PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol 11(3): 152-158
https://doi.org/10.14719/pst.2513

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RESEARCH ARTICLE

Studies on reproductive behaviour and phenology cycle of *Tecomella undulata* (Sm.) Seem.

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OPEN ACCESS

ARTICLE HISTORY

Received: 05 May 2023
Accepted: 08 October 2023

Available online
Version 1.0 : 29 June 2024
Version 2.0 : 01 July 2024

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

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Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

CITE THIS ARTICLE

Daneva V, Johar V, Pathak S, Rawat V, Khan S. Studies on reproductive behaviour and phenology cycle of *Tecomella undulata* (Sm.) Seem. Plant Science Today. 2024; 11(3): 152-158. https://doi.org/10.14719/pst.2513

Abstract

The study on the phenology and reproductive biology of Rohida (*Tecomella undulata*) was conducted in Luttu village, Jhunjhunu, Rajasthan, situated at 28.216^{0}N and 75.250^{0}E. It was observed that the defoliation started in the last week of November and continued till the last week of March, although a complete leaflessness stage was never observed in any of the trees and the peak period of flowering varied from 22 to 30 days, with the tree in full bloom during 2nd fortnight of April. The flower buds took approximately 20 days from initiation to opening. The duration from the start of bud emergence to the maturity of the pod ranged from 141 to 152 days. It was also observed that the staining of the pollen for viability, carried out in a solution of Acetocarmine (1%), varied from 80.00 to 88.18%, or overall, 82.97% under the electron microscope. The pod setting under open pollination ranged between 7.14 and 17.50%, with an average of 12.40%, while there was no pod setting under selfing. This type of breeding behaviour represents the open-pollinated nature of this particular tree.

Keywords

Phenology; biology; defoliation; flowering; bud development; breeding behaviour

Introduction

Tecomella undulata (Sm.) Seem. (i.e., marwar teak or rohida), is a tree belonging to the family Bignoniaceae. It is an essential species in the arid and semi-arid zones of Western India. This species is primarily found in the western regions of Rajasthan, particularly in districts such as Barmer, Jaisalmer, Jodhpur, Pali, Ajmer, Nagaur, Bikaner, Churu, and Sikar (1). These areas of Rajasthan experience lower and irregular annual rainfall (100–500 mm), high-temperature variability (-2 to 50 °C), and varying soil pH (6.5–8.0), with extensive dunes. Due to its presence and significance in these zones, it is also referred to as Desert Teak and serves as the principal timber source in the Shekhawati and Marwar regions of Rajasthan. It is valued for its timber, prized for qualities such as durability and resistance to insect pest attack, surpassing those of other tree species found in the same region such as *Prosopis cineraria, Ailanthus excels,* and *Accacia nilotica* (2). This species is primarily utilized for timber purposes and its leaves are used as fodder. The metabolites present in the bark and wood are utilized for curing various diseases. A diverse array of products, such as engraved furnishings, agricultural implements, carvings, and handicraft toys, are crafted from the wood

of this tree due to its softness and durability over time. Additionally, the activity of this tree also influences edaphic factors, leading to an increase in nitrogen and phosphorous levels in the soil (3).

T. undulata has a deep root system and is considered a shrub or small tree, with heights ranging from 4 to 8 m. The main trunk of the species typically has a girth of 50 to 80 cm, and the leaves exhibited variegated colour variability, ranging from yellow to dark green. The colour and downward-facing nature of the flowers add to the scenic beauty, and it is designated as the state flower of Rajasthan (4, 5). The seeds are lightweight and covered with a wing-like structure, facilitating wind dispersal (5). Propagation is typically achieved through seeds, as vegetative propagation has not been successfully established. The seeds have a short viability period, decreasing steadily and reaching zero viability after one year (6, 7). *In vitro* propagation of *T. undulata* using seedling explants and mature explants has been reported to have limited rooting potential, with challenges in culture and field establishment using mature explants remaining significant obstacles (8).

To initiate any breeding program, knowledge of reproductive biology is paramount. The development and availability of high-quality seeds and planting materials rely on the understanding of various factors influencing reproductive studies, such as variations in flowering, pollination behaviour, seed set, seed quality, seed viability, and seed vigour. The efficiency of breeding behaviour depends on our understanding of these factors. Factors like seed production and development, genetic drift, seed fertility or sterility, hybrid development, and the genetic makeup of the tree community are determined by the pollination behaviour of the species. Seed vigor refers to those qualities of a seed that determine its ability to emerge quickly and develop into a normal, healthy seedling under a wide range of environmental conditions (9). The present study is conducted to understand the reproductive behaviour and phenological cycle of *T. undulata* (Sm.) Seem.

Materials and Methods

From 2017 to 2019, phenological pattern, flowering behaviour, and reproductive biology were studied on ten randomly selected *Tecomella undulata* trees in the village of Luttu, located in the Jhunjhunu district of Rajasthan, India (28.216^0 N and 75.250^0 E). Phenological studies were conducted on trees selected during various phenological periods, including defoliation, growth and development, flower and fruit production, and the development and growth of different parts of the tree. Morphological changes in the shape and size of flower buds were observed as they progressed from the time of their emergence to the initial stage (10). Various stages of bud development were identified based on their distinct characteristics. For this study, 50 buds were labeled on each selected tree immediately after their emergence to record information on botanical bud development and the time taken to transient from one stage to another, as well as the total time taken to develop into fully mature flowers. To observe the time of flower opening, fully developed buds on selected branches, expected to open the next morning, were labeled the evening before, while immature buds on the same branches were removed.

To monitor flowering time, mark the buds of selected branches expected to open in the evening of the previous day or the following morning, and remove immature buds from the same branch. Pollen morphology and viability were assessed by placing the pollen on a 1% acetyl carmine stain under an electronic microscope, while stigma receptivity was determined by visually inspecting the stigma surface with the aid of a magnifying glass. A self-testing examination was conducted on recently opened flowers. Unopened flower buds were checked and secured with muslin material sacks, tied firmly at various sides of chosen plants. Flower buds that were already open and small were removed before securing. The pod setting percentage was then determined. Approximately an equal number of flower buds were left open near the secured branches of chosen trees. Each of these buds was counted, and the number of fruit sets on these branches was noted to calculate the fruit setting percentage.

Results and Discussion

Analysis of *Tecomella undulata* defoliation pattern showed slight defoliation starting in the last week of November and continuing through the 4th week of March. However, leaf fall was observed in naturally dispersed plants in the first week of February. In most trees, leaves turn yellow-brown in the last week of December, followed by a high rate of defoliation, but not all defoliation was observed simultaneously in any of the trees. New vegetative growth and new leaves appear before the old leaves fall off in adult trees. Tender green leaves appear 5–6 days after germination and turn light green within 10–15 days after germination. The leaves grow and turn dark green approximately 20–25 days after germination. Flower buds appear within one week after leaf emergence, typically in the 4th week of February and lasting until the 1st week of March in randomly selected trees (Supplementary Table 1).

Raceme-type inflorescences were observed in *T. undulata* (Fig. 1). Analysis of flowering behavior revealed that flower buds began to exhibit small protruding structures in the 4th week of February. A large number of well-developed flower buds were observed on all trees from March 6 to March 25. Flower buds started to open in the 4th week of March, and the flowering pattern was found to be asynchronous in all selected trees. The trees were in full bloom in the first two weeks of April, with the flowering period ranging from 22 to 30 days (Fig. 2). Flowering continued from the end of April to the 1st week of May. Pods began to form in the 2nd week of May after the flowering period ended. The growth and development period of the fruit is 65 to 72 days (Supplementary Table 1). Begin monitoring the pods for maturity in the second week of June. The time from bud emergence to pod growth ranged from

Table 1. Chronology of bud size in different stages from bud to flower opening in *Tecomella undulata.*

Tree No	Stage - I	Stage - II	Stage - III	Stage - IV	Stage - V
1	9.14	18.46	24.80	36.24	59.47
2	6.50	14.82	21.62	34.20	55.50
3	10.25	20.12	26.34	38.62	61.24
4	12.10	22.14	28.20	40.65	63.60
5	10.32	21.06	27.16	39.32	62.42
6	7.84	16.46	23.82	35.50	57.32
7	6.13	15.32	22.64	34.36	55.72
8	8.64	19.60	25.94	37.75	60.64
9	9.76	19.82	26.24	38.40	60.92
10	11.45	22.92	29.40	41.60	64.90
Mean	9.21	19.07	25.62	37.66	60.17
Range	6.50 - 12.10	14.82 - 22.92	21.62 - 29.40	34.20 - 41.60	55.50 - 64.90

Fig. 1. Inflorescence of *Tecomella undulata.*

Fig. 2. Full bloomed tree of *Tecomella undulata.*

141 to 152 days. The buds of all sizes were examined from initiation to opening. The lifespan of a bud was divided into five distinct stages (Table 1 and Fig. 3), summarized as follows:

Stage I: The green buds at this stage resemble small specimens, with lengths ranging from 6.5 to 12.1 mm and an average of 9.21 mm.

Stage II: Buds at this stage are spherical and green, with the calyx surrounding the crown. They measure between 14.82 and 22.92 mm in length and 19.07 mm in diameter. Buds reach this stage approximately 8 to 12 days after Stage I.

Stage III: The crown becomes slightly visible at this stage. Bud sizes range from 21.62 to 29.40 mm in length, with an average of 25.62 mm. Buds appear cylindrical, with the base green and the tip yellow. It takes about 5–7 days for buds to grow from Stage II to Stage III.

Stage IV: At this stage, the crown is fully open and large. Bud lengths vary between 34.20 mm and 41.60 mm, with an average of 37.66 mm each. The transition from Stage III to Stage IV takes only one day.

Stage V: Stage IV buds take 2 to 3 days to reach Stage V, completing bud development. The length of buds at this stage ranges from 55.50 to 64.90 mm.

The data indicates that the flower buds took approximately 20 days from initiation to opening. The period of bud development varied depending on the sequence of their emergence. Changes in bud development were observed to be rapid from stage III to stage V.

The flowers present in the raceme type of inflorescence were hermaphrodite with varied colour ranging from yellow to reddish (Fig. 4 & Fig. 5). The calyx was campanulate, 8-9 mm long, and had broadly ovate flaps. The corolla was campanulate, 5–7 cm long, and had subequally 5-lobed petals. The stamens were exerted with globous filaments. The stigma was bilamellated and elliptic. The capsules were directly elongated, bent, and smooth, and the seeds were apically winged.

The observations regarding the time of flower opening were recorded from 0400–1200 h at 1 hr intervals. The information is summarized in Table 2. Flower opening

Fig. 3. Different stages of bud development in *Tecomella undulata* for single flower.

Fig. 4. Colour variability of flower in *Tecomella undulata.*

The data on pollen morphology and stainability are displayed in Table 3. Pollen grains were circular. Following staining with acetocarmine, stained pollen grains appeared dark in color and exhibited dynamic movement, indicating viability, while unstained pollen grains were inert or non-viable. Pollen stainability in 1% acetocarmine ranged from 80.00 to 88.18%, with an average of 82.97% under electronic magnification.

Pod setting resulting from selfing and open fertilization was observed during 2018–19, and the data are displayed in Table 4. No pod setting or fruit development was observed under bagged conditions, indicating the absence of self-pollination in *T. undulata*. Pod settings under open fertilization ranged between 7.14% and 17.50%, with an average of 12.40%. It is evident from Table 4 that the average pod setting under selfing and open fertilization varied significantly. Thus, the results of the present study indicate that *T. undulata* is capable of producing pods only through open fertilization. This type of breeding behavior indicates the open-pollinated nature of this particular species. Apomixis, i.e., pod and seed setting without fertilization, was observed by bagging the castrated flower buds. Since no pod set was observed under such conditions, it suggests that apomixis is absent in *T. undulata*.

The study encompassed defoliation, leaf bud emergence and growth, flowering and fruit set, and maturation and growth behavior. Small leaves started shedding from the last week of November until the end of March. However, leaf fall was observed in the established trees during the first week of February. Most of the leaves turn yellow-brown by the last week of December, followed by a period of high defoliation. No further leaffall was observed after that. Analysis of flowering behavior revealed that flower buds begin to appear as small, elevated structures. The greatest number of beautiful flowers on each tree appears between March 6 and March 25.

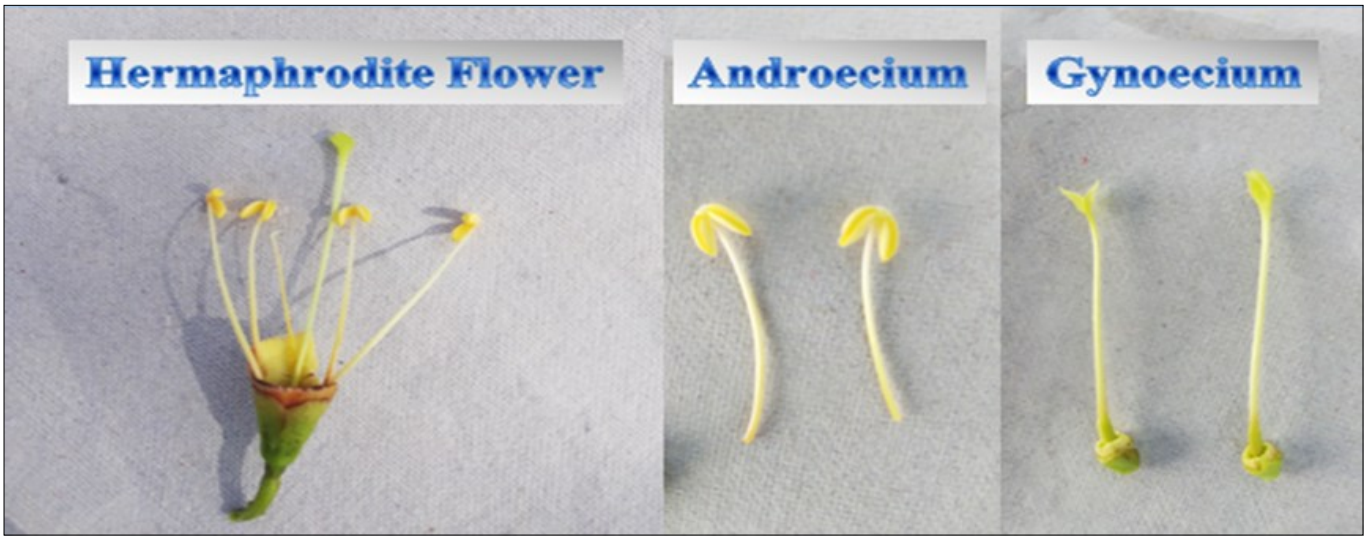

Fig. 5. Complete flower showing Androecium and Gynoecium part.

began between 0500–0600 h, and the peak blooming (37.21%) was recorded between 0800–0900 h. Most buds opened by 1100 h; however, anthesis continued until 12 h. The dehiscence of anthers began at approximately 0730 h and continued until 1130 h, with the highest frequency between 0800–0950 h.

Buds start to open in the last week of March. Flowering occurs asynchronously, with new flowers appearing on the same tree at different times. The trees reach full bloom in the last two weeks of April, with the flowering period lasting between 22 and 30 days. Flowering contin-

Table 2. Number of flowers opened during different interval of time in *Tecomella undulata* during flowering season (2018-19).

Period	Percentage (%) flower opened during						
	March last week		April first week		April third week		Mean
Time	Saturday	Sunday	Saturday	Sunday	Saturday	Sunday	
04-05 AM	-	-	-	-	-	-	-
05-06 AM	2.36	-	5.4	-	-	-	1.29
06-07 AM	6.12	9.56	7.82	8.89	7.46	6.24	7.68
07-08 AM	14.32	15.46	14.36	15.56	15.56	14.29	14.93
08-09 AM	34.56	32.94	35.75	36.58	45.21	38.24	**37.21**
09-10 AM	25.61	24.16	18.42	20	17.56	16.33	20.35
10-11 AM	9.34	12.45	10.23	11.15	5.13	11.36	9.94
11 AM-12 PM	6.36	4.56	3.67	5.4	8.57	4.16	5.45

Table 3. Pollen stainability in *Tecomella undulata* under electronic microscope.

Date of observation	Total pollen (No.)	Stainable pollens (No.)	Non-stainable pollens (No.)	Pollen stainability (%)
15-04-2019	110	97	13	88.18
16-04-2019	114	96	18	84.21
17-04-2019	90	72	18	80.00
18-04-2019	124	102	22	82.26
20-04-2019	106	85	21	80.19
Range	90 - 124	72 - 102	13 – 22	80.00 - 88.18
Mean	108.8	90.4	18.4	82.97

Table 4. Pod setting percentage under controlled (self) and open pollination in *Tecomella undulata.*

Tree No.	No. of floral buds		No. of pod setting		Pod setting percentage		Difference
	Left open	Bagged	Open pollination	Selfing (Bagging)	Open pollination	Selfing (Bagging)	
1	40	36	7	0	17.50	0	17.50
2	36	39	6	0	16.67	0	16.67
3	42	41	4	0	9.52	0	9.52
4	52	45	5	0	9.62	0	9.62
5	39	36	6	0	15.38	0	15.38
6	45	44	5	0	11.11	0	11.11
7	48	40	6	0	12.50	0	12.50
8	35	45	3	0	8.57	0	8.57
9	42	32	3	0	7.14	0	7.14
10	50	38	8	0	16.00	0	16.00
Range	35-52	32-45	3-7	0	7.14 – 17.50	0	7.14 – 17.50
Mean	42.90	39.60	5.30	0.00	12.40	0.00	12.40

ues from the end of April to the first week of May. There may be minor variations in these observations among different plants in the same season due to changes in microclimate and genetic makeup. Pod formation begins in the second week of May after the flowering period ends. The pods take 65 to 72 days to mature. Monitoring for pod maturity should commence in the week of June. The time from germination to pod growth ranges from 141 to 152 days. Similar studies on the phenology of *T. undulata* have been conducted in Balsamand, Hisar (11). They observed that budding starts in the last week of February and continues until the third week of May. The flowering of this species initiates in February, gains momentum in mid-March and April, and concludes by the end of April. The duration from germination to pod growth ranges from 141 to 152 days under open or ex-situ conditions. Similar findings have been reported in several other species, including *Ailanthus excelsa* (10), *Acacia nilotica* (12), *Jatropha curcas* (13) and *Prosopis cineraria* (14).

` In the study of floral bud development, it was observed that there were 5 distinct stages of bud development from initiation to maturity, which varied in size, shape, and slightly in color. Previous research on bud development indicated different numbers of stages in various plant species, such as 8 stages in *G optiva* (15), 5 stages in *A. excelsa* (10), *T. undulata* (11), *Dalbergia sissoo* (16) and *Melia composita* (17) and 3 stages in *P. cineraria* (14). The data revealed that the flower buds took approximately 20 days from initiation to opening, with the period of

bud development varying depending on the sequence of their emergence. Changes in bud development were observed to be rapid from stage III to stage V. In a specific study on *T. undulata*, the development of flower buds was divided into 5 different stages (11). During the initial stages of development, the flower bud took 15.5 to 19.5 days, with an average of 16.40 days, while the transition from stage IV to stage V occurred within 2 to 4 days.

T. undulata exhibits hermaphrodite flowers, indicating the presence of both androecium and gynoecium within the same flower. To investigate the pollination behavior of the flowers, some buds were covered with muslin cloth while others were left open in close proximity. Upon examination, it was observed that no fruit setting occurred in the covered buds, whereas fruit setting was observed in the open buds due to the action of air. The percentage of pod setting ranged from 7.14 to 17.50 in open pollination, while no pod setting occurred in self-pollination. Therefore, this study suggests that *T. undulata* is a cross-pollinated species due to the presence of protogynous flowers. Furthermore, the results obtained in this study are consistent with findings from several other researchers who reported similar pollination behavior in tree species (11, 18).

Conclusion

Due to the overexploitation of *Tecomella undulata* and its valuable features, there is a pressing need to increase the availability of new materials and seedlings of this species. Therefore, knowledge of its breeding behavior and phenology is essential. Following these requirements, relevant data are summarized in the text, providing valuable insights into the growth and development of this particular tree species.

Acknowledgements

We extend our sincere gratitude to the Department of Forestry at CCS Haryana Agricultural University, Hisar, for their invaluable help and unwavering support during the execution of the present study. Their expertise and cooperation significantly contributed to the success of our research and we are truly appreciative of their commitment.

Authors' contributions

VD carried out the phenological studies. VJ and SK participated in the design and coordination of work. SP and VR participated in the final data analysis and the design and proofreading of the manuscript. Also, all authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None.

Supplementary data

Supplementary Table. 1. Phenological studies on flowering and pod behavior in *Tecomella undulata*.

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