



THE PHENOLOGY OF THE NEEM TREE (*AZADIRACHTA INDICA* A.JUSS) IN AGROCLIMATIC ZONE VIII

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ABSTRACT: The neem tree (*Azadirachta indica*) is an integral part of the landscape and culture in India, revered for its medicinal properties and ecological benefits. In the states of Madhya Pradesh, Uttar Pradesh, and Rajasthan, which comes under agroclimatic zone VIII, neem trees are a common sight, thriving despite the varied climatic conditions. The phenology, or the study of cyclic and seasonal natural phenomena, of the neem tree, provides insight into its growth, flowering, fruiting, and seed dispersal patterns. Understanding how these patterns vary across different regions and conditions is crucial for effective conservation and utilization strategies. This study showcases the phenological differences among Madhya Pradesh, Rajasthan, and Uttar Pradesh.

Keywords: *Neem, Azadirachta indica, Phenology, Agroclimatic zones*

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INTRODUCTION

The phenology of the Neem (*Azadirachta indica*) in central India, encompassing states like Madhya Pradesh, Uttar Pradesh, and Rajasthan, is influenced by variations in fruit size due to water availability, particularly rainfall patterns. Studies have shown that neem trees exhibit distinct phenological responses to changes in water availability, impacting fruit development. The variability and trends of extreme rainfall events in central India have been analyzed over a significant period, highlighting the importance of water availability (Rajeevan *et al.*, 2008). Neem's reproductive biology, including phenology, has been studied in different regions of India, shedding

light on how water availability affects its growth and fruit development (Vikas and Tandon, 2010). Neem oils from various locations in India have been examined for their bioactivities, indicating a relationship between neem products and environmental factors like rainfall (Isman *et al.*, 1990).

Neem, a versatile plant with medicinal and agricultural applications, has been extensively studied in India. Its antioxidant properties and potential as a bioinsecticide have been explored, showcasing its diverse uses (Heyman *et al.*, 2017). Furthermore, neem's impact on cancer prevention and treatment has been investigated, demonstrating its pharmacological potential (Fang

et al., 2014). The genomic and metabolomic analyses of neem have revealed its vast herbal preparations and local practices in India, emphasizing its role in traditional medicine and agriculture (Kuravadi *et al.*, 2015). Neem's physiological responses to weather conditions, including water availability, have been documented, providing insights into its growth patterns under varying climatic conditions (Pugazenthi *et al.*, 2021).

The phenology of the neem tree (*Azadirachta indica*) in India is a topic of interest due to its ecological and medicinal significance. Neem, an evergreen tree native to India, has been extensively studied for its various properties and applications. Research has shown that neem extracts from different parts of the tree, including leaves, seeds, flowers, and bark, possess a wide range of beneficial properties such as insecticidal, antifungal, and anticancer activities (Braga *et al.*, 2021; Brahmachari, 2004; Moga *et al.*, 2018; Fang *et al.*, 2014; Reddy & Neelima, 2022; Khanpara & Jadeja, 2022). The phenology of the neem tree includes several stages: leaf flush, flowering, fruit set, and fruit maturation. These stages are influenced by environmental factors such as temperature, rainfall, and soil moisture. In India, neem trees typically begin leaf flush in early spring and flowering in late spring to early summer. Fruit set and maturation occur in the summer, with seeds dispersing in the late summer to early autumn.

MATERIAL AND METHODS

STUDY AREA AND SITE SELECTION

The study was conducted in agroclimatic zone VIII of India, encompassing three states - Madhya Pradesh, Uttar Pradesh, and Rajasthan. Neem trees (*Azadirachta indica* A. Juss) were selected from representative locations in each state to capture the variability in phenological behavior attributed to regional climatic differences. At least 20 mature trees were marked and observed at the Katni, Madhya Pradesh site for consistent data

collection across three consecutive growing seasons (2022–2024).

PHENOLOGICAL OBSERVATIONS

Phenological observations were made from January 2022 to December 2024, covering the entire annual cycle of the neem tree. Key phenological stages recorded included leaf flushing, flowering, fruit set, fruit maturation, and seed dispersal. Observations were performed in situ by direct visual assessment of marked trees using standard phenological scales.

DATA COLLECTION AND ANALYSIS

The presence and absence of the particular phenological activity were observed. The timing and duration of each phenological stage were compared across locations. Climatic data such as rainfall and temperature were obtained from regional meteorological departments to correlate phenological trends with environmental variables, particularly water availability.

Observations focused on the following phenological stages:

- **LEAF FLUSH:** The time when new leaves emerge, typically in early spring.
- **FLOWERING:** The period when the neem tree blooms, usually occurring in late spring to early summer.
- **FRUIT SET:** The time when flowers are pollinated and fruit begins to develop, usually during the summer months.
- **FRUIT MATURATION AND SEED DISPERSAL:** The final stage, occurring in late summer to early autumn when the fruits mature and seeds are dispersed.

Observations were recorded at regular intervals (monthly) during the growing season to capture the onset and duration of each phenological phase.

CLIMATIC DATA:

Climatic data, including temperature, relative

humidity, and rainfall, were obtained from local meteorological stations in each region for the years 2022 to 2024. These data were used to analyze the relationship between environmental factors and the phenological events of the neem tree.

1. **TEMPERATURE:** Average monthly temperatures were recorded to assess the

influence of temperature on the phenological phases.

2. **RAINFALL:** Monthly rainfall data were used to study the impact of water availability on fruit development and maturation.

3. **RELATIVE HUMIDITY:** Data on humidity were considered to understand how moisture levels in the air affect flowering and fruiting.

Table 1. Climatic Conditions in the Three States (2022-2024)

Region	Average Annual Rainfall (mm)	Temperature (°C)	Relative Humidity (%)	Rainfall (2022)	Rainfall (2023)	Rainfall (2024)
Madhya Pradesh	1,000 - 1,600	25 - 40	60 - 80	1,200	1,400	1,500
Uttar Pradesh	600 - 1,200	28 - 42	50 - 75	900	1,100	1,000
Rajasthan	200 - 500	30 - 45	30 - 60	400	350	500

TOOLS AND INSTRUMENTS USED

Standard field notebooks, GPS devices for geo-referencing, and digital cameras were used for recording observations. Meteorological data were collected using rain gauges, temperature loggers, and government climate datasets from the Indian Meteorological Department (IMD).

REGIONAL CLIMATIC CONDITIONS

- 1. **MADHYA PRADESH:** Characterized by a tropical climate, Madhya Pradesh experiences a hot summer, a monsoon season, and a cool winter. The average annual rainfall ranges from 1,000 to 1,600 mm, with higher precipitation in the eastern part of the state.
- 2. **UTTAR PRADESH:** This state experiences a subtropical climate with hot summers, a monsoon season, and cool winters. The average annual rainfall varies significantly,

from 600 mm in the western regions to 1,200 mm in the east.

- 3. **RAJASTHAN:** Known for its arid and semi-arid climate, Rajasthan has extreme temperatures and low rainfall, averaging around 500 mm annually, primarily during the monsoon season. The western part of the state is particularly dry, with some areas receiving less than 200 mm of rainfall annually.

PHENOLOGICAL PATTERNS AND WATER AVAILABILITY

Water availability plays a crucial role in the phenology of the neem tree, influencing the size and quality of fruits. The following sections describe how the phenological stages of neem trees vary across Madhya Pradesh, Uttar Pradesh, and Rajasthan.

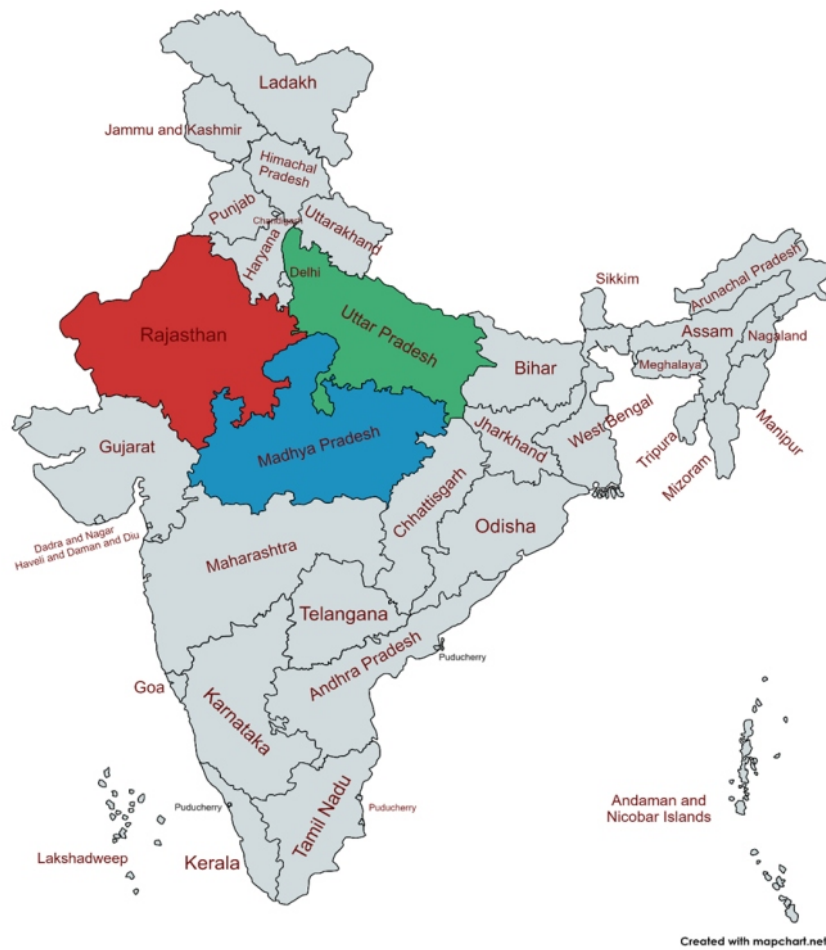


Fig. 1. Map of India showing agroclimatic zone VIII, including the states: MP, UP, and Rajasthan.

LEAF FLUSH MADHYA PRADESH: With its relatively higher and more consistent rainfall, neem trees in Madhya Pradesh exhibit a vigorous leaf flush in early spring (March-April). Adequate soil moisture and moderate temperatures promote the growth of lush green foliage, which is essential for photosynthesis and overall tree health.

UTTAR PRADESH: In Uttar Pradesh, the timing of leaf flush is similar to Madhya Pradesh, occurring in March-April. However, regions with lower rainfall may see a less vigorous leaf flush. Neem trees in areas with adequate irrigation or natural water sources tend to have a more robust leaf flush compared to those in drier regions.

RAJASTHAN: The arid conditions in Rajasthan result in a delayed and less vigorous leaf flush,

often occurring in late April to early May. Limited soil moisture and high temperatures can stress the trees, leading to sparser foliage compared to the other states. Neem trees in irrigated areas or regions with higher water availability show a comparatively better leaf flush.

FLOWERING

Understanding the flowering periodicity of trees like neem is crucial for ecological studies. Studies have highlighted the importance of environmental factors such as climate and photoperiod in influencing the flowering patterns of tropical tree species, including neem (Borchert et al., 2004; Singh & Kushwaha, 2005; Selwyn & Parthasarathy, 2006; Kushwaha et al., 2010). The synchronization of flowering with the dry season in

Central America has been proposed as an adaptive strategy for maximizing reproductive success (Janzen, 1967).

Additionally, the diversity of flowering and fruiting phenology in tropical deciduous forests in India has been documented, showing unique adaptations to seasonal climates (Singh and Kushwaha, 2005).

MADHYA PRADESH: Flowering in neem trees begins in late April to early May, coinciding with rising temperatures. The relatively high humidity and sufficient soil moisture create favorable conditions for abundant flowering. The inflorescences are large and well-developed, attracting various pollinators.

UTTAR PRADESH: Flowering in Uttar Pradesh also occurs in late April to early May. Regions with higher rainfall and better soil moisture conditions see more prolific flowering. In drier areas, the number of flowers and the size of inflorescences may be reduced.

RAJASTHAN: In Rajasthan, flowering is often delayed until May due to the harsh climatic conditions. The lower humidity and soil moisture result in fewer and smaller inflorescences. However, neem trees near water sources or in irrigated areas can still produce a reasonable number of flowers.

Moreover, the reproductive biology of neem, including phenology, floral biology, and pollination ecology, has been investigated in natural populations in India, shedding light on the breeding system of this medicinal tree species (Vikas and Tandon, 2010). Studies have also explored the impact of mycorrhizal inoculation on neem trees, demonstrating enhanced azadirachtin content in seed kernels (Venkateswarlu *et al.*, 2007). Furthermore, the response of neem trees to weather conditions, particularly in rainfed semi-arid regions of India, has been studied, emphasizing the adaptability of neem to different environmental conditions (Pugazenthi *et al.*, 2021).



Fig. 2. Leaves and fruits of Neem trees at Katni, Madhya Pradesh

FRUIT SET AND MATURATION

MADHYA PRADESH: Neem fruits are set in late May to early June, with maturation occurring by late June to July. The ample water availability and moderate temperatures ensure a good fruit set. The fruits in Madhya Pradesh are typically larger and more numerous due to the favorable conditions.

UTTAR PRADESH: The fruit set in Uttar Pradesh occurs around the same time i.e. late May to early July, as in Madhya Pradesh. Regions with sufficient rainfall and soil moisture see larger and more numerous fruits. In contrast, drier regions may have smaller fruits and a reduced yield.

RAJASTHAN: In Rajasthan, the fruit set is often delayed until June, with maturation extending into August. The harsh conditions result in smaller and fewer fruits. However, in areas with better water availability, such as near rivers or where irrigation is practiced, the fruit size and yield can be comparable to those in more favourable regions.

SEED DISPERSAL

MADHYA PRADESH: Seed dispersal in Madhya Pradesh begins in late summer (August-September). The seeds are typically large and viable, ensuring good germination rates. The ample water availability during the monsoon season aids in seed germination and seedling establishment.

UTTAR PRADESH: Seed dispersal in Uttar Pradesh also occurs in late summer. In regions with better rainfall, the seeds are larger and more viable. However, in drier areas, the seeds may be smaller and less viable, affecting the overall germination rates.

RAJASTHAN: In Rajasthan, seed dispersal extends into September - October. The harsh climatic conditions result in smaller and less viable seeds. However, in regions with better water availability, the seed size and viability are improved, leading to better germination rates.

Table 2. Phenological pattern of the Neem tree across agroclimatic zone VIII

S.No.	Agroclimatic zone VIII (State)	Leaf flush	Flowering	Fruit maturation	Seed dispersal
1	Madhya Pradesh	March – April (Early spring)	Late April – Early May	Late May – Early June	In late summer (Early June-August)
2	Uttar Pradesh	March – April	Late April – Early May	May to early June	In late summer (Late June- Late August)
3	Rajasthan	April – early May	Late April – Late May	Late June – early August	Late July-Early September

Table 3. Month-wise phenological observations of Katni, M.P. Neem trees, showing Leaf flush

Tree number	Months											
	Jan	Feb	Mar	Apr	May	June	July	August	Sept	Oct	Nov	Dec
KAT1	-	-	+++	+++	-	-	-	-	-	-	-	-
KAT2	-	-	+++	+++	-	-	-	-	-	-	-	-
KAT3	-	-	+++	+++	-	-	-	-	-	-	-	-
KAT4	-	-	+++	+++	-	-	-	-	-	-	-	-

Table Contd...

KAT5	-	-	+++	+++	-	-	-	-	-	-	-	-
KAT6	-	-	+++	+++	-	-	-	-	-	-	-	-
KAT7	-	-	+++	+++	-	-	-	-	-	-	-	-
KAT8	-	-	+++	+++	-	-	-	-	-	-	-	-
KAT9	-	-	+++	+++	-	-	-	-	-	-	-	-
KAT10	-	-	+++	+++	-	-	-	-	-	-	-	-
KAT11	-	-	+++	+++	-	-	-	-	-	-	-	-
KAT12	-	-	+++	+++	-	-	-	-	-	-	-	-
KAT13	-	-	+++	+++	-	-	-	-	-	-	-	-
KAT14	-	-	+++	+++	-	-	-	-	-	-	-	-
KAT15	-	-	+++	+++	-	-	-	-	-	-	-	-
KAT16	-	-	+++	+++	-	-	-	-	-	-	-	-
KAT17	-	-	+++	+++	-	-	-	-	-	-	-	-
KAT18	-	-	+++	+++	-	-	-	-	-	-	-	-
KAT19	-	-	+++	+++	-	-	-	-	-	-	-	-
KAT20	-	-	+++	+++	-	-	-	-	-	-	-	-

Where, '+' denotes presence, '-' denotes absence of particular phenological activity and '+++' denotes the presence of a large amount of particular phenological activity

Table 4. Month-wise phenological observations of Katni, M.P. Neem trees, showing Flowering

S.No.	Months											
	Jan	Feb	Mar	Apr	May	June	July	August	Sept	Oct	Nov	Dec
KAT1	-	-	-	++	++	-	-	-	-	-	-	-
KAT2	-	-	-	++	++	-	-	-	-	-	-	-
KAT3	-	-	-	++	++	-	-	-	-	-	-	-
KAT4	-	-	-	++	++	-	-	-	-	-	-	-
KAT5	-	-	-	++	++	-	-	-	-	-	-	-
KAT6	-	-	-	++	++	-	-	-	-	-	-	-
KAT7	-	-	-	++	++	-	-	-	-	-	-	-
KAT8	-	-	-	++	++	-	-	-	-	-	-	-
KAT9	-	-	-	++	++	-	-	-	-	-	-	-
KAT10	-	-	-	++	++	-	-	-	-	-	-	-
KAT11	-	-	-	++	++	-	-	-	-	-	-	-

Table Contd...

KAT12	-	-	-	++	++	-	-	-	-	-	-	-
KAT13	-	-	-	++	++	-	-	-	-	-	-	-
KAT14	-	-	-	++	++	-	-	-	-	-	-	-
KAT15	-	-	-	++	++	-	-	-	-	-	-	-
KAT16	-	-	-	++	++	-	-	-	-	-	-	-
KAT17	-	-	-	++	++	-	-	-	-	-	-	-
KAT18	-	-	-	++	++	-	-	-	-	-	-	-
KAT19	-	-	-	++	++	-	-	-	-	-	-	-
KAT20	-	-	-	++	++	-	-	-	-	-	-	-

Where, '+' denotes presence, '-' denotes absence of particular phenological activity and '+++' denotes the presence of a large amount of particular phenological activity

Table 5. Month-wise phenological observations of Katni, M.P. Neem trees, showing Fruit maturation

S.No.	Months											
	Jan	Feb	Mar	Apr	May	June	July	August	Sept	Oct	Nov	Dec
KAT1	-	-	-	-	+	++	+++	-	-	-	-	-
KAT2	-	-	-	-	+	++	+++	-	-	-	-	-
KAT3	-	-	-	-	+	++	+++	-	-	-	-	-
KAT4	-	-	-	-	+	++	+++	-	-	-	-	-
KAT5	-	-	-	-	+	++	+++	-	-	-	-	-
KAT6	-	-	-	-	+	++	+++	-	-	-	-	-
KAT7	-	-	-	-	+	++	+++	-	-	-	-	-
KAT8	-	-	-	-	+	++	+++	-	-	-	-	-
KAT9	-	-	-	-	+	++	+++	-	-	-	-	-
KAT10	-	-	-	-	+	++	+++	-	-	-	-	-
KAT11	-	-	-	-	+	++	+++	-	-	-	-	-
KAT12	-	-	-	-	+	++	+++	-	-	-	-	-
KAT13	-	-	-	-	+	++	+++	-	-	-	-	-
KAT14	-	-	-	-	+	++	+++	-	-	-	-	-
KAT15	-	-	-	-	+	++	+++	-	-	-	-	-
KAT16	-	-	-	-	+	++	+++	-	-	-	-	-

Table Contd...

KAT17	-	-	-	-	+	++	+++	-	-	-	-	-
KAT18	-	-	-	-	+	++	+++	-	-	-	-	-
KAT19	-	-	-	-	+	++	+++	-	-	-	-	-
KAT20	-	-	-	-	+	++	+++	-	-	-	-	-

Where, '+' denotes presence, '-' denotes absence of particular phenological activity and '+++ denotes the presence of a large amount of particular phenological activity

Table 6. Month-wise phenological observations of Katni, M.P. Neem trees, showing Seed dispersal

S.No.	Months											
	Jan	Feb	Mar	Apr	May	June	July	August	Sept	Oct	Nov	Dec
KAT1	-	-	-	-	-	-	-	+	+++	-	-	-
KAT2	-	-	-	-	-	-	-	+	+++	-	-	-
KAT3	-	-	-	-	-	-	-	+	+++	-	-	-
KAT4	-	-	-	-	-	-	-	+	+++	-	-	-
KAT5	-	-	-	-	-	-	-	+	+++	-	-	-
KAT6	-	-	-	-	-	-	-	+	+++	-	-	-
KAT7	-	-	-	-	-	-	-	+	+++	-	-	-
KAT8	-	-	-	-	-	-	-	+	+++	-	-	-
KAT9	-	-	-	-	-	-	-	+	+++	-	-	-
KAT10	-	-	-	-	-	-	-	+	+++	-	-	-
KAT11	-	-	-	-	-	-	-	+	+++	-	-	-
KAT12	-	-	-	-	-	-	-	+	+++	-	-	-
KAT13	-	-	-	-	-	-	-	+	+++	-	-	-
KAT14	-	-	-	-	-	-	-	+	+++	-	-	-
KAT15	-	-	-	-	-	-	-	+	+++	-	-	-
KAT16	-	-	-	-	-	-	-	+	+++	-	-	-
KAT17	-	-	-	-	-	-	-	+	+++	-	-	-
KAT18	-	-	-	-	-	-	-	+	+++	-	-	-
KAT19	-	-	-	-	-	-	-	+	+++	-	-	-
KAT20	-	-	-	-	-	-	-	+	+++	-	-	-

Where, '+' denotes presence, '-' denotes absence of particular phenological activity and '+++ denotes the presence of a large amount of particular phenological activity

THE ROLE OF WATER AVAILABILITY

Water availability is a critical factor influencing the phenological stages and fruit size of neem trees. In regions with higher rainfall and better soil moisture, neem trees exhibit more vigorous growth, larger and more numerous flowers, and larger fruits. In contrast, in arid regions with limited water availability, neem trees show delayed phenological stages, reduced growth, and smaller fruits.

ADAPTATIONS AND SURVIVAL STRATEGIES

Neem trees have developed several adaptations to survive and thrive in diverse climatic conditions:

1. **DEEP ROOT SYSTEM:** Neem trees have a deep taproot system that allows them to access groundwater in arid regions. This adaptation helps them survive prolonged dry periods and continue their growth and reproductive cycles.
2. **DROUGHT TOLERANCE:** Neem trees are highly drought-tolerant, able to withstand extended periods of low rainfall. Their leaves have a waxy coating that reduces water loss through transpiration.
3. **PHENOTYPIC PLASTICITY:** Neem trees exhibit phenotypic plasticity, allowing them to adjust their growth and reproductive strategies based on environmental conditions. In regions with limited water, they may delay or reduce certain phenological stages to conserve resources.
4. **EFFICIENT WATER USE:** Neem trees have evolved to use water efficiently, with specialized structures such as sunken stomata that minimize water loss. This adaptation is particularly beneficial in arid regions like Rajasthan.

IMPLICATIONS FOR CONSERVATION AND UTILIZATION

Understanding the phenology of neem trees and the influence of water availability is crucial for effective conservation and utilization strategies.

Here are some implications for various stakeholders:

1. **FORESTRY MANAGEMENT:** Forestry departments can use phenological data to plan afforestation and reforestation programs. Planting neem trees during optimal seasons and ensuring adequate water availability can enhance survival rates and growth.
2. **AGRICULTURAL PRACTICES:** Farmers can benefit from understanding neem tree phenology, particularly in agroforestry systems. Integrating neem trees with crops can provide shade, reduce soil erosion, and improve soil fertility.
3. **WATER MANAGEMENT:** Efficient water management practices, such as rainwater harvesting and drip irrigation, can enhance the growth and productivity of neem trees in arid regions. Ensuring adequate water availability during critical phenological stages can improve fruit size and yield.
4. **MEDICINAL AND COMMERCIAL USES:** The size and quality of neem fruits are important for their medicinal and commercial uses. By understanding the influence of water availability, producers can optimize the conditions for harvesting high-quality fruits and seeds.

DISCUSSION

The study aimed to understand the phenological patterns of *Azadirachta indica* (neem tree) across the three states of Madhya Pradesh, Uttar Pradesh, and Rajasthan in Agroclimatic Zone VIII. Phenology is a key aspect in understanding plant growth, reproduction, and how species interact with environmental conditions, including temperature, humidity, and most notably, water availability. The results highlight significant differences in the rainfall patterns and how these variations influence the phenological phases of neem trees.

CLIMATIC INFLUENCE ON PHENOLOGY

Water availability, as influenced by rainfall patterns, was a critical factor affecting the phenology of neem trees in the three states.

In **Madhya Pradesh**, which received relatively higher rainfall (1,200 to 1,500 mm annually), neem trees displayed a consistent pattern of leaf flush in early spring, followed by flowering in late spring. This rainfall pattern facilitated healthy fruit set and maturation, leading to robust seed dispersal. The relatively high humidity and temperature also supported the reproductive cycles of neem trees, promoting healthy vegetative and reproductive growth.

In **Uttar Pradesh**, with rainfall varying from 600 mm in the west to 1,200 mm in the east, neem trees exhibited more variability in phenological timing, particularly in the western region, where lower rainfall may have delayed leaf flush and flowering. Despite the variation, the availability of monsoon rains helped induce flowering and fruit set in the eastern regions, albeit with fewer and smaller fruits in the western regions.

Rajasthan, characterized by a much drier climate with average annual rainfall ranging from 200 mm to 500 mm, showed a pronounced effect of water scarcity on neem's phenology. In the drier western parts of Rajasthan, neem trees experienced delayed leaf flush and flowering, with some trees not fully maturing fruit within a season. The lower rainfall and higher temperatures likely stressed the trees, limiting their reproductive output. This highlights the resilience of neem to survive in arid conditions, though at the cost of reduced reproductive success.

INTERANNUAL VARIABILITY

Across all three states, the interannual variation in rainfall from 2022 to 2024 had a noticeable impact on the timing and duration of phenological events. For instance, the higher rainfall observed in 2023 and 2024 in Madhya Pradesh likely led to earlier and more synchronized phenological events, while

drier conditions in Rajasthan and parts of Uttar Pradesh resulted in more scattered and delayed events. These findings support previous studies that highlight the influence of rainfall on the flowering and fruiting patterns of neem trees (Rajeevan *et al.*, 2008; Vikas and Tandon, 2010).

IMPLICATIONS FOR CONSERVATION AND MANAGEMENT

This study provides valuable insights into the relationship between water availability and the phenology of neem trees, which has implications for conservation and management strategies. In regions with insufficient rainfall, like Rajasthan, strategies such as water conservation, irrigation, or the selection of drought-resistant neem varieties may be necessary to ensure consistent fruiting. On the other hand, regions like Madhya Pradesh, which receive sufficient rainfall, could serve as ideal zones for large-scale neem cultivation, especially for medicinal and agricultural purposes.

Furthermore, understanding the phenological patterns of neem trees across varying climatic conditions can also help in forecasting the best harvest periods and improve the timing of interventions like pest control or seed collection for reforestation programs.

CONCLUSION

The study underscores the complex relationship between climate and plant phenology, particularly for species like *Azadirachta indica*, which plays a critical role in both the environment and traditional medicine. By examining the phenology of neem trees across diverse climatic regions in Agroclimatic Zone VIII, this research contributes to the broader understanding of how neem can be utilized and conserved under changing climate conditions.

The neem tree, with its myriad benefits and ecological significance, thrives in diverse climatic conditions across Madhya Pradesh, Uttar Pradesh, and Rajasthan. Its phenological stages, particularly fruit size and quality, are heavily

influenced by water availability. Understanding these patterns helps in formulating effective conservation, forestry management, and agricultural practices, ensuring that the neem tree continues to provide its valuable benefits to the environment and communities.

In regions with better water availability, neem trees exhibit more robust growth, larger fruits, and higher yields. Conversely, in arid regions like Rajasthan, the trees show remarkable adaptations to survive and reproduce, albeit with smaller and fewer fruits. By harnessing the knowledge of neem tree phenology and ensuring adequate water management, we can enhance the sustainability and productivity of this vital tree species.

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