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Phenological Characterization of Mango (*Mangifera indica* L.) Cv. Ratna

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Abstract— *The present investigation was conducted during 2024–25 and 2025–26 at Department of Fruit Science, College of Horticulture, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Maharashtra, to characterize the phenological growth stages of mango (Mangifera indica L.) cv. Ratna using BBCH scale and to assess the influence of different physico-chemical interventions on the advancement of vegetative and flowering phenology. Uniform, healthy and true-to-type 40-year-old Ratna mango trees were evaluated under eight treatments arranged in a randomized block design with three replications and four trees per treatment. Post-harvest pruning was common to treatments T_1 to T_7, while T_8 served as the untreated control. Phenological observations were recorded at weekly intervals for bud development (BBCH 010–019), leaf development (110–119), shoot development (311–319), inflorescence emergence (510–519), and flowering (610–631). The results demonstrated a pronounced advancement of phenological development in pruned trees compared with the unpruned control. Bud dormancy (BBCH 010) occurred approximately 25 to 27 days earlier in treated trees than in T_8, while bud break (019), leaf expansion (119), and shoot elongation (319) were also advanced substantially. Among the treatments, T_5, comprising post-harvest pruning followed by soil application of paclobutrazol, recorded the earliest transition to reproductive development. T_5 attained BBCH 510 on 14 November 2024 and 18 November 2025, whereas the control reached this stage on 22 December 2024 and 26 December 2025. Similarly, first flower opening (BBCH 610) occurred in T_5 on 28 December 2024 and 2 January 2026, compared with 26 January 2025 and 1 February 2026 in the control. Full flowering (BBCH 615) was reached in T_5 approximately 32 days earlier than the control in both years. The study demonstrated that the extended BBCH scale provided a systematic and reproducible framework for describing phenological transitions in Ratna mango under Konkan conditions. The combination of post-harvest pruning and paclobutrazol soil application produced the most pronounced advancement of flowering phenology, indicating the potential of phenology-based management for manipulating the flowering calendar of Ratna mango.*

Keywords— ***BBCH scale, mango, Ratna, phenology, pruning, paclobutrazol, flowering induction.***

I. INTRODUCTION

Mango (*Mangifera indica* L.) is one of the most significant tropical fruit crops and its productivity is closely associated with the timing and synchronization of vegetative and reproductive development. The transition from vegetative growth to reproductive development is influenced by cultivar, environmental conditions, tree architecture and nutritional status and management practices. Accurate characterization of these phenological events is therefore essential for developing appropriate orchard management strategies and for comparing crop development across environments.

The BBCH scale provides a standardized decimal coding system for describing crop phenology. It was initially developed as a generalized system for documenting growth stages of different crop species and was subsequently adapted for several perennial fruit crops. The system provides a sequential numerical description of developmental events, thereby permitting objective comparison among cultivars, locations, seasons and management practices.

In mango, the BBCH framework has been adapted to describe important stages of bud development, leaf emergence, shoot development, inflorescence development, flowering and fruit development. Hernandez *et al*. (2011) developed an extended BBCH scale for mango, while Rajan *et al.* (2011) subsequently applied the system for characterization of phenological development in mango cv. Totapuri under Indian conditions. However, systematic documentation of BBCH stages in mango cv. Ratna under the Konkan agroclimatic conditions of Maharashtra has been limited.

Ratna is an important mango hybrid developed from Neelam × Alphonso. It is characterized by regular bearing, high fruit set and freedom from spongy tissue; however, its harvest season extends considerably later than that of Alphonso. Consequently, manipulation of its phenological cycle, particularly advancement of flowering, has practical importance for developing an earlier production calendar.

Post-harvest pruning and other physico-chemical interventions can modify the vegetative growth cycle and potentially influence the subsequent reproductive phase. In the present investigation, different management practices were evaluated in combination with post-harvest pruning, while the extended BBCH scale was used to objectively characterize the progression of phenological stages.

Therefore, the present study was undertaken to characterize the vegetative and reproductive phenological development of mango cv. Ratna using the extended BBCH scale and to determine the extent to which different physico-chemical treatments could advance the transition from bud development to flowering under Konkan conditions.

II. MATERIALS AND METHODS

2.1 Experimental site

The investigation was conducted during 2024–25 and 2025–26 at the Department of Fruit Science, College of Horticulture, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, District Ratnagiri, Maharashtra. The experimental orchard was situated at approximately 17°75′ N latitude, 73°18′ E longitude and 168 m above mean sea level. The region is characterized by a warm and humid climate with substantial monsoon rainfall. During the two experimental years, the orchard experienced annual rainfall of approximately 4000–4400 mm and 4500–4900 mm, respectively.

2.2 Experimental material

Uniform, healthy and true-to-type 40-year-old mango trees of cv. Ratna planted at 5 × 5 m spacing was selected. The trees were uniform with respect to canopy size, growth vigour and previous yield history. Ratna is a hybrid developed through a cross between Neelam and Alphonso.

2.3 Experimental design and treatments

The experiment was conducted using a randomized block design comprising eight treatments, three replications and four trees per treatment, giving a total of 96 experimental trees.

The treatments were:

Treatment	Treatment details
T_1	Post-harvest pruning of shoots
T_2	T_1 + basin exposure during September and October
T_3	T_1 + girdling + tip pruning of tertiary branches
T_4	T_1 + tip pruning
T_5	T_1 + PBZ soil application
T_6	T_1 + PBZ 1000 ppm foliar application
T_7	T_1 + Ortho-phosphoric acid 1.0%
T_8	Control

Post-harvest pruning was the common basal treatment imposed on T1–T7. The treatments were applied according to the schedule specified in the experimental methodology.

2.4 Phenological observations

Phenological observations were recorded at weekly intervals on tagged shoots and were photographically documented. The extended BBCH scale was used to characterize the principal phenological stages. The stages considered in the present article were:

- BBCH 010–019: Bud development
- BBCH 110–119: Leaf development
- BBCH 311–319: Shoot development
- BBCH 510–519: Inflorescence emergence
- BBCH 610–631: Flowering

The BBCH observations followed the sequential developmental changes from quiescent buds through bud swelling, leaf unfolding, shoot elongation, inflorescence emergence and flowering.

III. RESULTS AND DISCUSSION

3.1 Bud development (BBCH 010–019)

Data regarding effect of different physico-chemical treatments on bud development in mango (*Mangifera indica* L.) Cv. Ratna is presented in Table 1. Bud dormancy (Stage 010) in cv. Ratna was first observed in pruned trees from 13th July (T_2) to 19th July (T_7) in Year (2024), and from 18th July (T_3) to 24th July (T_7) in Year 2025. In contrast, the untreated control T8 did not enter Stage 010 until 11th August 2024 and 15th August 2025, a delay of approximately 25 to 27 days over the pruned trees. This substantial difference in the onset of bud dormancy between pruned and unpruned trees might be due to post-harvest shoot pruning, which was the common base operation in all treatments T1 to T7. Pruning removes the apical dominance of the terminal shoot and redistributes assimilates toward the axillary buds, thereby triggering early entry into the dormancy-preparatory phase.

Bud break (Stage 019) was observed in pruned trees between 29th July to 2nd August 2024 (YI), and between 3rd August to 8th August 2025 (YII). T8 (control) reached Stage 019 only by 29th August 2024 and 2nd September 2025. The entire bud development stage (010 to 019) was completed in 13 to 22 days across pruned trees which is consistent with the 15 to 20-day bud development duration reported for cv. Totapuri at Lucknow by Rajan *et al*. (2011) during the August standard weeks (33 to 36). The Konkan location receives substantial monsoon rainfall during July to September, with temperatures in the range of 26 to 32°C, which provides warm and humid conditions conducive for rapid bud swelling and break.

3.2 Leaf Development (BBCH 110-119)

Data pertaining to effect of different physico-chemical treatments on leaf development in mango (*Mangifera indica* L.) Cv. Ratna is presented in Table 2. Leaf tips exceeding 10 mm above bud scales (Stage 110) were recorded in pruned trees between 30th July to 5th August 2024 (YI) and 5th to 9th August 2025 (YII). The unpruned control T_8 reached Stage 110 only by 31st August 2024 and 5th September 2025, representing a delay of approximately 26 to 27 days compared to the earliest treated plots. Complete leaf expansion (Stage 119) was achieved in pruned trees by 10th to 14th August 2024 (YI) and 17th to 18th August 2025 (YII), while T_8 completed leaf expansion only by 10th September 2024 and 14th September 2025.

The entire leaf development stage (110 to 119) was completed in 8 to 15 days across all treatments, consistent with the duration expected under warm monsoon conditions of Konkan where temperatures remain in the range of 27 to 32°C through August. This is comparable to the 8 to 15-day leaf development duration observed in the Konkan location in the multi-location study by Rajan *et al*. (2011), who documented that the high degree of variation in percentage of shoots at leaf development stages was attributed to the simultaneous transition of these stages during standard weeks 33 to 42.

3.3. Shoot Development (BBCH 311-319)

Data pertaining to shoot elongation in mango (*Mangifera indica* L.) Cv. Ratna after exposure of different physico-chemical treatments on is presented in Table 3. Shoot elongation (Stage 311, beginning of shoots growth at approximately 10 % of final length) commenced in pruned trees between 14th to 18th August 2024 (YI) and 20th to 22nd August 2025 (YII). The control T_8 showed Stage 311 only on 15th September 2024 and 17th September 2025, a delay of 28 to 30 days over the earliest treated plots. Full shoot elongation to approximately 90 % of final length (Stage 319) was completed in treated plots between 5th to 8th September 2024 (YI) and 8th to 12th September 2025 (YII), whereas T_8 completed Stage 319 only on 4th October 2024 and 6th October 2025.

The shoot development stage (311 to 319) was completed in 18 to 25 days across all treatments, within the expected 15 to 20-day range for this phenostages reported for mango under subtropical conditions. Rajan *et al*. (2011) observed that the longer and shorter duration between stages 010 and 319 during different parts of the year indicated slow and rapid growth periods, noting that shoot development occurred simultaneously with leaf development during standard weeks 33 to 42 in cv. Totapuri at Lucknow. In the Konkan region, where August

temperatures average 28 to 30°C with high humidity and active rainfall, shoot elongation proceeded rapidly generally completing within 20 to 22 days from Stage 311 to 319 in treated plots, confirming the temperature-driven rapid growth phase typical of the West Coast Ghat ecology.

3.4 Inflorescence emergence (BBCH 510–519)

Data pertaining to inflorescence emergence in mango (*Mangifera indica* L.) Cv. Ratna after exposure of different physico-chemical treatments on are presented in Table 3. The onset of inflorescence emergence (Stage 510, closed floral buds) marked the most critical phenological transition in the study. T5 (pruning + PBZ soil application) showed the earliest Stage 510 on 14th November 2024 (YI) and 18th November 2025 (YII), the earliest among all treatments across both years. T4 (pruning + tip pruning) followed on 18th November 2024 and 22nd November 2025, while T8 (control) showed Stage 510 only on 22nd December 2024 and 26th December 2025 a delay of 38 days over T5 this might be due to post-harvest pruning combined with gibberellin-inhibiting PBZ soil application advances the onset of floral bud dormancy by more than five weeks.

Bud burst initiating panicle development (Stage 513) was recorded in T5 on 27th November 2024 and 5th December 2025, while T8 reached Stage 513 only on 14th January 2025 and 2nd January 2026, a delay of approximately 28 to 48 days. Rajan *et al*. (2011) observed Stage 511 (initiation of inflorescence) in cv. Totapuri from standard week 3 (last week of January) at Lucknow, while Stage 513 began from standard week 4, significantly later than the November to December dates recorded for treated Ratna plants in the present study. This confirms the earlier phenological calendar of Konkan mango relative to the Lucknow subtropical ecology, likely due to the Konkan's earlier post-monsoon temperature decline (24 to 27°C by October-November) which serves as the cooling stimulus for mango floral induction at this West Coast location.

The inflorescence emergence stage (510 to 519) spanned 40 to 55 days in treated plots reflecting the extended panicle development period characteristic of Ratna mango's mixed panicle type. The earlier onset in T5 and T4 ensured completion of panicle development well ahead of the January cool-dry period when high flowering intensity is typically recorded in Konkan, providing a critical temperature window for pollen viability and insect visitation. Stage 515 (flowers visibly separated with secondary axes elongating) was completed in T5 by 8th December 2024 and 16th December 2025 while control T8 reached this stage only by 28th January 2025 and 12th January 2026. This seven-week difference in secondary axis elongation completion directly determines the time available for successful pollination and fruit set.

3.5 Flowering phenology (BBCH 610–619)

Data pertaining to flowering in mango (*Mangifera indica* L.) Cv. Ratna after exposure of different physico-chemical treatments are presented in Table 4. The first flower opening (Stage 610) was recorded in T5 on 28th December 2024 (YI) and 2nd January 2026 (YII) the earliest among all treatments across both years followed by T4 on 9th January 2025 and 15th January 2026. The untreated control T8 achieved Stage 610 only on 26th January 2025 and 1st February 2026, representing a delay of 29 days (YI) and 30 days (YII) compared to T5. Full flowering (Stage 615, more than 50% panicle flowers open) was recorded in T5 on 8th January 2025 (YI) and 15th January 2026 (YII), while T8 reached Stage 615 only on 9th February 2025 and 16th February 2026 a delay of 32 days in both years. This quantitative BBCH-based documentation confirms the 28 to 30-day advancement in flowering reported in the results of Experiment 1 (Tables 4.3 and 4.4).

Rajan et al. (2011) documented Stage 517 (swollen flower buds with first petal tips visible) from standard week 10 to 12 (approximately first to third week of March) in cv. Totapuri at Lucknow. In the present study, Stage 517 was recorded in T5 as early as 14th December 2024 (YI) and 20th December 2025 (YII) nearly 10 to 12 weeks earlier than the Lucknow calendar. This very early December flowering in Konkan cv. Ratna under T5 treatment contrasts sharply with the February to March flowering calendar at Lucknow and highlights the profound influence of the West Coast Ghat ecology where the post-monsoon temperature drop occurs from October onward, the Sharad-Hemant transition brings cooler nights (20 to 23°C) progressively from November, and the absence of severe winter does not impose a prolonged dormancy all of which collectively create an earlier and longer floral induction window than in the continental subtropical climate of Lucknow.

Flower fading (Stage 617) commenced in T5 on 16th January 2026 (YII) and fruit set (Stage 619) was completed by 29th January 2026, 28 days before T8 Stage 619 on 26th February 2026. Barren panicle (Stage 630) and completely dried panicle (Stage 631) were observed earliest in T5 on 1st to 4th February 2026 confirming that the entire flowering season was completed and resources redirected to developing fruits nearly a month earlier than control. This early completion of flowering in T5 is significant because it allows fruit development to begin under the relatively cool February temperatures of Konkan (21 to 26°C), which may reduce physiological fruit drop

and support better cell division during the critical early fruit development phase.

The overall flowering stage duration (610 to 619) spanned 35 to 45 days across treatments, which is within the 45 to 55-day range documented for the flowering stage in the broader analysis. Rajan *et al.* (2011) observed Stage 619 (fruit set) between standard weeks 12 and 16 (approximately 3rd week of March to 3rd week of April) at Lucknow. In the present study, fruit set (Stage 619) was recorded in T_5 by 29th January 2025 and 2nd February 2026 confirming that Ratna mango in Konkan achieves fruit set approximately 6 to 10 weeks earlier than cv. Totapuri at Lucknow, even under control conditions. Rajan *et al.* (2011) also cautioned that codes 630 and 631 indicating barren and dried panicles are not well defined in the existing BBCH scale. The present study recorded these stages distinctly as the panicle progressively drying and dropping after fruit set and used them as a reliable phenological marker for the end of the reproductive phase before entering the fruit development stage.

IV. CONCLUSION

The present investigation established a systematic BBCH-based phenological calendar for mango cv. Ratna under the Konkan agroclimatic conditions of Maharashtra. Significant differences in the timing of bud development, leaf development, shoot elongation, inflorescence emergence and flowering were observed among the management treatments.

Post-harvest pruning substantially advanced the vegetative phenological cycle compared with the untreated control. Among the tested interventions, the combination of post-harvest pruning with soil application of paclobutrazol (T5) produced the earliest reproductive transition and flowering. T5 advanced BBCH 510 by approximately 38 days and first flower opening (BBCH 610) by approximately 29–30 days compared with the untreated control, while full flowering (BBCH 615) was advanced by approximately 32 days.

The findings demonstrate the usefulness of the extended BBCH scale as a standardized tool for documenting and comparing phenological development in Ratna mango. The stage-wise phenological information generated in this study can provide a basis for phenology-oriented scheduling of orchard operations and further studies on early flowering and fruiting in Ratna mango under Konkan conditions.

Table 1. Effect of different physico-chemical treatments on bud development in mango Cv. Ratna

Treatments	010		011		013		017		019	
	2024-25	2025-26	2024-25	2025-26	2024-25	2025-26	2024-25	2025-26	2024-25	2025-26
T1	37	40	42	45	44	47	47	50	50	54
T2	33	42	39	44	43	48	46	51	49	55
T3	35	38	40	45	44	48	49	52	51	54
T4	37	43	43	48	45	48	48	51	52	55
T5	35	40	41	45	44	47	47	51	51	56
T6	38	42	42	48	44	48	46	51	50	54
T7	39	44	43	49	46	50	50	54	53	59
T8	62	66	68	71	72	76	76	80	80	84

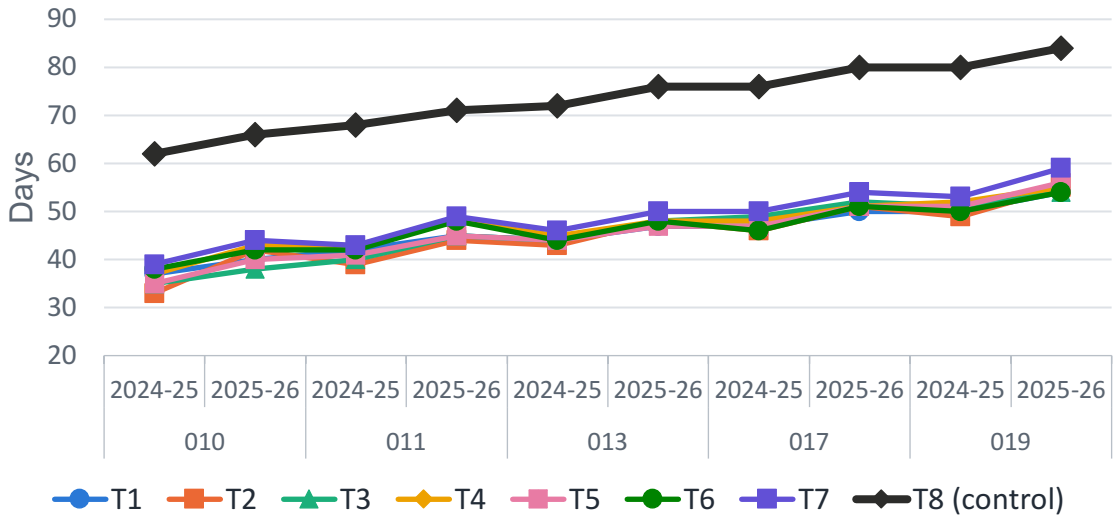


Fig.1. Effect of different physico-chemical treatments on bud development in mango cv. Ratna

Stage 0: Bud Development (BBCH 010-019)

Code	Description
010	Dormancy: leaf buds are closed and covered with green or brownish scales
011	Beginning of leaf bud swelling: bud scales begin to separate
013	End of leaf bud swelling: scales completely separated, light green buds emerged
017	Beginning of bud break: light green to dark coppery tan leaf tips just visible
019	Bud break: light green to dark coppery tan leaf tips visible 5 to 10 mm above bud scales

Table 2: Effect of different physico-chemical treatments on leaf development in mango Cv. Ratna

Treatments	110		111		115		119	
	2024-25	2025-26	2024-25	2025-26	2024-25	2025-26	2024-25	2025-26
T1	53	57	55	60	58	63	61	69
T2	52	58	54	61	57	63	61	68
T3	50	57	53	60	57	62	63	68
T4	55	59	56	62	59	65	65	68
T5	54	57	56	60	59	64	64	68
T6	52	56	54	59	57	63	65	69
T7	56	60	59	63	63	65	65	69
T8	82	87	85	90	88	92	92	96

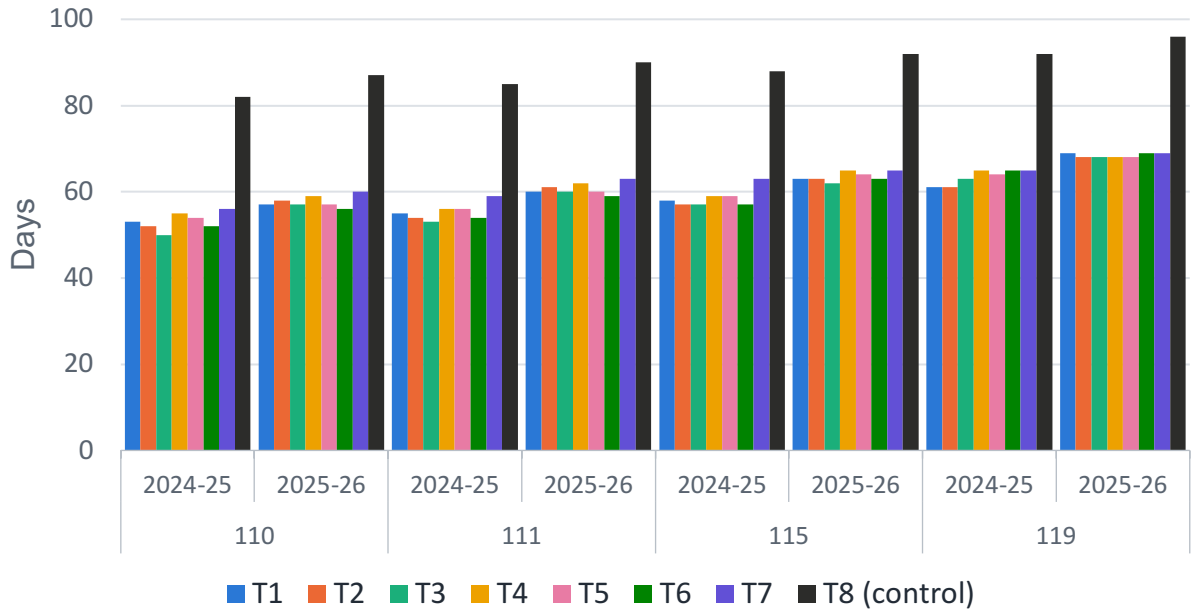


Fig.2. Effect of different physico-chemical treatments on leaf development in mango cv. Ratna

Stage 1: Leaf Development (BBCH 110-119)

Code	Description
110	Leaf tips more than 10 mm above bud scales
111	First leaf unfolded
115	More leaves unfolded: petioles visible
119	All leaves completely unfolded and expanded

Table 3: Effect of different physico-chemical treatments on shoot development in mango Cv. Ratna

Treatments	311		312		315		317		319	
	2024-25	2025-26	2024-25	2025-26	2024-25	2025-26	2024-25	2025-26	2024-25	2025-26
T1	65	72	69	74	73	77	77	81	87	90
T2	65	72	70	75	74	78	78	83	87	91
T3	66	73	70	75	73	77	77	81	88	90
T4	68	71	73	73	75	76	78	83	87	91
T5	67	72	69	75	73	77	77	80	87	91
T6	69	73	72	76	75	79	110	83	89	92
T7	69	73	73	76	77	80	80	84	90	94
T8	97	99	100	102	103	106	107	109	116	118

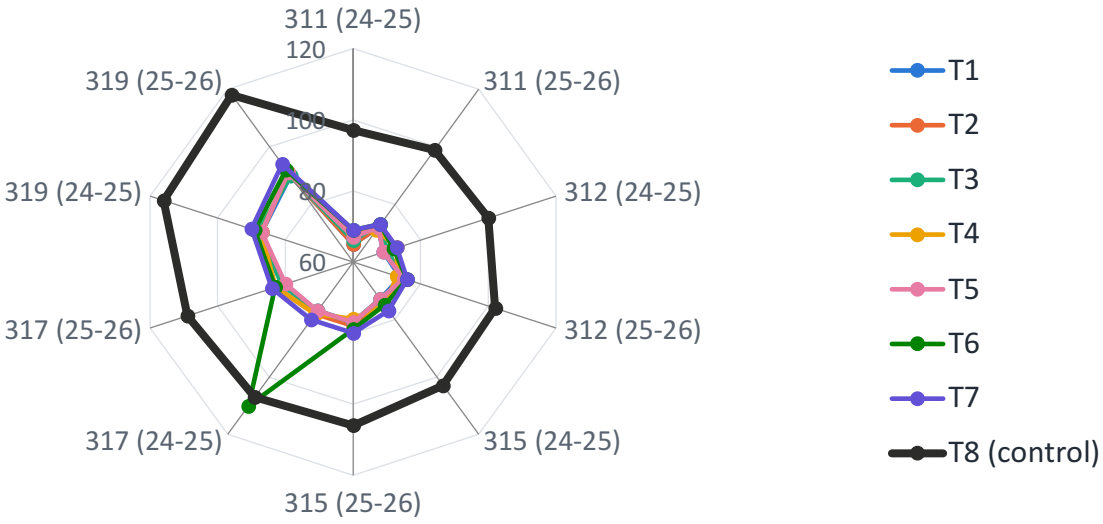


Fig.3. Effect of different physico-chemical treatments on shoot development in mango cv. Ratna

Stage 3: Shoot Development (BBCH 311-319)

Code	Description
311	Beginning of shoot growth: axes of developing shoots visible, about 10 % of final length
312	Shoots about 20% of final length
315	Shoots about 50% of final length
317	Shoots about 70% of final length
319	Shoots about 90% of final length

Table 4. Effect of different physico-chemical treatments on inflorescence emergence in mango Cv. Ratna

Treatments	Code 510		Code 511		Code 513		Code 514		Code 515	
	2024-25	2025-26	2024-25	2025-26	2024-25	2025-26	2024-25	2025-26	2024-25	2025-26
T1	171	175	193	197	200	203	208	215	212	219
T2	163	169	178	187	186	193	193	203	198	208
T3	169	173	183	191	191	195	197	205	203	209
T4	161	165	181	183	186	191	193	201	199	205
T5	157	161	165	173	170	178	176	184	181	189
T6	169	171	177	193	185	197	193	206	199	210
T7	171	173	179	195	186	199	195	207	201	211
T8	195	199	199	201	218	206	226	211	232	216

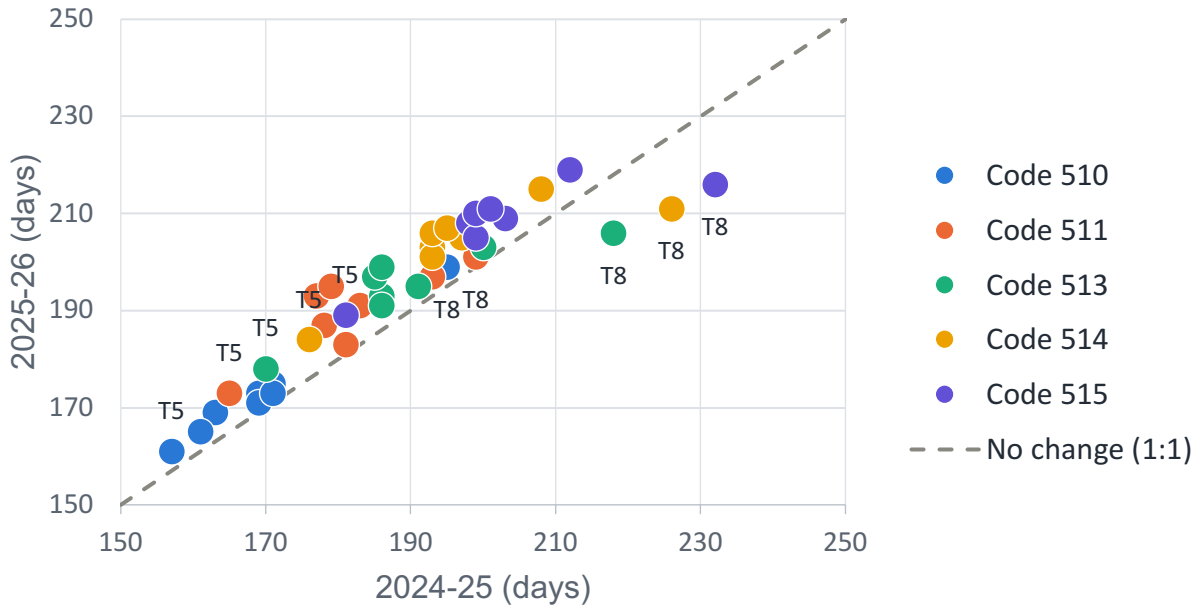


Fig.4. Effect of different physico-chemical treatments on inflorescence emergence in mango cv. Ratna

5: Inflorescence Emergence (BBCH 510-519)

Code	Description
510	Buds closed and covered with green scales
511	Beginning of bud swelling: scales begin to separate
513	Bud burst: first floral primordial just visible, panicle development begins
514	Panicle axis begins to elongate; leaves are visible in mixed panicles
515	Flowers are visibly separated; secondary axes begin to elongate
517	Secondary axes elongated, flower buds are swollen and first light green to crimson petal tips visible
519	End of panicle development: fully developed secondary axes, many flowers with green to crimson petal tips visible and some opened, leaves fully developed in case of mixed panicles

Table 5 (a). Effect of different physico-chemical treatments on flower emergence in mango Cv. Ratna

Treatments	517		519		610		611		615	
	2024-25	2025-26	2024-25	2025-26	2024-25	2025-26	2024-25	2025-26	2024-25	2025-26
T1	217	224	222	228	228	236	233	244	240	248
T2	205	212	210	215	214	220	221	230	227	236
T3	209	214	213	216	218	224	224	236	229	240
T4	203	210	208	214	213	219	220	228	225	232
T5	187	193	192	197	201	206	207	214	212	219
T6	206	213	212	218	217	222	223	229	228	237
T7	208	214	213	220	219	224	225	231	231	239
T8	219	222	224	228	230	236	239	246	244	251



Fig.5. Effect of different physico-chemical treatments on flower emergence in mango cv. Ratna

Table 5 (b). Effect of different physico-chemical treatments on flowering in mango Cv. Ratna

Treatment	617		619		630		631	
	2024-25	2025-26	2024-25	2025-26	2024-25	2025-26	2024-25	2025-26
T1	247	253	254	259	260	261	262	265
T2	236	241	245	248	249	253	251	255
T3	241	247	249	255	255	260	257	263
T4	229	237	241	245	244	249	248	251
T5	220	226	233	237	236	239	239	241
T6	237	243	248	252	253	256	255	259
T7	238	245	249	253	255	258	257	261
T8	249	255	255	261	263	266	265	269

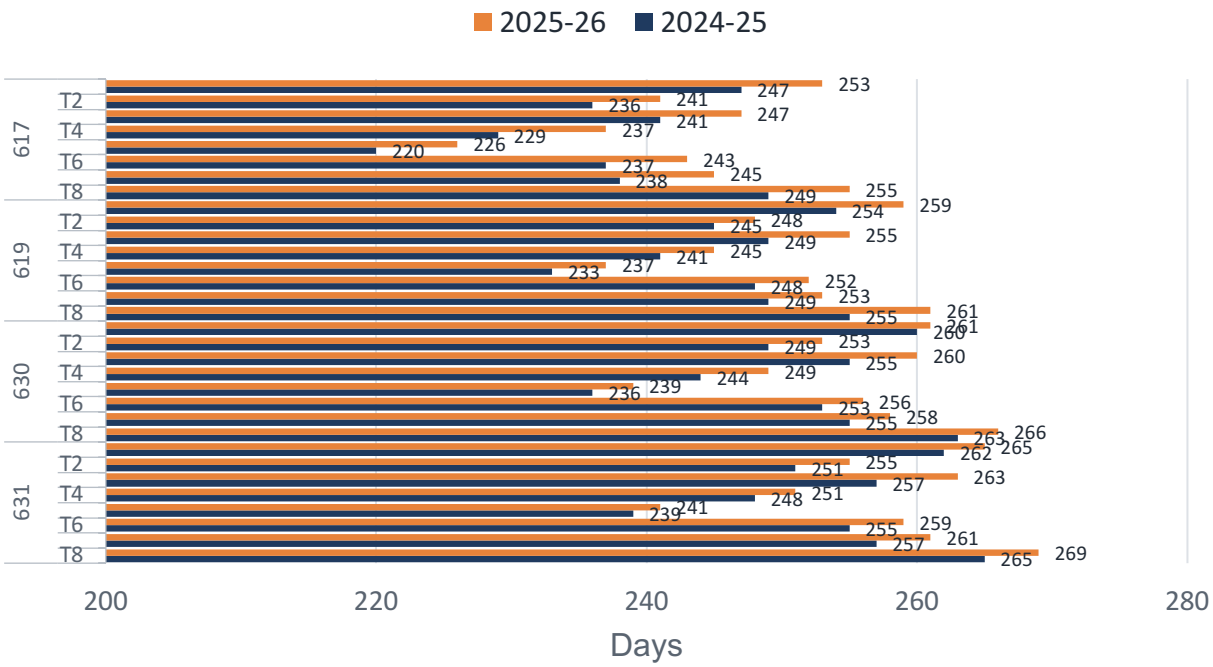
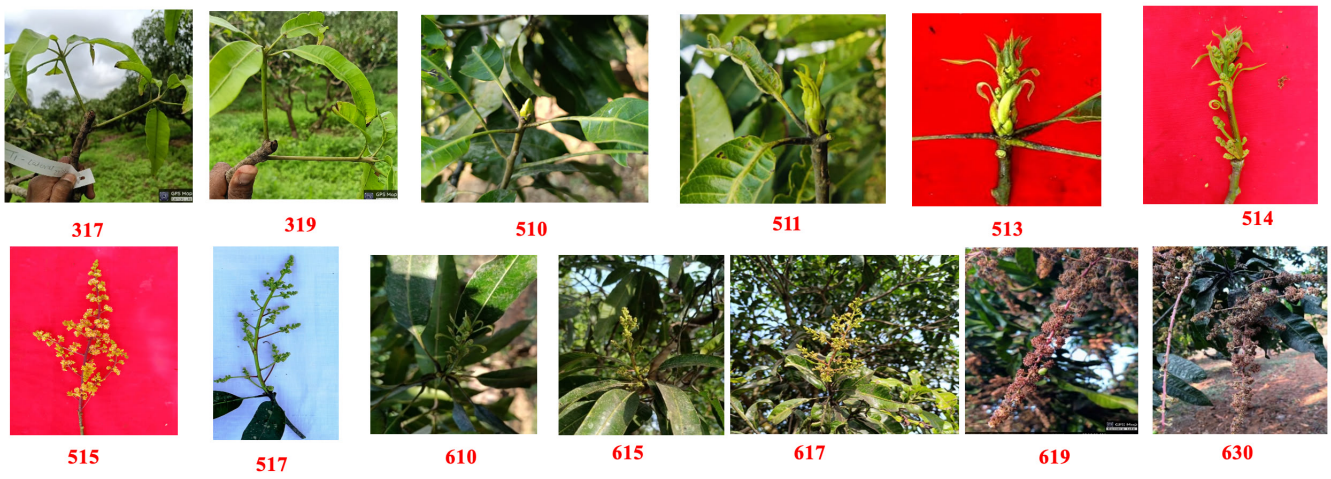


Fig.6. Effect of different physico-chemical treatments on flowering in mango cv. Ratna

6: Flowering (BBCH 610-631)

Code	Description
610	First flower open
611	Beginning of flowering: 10% of panicle flowers open
613	Early flowering: 30% of panicle flowers open
615	Full flowering: more than 50% of panicle flowers open
617	Flower fading: majority of petals fallen or dry
619	End of flowering: all petals fallen or dry, fruit set
630	Barren panicle
631	Panicle completely dried or dropped





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