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Variation in vegetative phenological traits among teak (*Tectona grandis* L.) genotypes in a clonal seed orchard

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Abstract
Teak (*Tectona grandis* L.) is a valuable tropical timber species known for its durability, strength, and economic significance. Clonal seed orchards (CSOs) are crucial for improving genetic gain and seed quality. However, phenological variation among clones influences synchronization and productivity. This study evaluated vegetative phenophases and genetic parameters among teak clones in a 45-year-old CSO at Karka, Karnataka. Fifteen teak clones representing northern, central, and southern provenances were assessed for leaf shedding initiation, leafless period, and leaf flushing traits through fortnightly observations from May 2024 to April 2025. Results revealed significant clonal differences across all vegetative phenophases. Northern clones exhibited delayed leaf shedding and prolonged dormancy, whereas southern and central clones showed earlier leaf flushing and shorter leafless periods, reflecting adaptation to local climatic conditions. Genetic analysis indicated high heritability and genetic gain for leaf flushing initiation (78.04%, 52.66%) and duration (73.23%, 27.16%), suggesting strong genetic control. Schematic phenograms illustrated temporal variation among clones, confirming distinct growth rhythms and genotype-specific responses to environmental cues. Vegetative phenology in teak is predominantly genotype-governed with moderate environmental influence. Traits such as leaf flushing initiation and duration are reliable for selecting superior clones with synchronized growth and enhanced adaptability, supporting effective teak improvement and sustainable orchard management.

Keywords: CSO, clone, phenology, synchrony, teak

Introduction
Teak (*Tectona grandis* L.) is one of the most valuable tropical timber species, widely recognized for its strength, durability, and high economic importance. The First teak plantation in India was established in Kerala during 1844 in Nilambur known as Connolly's Plot, this historic plantation spans 2.31 hectares and retains 117 surviving trees (Nagarajan *et al*., 2010) [8]. Currently, the teak plantations exist around 1.5 million hectares in India, and around 50,000 hectares of teak plantations are established annually (Sreekanth and Balasundaran, 2013) [9]. In India, teak occurs naturally across several states and has been extensively planted for over a century, with clonal seed orchards (CSO's) established to enhance genetic gain and improve seed quality However, variations in growth and reproduction among clones often arise due to differences in their phenological behavior.

Phenology, which deals with the timing of periodic biological events, is crucial in understanding growth rhythm, ecological adaptability, and reproductive efficiency in tree species. In teak, vegetative phenophases such as leaf shedding, leafless period, and leaf flushing are influenced by both genetic and environmental factors. Clonal variation in these traits can affect synchronization of flowering and seed production in CSO's, impacting overall productivity. The present study was carried out in a 45-year old clonal seed orchard to assess clonal differences in vegetative phenophases and estimate genetic parameters such as variability, heritability, and genetic gain, to identify superior genotypes with synchronized growth and better adaptability under Karnataka conditions.

Materials and Methods

The present study was carried out in teak CSO, Karka. It was established in the year 1980 by the Karnataka Forest Department in the Haliyal division (Fig. 1). The planting was done adopting a Randomized Complete Block Design (RCBD) with unequal replications over an area of 4 ha. CSO comprises 24 teak clones that were originally selected for their superior phenotypic traits from different provenances across Karnataka. For the purpose of this study and to facilitate statistical interpretation, 15 clones were considered. These were evaluated in three replications, each replication consisting of five trees, amounting to a total of 225 trees studied.

The details of CSO with respect to origin of the plus tree along with their geographic location and the location of the teak orchard is shown in the Fig.1. Details of the clones considered for the study are represented in Table 1.

Table 1: Details of clones considered for the study in teak CSO Karka

Sl. No.	Clonal I. D	Number of ramets	Geographical zones	Origin of the clone	
				Range	Division
1	MyHAD1	26	Northern	Barchi	Haliyala
2	MyHAD2	26	Northern	Barchi	Haliyala
3	MyHAD3	26	Northern	Barchi	Haliyala
4	MyHAD4	26	Northern	Barchi	Haliyala
5	MyHAV3	24	Northern	Gundvamoli	Haliyala
6	MyHAV5	26	Northern	Virnoli	Haliyala
7	MyHAV6	26	Northern	Virnoli	Haliyala
8	MyHAV7	17	Northern	Virnoli	Haliyala
9	MySA1	26	Central	Arasake	Shimoga
10	MySA2	26	Central	Arasake	Shimoga
11	MySS1	26	Central	Sacrebyle	Shimoga
12	MySS2	26	Central	Sacrebyle	Shimoga
13	MyHUT1	26	Southern	Thithimathi	Shimoga
14	MyHUT2	25	Southern	Thithimathi	Shimoga
15	MyHUT7	26	Southern	Thithimathi	Shimoga

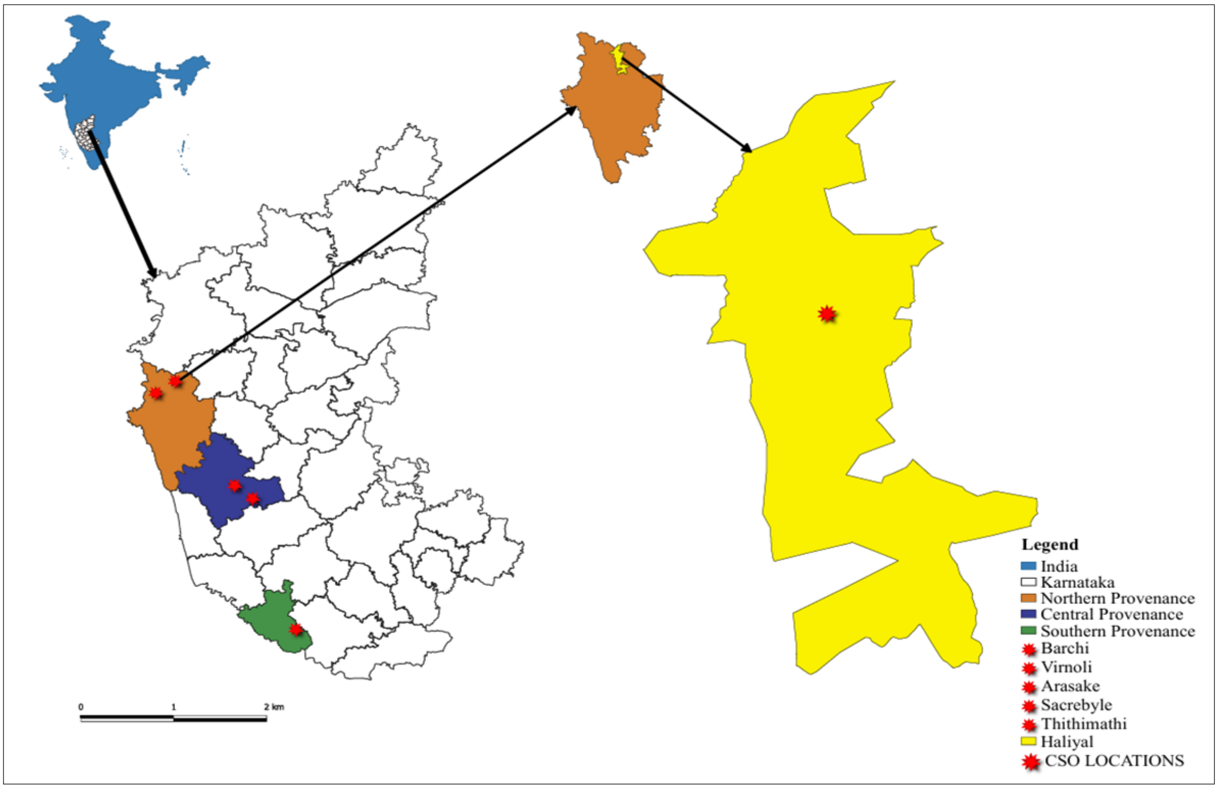

Fig 1: Map showing the origin of plus trees from which clones were derived across three geographic zones of Karnataka, and the location of teak CSO, Karka, Uttara Kannada, Karnataka

Phenological observation such as time of leaf shedding initiation (The initiation of leaf shedding was determined by calculating the number of days from 1st January to the date of the first appearance of leaf fall for each tree as suggested by Matziris (1994)) [7], leafless period (The duration during which a tree remained completely without leaves was considered the leafless period. This was calculated as the number of days between the completion of leaf shedding and the onset of new leaf flush), time of leaf flushing initiation (The initiation of leaf flush was recorded as the number of days from January 1st to the first visible appearance of new leaves on each tree) and leaf flushing duration (The leaf flushing period refers to the duration, in days, from the first visible emergence of new leaves to the point when the tree has fully developed and expanded its entire canopy of leaves) were recorded by visiting CSO at every fortnight intervals from May 2024 to April 2025.

Further, the data in the form of score was processed and further subjected to statistical analysis The average time of initiation for leaf flushing, and leaf shedding were calculated. Additionally, the average durations for leaf flushing, and leaf shedding was also determined.

Table 2: Details of the scores given for each phenological event in teak CSO, Karka

Score used	Phenological events	
	Leaf shedding	Leaf flushing
0	No event	No event
1	1-25%	1-25%
2	25-50%	25-50%
3	50-75%	50-75%
4	>75%	>75%

Note: Percentage value refers to percent of crown of each tree having these events.

The phenotypic coefficient of variation (PCV) and the genotypic coefficient of variation was calculated by using the formula given by Burton and Devane (1953) [2].

$$PCV\ (\%) = \frac{\sqrt{\sigma^2 p}}{\bar{X}} \times 100$$

Where, $\bar{X}$ = Population mean for each trait and $\sigma^2 p$ = Phenotypic variance.

$$GCV\ (\%) = \frac{\sqrt{\sigma^2 g}}{\bar{X}} \times 100$$

Where, $\bar{X}$ = Population mean for each trait and $\sigma^2 g$ = Genotypic variance.

Heritability was assessed following the method suggested by Matziris (1994) [7].

$$GA\ (\text{as \% of mean}) = \frac{GA}{Mean} \times 100$$

Below 10%: Low
10 - 20%: Moderate
Above 20%: High

Results and Discussion

The initiation of leaf shedding among teak clones exhibited significant clonal variation (Table 3). The initiation ranged between 315 to 375 days from 1st January 2024, with an overall mean of 339 days. Early initiation of leaf fall was observed in clones such as MyHaD1, MyHaD4, MyHaV5, and MyHuT2 (around 330 days), whereas the late initiation occurred in clone MyHaV7 (375 days) from the northern zone.

Teak, being a deciduous species, sheds leaves during the dry season as a water-conservation strategy. The observed variation among clones can be attributed to their genetic constitution and the environmental conditions of their provenance. Clones derived from northern origins such as Dandeli and Virnoli displayed relatively delayed leaf fall, likely reflecting adaptation to a longer wet season in their native regions. In contrast, early shedding by certain southern and central clones suggests adaptation to earlier onset of dry conditions.

Similar observations were made by Behera *et al.* (2015) [1] in a 33-year-old teak clonal seed orchard in Odisha, where peak leaf shedding occurred during January, varying from the first to last week among clones. Early-shedding genotypes (ORANP3, ORANP4, ORANP7, and ORANR2) were found to cease physiological activity earlier with the onset of cooler conditions, confirming that leaf fall timing is primarily genotype-driven. The congruence between the present study and theirs indicates that genetic makeup and provenance-origin strongly regulate leaf abscission timing in teak, while environmental factors such as temperature and rainfall play a modifying role. These results are also consistent with Gunaga (2000) [4] and Gunaga and Vasudeva (2005) [3], who observed similar provenance-based differences in leaf fall timing across Karnataka seed orchards. The variation seen in this study thus highlights teak's adaptive diversity, where clonal behavior continues to reflect the ecological patterns of their source populations even under uniform orchard conditions.

The duration of the leafless period among clones ranged between 15 to 75 days, with an overall mean of 26.57 days (Table 4). Clone MyHaV6 from Virnoli (northern zone) exhibited the shortest leafless period (18.75 days), while MyHaD4 from Dandeli recorded the longest (39 days). On an individual ramet basis, the maximum duration of 75 days was noted in MySA2 (Arasake) and MySS1 (Sacrebyle) from the central zone. The overall duration of the leafless phase among clones ranged from the 3rd week of February to the end of April (Fig. 2).

The leafless phase represents a physiological dormancy period in teak, during which the tree conserves resources before the onset of new leaf flush. Differences in leafless duration among clones may indicate differential adaptation to drought stress or microclimatic conditions of their provenance. Shorter leafless periods observed in clones like MyHaV6 and MyHaV3 may be attributed to their origin in humid or semi-moist areas, where higher soil moisture and atmospheric humidity support faster canopy renewal. Interestingly, clones from the central zone exhibited a longer duration of leaflessness, extending from 2nd week of February to 4th week of April (Fig. 2), suggests adaptation to relatively drier environments, delaying bud break until favorable conditions return. Gunaga (2000) [4] reported a maximum leafless duration of 28 days in northern zone clones, while the current study recorded a longer average, likely due to recent climatic variability, including erratic rainfall and prolonged dry spells. The findings reaffirm earlier observations by Gunaga and Vasudeva (2005) [3] and Surendra (2012) [10], who concluded that local climatic cues, especially temperature and moisture availability, significantly influence the dormancy and reactivation phases in teak.

Leaf flush initiation varied significantly among the teak clones in CSO, Karka (Table 5). The initiation occurred between 9 and 114 days from 1st January 2025, with an average of 65.27 days. The earliest leaf flushing was observed in clones MyHaV3 (Gundvamoli) and MyHaV6 (Virnoli) at 42 days, followed by MySS2 (Sacrebyle) at 43 days. Conversely, Dandeli clones MyHaD4 and MyHaD2 exhibited the latest flushing, at 103 and 97 days respectively. The coefficient of variation (15.42%) indicated moderate variability for this phenological phase.

The timing of leaf flush is a vital ecological and physiological event, marking the transition from dormancy to active growth. The wide range in flushing initiation observed among clones suggests genotypic control influenced by climatic factors such as temperature and rainfall. Early flushing observed in clones from the central and southern zones indicates adaptation to early onset of pre-monsoon showers and relatively higher humidity in their native regions. In contrast, the delayed flushing of northern zone clones may reflect adaptation to longer dry spells and late moisture availability.

The present findings align with those of Behera *et al*. (2015) [1], who reported that leaf renewal in teak clones generally occurred in May, varying from the first to last week among provenances in Odisha. They attributed this variation to genetic factors controlling vegetative bud initiation in response to rising temperature and pre-monsoon onset. Compared with their findings, the earlier flushing period (late January to April) observed in Karka may be due to differences in regional climate—particularly the influence of the Western Ghats' monsoon gradient—indicating that teak clones retain genetic control of phenology but express it differently under local climatic cues. The flushing behavior observed here also corroborates earlier reports by Gunaga (2000) [4] and Surendra (2012) [10], who found that temperature, humidity, and soil moisture substantially influence the initiation of new leaf flush. Together, these studies confirm that while teak's vegetative phenology is environmentally responsive, the genetic foundation of leaf flushing remains strong and provenance-specific, offering opportunities for selection and synchronization in breeding programs.

Significant variation was observed in the duration of leaf flushing among teak clones, with the overall range extending from 30 to 90 days and a mean duration of 62.80 days (Table 6). The shortest duration was recorded in clone MyHaD4 (41 days), followed by MyHaD2 (45 days), both from the Dandeli provenance, while the longest period was seen in clone MyHaV7 (75 days) from the Virnoli provenance. The overall period of leaf emergence in the CSO, Karka spanned from the 3rd week of January to the 4th week of May (Fig. 3)

Leaf flushing duration reflects both genetic potential for canopy development and environmental influences that regulate photosynthetic recovery after dormancy. Clones with shorter flushing periods, such as those from Dandeli, may be genetically predisposed to rapid canopy restoration in response to brief favorable conditions, while clones from Virnoli and Gundvamoli with extended flushing durations may represent genotypes adapted to prolonged humid conditions that support gradual leaf expansion. These differences in leaf development strategies are consistent with the findings of Gunaga and Vasudeva (2005) [3], who reported that northern provenance clones tend to exhibit a shorter leaf expansion phase compared to central and southern counterparts.

Among the traits, the leafless period (GCV = 2.36%) and leaf flushing duration (GCV = 1.36%) showed higher genotypic variability than leaf shedding initiation (GCV = 0.27%) (Table 7), indicating greater potential for selection. The PCV was highest in leaf flushing (32.92%), followed by the leafless period (25.76%), suggesting wide phenotypic expression, while leaf shedding initiation exhibited low PCV (3.46%), implying uniformity across clones. Leaf shedding initiation recorded the highest heritability (86.09%) with low PCV, reflecting strong genetic control and minimal environmental influence. In contrast, the leafless period showed moderate heritability (39.26%) and high PCV, indicating greater environmental impact. Both leaf flushing initiation (78.04%) and leaf flushing duration (73.23%) exhibited high heritability coupled with high genetic gain (52.66% and 27.16%), highlighting their importance for selection and synchronization of vegetative phenology.

Similar findings were reported by Gunaga and Vasudeva (2005) [3] and Surendra (2012) [10], who confirmed that although environmental factors influence the timing of phenological events, traits such as leaf flush initiation and leaf flushing duration are predominantly under genetic control, making them reliable criteria for teak improvement. Behera *et al*. (2015) [1] also observed comparable trends, reporting high heritability (> 90%) for phenological and reproductive traits; including leaf shedding and leaf renewal in a 33-year-old teak clonal orchard in Odisha. Their study demonstrated that teak phenological traits are genetically governed yet environmentally modulated, with high heritability and moderate genetic advance indicating strong genetic control coupled with adaptive flexibility. In line with these observations, Gunaga *et al*. (2012) [15] reported high broad-sense heritability for vegetative traits such as leaf flush initiation and leaf flushing duration, along with moderate to high genetic gain, suggesting substantial additive genetic variance and confirming that these traits are largely genetically determined. Collectively, these findings indicate that teak exhibits genotype-specific phenological rhythms, and that traits like leaf flush initiation and leaf flushing duration can serve as reliable selection indices for identifying superior clones with synchronized growth and improved adaptability to diverse climatic conditions.

Table 3: Clonal variation for leaf shedding initiation in teak CSO, Karka (expressed as number of days from 1st January 2024)

Clone I. D	Geographical zone	Range		Mean
		Min	Max	
MyHaD1	NORTHERN	330	345	330.00
MyHaD2		330	375	341.00
MyHaD3		330	375	346.00
MyHaD4		315	345	330.00
MyHaV3		330	375	336.00
MyHaV5		315	345	330.00
MyHaV6		315	345	332.00
MyHaV7		375	375	375.00
MySA1	CENTRAL	330	345	340.00
MySA2		330	375	337.00
MySS1		330	345	341.00
MySS2		315	375	337.00
MyHuT1	SOUTHERN	330	345	340.00
MyHuT2		315	345	330.00
MyHuT7		330	375	340.00
Mean		315	375	339.00
C.V. (%)		1.29		
SEm±		2.52		
C.D @ 5%		7.35		

Table 4: Clonal variation for duration of leaf less period (days) in teak CSO, Karka

Clone I. D	Geographical zone	Range		Mean
		Min	Max	
MyHaD1	NORTHERN	15	45	30.00
MyHaD2		15	45	32.00
MyHaD3		15	45	28.00
MyHaD4		30	60	39.00
MyHaV3		15	30	19.17
MyHaV5		15	30	23.33
MyHaV6		15	30	18.75
MyHaV7		15	60	23.25
MySA1	CENTRAL	15	30	25.42
MySA2		15	75	25.83
MySS1		15	75	28.58
MySS2		15	45	27.67
MyHuT1	SOUTHERN	15	60	31.00
MyHuT2		15	45	21.50
MyHuT7		15	30	25.00
Mean		15	75	26.57
C.V. (%)		20.07		
SEm±		3.07		
C.D @ 5%		8.96		

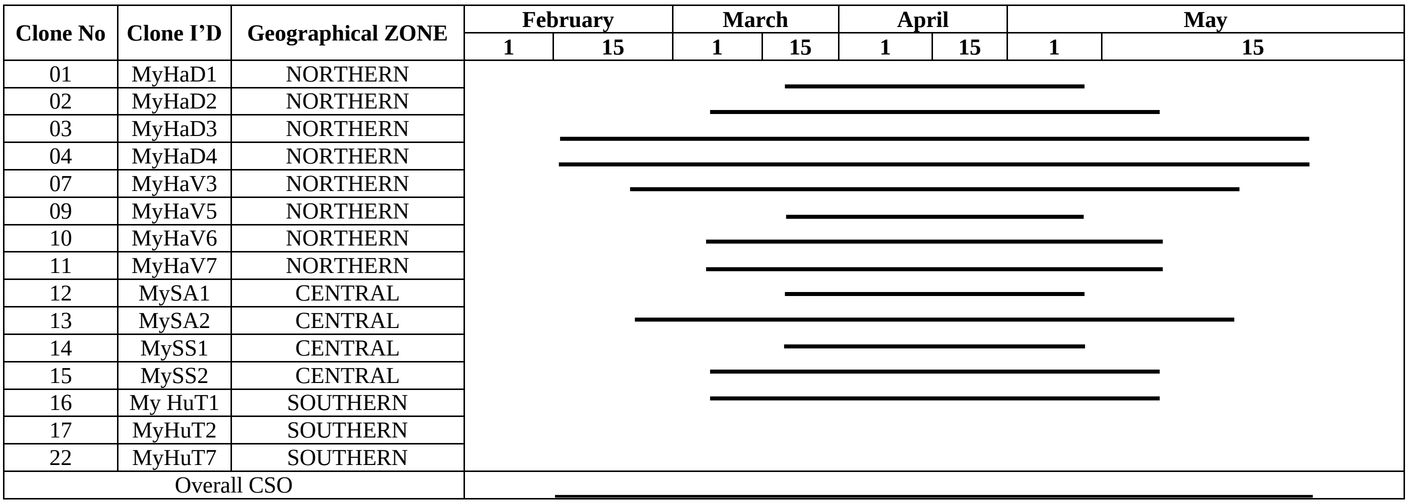

Fig 2: Phenogram showing clonal variation for leafless period in teak CSO, Karka 2024-25

Table 5: Clonal variation for leaf flushing initiation in teak CSO, Karka (expressed as number of days from 1st January 2025)

Clone I. D	Geographical zone	Range		Mean
		Min	Max	
MyHaD1	NORTHERN	24	99	86.00
MyHaD2		39	114	97.00
MyHaD3		39	114	86.00
MyHaD4		99	114	103.00
MyHaV3		9	99	42.00
MyHaV5		39	99	57.00
MyHaV6		9	99	42.00
MyHaV7		54	99	69.00
MySA1	CENTRAL	39	69	61.00
MySA2		39	99	57.00
MySS1		39	114	64.00
MySS2		9	99	43.00
MyHuT1	SOUTHERN	39	99	69.00
MyHuT2		39	99	58.00
MyHuT7		9	99	45.00
Mean		9	114	65.27
C.V. (%)		15.42		
SEm		5.81		
C.D @ 5%		16.92		

Table 6: Clonal variation for duration of leaf flushing period (days) in teak CSO, Karka

Clone I. D	Geographical zone	Range		Mean
		Min	Max	
MyHaD1	NORTHERN	45	45	51.00
MyHaD2		30	75	45.00
MyHaD3		30	75	52.00
MyHaD4		30	45	41.00
MyHaV3		45	90	67.00
MyHaV5		45	90	72.00
MyHaV6		45	90	69.00
MyHaV7		45	90	75.00
MySA1	CENTRAL	45	90	69.00
MySA2		45	90	67.00
MySS1		30	90	66.00
MySS2		45	90	68.00
MyHuT1	SOUTHERN	45	90	65.00
MyHuT2		45	90	66.00
MyHuT7		45	75	69.00
Mean		30	90	62.80
C.V. (%)		9.35		
SEm±		3.39		
C.D @ 5%		9.88		

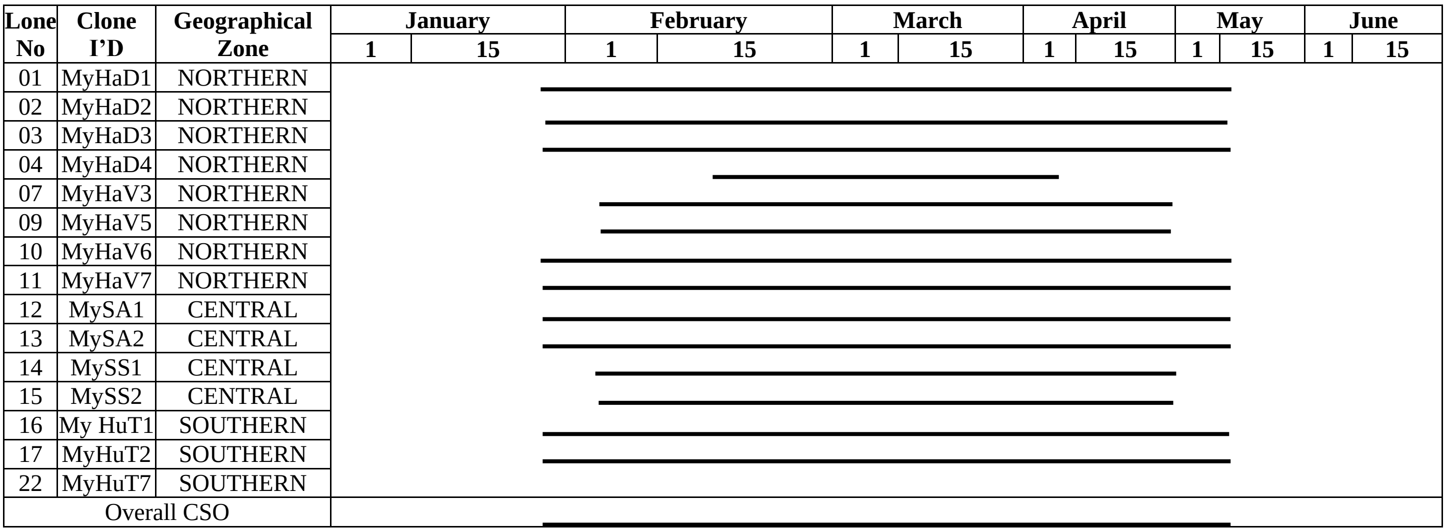

Fig 3: Phenogram showing clonal variation for Leaf flushing duration in teak CSO, Karka 2025

Table 7: Estimation of genetic variability, heritability and genetic gain for vegetative trait in teak

Parameters	Mean	Genotypic variance	Phenotypic variance	PCV	GCV	Heritability Broad sense	GA	Genetic Gain (%)
Leaf shedding initiation	339	0.838	137.58	3.46	0.27	0.8609	20.691	6.10
Leafless period	26.57	0.393	46.85	25.76	2.36	0.3926	5.508	20.73
Leaf flushing	65.27	0.776	461.69	32.92	1.35	0.7804	34.374	52.66
Leaf flushing duration	62.8	0.729	129.06	18.09	1.36	0.7323	17.054	27.16

Conclusion

The study revealed significant clonal variation in all vegetative phenophases of teak under uniform orchard conditions, demonstrating that phenological behavior is strongly influenced by genetic factors with a secondary effect of environment. Clones from the northern zone exhibited delayed leaf shedding and extended dormancy, while those from the central and southern zones showed earlier leaf flushing and shorter leafless periods, reflecting provenance-based adaptation. High heritability and moderate to high genetic gain for traits such as leaf flushing initiation and leaf flushing duration indicate their strong genetic control and suitability as reliable selection criteria. Overall, the results highlight that vegetative phenophases in teak are genotype-specific, environmentally responsive, and offer valuable parameters for identifying superior clones with synchronized growth and improved adaptability under changing climatic conditions.

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