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Phenology of *Terminalia chebula* tree in the Dry Deciduous Forest of Cauvery Wildlife Sanctuary, Karnataka, Southern India

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ABSTRACT

The study was conducted at Cauvery wildlife sanctuary, Karnataka, India from 2015 to 2019. This study intended to understand the periodic events in biological life cycles concerning changes in the timings of seasonal events. It includes leafing, flowering, and fruiting patterns among the selected tree species of *Terminalia chebula* Retz., which is an important non-timber forest product (NTFPs) species in the Cauvery wildlife sanctuary. A total of 32 adult individual trees, from two transects at different places were selected and were observed at thirty days intervals. It was observed that there was a species-specific phenological relationship between the deciduous period and the initiation of seasonal rainfall and warm periods. Leaf maturity peak was in August. Leaf fall activity was in January before the arrival of an intense dry period. The reproductive phenology like flowering, fruiting, and fruit obsession was significantly varied across the different seasons among the observed tree species. The majority of tree species (56%) revealed synchronous flowering with Leaf flush activity. The results indicate that Leafing (58%) and flowering phenology (75%) occur during the dry period before the onset of first rains and fruiting, fruit fall timing was in consequence to utilize the growing season. Thus, species specificity was recorded concerning flowering and fruiting and was found to be with the seasonal rainfall distribution and in turn soil moisture availability in the study area. The results of the study would help in better management of fruiting tree species in natural forests.

KEYWORDS: Cauvery wildlife sanctuary, flowering, fruiting, phenology, seasonality

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1. INTRODUCTION

Phenological studies reveal the pattern of leafing, flowering and fruiting of a plant species and levels of asynchrony among individuals and between species. It would benefit to understand the impact of climate change on tropical tree species. It also elucidated the potential consequences of phenological changes on the biological community as a whole (Vitasse et al., 2009, Powe and Bentz, 2014, Gonzalez-Rodriguez et al., 2014, Anonymous, 2023). The seasonality of tropical tree phenology is mainly determined by the length and intensity of seasonal microclimatic change such as amount of rainfall, number of rain dyas and temperature of the region (Murali and Sukumar, 1993, Krishnan, 2002). However, few studies were focused on community-level phenology change in the deciduous forest of India (Nanda et al., 2014, Singh and Sahoo, 2019, Olsson et al., 2013) and only one study conducted in montane forests in Nilgiris have been reported in seasonality studies (Suresh and Sukumar, 2011).

Among the plants, the deviations in phenological events such as leaf fleshing, leaf development, leaf fall, flower initiation, flowering synchrony, and fruit initiation, fruit maturation and senescence are directly associated with seasons, rainfall patterns, soil moisture, and temperature (Yadav and Yadav, 2008). Tree communities in the dry tropical forest grow with marked dry and wet conditions in an annual period (Saha, 2007, Jeganathan et al., 2014, Anonymous, 2023). Many studies observed that high variations in vegetative and reproductive phonological patterns in natural forests are determined by climatic and soil factors (Powe and Bentz, 2014). The phenological patterns of tree species some extent also determined by biotic factors like pollinator attraction, competition for seed dispersers, and avoidance of herbivores different in tropical dry forests (Saravanan and Muthuchelian, 2014, Singh and Sahoo, 2019).

Plants are very sensitive to microclimatic change and it has been reflected in phenological patterns. Particularly in seasonal tropical forests, plant phenological patterns were controlled by various interactions between biotic and climatic factors, especially seasonal variation in rainfall, dry periods which influence soil moisture, and tree water status are considered the principal factors influencing the timings of the periodic phenological of growth and reproduction (Sakai, 2001, Khanduri et al., 2013, Suresh and Sukumar, 2018). Thus, phenological events should be measured by both abiotic factors and plant functional traits (leafing flowering and fruiting) to realize the understanding of tree community (Hatfield and Prueger, 2015). Studies revealed that in the dry tropical forest, the highest leaf flushing activity and flowering events occur together during the dry period before the onset of the first rains (Saravanan and Muthuchelian, 2014, Nanda et al., 2014, Anonymous, 2022).

The populations of *T. chebula* spatially occurs at lower elevations (<900 m), in scrub forests to dry deciduous forests (Setty et al., 2008). *T. chebula* is slow-growing shade-tolerant species and has poor seed germination capacity in natural conditions. *Terminalia chebula* is commonly known as Harar and it is extensively used in Ayurvedic medicine and other cosmetics.

Consequently, seasonal rains (soil moisture availability) and the extent of the deciduous period (photoperiod) influence the leafing and reproductive phenological events in dry deciduous forest trees (Zhang et al., 2017, Mastan et al., 2020). Therefore, it is important to observe, monitor and record the leafing, flowering and fruiting patterns with respect to seasons and micro climatic changes. This paper intended to understand the pattern and relationship with climatic variables such as rainfall and temperature. The objectives of the study are to understand the phenological patterns of the *T. chebula* population in the dry deciduous forest, to make analysis of factors that determine the phenological behaviour and anthropogenic impacts on general phenological patterns of the study species.

2. MATERIALS AND METHODS

2.1. Study site

The study was conducted in during 2015–2019 period in Cauvery Wildlife Sanctuary (CWS), Karnataka, India which is located between latitude 11°56'55.45"N to 12°24'36.70"N Longitude: 77°9'35.13"E to 77°46'40.60"E. The Sanctuary covers an area of 1097 km^2, and it is one of the largest protected areas in Karnataka, India. It was established in 1987, partly to protect the Cauvery River. The altitude varies from 250–1,500 m.

The average annual rainfall ranges from 750 to 800 mm, and the temperature ranges between 15°C and 38°C (Running and Zhao, 2017; Wan et al., 2021) (Figure 2). The Cauvery River flowing through the hills offers many places of tourist interest and religious importance. The CWS mainly consists of dry deciduous forests, thorn scrub, tropical moist deciduous, and bamboo forests. Ground fires used to occur during summers (March–May) every year until 2016 when the Karnataka Forest Department (KFD) prohibited burning (Figure 1).

2.2. Methods

There were two transect (Honnemarada sonne and Ganalulubetta) marked in CWS and a total of 32 tree individuals of *T. chebula* having girth at breast highest (GBH) >5.5 cm, were selected for the phenological

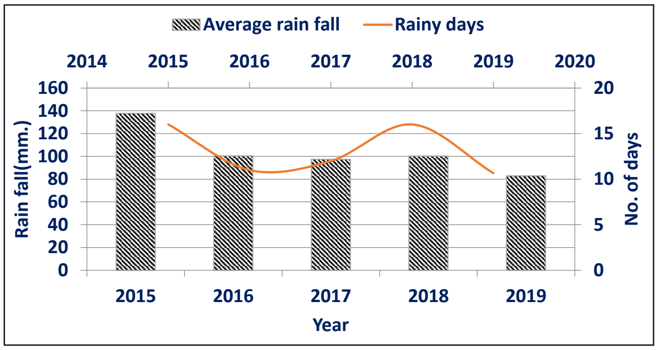

Figure 1: Rain fall and rainy days for the study area

observations (Figure 1). Two branches (A & B) of 32 reproductively matured individuals of each species were marked and monitored every 30 days intervals over4 years from August 2015 to August 2019.

The phenology like leaf flush, leaf mature, leaf fall, leafless, flowering, fruiting, and fruit fall was recorded. If at least five individuals in the species feature phenology it was considered as the initiation of that particular activity and the extension of that activity was noticed till at least eight individuals have promulgated the phenological activity. The average of the four years' data was taken into consideration for the analysis (Table 1).

Table 1: Transect location and variables used

Variables	Transect name	
	Ganalubetta	Honnemaradasonne
Number of trees	16	16
DBH range (cm.)	4.4 to 18.1	9.8 to 22.9
Height (m.)	3.5 to 8	5.0 to 10.0
Latitude	12 332.98	77 345.558
Longitude	12 21.353	77 152.047
Elevation (m.)	636	632
Number of months monitored	48 months	48 months
Forest type	Dry deciduous	Dry deciduous
Observation recorded	Leaf, flower and fruit	Leaf, flower and fruit

The phenotypic variations in the leaf viz., leaflessness (LL), leaf bud (LB), leaf tender (LT),

leaf mature (LM), and leaf senescence (LS) were noted every month. The flower formation events as flower bud (FB), flower open (FO), and flower abscission (FA) during flowering /non-flowering season (if any) were recorded. Furthermore, the fruit formation events as fruit bud (FRB), fruit immature (FRI), fruit mature (FRM), and fruit abscission (FRA) during fruiting/nonfruiting season (if any) were recorded too. The rainfall and temperature data for three years were collected from the forest department.

2.3. Data analysis

The phenological data analysis was carried out using a spreadsheet and R (version 3.3.1) (Table 1). Spearman's rank correlation with current and lagmonths was performed to assess the independent influence of each environmental factors.

The phenological variables and dates of observation were used in Circular statistical analyses to create seasonal graphs and patterns. To calculate the circular statistical parameters, months were converted to angles, from 0°=January (number 1) to 330°=December (number 12) at intervals of 30°. We converted the day of observation in a given month to angles. Rayleigh's Z test interpretation formula was used as given below.

Rayleigh's Z test interpretation:

a ¼ 360x=k.................(1)

Where 'a' is the angular direction (in degrees), 'x' is the conversion of the date of observation from months to days, and 'k' is the number of days in the year (k=365, or 366 in a leap year). The frequency of occurrence of species at each phenological variable within each angle was calculated and the following parameters were estimated for each study site: the mean angle 'a, the angular dispersal, confidence limits of the frequency distribution for each phenological variable, and vector 'r', a measure of concentration around the mean angle.

Spearman rank correlations were carried out to obtain coefficients for the number of tree species in each phenology in a month by the current and one to three-month lag period rainfall data using procedures described by Zar (2007) (Formula was adapted with relevant modification from Nanda et al. 2014).

3. RESULTS AND DISCUSSION

3.1. Leaf phenology

Leaf phenology being the study of the timing of leaf initiation; its expansion and leaf fall (Figure 2). which is responsible for the capture of carbon dioxide and photosynthesis connected to the productivity of the tree. With the advent of a favourable climate, the trees start the beginning of young leaves leading to the formation of leaf flush essential for the development of plants by photosynthesis and the productivity of the forest.

The pattern of leaf phenology of *T. chebula* started with leaf initiation and it was first recorded during March and reached a peak during May (38%) followed by June (14%).

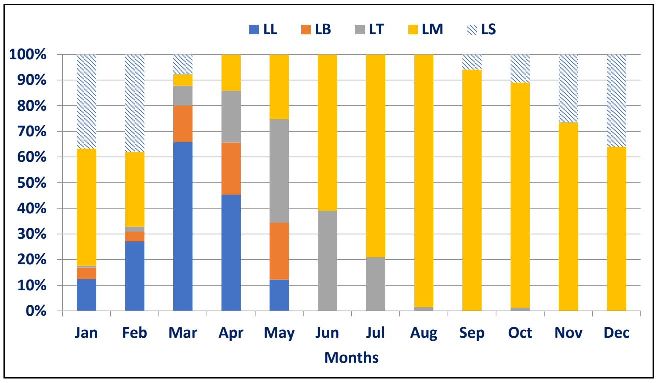

Figure 2: Leaf phenological patterns of *T. chebula* in CWLS

In all the 32 tree individuals, leaf flushing activity had conspicuously started on the total leafless twigs. Further, the majority of the trees (85.7%) had propagated their first leaves in the summer period before the onset of rains, and few trees have produced new leaves after the first rains concurring with the onset of the monsoon period.Leaf fall was recorded just after the end of the monsoon period and well before the onset of the dry period in November. Distinct leafless period (Deciduous period) was as low as 14, and 16 days in Ganalubetta (Deciduous slope forest) and Honnemaradasonne (ravine) respectively, and as high as 106 days in and 105 days in Ganalubetta and Honnemaradasonne respectively.

3.2. *Flower and fruit phenology*

Flowering and fruiting phenology were monitored at monthly intervals for four years. Peak flowering occurred during the dry month of May and the fruiting peak was recorded the during monsoon months of June–July. The synchronized flowering period was one month which was also recorded as the highest temperature in a year. The May month was the flowering season recorded (>80%) regularly throughout the study period. However, flower bud break was first recorded in January, followed by February, and

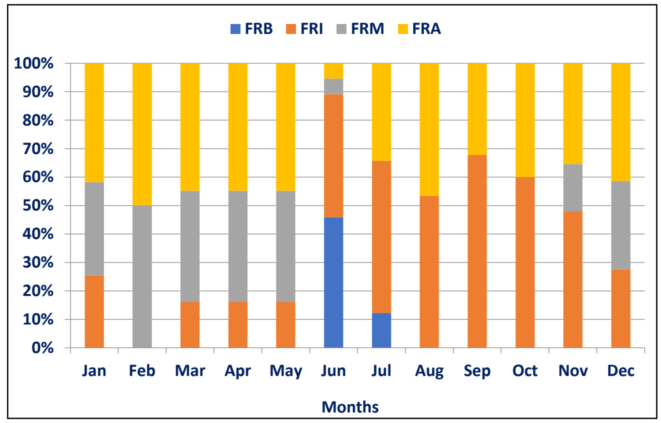

Figure 3: Fruit phenological patterns of *T. chebula* in CWLS

continued in March (47%) and extended during April (10.5%), and May (15.8%). The phenology of fruits opening from fruit imitation up to seed dispersal was shown the importance of the productivity of trees in diverse ecosystems with varying climatic conditions (Figure 3). The low fruit set rate is reported to be due to poor pollination and a high rate of immature fruit abscission (Varghese et al., 2015).

3.3. *Relationship between phenological patterns and climatic variables*

Leaf flushing activity revealed a nonsignificant negative correlation with the current month's rainfall and a significant negative relation with three-month lag rainfall amounts (Table 2). The leaf initiation period was in the range of 31–77 days. The leaf expansion period started in May with a peak in June (52%) and extended during July (14%), August (9.5%), and up to September. A high duration of the leaf at least four months of the growing season was recorded in the rest of the 23 trees. The leaf fall activity and rainfall had a significant negative relationship with current rainfall and the negative relationship was highly correlated with one-month lag rainfall (Table 2).

Table 2: Spearman rank correlation values between four different phenological statuses and current rainfall amounts and one to three months lag rainfall amounts

Phenological status	Correlation type	Correlation with variable	Significance NS=Not Significant S^*=Significant at 0.05 level
Leaf flush	Negative	With current monthly rainfall amount	r=-0.138 $p>0.05$ (NS)
	Negative	With three-month lag rainfall amount	r=-0.77 $p<0.05$ (S^*)
Leaf fall	Negative	With current rainfall	r=-0.57 $p<0.05$ (S^*)
	Negative	With one month lag rainfall amount	r=-0.78 $p<0.05$ (S^*)
Flower bud break	Negative	With current monthly rainfall amount	r=-0.38 $p>0.05$ (NS)
Flower bud break	Negative	With three month lag rainfall amount	r=-0.86 $p<0.05$ (S^*)
Fruit bud break	Positive	With current monthly rainfall amount	r=0.41 $p>0.05$ (NS)
Fruit bud break	Positive	With one month lag rainfall amount	r=0.58 $p<0.05$ (S^*)

Flower bud break and rainfall indicated a negative relationship with current rainfall, but showed a significant positive relationship with three-month lag rainfall (Table 2). Flowering was recorded on completely leafless twigs in 25 individuals in the summer season; seven individuals registered synchronous leaf initiation and produced flowers after the leaf initiation period was completed. A total of 23 trees (47%) have registered a lesser flowering period (≤30 days) and the rest of them have a >30 days flowering period with a maximum period of 61 days. The fruit bud break was observed distinctly in February and has produced flowers lately in the forest during October. The peak fruiting activity was registered in April (31.5%), extended during May (15.8%), and June (15.8%), and another lower peak was recorded in August (26.3%).

The fruit maturation period was in the range of 30–214 days with a remarkably high period. The peak condition for fruit/seed dispersal was registered in November and the range was 30–90 days with a minimum period shown by dispersal occurring during January of the next calendar year. Fruiting phenological activity among the species and rainfall had a positive relationship and with one-month lag rainfall the relationship was significant (Table 2).

3.4. Seasonality among leafing, flowering and fruiting

Leafing seasonality was intensely marked. Rayleigh's Z values are highly significant. The leafing pattern is indicated by the mean angle. Most trees are leafless in the middle of February as indicated by the mean angle (68.32). Leaf initiation starts in the middle of May (124.03), leaf expansion at the end of May (135.81), and senescence in the middle of January (21.74). The power of seasonality measured by the vector r specifies that the leaf senescence (0.63) event has robust seasonality, followed by leaf initiation (0.52) and leaf maturity (0.28) (Table 3).

The flowering seasonality was also strongly pronounced. Rayleigh's Z values are highly significant as shown by the mean angle. In dry deciduous forests. *T. chebula* initiates flower bud in the middle of May (128.41), and opens and become pollinated flowers during late May (139.72). The power of seasonality recorded by the vector r indicates that open flowers (r=0.31) have strong seasonality, followed by flower initiation (r=0.38) (Table 4).

Table 3: Leafing phenology seasonality of T. chebula in CWL

Parameters	Leafless	Leaf tender	Leaf mature	Leaf senescence
Mean angle	68.32	124.03	135.81	21.74
Mean vector r	0.521	0.22	0.28	0.63
Angular SD	48.35	72.54	68.32	64.21
Rayleigh's Z	27.46	20.31	18.92	46.73
p value	<0.00	<0.00	<0.000	<0.00

Table 4: Flowering phenology seasonality of *T. chebula* in CWL

Parameters	Flower bud	Flower open	Flower obsession
Mean angle	128.41	139.72	151.35
Mean vector r	0.31	0.38	0.18
Angular SD	83.41	78.43	87.42
Rayleigh's Z	9.62	10.32	6.72
p value	<0.000	<0.000	<0.000

The fruiting seasonality was remarkably shown a strong relationship. Rayleigh's Z is greatly significant, and the significance of the fruiting pattern is specified by the mean angle. Fruit initiation happened during the middle of February (53.42). Immature fruits were observed during the middle of November (214.43), fruits ripened at the beginning of February (135.22), and fruit fall occurred in the middle of March (69.62). The power of seasonality measured by vector r specified that fruit fall (r=0.48) has robust seasonality, and immature and ripened fruit (r=0.23) showed similar seasonality, followed by fruit initiation (r=0.31) (Table 5).

Table 5: Fruiting phenology seasonality of *T. chebula* in CWL

Parameters	Fruit bud	Fruit initiation	Fruit mature	Fruit obsession
Mean angle	53.42	214.43	135.22	69.62
Mean vector r	0.08	0.31	0.23	0.48
Angular SD	132.71	100.04	83.92	78.92
Rayleigh's Z	0.15	12.63	10.53	18.58
p value	<0.15	<0.02	<0.05	<0.001

T. chebula trees of Cauvery wildlife sanctuary showed a concentration (85.7%) of leaf initiation activity during the dry season and negative relation with a time lag of three months rainfall was noticed similar patterns were observed in dry deciduous forests of Bhadra wildlife sanctuary (Nanda et al., 2014). The triggering events for a new set of leaves might be influenced by the photoperiod (increasing day length) as the timings of high-frequency leaf initiation events corresponds with the initiation of the spring equinox period where the day length period started increasing.

The leaf initiation timings in the dry period suggested that trees were sure of better utilizing the short growing season by projecting well-formed leaves well before the advent of monsoon periods as also observed in Vindhyan dry forests (Singh and Kushwaha, 2006). Such a high frequency of leaf senescence events at the advent of a low-temperature dry period helped the trees to maintain turgidity in the shoots which helped in leaf bud and flower bud break-up in the dry period itself strengthening the water stress hypothesis (Elliott et al., 2006).

Individual trees had shown varied deciduous periods (30–136 days) which indicated that certain individuals could tolerate, and few individuals avoided the water stress conditions in the hot dry season, that were dependent on the microhabitat condition of the location. The majority of individuals produced flowers during the dry season as well as on leafless twigs. These observations were in line with reports that water deficit conditions in branch tips would induce flower bud development and break-ups in dry forests and the presence of flowers on the leafless twigs provided better opportunities for pollinators' visits (Singh and Kushwaha, 2005). Moreover, synchrony between flower and leaf initiation was noticed during the dry season also recorded in Mudumalai dry forests and dry forests of Rajasthan (Yadav and Yadav, 2008) which seemed to relate to moisture and day length. It indicated the water storage ability in tree trunk individuals to maintain high stem water potential and as well produce flowers in the dry period (Saha, 2007, Schongart et al., 2002).

Fruiting was recorded in both wet and dry seasons registering two peaks in these dry forests. This indicated that both advents of rains and concentrated rainfall events triggered the fruit bud break-ups and a similar trend was observed in Lankamalleswara forests (Mastan et al., 2020). Thus Fruit/ seed dispersal events coincided with the onset of the monsoon period for better germination success rates. Many phenological studies in India revealed that seasons of leafing and fruiting at the population level were more synchronized and seasonal (Singh and Sahoo, 2019, Murali and Sukumar, 1993). Spearman correlation and Rayleigh's Z test showed that seasonal responses were more significantly related to climatic factors

4. CONCLUSION

The observations viz., occurrence of leaf flush before the dry period, flowering activity in dry period, synchrony between leaf initiations and flowering in the late dry period, leaf expansion in the wet monsoon, and fruit fall in the post-monsoon period indicated prevalence of seasonality in the occurrence phenology. Phenology related to the dry period and rainfall period either in the month or in the previous months of their occurrence made them as prominent factors influencing the phenology in the dry forests.

5. AUTHORS' CONTRIBUTION STATEMENT

KBR and RPH contributed to the study conception, design, conceptualization, methodology, software, investigation, and data curation. The first draft of the manuscript was written by KBR and RPH. Material preparation, data collection, and analysis were performed by KBR and RPH. SA provided temperature, humidity and rainfall data, the SSR, KK, MMS supervised and validated the work. All authors commented on previous versions of the manuscript, and read and approved the final manuscript.

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