

Characterisation of Three Flower Colour Morphotypes of *Tecomella undulata* (Rohida) Based on Density, Distribution, Phenology and Morphological Traits in Rajasthan

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Abstract— *Tecomella undulata* (Rohida) is an economically and ecologically important timber yielding tree species of the Indian arid region. It is also a valuable multipurpose tree for agroforestry and range management systems, where its adaptation to drought prone environments and contribution to soil and ecosystem restoration can support the rehabilitation of degraded rangelands and enhance the resilience of production systems in arid and semi-arid regions. Understanding its population distribution, phenological behaviour and morphological variability is therefore important for identifying suitable genetic resources for tree improvement programmes, conservation, agroforestry based land use systems and restoration programmes. *T. undulata* exhibits considerable phenotypic variation, particularly in flower colour, canopy architecture, and reproductive characteristics. The present study was conducted to assess the density and distribution pattern of the species and to evaluate the flowering and fruiting pattern and compare pod, seed, and leaf characteristics among three flower colour morphotypes. The survey was conducted in eight districts of Rajasthan and identified and marked fourteen populations of Rohida for assessment of population structure and marked one population at Bhadrajun village of Jalore district, Rajasthan for phenological studies. In the survey it was observed that orange morphotype was dominant and found to be more followed by the yellow and red flowered morphotypes in Rajasthan respectively. Flowering occurred from December to March, with peak flowering during February and March, whereas fruiting extended from April to June, reaching maximum intensity in the month of May. The results also revealed that orange flowered morphotype exhibits highest flowering and fruiting percentages throughout the reproductive season. Whereas morphological evaluation revealed considerable variation among three different colour morphotypes. The orange morphotype recorded the greatest pod length (23.09 ± 0.19 cm) and leaf length (9.45 ± 0.07 cm), whereas the yellow morphotype exhibited the shortest pods (21.79 ± 0.18 cm) but the widest pods (1.95 ± 0.13 cm). The results of the study revealed significant intra-specific variability in *T. undulata*, highlighting the orange morphotype as a most abundant morphotype exhibiting greater observed phenological and morphological traits at the study sites, thus making it a promising candidate for further genetic evaluation and production of quality planting material.

Keywords— *Tecomella undulata*, genetic and Morphological variability, Morphotypes, Phenology, Rajasthan.

I. INTRODUCTION

Tecomella undulata (Sm.) Seem., commonly known as Rohida, is one of the most valuable indigenous timber species of the Indian Thar Desert and adjoining semi-arid regions. The species belongs to the family Bignoniaceae and is well adapted to harsh arid climatic conditions (Kritikar and Basu 1993; Nadkarni 2000). Due to overexploitation for wood and medicinal uses, the species is categorised under endangered section in Rajasthan. Besides its importance as quality timber, it contributes significantly to biodiversity conservation, agroforestry systems, and restoration of degraded landscapes thus considered as key stone species of Rajasthan (Kumar et al, 2008). Beyond its importance as a timber species, *T. undulata* has considerable relevance to agroforestry and range-management systems in the arid and semi-arid regions of Rajasthan. Its ability to survive

under low rainfall, high temperature and poor soil conditions makes it a suitable tree component for dryland-based agroforestry and silvopastoral systems. The species can contribute to the diversification and resilience of production systems while providing tree-based ecosystem services and supporting the restoration of degraded lands and rangelands. Incorporation of well-adapted and genetically superior *T. undulata* planting material into agroforestry and restoration programmes may therefore help in improving the sustainability of land-use systems in the Thar region. Knowledge of its natural distribution, phenological behaviour and morphological variation is particularly important for identifying suitable populations and morphotypes for conservation, enrichment planting and future agroforestry and range-management interventions. This species exhibits considerable phenotypic variation, particularly in flower colour (Fig 1), canopy architecture, and reproductive characteristics (Chakrawati and Chand, 1975; Negi et al., 2011). Due to variation in flower colour, the species is recognised as State flower of Rajasthan (Fig 1) (Chal et al. 2011). Phenological studies particularly flowering and fruiting are vital to develop viable conservation and breeding strategies. Thus knowledge on distribution and phenological pattern of any species is an important approach for improvement and breeding programmes and conservation planning (Beniwal, 2005). Similarly, variability in pod, seed, and leaf traits is also an important step because it serves as important criteria for selecting superior genotypes for quality planting material and genetic improvement. Despite the ecological and economic importance of Rohida, no information is available regarding comparative phenological performance among different flower colour morphotypes. Therefore, to the best of my knowledge present study was carried out to record flowering and fruiting pattern, evaluate variability in pod, seed, and leaf characteristics, and document density and distribution among three different flower colour morphotypes of *T. undulata* in Rajasthan.

Novelty and Contribution of this Study: While earlier studies have documented morphological variation in *T. undulata* (Chakravarty and Chand, 1975; Negi et al., 2011) and molecular differentiation among flower colour morphotypes (Kaur et al., 2018; Meena et al., 2025), no study has comparatively assessed the phenological performance of the three flower colour morphotypes across reproductive seasons. This study makes three specific contributions. First, it provides the first comparative account of flowering and fruiting patterns among orange-, red-, and yellow-flowered morphotypes of *T. undulata* monitored over two consecutive reproductive seasons. Second, it integrates density and distribution data from 14 natural populations across eight districts with morphological and phenological data from a single representative population, thereby linking population-level patterns with individual-tree performance. Third, it reports effect sizes for morphological traits and interprets phenotypic differences cautiously in relation to prior molecular evidence, providing a basis for conservation and quality planting material programmes. By distinguishing between observed phenotypic differences and confirmed genetic differentiation, the study aims to guide future integrated research on this endangered arid-zone tree.



FIGURE 1: Three different flower colour morphotypes of *T. undulata*

II. MATERIALS AND METHODS

2.1 Survey and Population Identification

Extensive field surveys were conducted across Rajasthan and fourteen natural populations of Rohida were identified from eight districts (Barmer, Jaisalmer, Jodhpur, Jalore, Bikaner, Churu, Nagaur, Sikar). Sites were selected based on the presence of natural *T. undulata* populations, accessibility, representation of different agro-climatic conditions within the Thar region, and,

where possible, the co-occurrence of more than one flower colour morphotype. Quadrat sampling method was used to assess the distribution and relative abundance of different flower colour morphotypes of *T. undulata*. At each selected site, ten quadrats of 30 × 30 m were laid randomly and all the number of trees falling under the quadrates were recorded with the colour of the flower. Random placement was achieved by selecting quadrat positions along pre-determined transects with random starting points, ensuring that quadrats were distributed across the representative vegetation of each site. Flower colour of each recorded tree was scored visually by trained field personnel against a standard reference of the three recognized morphotypes (orange, red, and yellow); where ambiguity existed, trees were re-examined during peak flowering to confirm classification. The data recorded were used to calculate colour wise percentage composition of the species across the Rajasthan. The percentage of each flower colour was calculated as:

$$\text{Percentage of flower colour type} = \frac{\text{Number of trees of that flower colour}}{\text{Total number of } T.undulata \text{ trees recorded}} \times 100 \quad (1)$$

2.2 Phenological Monitoring

Further to evaluate the flowering and fruiting pattern of the three morphotypes, the natural population located in the Bhadrajun region of Jalore district, Rajasthan was selected based on the density, and availability of three flower morphotypes at one place. The area represents the typical hot arid ecosystem characterized by sandy loam soils, low annual rainfall (300–450 mm), and extreme summer temperatures exceeding 45°C. Ninety healthy mature trees representing thirty trees for each flower colour morphotype were selected, tagged and monitored throughout the study period. Trees were selected to be representative of the size and canopy classes present at the site, and only trees with confirmed morphotype identity were included.

For phenological observations various parameters like initiation of flowering, peak flowering, completion of flowering, fruit initiation, peak fruiting, fruit maturity were monitored and monthly flowering and fruiting percentages were calculated for each morphotype for two consecutive years from December 2018 to March 2020 at regular intervals. For each tagged tree, the proportion of the canopy bearing flowers (flowering percentage) and the proportion of the canopy bearing fruits (fruiting percentage) were visually estimated on a monthly basis by the same observer throughout the study period, using a standardized visual scale (0–100% in 10% intervals). Monthly values reported for each morphotype represent the mean of the thirty tagged trees.

2.3 Morphological Measurements

Further to estimate the morphological variations, fully mature pods (30 pods/tree), seeds (100 seeds), and leaves were collected from each of the morphotype and Pod length (cm), Pod width (cm), Seed length (cm), Seed width (cm), Leaf length (cm), Leaf width (cm), Mean values and standard errors were calculated. Morphological sampling was carried out on the same set of tagged trees used for phenological monitoring, with a subset of ten trees per morphotype randomly selected for pod, seed, and leaf collection. Pod length and width, seed length and width, and leaf length and width were measured using a digital vernier caliper (0.01 cm precision). The data recorded were analysed through one way analysis of variance (ANOVA) followed by Tukey's HSD comparable test among different morphotypes using SPSS 16. Prior to ANOVA, normality (Shapiro–Wilk test) and homogeneity of variances (Levene's test) were checked; where assumptions were met, untransformed data were analysed. Effect sizes were calculated as eta-squared (η^2) for significant traits.

III. RESULTS

3.1 Density and Distribution Pattern

To assess the density and distribution pattern of the species with reference to these three morphotypes, an exhaustive survey was carried out in eight districts of Rajasthan and identified 14 sites having natural population of *T. undulata* trees. For this study ten quadrates of 30*30m were laid down at each site. The estimation was based on the data collected from 140 sample plots covering 14 sites from 8 districts of Rajasthan (Table 1, Fig 2, Graph 1). In the survey it was observed that orange morphotype was found to be more followed by the yellow and red flowered morphotypes in Rajasthan respectively. Maximum density (per hectare) of orange morphotype was found in Nagaur district (5.2±3.6) and minimum density (per hectare) in Jodhpur district (1.05±1.1). Likewise, maximum number of yellow morphotype (4.3±2.3 plant/hectare) was found in Jodhpur district whereas minimum (0.5±0.7 plant/hectare) in Churu district. Similarly, maximum and minimum density (per hectare) in red morphotype was found in Jaisalmer (2.5±1.6) and Churu (0.25±0.5) districts respectively (Table 1).

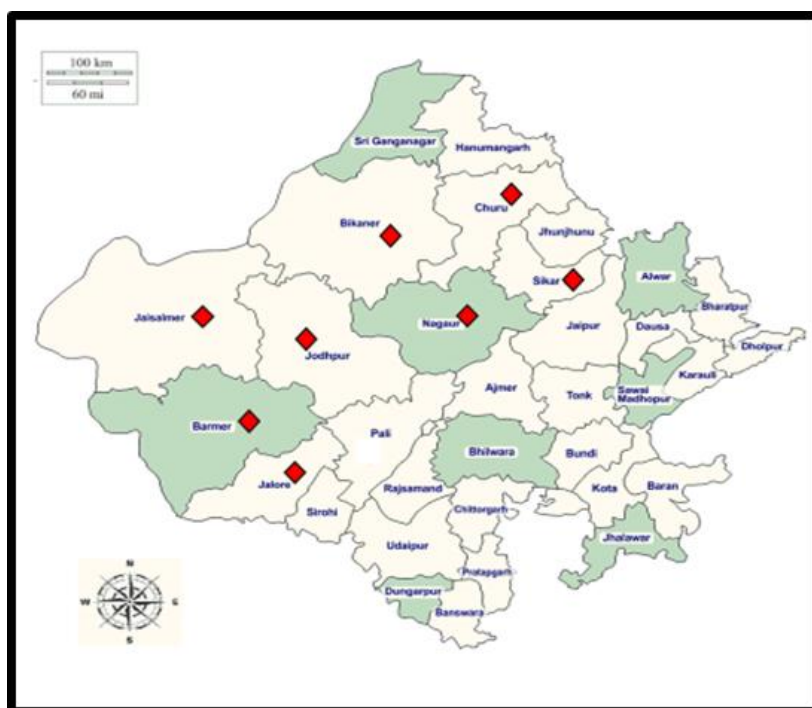


FIGURE 2: Districts surveyed for population density study of *T. undulata* in Rajasthan

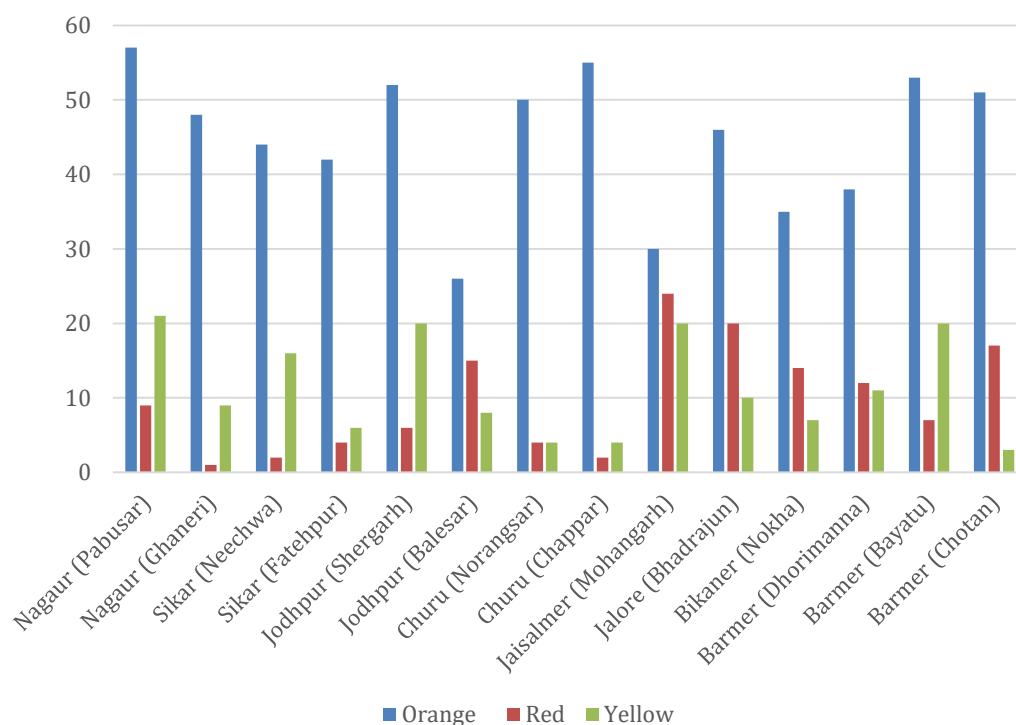
TABLE 1

DISTRICT WISE INFORMATION ON FOREST COVER, *T. UNDULATA* OCCURRENCE AREA AND POPULATION DENSITY ha⁻¹

Districts (No. of sites)	Forest Cover (ha)#	<i>T. undulata</i> area (ha)#	<i>T. undulata</i> area (%)	No. of sample plots	Avg. no. of plants plot ⁻¹	Sample SD	Avg. no. of Orange plants plot ⁻¹	Avg. no. of Red plants plot ⁻¹	Avg. no. of Yellow plants plot ⁻¹	Avg. no. of total plants per site (all plots)
Barmer (3)	27300	1200	4.39	30	7.03	2.94	4.8±2.7	1.2±1.3	1±1.3	78.1
Bikaner (1)	24700	450	1.82	10	5.6	1.28	3.4±1.8	1.4±1.1	0.6±0.7	62.2
Churu (2)	8200	450	5.48	20	5.95	1.72	4.9±2.3	0.25±0.5	0.5±0.7	66.1
Jaisalmer (1)	31300	170	0.54	10	7.4	2.94	3±1.6	2.5±1.6	1.9±2.2	82.2
Jalore (1)	27500	220	0.8	10	7.5	1.96	4.4±2	1±0.9	2.1±1.4	83.3
Jodhpur (2)	10500	420	4	20	6.95	2.67	1.05±1.1	1.4±1.5	4.3±2.3	77.2
Nagaur (2)	14300	900	6.29	20	7.2	3.7	5.2±3.6	0.5±1.1	1.45±1.9	80
Sikar (2)	19200	595	3.09	20	5.7	2.22	4.3±0.7	0.3±0.7	1.1±1.7	63.3
Total	163000	4405	2.7	140	5.19	2.429	4.4±2.7	0.9±1.2	1.2±1.6	—

Forest cover and *T. undulata* area values are from district-level records; "Avg. no. of total plants per site" refers to the mean of the total number of *T. undulata* trees recorded across all plots at each site (calculated across the district sample).

Site-level plots: 10 quadrats (30 × 30 m) per site.



GRAPH 1: Density of Rohida trees at identified sites of Rajasthan

Further, the survey and quadrat sampling method conducted across fourteen natural populations revealed that the orange morphotype was dominant throughout Rajasthan. The orange morphotype constituted 67.48% of the total population, whereas the red and yellow morphotypes represented 14.93% and 17.59%, respectively (Fig 3).

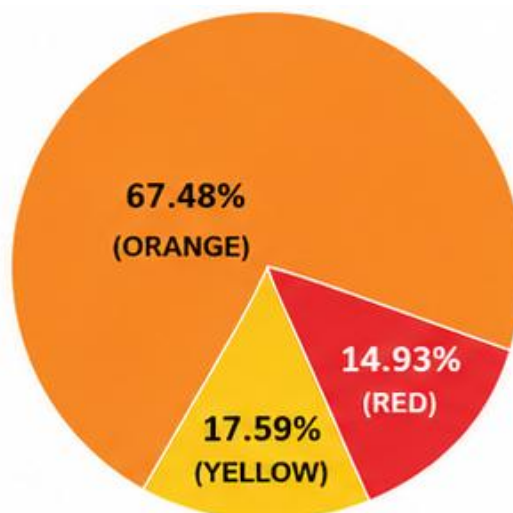
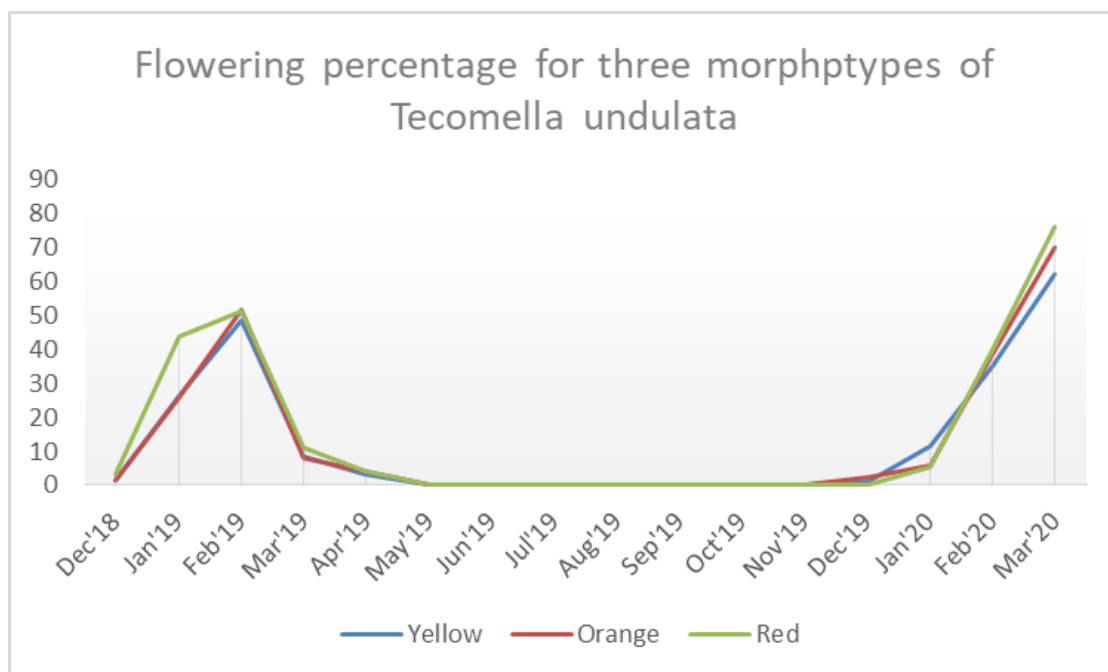


FIGURE 3: Overall distribution of three morphotypes of *T. undulata* in Rajasthan

3.2 Flowering Pattern

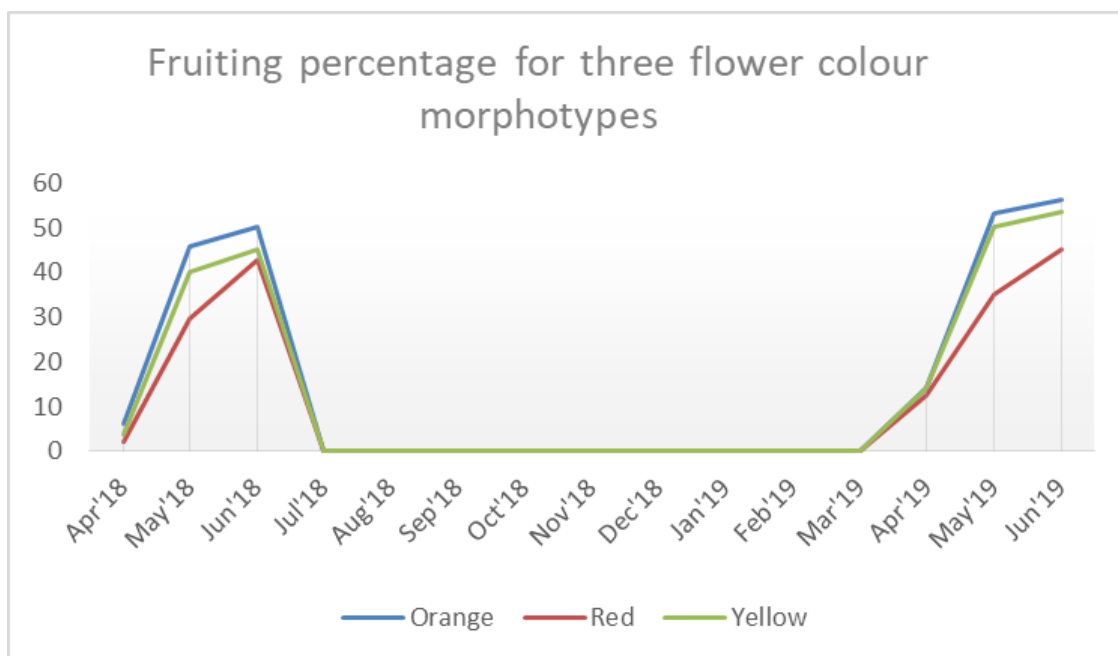
Variations in the onset of the flowering seasons among the three morphotypes were also observed during the survey. The flowering pattern was monitored monthly and it was observed that flowering initiated during December and gradually increased until February and March which was recorded as its peak flowering season. Further the flowering declined sharply during the month of March and transition phase from flowers to pods were observed. It was also recorded that orange and red morphotypes show flowering about two-three weeks earlier than the yellow morphotype. Also the orange-flowered trees consistently exhibited the highest flowering intensity throughout the season, followed by the red morphotype, whereas yellow-flowered trees showed comparatively lower flowering percentages (Graph 2).



GRAPH 2: Monthly flowering percentage of three flower colour morphotypes of *T. undulata*

3.3 Fruiting Pattern

It was observed that fruiting began during April and reached its maximum during the month of May, and gradually declined by the end of the June. The orange morphotype exhibited the highest fruiting percentage, indicating superior performance compared to other morphotypes. Red-flowered trees produced moderate fruiting, while the yellow morphotype consistently recorded the lowest fruit production (Graph 3).



GRAPH 3: Monthly fruiting percentage of three flower colour morphotypes of *T. undulata*

3.4 Morphological Variability

Considerable variation was observed among the three morphotypes for pod, seed, and leaf characteristics (Table 2, Fig 4). The orange morphotype recorded the maximum pod length (23.09 ± 0.19 cm) and leaf length (9.45 ± 0.07 cm). The red morphotype exhibited intermediate values for most traits, whereas the yellow morphotype produced comparatively shorter pods ($21.79 \pm$

0.18 cm) but wider pods (1.95 ± 0.13 cm). Seed dimensions showed relatively minor variation among morphotypes, suggesting greater stability of reproductive structures than vegetative characters.

TABLE 2

VARIABILITY ESTIMATES FOR PODS, SEEDS AND LEAF CHARACTERS AMONG DIFFERENT FLOWER COLOUR MORPHOTYPES OF *T. UNDULATA*

Trait	Orange Mean $\pm$ SE (n = 10 trees)	Red Mean $\pm$ SE (n = 10 trees)	Yellow Mean $\pm$ SE (n = 10 trees)	F (2,27)	P-value	η^2
Pod length (cm)	23.09 ± 0.19	22.38 ± 0.20	21.79 ± 0.18	1.47	0.236	—
Pod width (cm)	1.57 ± 0.09	1.18 ± 0.01	1.95 ± 0.13	1.53	0.222	—
Seed length (cm)	1.88 ± 0.02	1.80 ± 0.01	1.81 ± 0.00	1.22	0.301	—
Seed width (cm)	0.85 ± 0.01	0.87 ± 0.02	0.85 ± 0.01	0.3	0.738	—
Leaf length (cm)	$9.45 \pm 0.07a$	$8.22 \pm 0.06b$	$7.77 \pm 0.05b$	13.06	<0.001	0.231
Leaf width (cm)	2.03 ± 0.04	1.91 ± 0.04	1.74 ± 0.03	4.88	0.0098	0.101

Means followed by different superscript letters differ significantly according to Tukey's HSD test ($P < 0.05$). n = number of trees sampled per morphotype; 30 pods per tree for pod traits and 100 seeds per tree for seed traits; leaf measurements based on ten leaves per tree.



FIGURE 4: Leaf, pods and seeds of *T. undulata*

Significant variation was observed among the three flower colour morphotypes of *T. undulata* for the measured leaf traits, whereas the pod and seed traits showed comparatively limited differentiation. The results revealed that the leaf length differed significantly among yellow, red and orange flowered trees ($F = 13.06$, $P < 0.001$). The mean leaf length was highest in orange flowered trees (9.45 cm), followed by red flowered (8.22 cm) and yellow-flowered trees (7.77 cm). The Tukey's HSD test performed, indicated that orange flowered trees had significantly longer leaves than both yellow and red flowered trees, whereas the difference between yellow and red flowered trees was non-significant. The effect size ($\eta^2 = 0.231$) indicated that flower colour group accounted for approximately 23% of the observed variation in leaf length.

Similarly, the leaf width also differed significantly among flower colour groups ($F = 4.88$, $P = 0.0098$). The orange flowered trees showed the highest mean leaf width (2.03 cm), followed by red (1.91 cm) and yellow (1.74 cm) trees. Tukey's test showed a significant difference between orange and yellow flowered morphotypes, while the orange–red and red–yellow comparisons were non-significant. The effect size for leaf width was $\eta^2 = 0.101$, indicating a moderate contribution of flower colour morphotypes to variation in this trait. In contrast, none of the measured pod or seed characters differed significantly among the three flower-colour morphotypes. The pod length varied from 22.38 cm in red flowered trees to 23.09 cm in orange flowered trees ($F = 1.47$, $P = 0.236$). Similarly, pod width showed no significant differences ($F = 1.53$, $P = 0.222$). The seed size (length and width) also remained statistically comparable among colour morphotypes, with P values ranging from 0.301 to 0.738. Thus

the comparative analysis reveals that the flower colour was associated more strongly with leaf morphology than with the measured pod and seed characteristics.

IV. DISCUSSION

The present study provides an integrated account of the phenotypic and morphometric variation and distribution of flower colour morphotypes of *T. undulata* in Rajasthan. Various researchers have studied the flowering and reproductive pattern without considering their flower morphotypes which makes this study different from earlier reported literature. In the present study, *T. undulata* showed a distinct seasonal reproductive cycle, with flowering beginning during December, attaining maximum intensity during February and March and declining during April, whereas fruiting initiated during April, reached its maximum during May and declined by June. The timing of these phenophases indicates that reproductive activity in *T. undulata* is closely associated with the seasonal climatic conditions of the arid region. Earlier studies have also documented a pronounced seasonal reproductive pattern in Rohida, although the exact timing of flowering varies geographically. Tripathi and Jaimini (2002) reported flowering from January to the second week of May, with anthesis occurring mainly between 06:00 and 12:00 h. More recently, Daneva et al. (2024) reported flower-bud initiation and peak flowering during April in Jhunjhunu, Rajasthan, with approximately 20 days required from bud initiation to anthesis. Such differences among studies may reflect variation in temperature, moisture availability and local environmental conditions among sites.

The flowering period observed in the present study, particularly the peak during February and March, is earlier than that reported from Jhunjhunu by Daneva et al. (2024). This difference is biologically possible because phenological events in woody species of arid and semi-arid ecosystems are strongly influenced by local climatic conditions. Differences in latitude, winter temperature, soil moisture and the onset of summer conditions may alter the timing of bud initiation and anthesis. The occurrence of flowering during the relatively cooler part of the year may also be advantageous because it allows reproductive development to occur before the onset of extreme summer temperatures and moisture stress characteristic of western Rajasthan.

The fruiting pattern observed in the present study, with fruit initiation during April and maximum fruiting during May, is also consistent with the reproductive behaviour previously reported for Rohida by various researchers. Tripathi and Jaimini (2002) reported that fruit development follows flowering and that the number of seeds per fruit varies with fruit size. Daneva et al. (2024) reported a period of approximately 141–152 days from bud emergence to pod maturity. The present observations therefore support the existence of a well-defined transition from winter flowering to summer fruit development in *T. undulata*.

The consistently higher observed flowering and fruiting percentages in the orange-flowered morphotype are an important finding of the present study. However, this pattern should be interpreted cautiously because reproductive performance can be influenced by several factors, including tree size, resource availability, microclimate, pollinator visitation and genetic constitution. Because phenological monitoring was conducted at a single population, site-specific effects cannot be fully separated from morphotype effects; the observed differences should therefore be regarded as comparative under the conditions of the Bhadrajun site rather than as generalized morphotype traits.

The higher reproductive performance observed in the orange morphotype could therefore potentially be related to differences in pollinator attraction or visitation however, this hypothesis cannot be confirmed from the present study because pollinator behaviour was not directly quantified. Flower colour is known to influence visual attraction of pollinators in many plant species, and the occurrence of distinct flower-colour forms in *T. undulata* provides an interesting system for investigating plant–pollinator interactions. More broadly, flower colour polymorphism in plants is often maintained by a combination of pollinator-mediated selection, pleiotropic effects, and environmental heterogeneity, and its persistence in *T. undulata* may reflect such interacting processes (Rausher, 2008; Renoult et al., 2013; Ellis and Field, 2016; Sapir et al., 2021). Future studies should therefore examine pollinator visitation frequency, pollen deposition, fruit set and seed production separately for the three morphotypes.

The morphological assessment revealed noticeable differences among the three flower colour morphotypes. The orange morphotype recorded the highest pod length (23.09 ± 0.19 cm), seed length (1.88 ± 0.02 cm), leaf length (9.45 ± 0.07 cm) and leaf width (2.03 ± 0.04 cm). In contrast, the yellow morphotype recorded the greatest pod width (1.95 ± 0.13 cm), while seed width remained relatively similar among the three morphotypes. These observations indicate that flower-colour morphotypes are associated with differences in several easily measurable phenotypic traits. The particularly pronounced difference in leaf length among the morphotypes suggests that vegetative characters may complement flower colour as descriptors for field identification and characterization of Rohida germplasm.

The observed morphological differentiation is particularly interesting in light of previous molecular studies. Kaur et al. (2018) investigated the three flower-colour morphotypes of *T. undulata* using RAPD markers and reported substantial molecular polymorphism. Their study generated 87 RAPD fragments, of which 75 were polymorphic, and the orange-flowered accessions showed relatively high genetic diversity. The authors concluded that the observed intraspecific variability had a molecular genetic basis and emphasized the potential importance of the morphotypes for conservation and breeding.

Further molecular evidence reported by Meena et al. (2025) revealed genetic variation among the three flower-colour morphotypes using Start Codon Targeted (SCoT) markers. Their findings provide additional support for the existence of genetic differentiation associated with the morphotypes. This molecular evidence is complementary to the phenotypic differences documented in the present investigation. However, the morphological data generated in the present study alone should not be interpreted as direct evidence of genetic differentiation because environmental effects cannot be separated from genetic effects under field conditions. Confirmation of the genetic basis of the observed phenotypic differences will require common-garden experiments, progeny trials, and multi-location evaluation, ideally integrated with molecular markers.

The distribution survey across 14 natural populations showed that the orange morphotype was the predominant form, accounting for approximately 67.48% of the observed trees, while yellow and red morphotypes accounted for 17.59% and 14.93%, respectively. The predominance of the orange morphotype across the surveyed populations is noteworthy, particularly because it was also associated with comparatively higher flowering and fruiting performance at the Bhadrajun study site.

The presence of red and yellow morphotypes at lower frequencies is nevertheless important from a conservation perspective. Rare or less abundant morphotypes may contain unique genetic combinations and should therefore not be excluded from conservation or breeding programmes simply because they occur at lower frequencies. This is particularly relevant because previous molecular studies have confirmed intraspecific genetic variation among the flower-colour morphotypes.

The findings also have implications for conservation and genetic resource management of *T. undulata*. The species is an important component of the arid and semi-arid ecosystems of western India and has considerable economic and ecological value. The identification and documentation of distinct flower-colour morphotypes across natural populations can facilitate the development of representative germplasm collections and support selection of suitable trees for future breeding and production of quality planting material programmes. Recent work has also demonstrated the potential of digital approaches for rapid identification and classification of flower-colour morphotypes, further highlighting the value of systematic documentation of this intraspecific diversity.

Overall, the present study demonstrates that *T. undulata* exhibits distinct seasonal reproductive behaviour and appreciable phenotypic differences among orange-, red- and yellow flowered morphotypes. The orange morphotype showed comparatively higher observed flowering and fruiting performance and larger values for several pod and leaf traits, while the yellow morphotype was characterized by greater pod width. These findings, together with earlier molecular evidence of genetic variation among flower-colour morphotypes, indicate that the three forms represent valuable components of the species' biological diversity.

Future Research Directions: Priority research should include: (1) multi-location and multi-year phenological monitoring of the three morphotypes; (2) quantification of pollinator visitation, pollen deposition, and fruit set across morphotypes; (3) common-garden and progeny trials to separate genetic and environmental effects; (4) integration of morphological data with molecular markers (RAPD, SCoT, microsatellites) for marker-assisted selection; and (5) evaluation of orange morphotype planting material under different agroforestry and restoration contexts.

V. CONCLUSION

The present study demonstrates considerable phenological and morphological variability among flower colour morphotypes of *T. undulata*. The results of the study reveal that orange morphotype constituted approximately 67.48% of the natural population among the sampled populations in Rajasthan and exhibited comparatively higher observed flowering and fruiting performance under the study conditions which makes it a promising candidate for genetic improvement, conservation, and quality planting material production. The yellow morphotype was characterized by the widest pods, while seed traits remained relatively stable across morphotypes. Although the orange morphotype appears promising under the study conditions, confirmation of the genetic basis of these differences will require integrated studies involving molecular markers, common-garden experiments, progeny trials, and multi-location evaluation. The three morphotypes together represent valuable components of the biological

diversity of *T. undulata*, and should be conserved as part of representative germplasm collections for future breeding and restoration programmes.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest related to this work. No financial, personal, or professional relationships influenced the research, analysis, interpretation of results, or preparation of this manuscript.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

REFERENCES

- [1] Beniwal, R. S. (2005). *Studies on flowering behaviour of arid zone plants*.
- [2] Chakravarty, A. K., & Chand, G. (1975). Phenotypic variation in desert teak *Tecomella undulata*. *Annals of Arid Zone*, *14*(1).
- [3] Chal, J., Kumar, V., & Kaushik, S. (2011). A phytopharmacological overview on *Tecomella undulata* G. Don. *Journal of Applied Pharmaceutical Science*, *1*, 11-12.
- [4] Daneva, V., Johar, V., Pathak, S., Rawat, V., & Khan, S. (2024). Studies on reproductive behaviour and phenology cycle of *Tecomella undulata* (Sm.) Seem. *Plant Science Today*. <https://doi.org/10.14719/pst.2513>
- [5] Kaur, N., Gill, A., & Saggoo, M. I. S. (2018). Cytological investigation and genetic diversity studies in the morphotypes of an endangered tree, *Tecomella undulata* from Punjab, India. *Cytologia*, *83*(3), 283-287. <https://doi.org/10.1508/cytologia.83.283>
- [6] Kritikar, K. R., & Basu, B. D. (1993). *Indian medicinal plants*. International Book Distributor.
- [7] Kumar, A., Ram, H., Sharma, S. K., & Rao, S. R. (2008). Comparative meiotic chromosome studies in nine accessions of *Tecomella undulata* (Sm.) Seem., threatened tree of Indian desert. *Silvae Genetica*, *57*, 301-306.
- [8] Meena, D., Sharma, A., & Chouhan, A. S. (2025). Assessment of genetic variation among three different flower colour morphotypes of *Tecomella undulata* using start codon targeted markers. *Indian Forester*, *151*(4), 309-316. <https://doi.org/10.36808/if/2025/v151i4/170455>
- [9] Nadkarni, K. M. (2000). *Indian materia medica*. Popular Prakashan.
- [10] Negi, R. S., Sharma, M. K., Sharma, K. C., Kshetrapal, S., Kothari, S. L., & Trivedi, P. C. (2011). *Genetic diversity and variations in the endangered tree (Tecomella undulata) in Rajasthan*.
- [11] Singh, V. K., Barman, C., & Tandon, R. (2014). Nectar robbing positively influences the reproductive success of *Tecomella undulata* (Bignoniaceae). *PLoS ONE*, *9*(7), e102652.
- [12] Tripathi, J. P. M., & Jaimini, S. N. (2002). Floral and reproductive biology of Rohida (*Tecomella undulata* (Sm.) Seem.). *Indian Journal of Forestry*, *25*(3), 341-343. <https://doi.org/10.54207/bsmps1000-2002-SPT7TE>.