.54	0.55	0.47	0.43	0.51	0.84	0.80	0.72	0.70	0.67	0.74
V ₂	0.62	0.58	0.53	0.50	0.45	0.53	0.86	0.83	0.79	0.73	0.71	0.78
V ₃	0.56	0.51	0.49	0.43	0.42	0.48	0.79	0.75	0.70	0.66	0.63	0.70
V ₄	0.81	0.61	0.57	0.53	0.49	0.60	0.96	0.85	0.80	0.77	0.74	0.82
V ₅	0.53	0.48	0.44	0.41	0.29	0.43	0.76	0.70	0.68	0.62	0.41	0.63
Mean M	0.62	0.54	0.51	0.47	0.41		0.84	0.78	0.74	0.69	0.63	
For comparing means of			S.Em±		C.D @ 5%			S.Em±			C.D @ 5%	
Varieties (V)			0.01		0.02			0.01			0.02	
Months (M)			0.01		0.02			0.01			0.02	
M × V			0.02		0.05			0.02			0.05	
Varieties (V): Champagne Yellow (V ₁); Artic Queen White (V ₂); Lollipop Pink (V ₃); Bright Orange (V ₄); Bright White (V ₅)												
Months (M): August (M ₁); September (M ₂); October (M ₃); November (M ₄); December (M ₅)												
DAT: Days after transplanting												

Table 5b: Stem girth at 90 and 120 DAT as influenced by varieties and planting months.

Stem girth (cm)												
Varieties (V)	Month (M)											
	90 DAT						120 DAT					
	M ₁	M ₂	M ₃	M ₄	M ₅	Mean V	M ₁	M ₂	M ₃	M ₄	M ₅	Mean V
V ₁	1.12	1.08	1.04	1.00	0.94	1.03	1.29	1.23	1.18	1.16	1.11	1.19
V ₂	1.15	1.13	1.09	1.02	0.99	1.07	1.34	1.27	1.21	1.18	1.12	1.22
V ₃	1.09	1.05	1.03	0.96	0.94	1.01	1.27	1.19	1.13	1.13	1.06	1.16
V ₄	1.38	1.14	1.12	1.08	1.04	1.15	1.54	1.31	1.27	1.25	1.20	1.31
V ₅	1.05	0.99	0.96	0.93	0.74	0.93	1.20	1.16	1.12	1.06	0.78	1.06
Mean M	1.16	1.08	1.04	1.00	0.93		1.33	1.23	1.18	1.16	1.05	
For comparing means of			S.Em±		C.D @ 5%			S.Em±			C.D @ 5%	
Varieties (V)			0.01		0.03			0.02			0.04	
Months (M)			0.01		0.03			0.02			0.04	
M × V			0.03		0.07			0.03			0.10	
Varieties (V): Champagne Yellow (V ₁); Artic Queen White (V ₂); Lollipop Pink (V ₃); Bright Orange (V ₄); Bright White (V ₅)												
Months (M): August (M ₁); September (M ₂); October (M ₃); November (M ₄); December (M ₅)												
DAT: Days after transplanting												

August planting (M₁) produced the thickest stems (0.62, 0.84, 1.16 and 1.33 cm) due to favourable thermo-photoperiodic conditions that enhanced photosynthesis and carbohydrate accumulation (Sajid, 2025; Sadhna, 2025) [30]. Late-season December planting (M₅) recorded the minimum (0.41, 0.63, 0.93 and 1.05 cm) due to reduced light intensity and sub optimal temperatures (Van der Ploeg and Heuvelink,

2020) [45].

The M₁V₄ treatment recorded maximum stem girth (0.81, 0.96, 1.38 and 1.54 cm), while M₅V₅ recorded the lowest (0.29, 0.41, 0.74 and 0.78 cm), demonstrating how harsh low-light winter conditions can further stunt a variety already possessing low growth vigour. This synergistic relationship is supported by Kumari *et al.* (2023) [17] and Sadhna (2025), who emphasise the importance of

identifying suitable variety-season combinations for specific farming objectives.

Internodal Length (cm)

Significant variation in internodal length was observed across varieties. Bright Orange (V₄) exhibited the greatest internodal stretching 1.97, 2.23, 2.48 and 2.84 cm at 30, 60, 90 and 120 DAT suggesting superior endogenous gibberellin activity and more efficient cell elongation (Singh *et al.*, 2014; Patel *et al.*, 2015) [21, 36]. Artic Queen White (V₂) followed with 1.91, 2.15, 2.42 and 2.77 cm, while Bright White (V₅) showed the minimum (1.75, 2.00, 2.24 and 2.51 cm).

August planting (M₁) yielded significantly longer internodes (1.98, 2.24, 2.52 and 2.83 cm) due to the ideal thermo-photoperiodic window with extended daylight and favourable temperatures facilitating rapid cell expansion,

boosting photosynthetic rate and carbohydrate reserves essential for stem stretching (Sajid, 2025) [30]. December planting (M₅) resulted in the shortest internodes (1.74, 2.00, 2.25 and 2.54 cm), likely due to inhibition of auxin and gibberellin synthesis under short-day and low-temperature conditions (Van der Ploeg and Heuvelink, 2020) [45].

The M₁V₄ combination recorded the widest internodal length (2.13, 2.41, 2.88 and 2.97 cm), followed by M₁V₂ (1.98, 2.26, 2.50 and 2.91 cm). The M₅V₅ combination showed the narrowest internodes (1.41, 1.75, 2.10 and 2.15 cm), where cold and dark winter conditions further stunted a variety already naturally slow in growth. As noted by Kumari *et al.* (2023) [17], these results demonstrate that while a variety's genetics provides the blueprint for growth, the planting month provides the energy needed to realise that potential.

Table 6a. Internodal length at 30 and 60 DAT as influenced by varieties and planting months.

Internodal length (cm)												
Varieties (V)	Month (M)											
	30 DAT						60 DAT					
	M ₁	M ₂	M ₃	M ₄	M ₅	Mean V	M ₁	M ₂	M ₃	M ₄	M ₅	Mean V
V ₁	1.94	1.89	1.88	1.85	1.79	1.87	2.21	2.19	2.15	2.08	2.06	2.13
V ₂	1.98	1.96	1.89	1.92	1.84	1.91	2.26	2.16	2.12	2.13	2.08	2.15
V ₃	1.91	1.89	1.86	1.82	1.79	1.85	2.21	2.10	2.09	2.06	2.02	2.09
V ₄	2.13	1.97	1.96	1.92	1.87	1.97	2.41	2.25	2.24	2.16	2.11	2.23
V ₅	1.92	1.80	1.84	1.79	1.41	1.75	2.12	2.10	2.04	2.00	1.75	2.00
Mean M	1.98	1.90	1.88	1.86	1.74		2.24	2.15	2.12	2.08	2.00	
For comparing means of			S.Em±		C.D @ 5%		S.Em±			C.D @ 5%		
Varieties (V)			0.02		0.06		0.02			0.05		
Months (M)			0.02		0.06		0.02			0.05		
M × V			0.05		0.14		0.03			0.10		
Varieties (V): Champagne Yellow (V ₁); Artic Queen White (V ₂); Lollipop Pink (V ₃); Bright Orange (V ₄); Bright White (V ₅)												
Months (M): August (M ₁); September (M ₂); October (M ₃); November (M ₄); December (M ₅)												
DAT: Days after transplanting												

Table 6b. Internodal length at 90 and 120 DAT as influenced by varieties and planting months.

Internodal length (cm)												
Varieties (V)	Month (M)											
	90 DAT						120 DAT					
	M ₁	M ₂	M ₃	M ₄	M ₅	Mean V	M ₁	M ₂	M ₃	M ₄	M ₅	Mean V
V ₁	2.42	2.43	2.36	2.31	2.28	2.36	2.78	2.73	2.67	2.62	2.59	2.67
V ₂	2.50	2.46	2.42	2.39	2.32	2.42	2.91	2.81	2.73	2.70	2.68	2.77
V ₃	2.43	2.37	2.33	2.26	2.24	2.32	2.81	2.70	2.64	2.61	2.56	2.66
V ₄	2.88	2.47	2.35	2.38	2.32	2.48	2.97	2.88	2.85	2.81	2.71	2.84
V ₅	2.37	2.28	2.27	2.19	2.10	2.24	2.71	2.62	2.60	2.50	2.15	2.51
Mean M	2.52	2.40	2.35	2.30	2.25		2.83	2.75	2.70	2.65	2.54	
For comparing means of			S.Em±		C.D @ 5%		S.Em±			C.D @ 5%		
Varieties (V)			0.02		0.06		0.02			0.05		
Months (M)			0.02		0.06		0.02			0.05		
M × V			0.05		0.13		0.04			0.12		
Varieties (V): Champagne Yellow (V ₁); Artic Queen White (V ₂); Lollipop Pink (V ₃); Bright Orange (V ₄); Bright White (V ₅)												
Months (M): August (M ₁); September (M ₂); October (M ₃); November (M ₄); December (M ₅)												
DAT: Days after transplanting												

Physiological Parameters

Leaf area (cm²)

Significant differences in leaf area were observed across varieties. Bright Orange (V₄) recorded the maximum leaf area (2226.44 cm²), attributed to its naturally superior vigour and effective energy translocation (Halevy and Mayak, 1981; Beniwal *et al.*, 2021) [4, 10]. Artic Queen White (V₂) followed with 2067.73 cm², while Bright White (V₅) recorded the minimum (1788.55 cm²), reflecting its inherent

tendency towards compact growth. August planting (M₁) produced the largest leaf area (2229.21 cm²) as the long days and warm weather provided the perfect mix for leaf expansion before flowering initiation (Singh and Arora, 2009) [35]. Later planting months showed progressive reductions September (M₂) at 2080.95 cm² and December (M₅) at 1887.52 cm² as colder, shorter days slowed metabolism and prevented full leaf expansion (Sujatha *et al.*, 2023) [39]. The M₁V₄ interaction combination displayed the

maximum leaf area (2673.68 cm²), followed by M₁V₂ (2335.13 cm²), confirming that a vigorous variety performs best under favourable environmental conditions (Wilkins and Dodson, 1985) [47]. The minimum was recorded in M₅V₅ (1621.63 cm²), as a less vigorous variety was exposed to unfavourable winter conditions (Khan and Qureshi, 2017; Srivastava *et al.*, 2022) [12, 38].

Leaf Area Index (LAI)

Significant variation in LAI was observed among varieties. Bright Orange (V₄) recorded the maximum LAI of 1.62,

indicating its natural superiority in building a thick canopy that captures more sunlight, followed by Artic Queen White (V₂) with 1.54 (Beniwal *et al.*, 2021) [4]. Bright White (V₅) recorded the least LAI (1.35), reflecting its compact plant architecture (Sujatha *et al.*, 2023) [39].

August planting (M₁) yielded the maximum LAI (1.72) as the planting date gave adequate good-weather days for leaf development before flowering (Singh and Arora, 2009) [35]. December planting (M₅) showed the lowest LAI (1.30), as shorter days and colder weather signalled the plant to slow down leaf growth.

Table 7. Leaf area and Leaf area index as influenced by varieties and planting months.

Varieties (V)	Month (M)											
	Leaf area (cm)						Leaf area index					
	M ₁	M ₂	M ₃	M ₄	M ₅	Mean V	M ₁	M ₂	M ₃	M ₄	M ₅	Mean V
V ₁	2185.01	2085.75	2110.29	1902.95	1863.61	1990.65	1.69	1.52	1.54	1.41	1.40	1.51
V ₂	2335.13	2167.85	2051.33	2016.68	2035.07	2067.73	1.76	1.56	1.58	1.43	1.38	1.54
V ₃	2075.65	1963.53	1918.21	1904.81	1775.33	1890.47	1.61	1.49	1.45	1.42	1.32	1.46
V ₄	2673.68	2278.81	2270.78	2214.20	2141.99	2226.44	1.96	1.65	1.61	1.53	1.37	1.62
V ₅	187657	1908.84	1868.76	1754.96	1621.63	1788.55	1.60	1.47	1.37	1.29	1.04	1.35
Mean M	2229.21	2080.95	2043.87	1958.72	1887.52		1.72	1.54	1.51	1.41	1.30	
For comparing means of			S.Em±		C.D @ 5%		S.Em±			C.D @ 5%		
Varieties (V)			0.02		0.06		0.02			0.05		
Months (M)			0.02		0.06		0.02			0.05		
M × V			0.05		0.13		0.04			0.12		
Varieties (V): Champagne Yellow (V ₁); Artic Queen White (V ₂); Lollipop Pink (V ₃); Bright Orange (V ₄); Bright White (V ₅)												
Months (M): August (M ₁); September (M ₂); October (M ₃); November (M ₄); December (M ₅)												
DAT: Days after transplanting												

The M₁V₄ combination achieved the maximum LAI of 1.96, followed by M₁V₂ with 1.76 (Wilkins and Dodson, 1985) [47]. The M₅V₅ combination recorded the minimum LAI of 1.04, demonstrating how a less vigorous variety is further constrained by poor winter growing conditions (Khan and Qureshi, 2017) [12].

Crop growth rate 45 to 75 dap (g m⁻² day⁻¹)

Significant differences in CGR were observed among varieties. Bright Orange (V₄) recorded the highest CGR of 8.71 g m⁻² day⁻¹, reflecting superior biomass accumulation efficiency, followed by Artic Queen White (V₂) with 8.39 g m⁻² day⁻¹ and Champagne Yellow (V₁) with 8.23 g m⁻² day⁻¹. Bright White (V₅) recorded the minimum CGR (7.11 g m⁻² day⁻¹), attributable to its compact growth habit and lower assimilation efficiency (Ratika *et al.*, 2025).

August planting (M₁) recorded the highest CGR (9.21 g m⁻² day⁻¹) due to favourable temperature and sunlight availability during the 45-75 DAP period supporting better crop growth, consistent with Yumkhaibam *et al.* (2023) [50]. December planting (M₅) showed the lowest CGR (6.94 g m⁻² day⁻¹) due to reduced day length and lower temperatures limiting photosynthesis.

The M₁V₄ treatment reached a maximum CGR of 10.01 g m⁻² day⁻¹, demonstrating that the genetic potential of a variety is only fully unlocked when synchronised with the ideal environment (Swaroop *et al.*, 2025) [42]. Conversely, M₅V₅ recorded the minimum (5.14 g m⁻² day⁻¹), illustrating a double-stress scenario where low varietal vigour was further inhibited by sub-optimal December conditions (Zhou *et al.*, 2025) [25].

Table 8. Crop growth rate and Relative growth rate as influenced by varieties and planting months.

Varieties (V)	Month (M)												
	Crop growth rate (g m ⁻² day ⁻¹)						Relative growth rate (g g ⁻¹ × 10 ⁻²)						
	M ₁	M ₂	M ₃	M ₄	M ₅	Mean V	M ₁	M ₂	M ₃	M ₄	M ₅	Mean V	
V ₁	9.39	8.63	8.10	7.76	7.28	8.23	1.66	1.68	1.58	1.67	1.57	1.63	
V ₂	9.62	8.92	8.18	7.71	7.51	8.39	1.93	1.69	1.85	1.78	1.64	1.78	
V ₃	8.85	8.26	7.95	7.39	7.15	7.92	1.54	1.57	1.46	1.23	1.32	1.42	
V ₄	10.01	9.26	8.51	8.14	7.63	8.71	1.96	1.91	1.83	1.85	1.82	1.87	
V ₅	8.18	7.79	7.45	7.05	5.14	7.11	1.25	1.36	1.41	1.13	1.05	1.24	
Mean M	9.21	8.57	8.03	7.61	6.94		1.67	1.64	1.62	1.53	1.48		
For comparing means of			S.Em±		C.D @ 5%			S.Em±			C.D @ 5%		
Varieties (V)			0.08		0.23			0.02			0.05		
Months (M)			0.08		0.23			0.02			0.05		
M × V			0.18		0.52			0.04			0.11		
Varieties (V): Champagne Yellow (V ₁); Artic Queen White (V ₂); Lollipop Pink (V ₃); Bright Orange (V ₄); Bright White (V ₅)													
Months (M): August (M ₁); September (M ₂); October (M ₃); November (M ₄); December (M ₅)													
DAT: Days after transplanting													

Relative Growth Rate 45 to 75 DAP ($\text{g g}^{-1} \times 10^{-2}$)

Significant differences in RGR were observed among varieties. Bright Orange (V_4) led with $1.87 \text{ g g}^{-1} \times 10^{-2}$, indicating its superior efficiency in reinvesting energy into new growth (Verma and Singh, 2024) [46]. Artic Queen White (V_2) followed with $1.78 \text{ g g}^{-1} \times 10^{-2}$, while Bright White (V_5) recorded the minimum RGR ($1.24 \text{ g g}^{-1} \times 10^{-2}$), suggesting a slower internal growth mechanism and lower assimilation efficiency (Mishra *et al.*, 2025) [19].

August planting (M_1) recorded the highest growth efficiency ($1.67 \text{ g g}^{-1} \times 10^{-2}$), attributable to favourable climatic conditions during late summer that supported sustained plant growth through accumulation of additional heat units (Prakash and Fatmi, 2023) [23]. December planting (M_5) showed the lowest efficiency ($1.48 \text{ g g}^{-1} \times 10^{-2}$), as low winter temperatures reduced nutrient movement within plants and limited biomass accumulation relative to plant size (Thakur, 2022) [43]. The M_1V_4 combination was the most efficient, recording a peak RGR of $1.96 \text{ g g}^{-1} \times 10^{-2}$, confirming that matching a fast-growing variety with optimal seasonal conditions further amplifies growth efficiency (Reddy and Gupta, 2025) [28]. The M_5V_5 treatment recorded the minimum RGR ($1.05 \text{ g g}^{-1} \times 10^{-2}$), demonstrating that a naturally slower variety is further constrained by the short, cold days of winter (Sharma *et al.*, 2018) [34].

Conclusion

The present investigation clearly demonstrates that both varietal selection and planting time are critical factors influencing the growth and physiological performance of cut *Chrysanthemum* under open field conditions in the Northern Dry Zone of Karnataka. Among the varieties evaluated, Bright Orange (V_4) exhibited superior performance across all growth parameters, including plant height, plant spread, number of primary branches, stem girth and internodal length, as well as physiological traits such as leaf area, leaf area index, crop growth rate and relative growth rate, which may be attributed to its strong genetic potential, higher photosynthetic efficiency and better assimilate translocation. With respect to planting time, August (M_1) was found to be the most favourable, promoting maximum vegetative growth and physiological efficiency due to optimal photoperiod, temperature and moisture conditions, whereas December (M_5) resulted in the poorest performance owing to unfavourable low temperature and short-day conditions. The interaction effect further revealed that the combination of August planting with Bright Orange (M_1V_4) produced the highest values for all observed traits, indicating that the full potential of a variety is realized only under suitable environmental conditions, while December planting with Bright White (M_5V_5) recorded the lowest performance. Overall, the study highlights the importance of genotype $\times$ environment interaction in *Chrysanthemum* cultivation and recommends planting Bright Orange in August to achieve enhanced growth, physiological efficiency and overall crop vigour in this agro-climatic region, while suggesting further research on flowering, yield and economic aspects for comprehensive recommendations.

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