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Impact of Weather on the Leafing, Flowering, and Fruiting Patterns of Woody Plant Communities in the Tropical Dry Forests of Bannerghatta National Park, India

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ABSTRACT

Phenological monitoring of woody individuals was undertaken to understand the patterns of leafing, flowering, and fruiting and the influence of weather. A total of 504 tagged individuals were monitored monthly for 4 years on two transects, namely, Thalewood House (TWH) and Bugarikallu (BGH), in the dry forests of Bannerghatta National Park. The leafing, flowering, and fruiting patterns in both transects had a similar trend. Peak leaf fall, leaf initiation, flower initiation, and fruit initiations were recorded in January, March, April, and May, respectively, in the transects. Exploratory analysis via predictive power scores showed that maximum temperature was a moderate predictor of leaf and flower initiation, while minimum temperature was a moderate predictor of leaflessness and leaf fall; soil moisture and humidity were a moderate predictor of fruit maturation. Spearman's correlations show that maximum temperatures positively influenced leaf initiation and flower initiation, while minimum temperatures negatively influenced leaflessness and leaf fall; fruit maturation was positively influenced by soil moisture and humidity. Principal component analysis and multiple regressions confirmed that moisture-related factors negatively influenced leaf initiation, leaflessness, and flower initiations and positively influenced fruit maturation. Maximum temperature positively influenced leaf initiation, leaf fall, and flower initiations. The presence of seasonality using circular statistics showed that leaf, flower, and fruit initiations were unimodal and significantly seasonal. Synchronicity in leaf initiations was high in most species in TWH and BGK transects, whereas synchrony in flower and fruit initiations was moderate to low. This study confirms that maximum temperatures trigger leaf and flower initiations, while moisture-related factors favour leaf and fruit maturations in tropical dry forests.

Key words: Phenophase, Circular statistics, Regression, Principal component analysis, Seasonality, Synchrony

INTRODUCTION

Plant phenology is the timing of recurring cycles of leafing, flowering, and fruiting and is influenced by abiotic (Alsubhi and Alzahrani 2023, Borchert et al. 2004, Fenner 1998) and biotic factors (Lobo et al. 2003, Wang et al. 2021). As per the bioclimatic law (Hopkins 1920, Liang 2016) and based on studies undertaken on the Hessian fly, an insect pest on cereal crops, the geographic location and altitude influence an organism's phenology. The bioclimatic law is also validated by studies on temporal patterns of vegetation phenology using PhenoCam data (Richardson et al. 2019). The phenology of tropical forests is not well understood, as variations among species and individuals of a species are seen. Studies have shown that no single environmental factor is responsible for the phenological events in tropical regions (Murphy and Lugo 1986).

Leafing in woody species is governed by abiotic factors such as rainfall, soil moisture, and day length. Unlike rain forests, seasonal dry tropical forests (SDTF) have drier months; consequently, woody species undergo moisture stress and shed their leaves to conserve water. Rainfall plays an important role in dry forests, as the dry forests are characterized by a dry season ranging from 2 to 7 months with < 10% of annual precipitation (Borchert 1994, Murphy and

Lugo 1986). Leaf initiation starts one to two months before the onset of monsoon rains. Deep-rooted trees are well adapted and can initiate leaves when the water potential is > -0.5 MPa (Borchert 1994). In contrast, the shallow-rooted plants depend completely on soil moisture and initiate leaves with the onset of rainfall. In the early dry season, increasing day length triggered leaf flushing in Cerrado communities of Brazil (Alberton et al. 2019, Elliott et al. 2006), dipterocarp-oak forest (Elliott et al. 2006) in Thailand, and Latin America (Rivera et al. 2002). Photoperiod was the dominant factor in controlling the vegetative growing season in Africa (Adole et al. 2019). Pre-season sunshine duration was the primary driver for the start of the growing season in natural rubber *Hevea brasiliensis* (Li et al. 2023) in a tropical island of China. Studies show that temperature and moisture seasonality have a role in the timing of leaf initiation and leaf fall (Jackson 1978). Peak leaffall occurs during the drier months, and water stress is the cue for leaffall (Wright and Cornejo 1990). Leaflessness in SDTF can last up to 7 months.

Flowering, an important reproductive process, is also influenced by abiotic factors. Photoperiodic induction of flowering occurs near the equator (Borchert et al. 2005). A 15-minute increase in day length accumulated over a week triggered flowering in the short-day plant *Oryza sativa* (Dore 1959). Studies show that temperature induces flowering in *Arabidopsis thaliana* (Balasubramanian et al. 2006) and *Eucalyptus* species (Hudson et al. 2010). Flowering occurs in a vernalization and ambient temperature pathways (Xuan et al. 2022). Maximum temperatures are critical for flowering; higher temperatures were associated with greater flower production in dry tropical forests (Pau et al. 2013). Flowering in tropical regions is during the dry season (Janzen 1967, Daubenmire 1972). In the tropical dry forest of Ceylon, the soil moisture content is lowest during the dry season, which is thought to be the reason for flowering (Koelmeyer 1960). In Costa Rica, flowering occurred twice, once during the dry season and another time during the onset of rains, with the number of species more significant during the dry season than the wet season (Frankie et al. 1974).

Fruiting, a reproductive process, is critical, as the development of new progeny depends on this process. Abiotic and biotic factors also influence the process of fruiting. Many species fruit during the rainy season (Griz and Machado 2001), as soil moisture is important for growth and development. Fruiting is usually staggered (McLaren and McDonald 2005, Murali and Sukumar 1994) in tropical regions as it depends on flowering and pollinators. Fruiting occurs during the wet season as seed germination and growth require soil moisture, while dehiscence occurs during the dry season. It has also been shown that woody species have a high interspecific fruiting variation (Cortés-Flores et al. 2019).

Seasonal patterns and synchrony in phenology are important as they influence plant-pollinator interactions and fruit sets. Climate-manipulation experiments have revealed that warmer temperatures reduced leaf initiation and flowering synchrony by about 55% (Zohner et al. 2018); in situ phenological records have demonstrated that warming due to climate change may disrupt synchrony (Wang et al. 2016). Recent manipulation studies involving warming and precipitation have shown that warming accelerated first flower timings in the Tibetan plateau, indicating that temperature controls flowering (Chen et al. 2023). Hence, warming brought on by climate change may affect synchrony in vegetative and reproductive processes.

The first phenological investigation published in India was from the sub-tropical areas of Meghalaya, Northeast India, in 1982 (Shukla and Ramakrishnan 1982). Many of the later studies are from North India (Kushwaha and Singh 2005), North-east India (Saha and Sundriyal 2010, Ramaswami et al. 2018, Singh and Sahoo 2019), the tropical regions of South India (Murali and Sukumar 1994, Nanda et al. 2015, Prasad and Hegde 1986), and North-western India (Yadav and Yadav 2008). The patterns of vegetative and reproductive phenophases and herbivory were examined in these studies.

The present study addresses (i) the patterns of leafing, flowering, and fruiting phenophases in the two communities of BNP and whether they resemble other dry tropical forest regions. Are the patterns among the transects similar, and do interannual variations in phenophases occur? (ii) do weather parameters influence the vegetative and reproductive phenophases? If so, which parameters, single or together, bring about changes in these phenophases?

and (iii) Do seasonality and synchrony occur in these woody species' leafing, flowering, and fruiting phenophases? If so, what is the strength?

METHODOLOGY

Study area

The phenology observation was undertaken in a protected area of Bannerghatta National Park (BNP) (12°34' and 12°50' N, 77°31' and 77°38' E) situated 22 km from Bengaluru city. BNP has an area of 260.51 km^2 and has been administratively divided into 4 ranges: Anekal, Bannerghatta, Harohalli, and Kodihalli. BNP is bounded by Tamilnadu state in the east and Ramanagara district in Karnataka state in the south and southeast. Two transects, viz., Thalewood House (TWH) and Bugarikallu (BGK), were laid in the Bannerghatta range of BNP (Fig. 1). The two transects were at a distance of 6 km apart and within a radius of 2.5 km from each of the one-

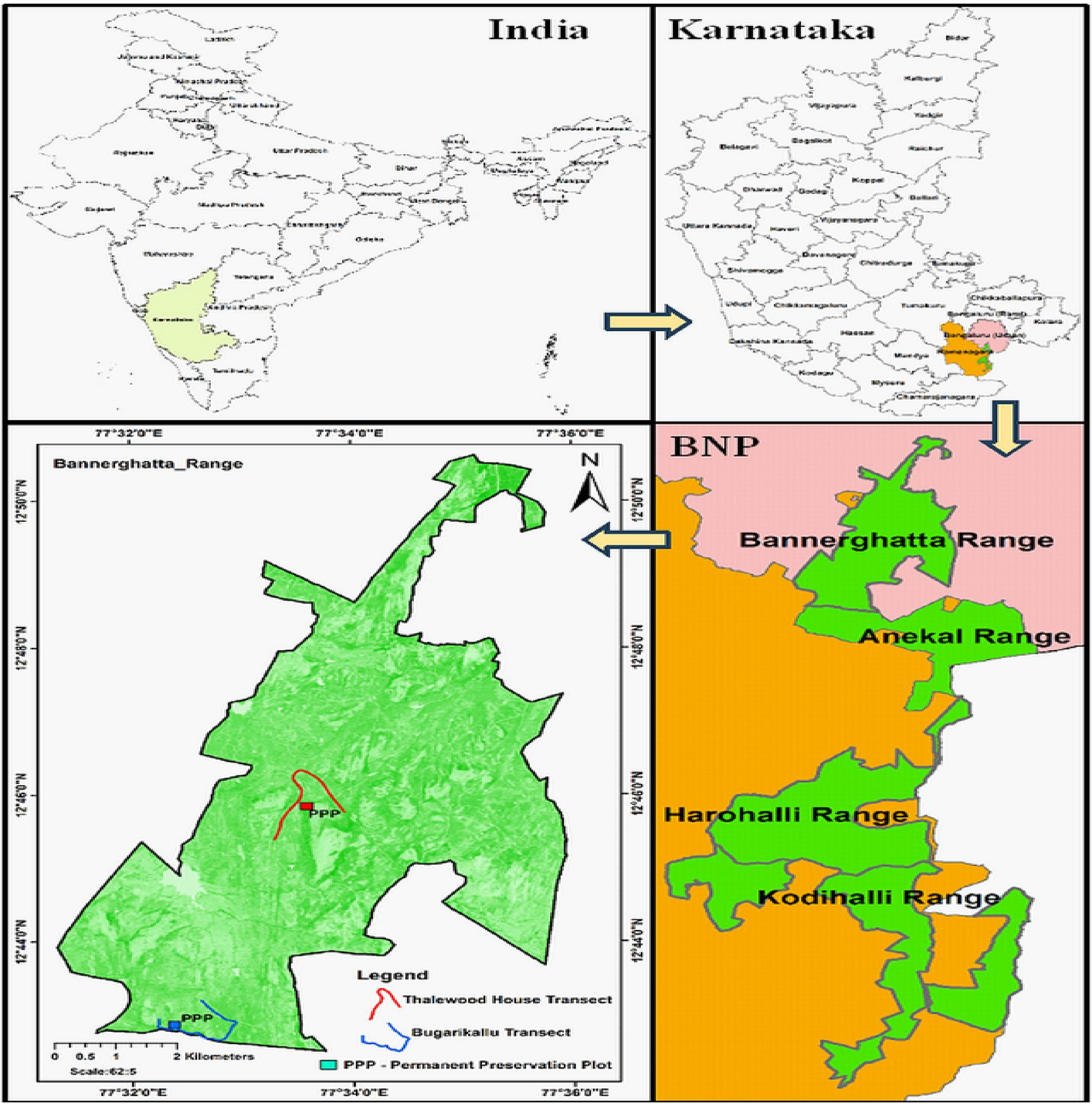

Figure 1. Depiction of transects in Bannerghatta National Park (BNP)

hectare permanent preservation plots (PPPs). The annual rainfall in the study area ranged from 939 to 1540 mm during 2019-2023, with a four-year mean of 1269 mm. The maximum temperature ranged from 30.7 to 43.1°C during 2019-2023, and the minimum temperature ranged from 9.2 to 20.6°C.

Vegetation

BNP has tropical dry deciduous vegetation in the core regions and scrub vegetation at the fringes. The upper regions of the park are covered by mixed deciduous vegetation. In contrast, the valleys and watercourses are covered by mixed moist deciduous vegetation, which is relatively undisturbed due to the highly undulating terrain. The woody species in these regions comprise many trees, shrubs, and lianas (Gopalakrishna et al. 2015, Kakkar et al. 2018, 2021). Some of the dominant woody species include *Anogeissus latifolia, Chloroxylon swietenia, Pterocarpus marsupium, Diosypros melanoxylon, Erythroxylon monogynum, Ixora arborea, Terminalia bellirica, Terminalia paniculata, Terminalia chebula, Grewia orbiculata,* etc.

Tagging of trees, phenological observations, soil sampling, and weather data

Tagging of trees

A total of 504 reproductively mature trees, preferably >30 cm girth at breast height (GBH), were tagged in both transects. The tagged trees represented the species in the permanent preservation plots (PPPs) established at TWH and BGK localities. Of the 504 individuals comprising trees and shrubs, 254 were in the TWH transect and 250 in the BGK transect. The TWH transect comprised 68 species, whereas the BGK transect contained 67 species. The number of unique species was 84 in both localities combined.

Phenological observations

Every month, on the same day, the same person monitored the leafing, flowering, and fruiting phenophases. The qualitative estimates of phenophases of leafing, flowering, and fruiting on the canopy were assessed by the naked eye and with the help of a pair of binoculars (Nikon Aculon A211, 10 x 50). The estimates were recorded as percentage occupancy of the canopy, which amounts to 100% in the field. The leafing, flowering, and fruiting phenophases included: no leaves (LF1), leaf initiation (LF2), leaf expansion (LF3), leaf maturation (LF4), and leaf fall (LF5); no flowers (FL1), flower initiation (FL2), flower opening (FL3), flower maturation/ pollination (FL4), and flower fall (FL5); no fruits (FR1), fruit initiation (FR2), fruit elongation (FR3), fruit maturation (FR4), and fruit dehiscence/fall (FR5). The presence of herbivory and frugivory was also noted.

Soil sampling

Soils were sampled manually at 0-30 cm depth using an auger from ten points each on both TWH and BGK transects. The samples were brought to the laboratory in airtight boxes, and the moisture was estimated using the oven-dry method (Anonymous 1973). The soil moisture content (%) in the transect is the average of the 10 sampled soils. Soils were sampled monthly from the transects and during the phenological observations.

Weather data

Weather parameters such as rainfall, temperature, sunshine hours, and humidity were obtained from the weather station installed in BNP. The station was relatively close to the transects. Rainfall is the monthly total, and temperature, sunshine hours, and humidity are the month's average. The data logged into the weather station were downloaded from the server's file transfer protocol (FTP). The daily data were converted into monthly data and used for the analysis. The specific weather data gaps were filled using regressions with the closely linked variables. The mean monthly weather data was calculated for four years (2019-20, 2020-21, 2021-22, and 2022-23). Similarly, mean monthly soil moisture was also calculated for four years, from 2019 to 2023, for both transects. The weather parameters were the same for both transects, whereas the soil moisture content differed for the transects.

Data analysis

Phenophase intensity

A measure known as "intensity" was used and was calculated by multiplying the percentage of canopy occupied by each phenophase with the species participating by the total (Eq. 1).

Intensity of phenophase=Average canopy percent of phenophase X (Number of participating species/Total number of species) .. (1)

The monthly intensities of each of the phenophases were used for the analysis.

Predictive power scores

Predictive power score (PPS) is a metric that can be used to quantify the predictive power of one variable (predictor x) on another variable (target y). It recognizes an asymmetrical relationship, i.e., PPS (x, y) is not the same as PPS (y, x). The predictive score ranges from 0 to 1; the range of the strengths is high predictive power (0.7 to 1), medium predictive power (0.3 to 0.7), and low predictive power (0 to 0.3). It is used here as an exploratory method to understand the effect of the weather data (predictor) on the phenophase intensities (target) using the 'R' package *ppsr* (van der Laken 2021). The monthly values (46 months) of the phenophase intensities and the monthly weather parameters (46 months) were used for the PPS analysis.

Correlations

Spearman's correlation between weather parameters and phenophase intensities was performed using the PAleontological STatistics (PAST) software package (Hammer et al. 2001). The monthly values (46 months) of the phenophase intensities and the monthly weather parameters (46 months) were used for correlations. We also performed time-lag correlations.

Kolmogorov-Smirnov (KS) test of distributions

A two-sample KS test was performed in PAST to understand whether the distribution of phenophase intensities between two localities (transects) is statistically significant. The null hypothesis is whether the samples were drawn from the same population; the alternate hypothesis is whether the samples were drawn from a different population.

Kruskal-Wallis test

The Kruskal-Wallis test was performed to check for interannual variations in important phenophases on both transects. The null hypothesis states that the medians of the four years are equal, while the alternate hypothesis states that at least one year's median is different from the others. The month-wise intensities across years were taken for the analysis. The test was performed in the PAleontological STatistics (PAST ver. 4.14) software package (Hammer et al. 2001).

Principal component analysis of weather data

Principal component analysis (PCA) of six weather parameters along with soil moisture content was performed in PAST. PCA for both transects was done separately; the six weather parameters were similar except for soil moisture content.

The Kaiser-Meyer-Olkin (KMO) measure, also known as the Measure of Sampling Adequacy (MSA) for PCA, was performed in 'R' using the package 'psych' (Revelle 2024).

Principal component regressions

Principal component regressions (PCR) or multiple regressions were performed in PAST. The PCA's first three principal components (PCs) that explained a large amount of variance were regressed with the monthly phenophase intensities.

Seasonality

Seasonality is the recurring patterns and timing of leafing, flowering, and fruiting. The seasonality of phenophases was estimated using the circular statistical analysis package Oriana 4.02. The observation date (X) was converted to angles (A) using equation 2, with K being 365 days. The intensity of the monthly phenophase was used along with the converted date (angles) for the analysis and depiction using a circular histogram.

$$A = ((360°)(X))/K \quad ..(2)$$

Seasonality is tested by understanding the phenophase intensity distribution around a circle: if the distribution is uniform, then there is no seasonality; if the distribution is not uniform and if it has a significant mean angle and mean direction at a particular date, then there is seasonality (Patricia et al. 2000). The strength of the seasonality is denoted by vector r; the degree of seasonality ranged from 0 (uniform distribution) to 1 (distributed around one date).

Synchrony

A synchrony index for a species was calculated as the ratio between the mean duration of a phenophase and the overall duration of the phenophase in the community (Devineau 1999). The index was calculated for each year, and the average of the four years was taken as the synchrony index of the species for that particular phenophase. The synchrony index ranged from 0 to 1, with 1 being completely

Table 1. Top ten species with highest individuals in Thalewood House (TWH) and Bugarikallu (BGK)

Thalewood House (TWH)	Individuals	Bugarikallu (BGK)	Individuals
Ixora arborea	23	*Anogeissus latifolia*	22
Phyllanthus polyphyllus	12	*Ixora arborea*	20
Polyalthia cerasoides	12	*Erythroxylon monogynum*	18
Vitex altissima	8	*Maytenus emarginata*	17
Anogeissus latifolia	7	*Acacia chundra*	14
Cassia fistula	7	*Grewia orbiculata*	10
Diospyros melanoxylon	7	*Polyalthia cerasoides*	9
Terminalia bellirica	7	*Diospyros melanoxylon*	7
Bauhinia racemosa	6	*Phyllanthus polyphyllus*	6
Canthium parviflorum	6	*Bauhinia racemosa*	5

synchronous and 0 being asynchronous. The synchrony index was calculated for all species having more than three individuals.

RESULTS

Monthly phenological observations of 504 woody individuals, 254 in TWH, and 250 in BGK transects were undertaken, and 46 months of observations were completed. Eighty-four species were monitored, 68 in TWH and 67 in BGH (Annexure 1). Of the 84 species, 51 were common between the transects, 17 were unique to TWH, and 16 were unique to BGH. The top ten species with the highest number of individuals are listed in Table 1. Unique species do not occur in the top ten species. During phenological observations, soil sampling was also completed to estimate soil moisture content. Due to the COVID-19 lockdown during April and May 2020, two months of phenological observations and soil sampling could not be undertaken.

Patterns of leafing, flowering, and fruiting

The vegetative and reproductive phenophase intensities between the TWH and BGK transects were compared. The patterns of leafing, flowering, and fruiting phenophases were similar in the transects (Fig. 1). Leaf fall (LF5) started in August and peaked in January of the following year, with the leafless stage (LF1) reaching its maximum in February (in TWH) and March (in BGK). Leaf initiation (LF2) started in February and peaked in March (in TWH) and April (in BGK); leaf expansion (LF3) reached its maximum during April. Flowering patterns in TWH and BGK were similar (Fig. 2). Flower initiations (FL2) started during January, preceding leaf initiation, and peaked during March (in TWH) and April (in BGK). Flower opening (FL3), mature flowers (FL4), and flower fall (FL5) peaked during April. The intensity of these three phenophases was comparatively lower than that of the flower initiations (Fig. 3). Fruiting phenophases between TWH and BGK transects were also similar (Fig. 4). Fruit initiations (FR2) started in March and peaked in May in both transects. Fruit elongations (FR3) also peaked during May (in TWH) and June (in BGK), while fruit maturation started from June onwards. Fruit fall (FR5) was at its maximum in February of the following year, during the onset of leaf and flower initiations.

Weather patterns and soil moisture content

The mean monthly rainfall for four years (2019-2023) was high during August, September, and October; the lowest was during January, February, and March. It is also important to note that rainfall during January and February was 0 during 2019-20, 2021-22, and 2022-23, whereas sparse rainfall was seen during the same period in 2020-21. The rainfall content was also the highest during October (Fig. 5) in the four years. The mean monthly maximum temperature was recorded in April (38.3°C), while the mean monthly minimum temperature was recorded in January (11.3°C). The maximum and minimum temperatures increased from January onward. The soil moisture was at its maximum during October in TWH (15.87%) and BGK (12.14%) transects.

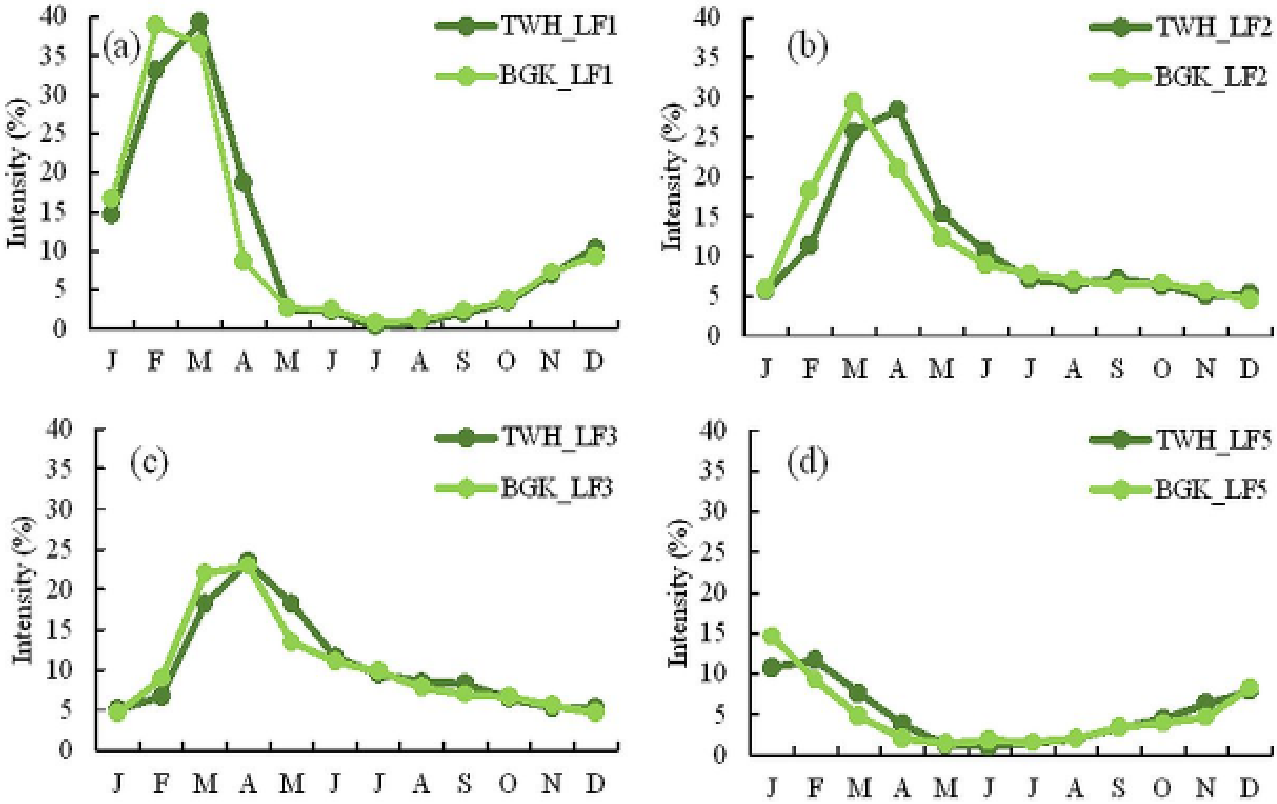

Figure 2. Mean monthly leafing phenophase intensities in Thalewood House (TWH) and Bugarikallu (BGK) transects from 2019-23: (a) no leaves (LF1), (b) leaf initiation (LF2), (c) leaf expansion (LF3), (d) leaf fall (LF5)

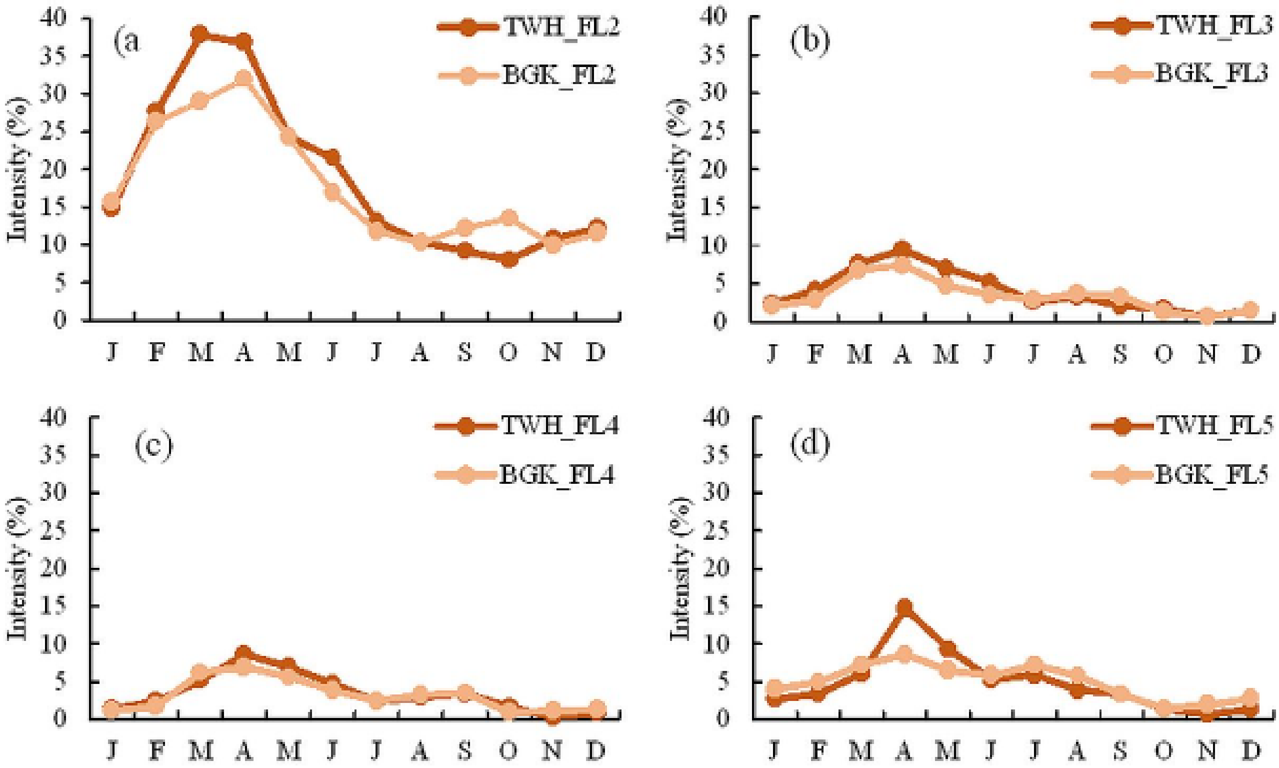

Figure 3. Mean monthly flowering phenophase intensities in Thalewood House (TWH) and Bugarikallu (BGK) transects from 2019-23: (a) flower initiation (FL2), (b) flower opening (FL3), (c) pollinated flowers/mature flowers (FL4), (d) falling flowers (FL5)

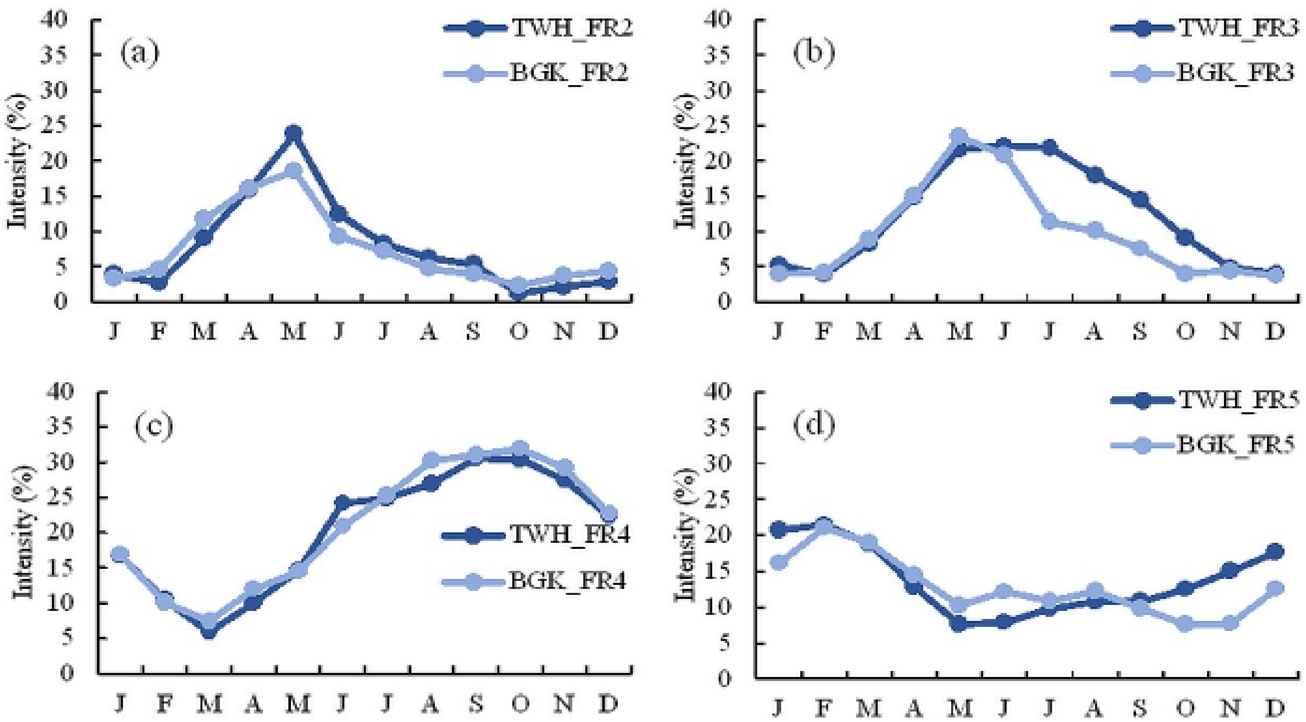

Figure 4. Mean monthly fruiting phenophase intensities in Thalewood House (TWH) and Bugarikallu (BGK) localities from 2019-23: (a) fruit initiation (FR2), (b) fruit elongation (FR3), (c) fruit maturation (FR4), (d) fruit fall/dehiscence(FR5)

The amount of sunshine increased from November onwards and was the highest (9.63 hours) during February in the dry season when the rainfall (10.22 mm) and soil moisture content were low (3.92% in TWH and 3.89% in BGK). The sunshine hours decreased from June onwards (9.56 hrs) and were the lowest during November (8.55 hrs). The humidity was also the lowest during February (61.67%) and March (61.05%), when the rainfall and soil moisture content were low.

Factors affecting leafing, flowering, and fruiting

The developmental cues for leafing, flowering, and fruiting phenophases are the weather parameters: temperature, sunshine hours, and moisture-related factors (rainfall, soil moisture, humidity, and number of rainy days). These factors, either individually or in combination, influence the outcome of the phenophases. The relationship between these weather factors and the phenophase intensities was unravelled using predictive power scores and correlations.

Predictive power scores

Maximum temperature was a medium predictor of leaf initiation and leaf maturation in both the transects (Table 2, Annexures 2, 3). The minimum temperature was a medium predictor of leaf fall in TWH, while prediction for BGK was low; the number of rainy days was a medium predictor of leaflessness and leaf maturation in both transects. Humidity was a medium predictor of leaf maturation and fruit maturation in both transects; soil moisture was a medium predictor of leaf maturation and fruit maturation. The matrix of PPS is shown in Annexures 2 and 3.

Correlations

Leaf initiations (LF2) were positively influenced by maximum temperature and were significant in TWH ($rs = 0.627$, $p < 0.01$) and BGK ($rs = 0.620$, $p < 0.01$) transects (Table 3); a two-month lag period showed a negative influence of humidity ($rs = -0.656$, $p < 0.01$ in TWH and $rs = -0.631$, $p < 0.01$ in BGK) and soil moisture ($rs = -0.764$, $p < 0.01$ in TWH and $rs = -0.694$, $p < 0.01$ in BGK) on leaf initiations (Annexure 4). Minimum temperature negatively influenced leaf fall (LF5) and was significant in both TWH ($rs = -0.814$, $p < 0.01$) and BGK ($rs = -0.792$, $p < 0.01$) transects during the corresponding months. Flower initiations (FL2) were also positively influenced by maximum temperature and were

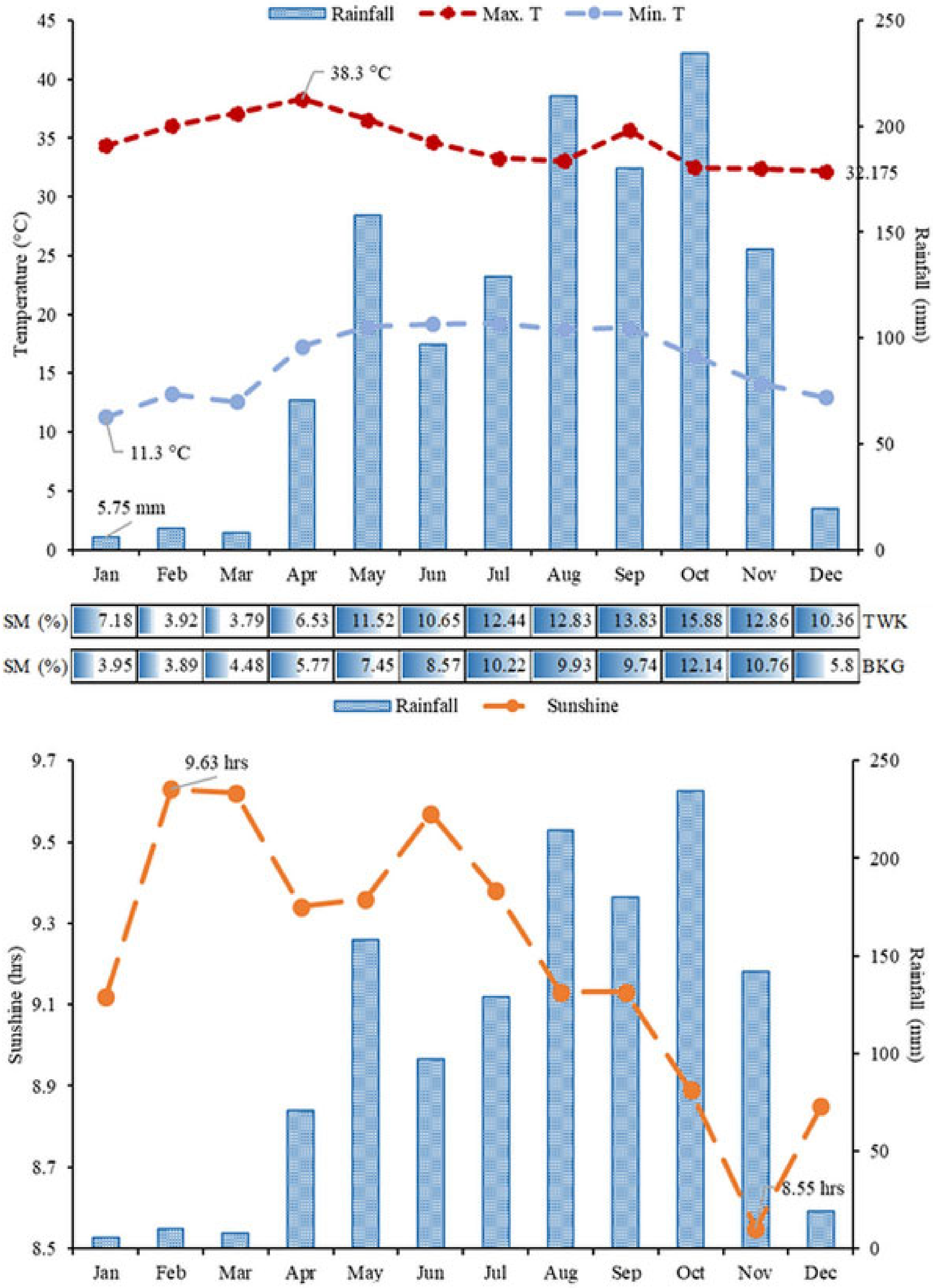

Figure 5. Mean monthly weather data and soil moisture content from 2019-2023: Top panel shows Rainfall Vs Temperature; middle panel shows the moisture content in the two transects; the bottom panel shows Rainfall Vs Sunshine hours

Table 2. Predictive power scores of weather data and important phenophases in Thalewood House (TWH) and Bugarikallu (BGK) transects

Predictor (x)	Target (y)									
	LF1		LF2		LF5		FL2		FR4	
	TWH	BGK	TWH	BGK	TWH	BGK	TWH	BGK	TWH	BGK
Maximum temperature (°C)	0.167	0.072	0.323	0.365	0.037	0.016	0.284	0.249	0.23	0.337
Minimum temperature (°C)	0.259	0.292	0.029	0.012	0.38	0.256	0.005	0.006	0.094	0.109
Total Rainfall (mm)	0.187	0.183	0.055	0.069	0.243	0.064	0.116	0.061	0.191	0.215
Number of rainy days	0.295	0.303	0.06	0.116	0.326	0.088	0.163	0.111	0.2	0.243
Sunshine (hrs)	0.032	0.05	0.169	0.181	0.007	0	0.07	0.071	0.054	0.033
Humidity (%)	0.222	0.258	0.174	0.277	0.164	0.001	0.263	0.245	0.324	0.428
Soil moisture (%)	0.404	0.085	0.168	0.123	0.181	0.085	0.288	0.049	0.317	0.342

Table 3. Spearman's correlation values of important phenophases with weather parameters

	Thalewood House (TWH)		**Bugarikallu (BGK)**	
Parameter	**Spearman's R**	**p-value**	**Spearman's R**	**p-value**
Leaf initiation (LF2) (df = 46)				
Maximum temperature	0.627	< 0.01	0.620	< 0.01
Leaf fall (df=46)				
Minimum temperature	-0.814	< 0.01	-0.792	< 0.01
Flower initiation (FL2) (df=46)				
Maximum temperature	0.605	< 0.01	0.604	< 0.01
Fruit elongation (FR3) (df=46)				
Minimum temperature	0.779	< 0.01	0.510	< 0.01
Fruit maturation (FR4) (df=46)				
Maximum temperature	-0.605	< 0.01	-0.621	< 0.01
Humidity	0.692	< 0.01	0.757	< 0.01
Soil moisture	0.747	< 0.01	0.719	< 0.01

significant in the TWH (rs = 0.605, $p < 0.01$) and BGK (rs = 0.604, $p < 0.01$) transects. In addition to flower initiations, flower opening (FL3), flower maturation (FL4), and flower fall (FL5) were positively influenced by maximum temperature and were significant (Annexure 4) in the transects during the corresponding months. A one-month lag period showed a positive influence of maximum temperature on flower opening and flower maturation and was significant.

Fruit elongation (FR3) was positively influenced by minimum temperature and was significant in both TWH (rs = 0.779, $p < 0.01$) and BGK (rs = 0.51, $p < 0.01$) transects. Fruit maturation (FR4) was positively influenced by rainfall, number of rainy days, humidity, and soil moisture and was significant, but it was also negatively influenced by maximum temperature in both transects.

Correlations were performed between leaf and flower initiations for both the transects, and it was seen that leaf initiation (LF2) was highly positively correlated with flower initiation (FL2) and was significant in both locations (rs = 0.838, $p<0.001$ for TWH and rs = 0.855, $p < 0.001$ for BGK).

Kolmogorov-Smirnov test (K-S test)

The K-S statistic ('D') obtained for all phenophases is not statistically significant. This indicates that the null hypothesis cannot be rejected, suggesting that the samples do not show sufficient evidence to be

Table 4. Summary of two-sample Kolmogorov-Smirnov test

Description	Leaf initiation (LF2) (TWH & BGK)	Flower initiation (FL2) (TWH & BGK)	Fruit elongation (FR3) (TWH & BGK)
Number of observations 'N'	46	46	46
K-S Statistic 'D'	0.0869	0.1739	0.2391
p-value	0.9927	0.4518	0.1228

considered from different population. The test results for some of the important phenophases are shown in Table 4.

Kruskal-Wallis test

The Kruskal-Wallis test was performed for both the TWH and BGK transects, and there was no significant interannual variation among 4 years for all the leafing and flowering phenophases. In the case of fruiting phenophases, except for fruitlessness and fruit fall, there was no significant interannual variation for the other fruiting phenophases. Hence, we fail to reject the null hypothesis as there is insufficient evidence to prove that the medians are not equal. There is a significant difference between the sample medians in fruitlessness (H = 10.57, df = 3 for TWH and H = 29.36, df = 3 for BGK) and fruit fall (H = 23.93, df = 3 for TWH and H = 21.16, df = 3 for BGK). A Dunn's post hoc analysis for fruitlessness and fruit fall showed a significant variation among certain years in TWH and BGK (Table 5).

Principal component analysis

The first three principal components (PCs) accounted for >85% of the variance among the seven; 86.47% of the variance is recorded for TWH, and 86.31% of the variance is recorded for BGK (Table 5). The

Table 5. Summary of Kruskal-Wallis test for fruitlessness and fruitfall

Description	Fruitlessness/No fruits (FR1)		Fruit fall/ dehiscence (FR5)	
	TWH	BGK	TWH	BGK
H (chi^2):	10.57	29.36	23.93	21.16
Hc (tie corrected):	10.59	29.41	23.93	21.16
p (same):	0.01417	1.84E-06	2.59E-05	9.75E-05
Dunn's post hoc (Raw p values, sequential Bonferroni significance)				
2019-20 vs 2020-21	0.48980	0.07359	0.56980	0.47380
2019-20 vs 2021-22	0.00272	0.00000	0.07404	0.11870
2019-20 vs 2022-23	0.39510	0.00036	0.00001	0.00078

Table 6. Summary of Principal Component Analysis

Principal Components (PC)	Thalewood House (TWH)		Bugarikallu (BGK)	
	Eigenvalue	% variance	Eigenvalue	% variance
1	3.79	54.20	3.76	53.79
2	1.60	22.92	1.60	22.91
3	0.65	9.36	0.67	9.59
4	0.38	5.47	0.42	6.00
5	0.23	3.34	0.24	3.46
6	0.19	2.65	0.18	2.54
7	0.14	2.05	0.12	1.67

correlation values for the first three principal components for both the transects are presented in Table 6.

The value of KMO for TWH data was 0.77; the value of KMO for BGK was 0.75. Both the data samples show a good measure of sample adequacy. The range for the 'good' measure of KMO is 0.7-0.8 (Hammer et al. 2001).

Principal component regression

Multiple regressions, or principal component regressions (PCR), were performed with the independent variables (the principal component scores (PCS) of the first three PCs of the PCA) and the phenophase intensities. There was a positive correlation (multiple R = 0.67, $p < 0.01$) between leaf initiations (LF2) and PCS (Table 7). There was also a positive correlation between flower initiation (FL2) and PCS. Similarly, fruit elongation correlated with the PCS and was significant (Table 8). The coefficient values of PC1 were negative, whereas they were positive for PC3 for leaf and flower initiations. In the case of fruit elongation, the coefficient of PC2 was positive and significant. The trend is the same in both TWH and BGK transects. Fruit maturation had significant correlations with the PCs and was significant (Annexure 5). The coefficient values for PC1 were positive, while the values for PC3 were negative and significant. The variance inflation factor (VIF) for all the multiple regressions is less than 4, implying that multi-collinearity is low and the independent variables used are independent and not correlated.

Seasonality of leafing, flowering, and fruiting

Leafing seasonality

Leaf fall was seasonal in both the TWH (r = 0.484) and BGK (r = 0.482) transects (Table 9). The mean angle for leaf fall was January in both TWH (mean angle = 9.90°) and BGK (19.45°) (Fig. 6). The mean angle for leaf initiation was March in TWH (92.28°) and BGK (95.22°), with the mean vectors r being 0.341 and 0.343. The significance of the mean angle at a 95% confidence interval was tested and found

Table 7. Correlation values of first three principal components of the PCA

Parameter	Thalewood House			Bugarikallu		
	PC 1	PC 2	PC 3	PC 1	PC 2	PC 3
Maximum temperature (°C)	-0.547	0.592	0.513	-0.545	0.593	0.526
Minimum temperature (°C)	0.482	0.799	-0.141	0.475	0.798	-0.144
Total Rainfall (mm)	0.797	0.136	0.433	0.807	0.134	0.417
Number of rainy days	0.885	0.325	0.020	0.892	0.324	0.004
Sunshine (hrs)	-0.506	0.692	-0.394	-0.503	0.692	-0.390
Humidity (%)	0.881	-0.105	-0.133	0.870	-0.105	-0.139
Soil moisture (%)	0.901	-0.017	-0.108	0.901	-0.015	-0.066

Table 8. Summary of Principal component regression of components with phenophase intensities

Description	Leaf initiation (LF2)				Flower initiation (FL2)				Fruit elongation (FR3)			
	TWH		BGK		TWH		BGK		TWH		BGK	
Observations N:	46		46		46		46		46		46	
Multiple R:	0.667		0.791		0.724		0.726		0.727		0.705	
p-value	< 0.01		< 0.01		< 0.01		< 0.01		< 0.01		< 0.01	
Variance inflation factor (VIF)	1.821		2.672		2.102		2.117		2.122		1.991	
Description	**Coeff**	**p-value**	**Coeff**	**p-value**	**Coeff**	**p-value**	**Coeff**	**p-value**	**Coeff**	**p-value**	**Coeff**	**p-value**
Intercept (constant)	10.96	< 0.01	11.18	< 0.01	18.60	< 0.01	17.56	< 0.01	12.35	< 0.01	9.62	< 0.01
PC1	-1.85	< 0.01	-2.16	< 0.01	-3.42	< 0.01	-2.18	< 0.01	1.32	< 0.01	0.26	< 0.55
PC2	1.47	< 0.05	1.12	< 0.12	0.64	< 0.51	0.73	< 0.34	3.82	< 0.01	2.84	< 0.01
PC3	4.02	< 0.01	4.20	< 0.01	5.15	< 0.01	4.70	< 0.01	-0.91	< 0.35	0.76	< 0.48

Table 9. Summary of seasonality using circular statistical analysis of leafing phenophases in Thalewood House and Bugarikallu transects

Description	No leaves (LF1)		Leaf initiation (LF2)		Leaf fall (LF5)	
	TWH	BGH	TWH	BGH	TWH	BGH
Number of observations (months)	46	46	46	46	46	46
Mean angle (vector m)	45.36°	54.72°	92.28°	95.22°	9.90°	19.45°
Length of mean vector (r)	0.68	0.68	0.34	0.34	0.48	0.48
Angular SD (circular SD)	49.52°	49.74°	84.06°	83.87°	69.02°	69.24°
Rayleigh's Z	243.02	239.045	57.14	59.36	56.22	52.21
p value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table 10. Summary of seasonality using circular statistical analysis of flowering phenophases in Thalewood House and Bugarikallu transects

Description	Flower initiation (FL2)		Flower opening (FL3)		Flower maturation (FL4)	
	TWH	BGH	TWH	BGH	TWH	BGH
Number of observations (months)	46	46	46	46	46	46
Mean angle (vector m)	80.83°	91.48°	102.61°	128.64°	126.66°	137.42°
Length of mean vector (r)	0.32	0.24	0.37	0.29	0.37	0.31
Angular SD (circular SD)	86.15°	96.31°	80.30°	90.14°	80.14°	87.94°
Rayleigh's Z	87.96	47.29	25.09	13.04	20.77	13.65
p value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

to be significant. The woody individuals were leafless during February, with a mean angle of 45.63° and 54.72°, which was significant. The mean vector r for LF1 in TWH and BGK were similar (0.688 and 0.686).

Flowering seasonality

Flowering was seasonal, but the strength was low; flower initiation had a mean angle of 80.83° in TWH and 91.48° in BGK; the mean value of flower initiation occurred during early March in TWH and BGK. The flower opening mean vector r was 0.374 in TWH and 0.29 in BGK; the mean angle was 102.61° and 128.64° in TWH and BGK and occurred during early April in TWH and the middle of April in BGK (Table 10, Fig. 7).

Fruiting seasonality

Fruiting was also seasonal; fruit initiation occurred maximally during May in TWH and BGK, with the mean angle being 133.07° and 131.05° and the mean vector r being 0.442 and 0.372. The mean angle for fruit elongation and fruit maturation was in June and July (Table 11, Fig. 8).

Synchrony in leafing, flowering, and fruiting

Synchrony in leafing

The species with the highest synchrony index in leafing are presented in Table 12. The synchrony index of leaf initiation among canopy species was the highest in *Polyalthia cerasoides, Pterocarpus marsupium,* and *Vitex altissima* in the TWH. At the same time, it was *Vitex altissima, Polyalthia cerasoides,* and *Pterocarpus marsupium* in the BGK. Understorey species *Ixora arborea, Maytenus emarginata,* and *Phyllanthus polyphyllus* had the highest leaf initiation synchrony in the TWH. At the same time, *Ixora arborea, Maytenus emarginata,* and *Erythroxylum monogynum* were in the BGK.

For leaf fall, synchrony was the highest among *Dalbergia paniculata, Terminalia bellirica,* and *Anogeissus latifolia* among the canopy species in TWH. At the same time, it was *Anogeissus latifolia, Dalbergia paniculata,* and *Polyalthia cerasoides* in

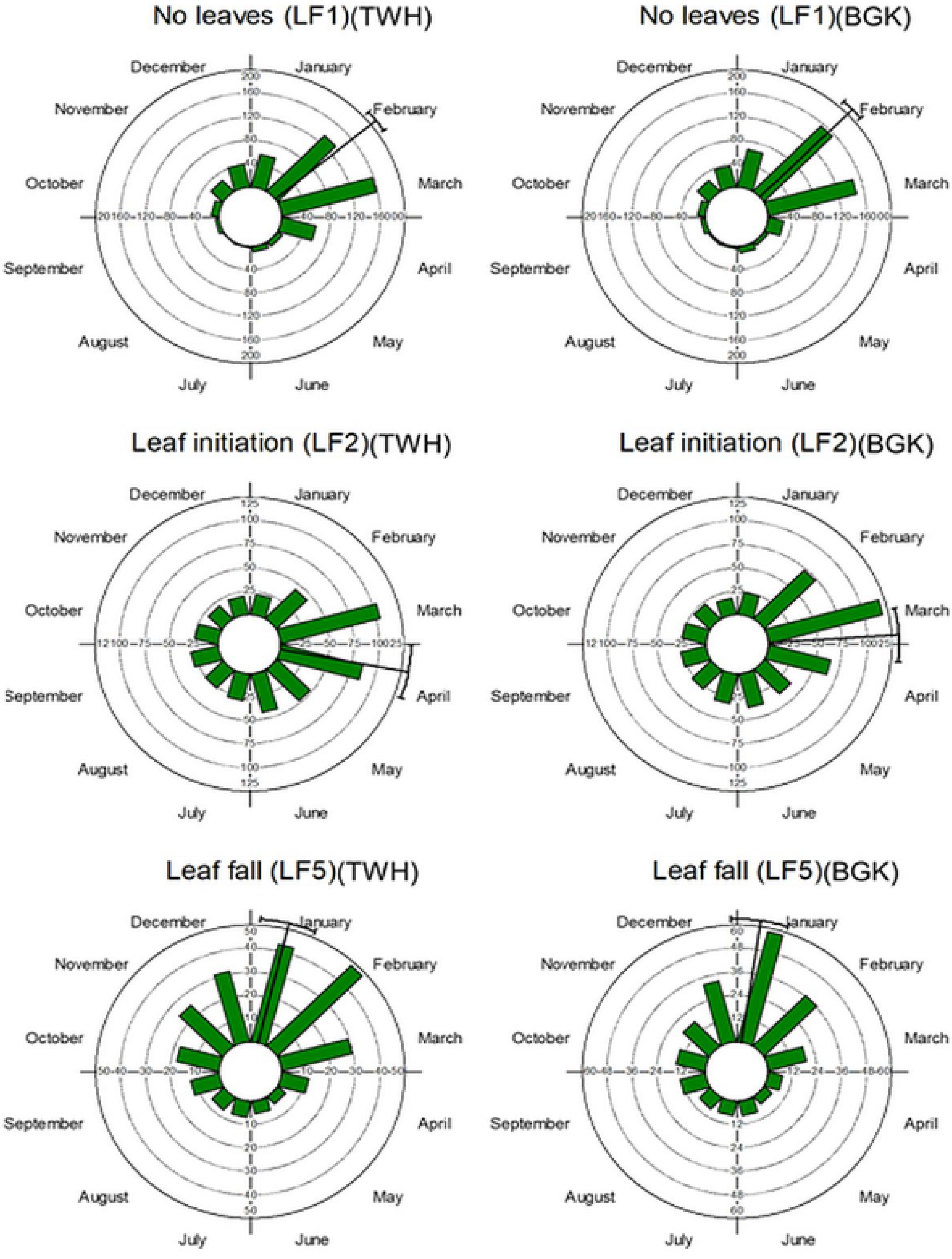

Figure 6. Circular histograms of leaf initiation (LF2), leaf elongation (LF3) and leaf fall (LF5) in Thalewood House (TWH) and Bugarikallu (BGK)

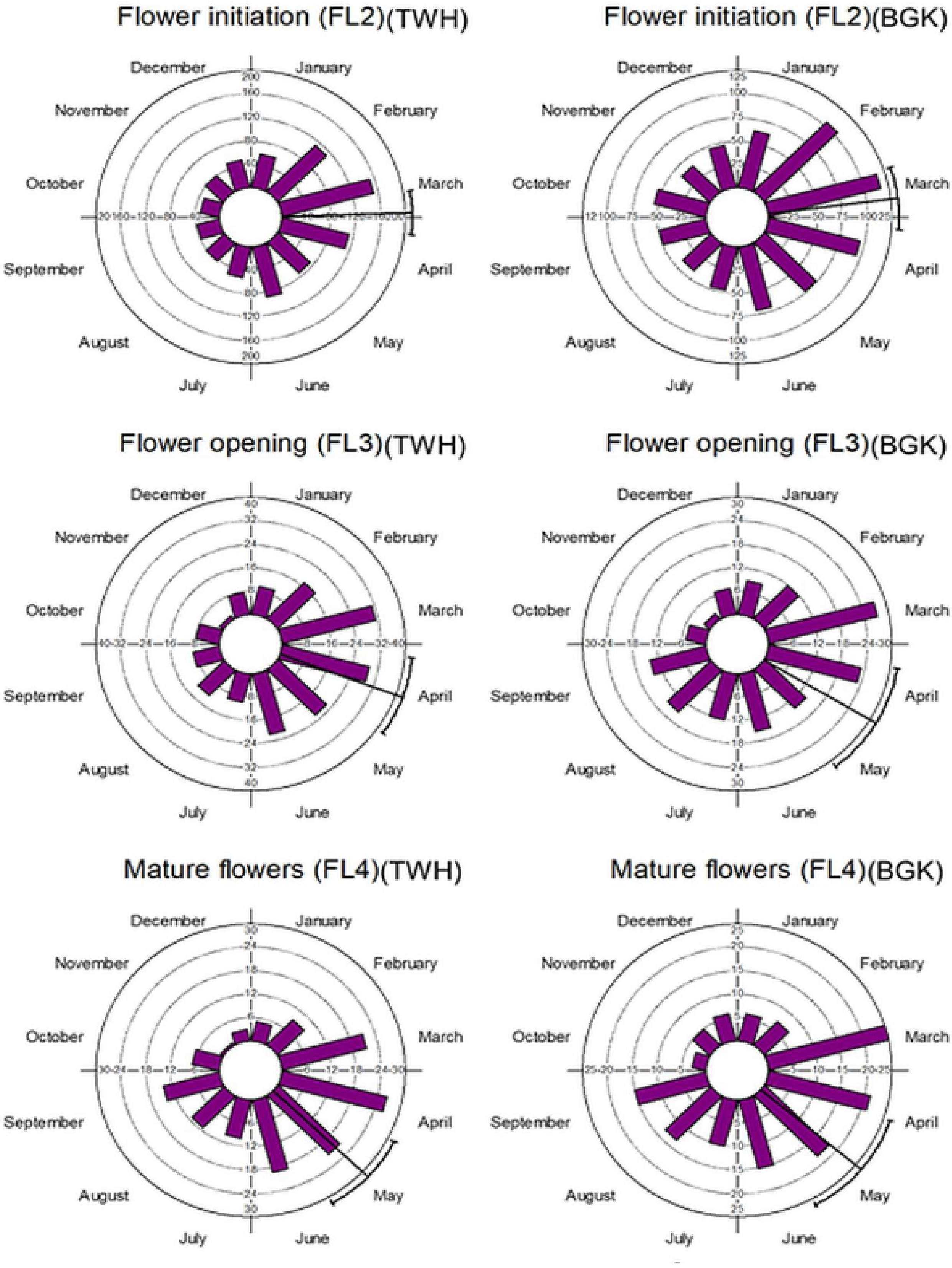

Figure 7. Circular histograms of flower initiation (FL2), flower opening (FL3) and flower maturation (FL4) in Thalewood House (TWH) and Bugarikallu (BGK)

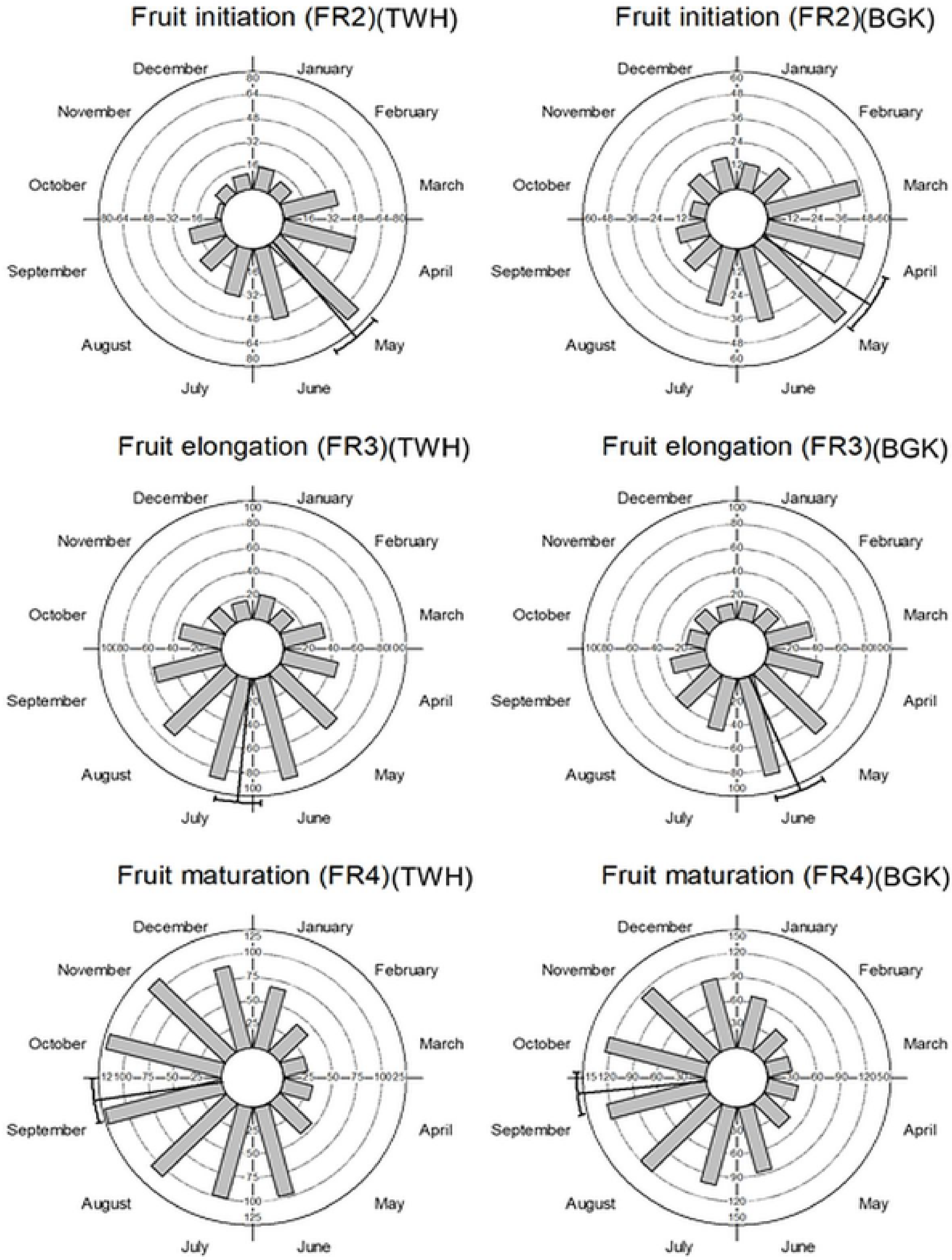

Figure 8. Circular histograms of fruit initiation (FR2), fruit elongation (FR3) and fruit maturation (FR4) in Thalewood House (TWH) and Bugarikallu (BGK)

Table 11. Summary of seasonality using circular statistical analysis of fruiting phenophases in Thalewood House and Bugarikallu transects

Description	Fruit initiation (FR2)		Fruit elongation (FR3)		Fruit maturation (FR4)	
	TWH	BGH	TWH	BGH	TWH	BGH
Number of observations (months)	46	46	46	46	46	46
Mean angle (vector m)	133.07°	131.05°	179.07°	164.12°	258.22°	274.03°
Length of mean vector (r)	0.44	0.37	0.37	0.39	0.28	0.29
Angular SD (circular SD)	73.16°	80.08°	80.23°	77.84°	90.73°	89.91°
Rayleigh's Z	65.58	45.64	78.53	68.05	77.62	83.65
p value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table 12. Synchrony indices of leafing phenophases in canopy and understorey species

Species	Leaf initiation (LF2)		Leaf fall (LF5)	
	TWH	BGK	TWH	BGK
Canopy				
Polyalthia cerasoides	0.98±0.04	0.82±0.21	0.63±0.06	0.68±0.19
Pterocarpus marsupium	0.98±0.04	0.78±0.14	0.63±0.11	0.41±0.11
Vitex altissima	0.95±0.05	0.93±0.09	0.45±0.05	0.52±0.11
Anogeissus latifolia	0.95±0.10	1±0	0.76±0.12	0.87±0.04
Dalbergia paniculata	0.9±0.20	0.75±0.18	0.93±0.08	0.85±0.14
Terminalia bellirica	0.85±0.05	0.63±0.08	0.83±0.15	0.64±0.18
Understorey				
Ixora arborea	0.98±0.05	0.98±0.05	1±0	1±0
Maytenus emarginata	0.93±0.15	0.95±0.1	0.3±0.14	0.45±0.05
Phyllanthus polyphyllus	0.9±0.20	0.82±0.18	0.8±0.1	0.87±0.11
Erythroxylum monogynum	0.75±0.13	0.93±0.15	0.5±0.12	0.59±0.11
Ochna obtusata	0.72±0.16	0.66±0.19	0.69±0.13	0.63±0.14
Holarrhena antidysenterica	0.44±0.13	0.43±0.22	0.57±0.14	0.6±0.18

the BGK. *Ixora arborea* and *Phyllanthus polyphyllus* had the highest synchrony for understorey species

Synchrony in flowering and fruiting

Flowering was not synchronous in most species, except for a few. The synchrony was weak for flower initiations in both transects for canopy and understorey species. *Polyalthia cerasoides* and *Vitex altissima* had the strongest synchrony in both transects among the canopy species, while *Erythroxylum monogynum* and *Phyllanthus polyphyllus* were among the understorey species (Table 13).

Synchrony in fruiting phenophases was also weak, with *Polyalthia cerasoides* having the strongest synchrony in fruit elongation in both transects, while *Erythroxylum monogynum* and *Holarrhena antidysenterica* were among the understorey species. Regarding fruit fall, *Pterocarpus marsupium* in TWH and *Acacia chundra* in BGK showed synchrony among the canopy species.

DISCUSSION

Patterns of leafing, flowering, and fruiting

Long-term phenological observations are needed to

Table 13. Synchrony indices of flowering and fruiting phenophases in canopy and understorey species

Species	**Flower initiation (FL2)**		**Fruit elongation (FR3)**		**Fruit fall (FR5)**	
	TWH	**BGK**	**TWH**	**BGK**	**TWH**	**BGK**
Canopy						
Polyalthia cerasoides	0.43±0.12	0.4±0.21	0.6±0.15	0.49±0.2	0.29±0.09	0.21±0.2
Vitex altissima	0.41±0.01	0.43±0.23	0.33±0.02	0.24±0.07	0.45±0.15	0.44±0.14
Pterocarpus marsupium	0.39±0.13	0.24±0.07	0.36±0.2	0.1±0.13	0.72±0.04	0.36±0.36
Terminalia bellirica	0.37±0.16	0.13±0.06	0.26±0.06	0.03±0.05	0.59±0.05	0.1±0.21
Cassia fistula	0.34±0.17	0.15±0.1	0.22±0.09	0.12±0.15	0.52±0.11	0.54±0.28
Acacia chundra	0.3±0.04	0.41±0.08	0.38±0.11	0.43±0.11	0.48±0.17	0.88±0.2
Understorey						
Erythroxylum monogynum	0.8±0.14	0.84±0.17	0.58±0.2	0.6±0.23	0.61±0.1	0.65±0.08
Phyllanthus polyphyllus	0.68±0.34	0.56±0.15	0.36±0.27	0.34±0.17	0.54±0.24	0.37±0.15
Maytenus emarginata	0.39±0.06	0.36±0.13	0.2±0.1	0.2±0.08	0.13±0.1	0.18±0.02
Ixora arborea	0.38±0.19	0.49±0.13	0.19±0.1	0.21±0.1	0.31±0.17	0.32±0.11
Holarrhena antidysenterica	0.28±0.04	0.37±0.06	0.53±0.23	0.47±0.25	0.67±0.3	0.65±0.03
Ochna obtusata	0.28±0.09	0.34±0.14	0.11±0.04	0.09±0.01	0.17±0.18	0.13±0.11

understand the variations in recurrent cycles within a community (Abernethy et al. 2018). The general patterns in BNP (TWH and BGK) largely correspond with other observations from tropical regions in India and elsewhere (Frankie et al. 1974, Kushwaha et al. 2011, Nanda et al. 2014, Sundarapandian et al. 2005). Generally, leaf initiations start after a dry season and peak during the pre-monsoon (March and April) after the first showers. Leaf initiation in BNP started in February when the day length was maximum, and rainfall, soil moisture, and humidity were low. This pattern was also observed in the dry forests of the Western Ghats (Murali and Sukumar 1993, Nanda et al. 2011, Sundarapandian et al. 2005). Similarly, leaf initiation in Argentina, Costa Rica, Java, and Thailand forests was due to an increase in day length in the absence of rains (Rivera et al. 2002). In contrast, peak leaf initiations were observed during February and March in the sub-tropical regions of Mizoram (Devi et al. 2023). Leaf fall peaked during the drier months of January and February in BNP. Similar leaf fall patterns were observed in India's dry forests (Nanda et al. 2020) and Barro Colarado Island, Panama (Wright and Cornejo 1990). Leaf fall and leaf litter production were the highest during the dry seasons in the tropical regions of Columbia (Obando Guzmán et al. 2023) and Barro Colarado Island, Panama (Wright and Cornejo 1990).

Flowering was caused by increasing day length during the dry season before the summer rains in many deciduous species (Borchert et al. 2004). Flower initiation peaked during March in TWH and April in BGK of BNP. The flower opening peaked in April in both TWK and BGK transects. Flower opening peaked during March and April during the dry season in Mudumalai and during April and May in Bhadra Wildlife Sanctuary (Suresh and Nanda 2021). Similarly, studies undertaken in the Andaman and Nicobar Islands on 73 species showed peak flowering during the March dry season (Singh et al. 2024).

Fruit initiations started in March and peaked during May in BNP (TWH and BGK). In Mudumalai, the fruit initiations started in February; two peaks were observed, one in May and the other in July, while in Bhadra, the peaks were during May and November (Suresh and Nanda 2021). There were no interannual variations among all the leafing and flowering phenophases. Only fruitlessness and fruit fall showed interannual variations between some years in TWH and BGK. This could be attributed to species differences in transects and the staggered nature of fruiting.

Factors influencing leafing, flowering, and fruiting

In both TWH and BGK, leaf initiations showed a positive correlation with maximum temperatures, similar to studies done at Bhadra Wildlife Sanctuary (Nanda et al. 2011). Rainfall, humidity, and soil moisture were positively correlated with leaf maturation, and maximum temperatures were positively correlated with leaf expansion. Rainfall, soil moisture content, and humidity were significantly and negatively correlated with leaf fall (Annexure 3).

Flower initiation, opening, and maturation were all positively influenced by maximum temperatures during the corresponding months in TWH and BGK as well as in the dry forests of Bhadra Wildlife Sanctuary (Nanda et al. 2014) and in the Andaman and Nicobar Islands (Singh et al. 2024). Flower initiation in TWH and BGK was significantly positively correlated with temperature. The flowering cue might be the increasing day length or sunshine hours as well as the temperatures, as seen in studies undertaken in the Vindhyan plateau (Singh and Kushwaha 2006). Molecular studies with the model plant Arabidopsis have confirmed that photoperiod and higher temperatures favour the shoot meristem to drive flowering (Liu et al. 2020, Susila et al. 2021).

Maximum temperature is a major environmental factor influencing flowering in dry tropical forests. In case of fruiting, no abiotic factor influenced initiations during the corresponding months in TWH and BGK and were similar to studies undertaken at Mudumalai (Suresh and Nanda 2021). Minimum temperatures during the corresponding months positively and significantly influenced fruit elongation. All the moisture-related factors positively influenced fruit maturation during the corresponding month and one-month lag and were significant. In contrast, studies in Bhadra show a negative influence of rainfall on fruit maturation during a corresponding month and an insignificant one-month lag (Nanda et al. 2011).

Our studies using principal component analysis and multiple regressions confirm that leaf and flower initiations are positively influenced by maximum temperature and negatively by moisture-related factors such as rainfall, humidity, the number of rainy days, and soil moisture content. A similar pattern was observed in most studies on dry forest phenology (McLaren and McDonald 2005; Suresh and Nanda, 2021). Moisture-related factors play a significant role in the onset of leafing phenophases in several parts of the globe. However, some studies have also shown that temperature and light availability are crucial in the onset of flowering phenophases (Borchert et al. 2005, Wright 1996).

Fruit elongation was influenced positively by minimum temperature, sunshine hours, and maximum temperature. Fruit maturation was positively influenced by moisture-related factors and negatively influenced by the maximum temperature in TWH and BGK. Fruiting is dependent on rainfall, and it has been shown that fruiting is significantly positively correlated with rainfall (Dunham et al. 2018, McLaren and McDonald 2005).

Seasonality

Medium seasonality was observed in various vegetative and reproductive phenophases. Leaf fall was significant (Rayleigh's Z = S, $p < 0.001$ for both TWH and BGK) and highly seasonal, occurring in January. The dry forests of Bhadra (Nanda et al. 2015), Mudumalai (Suresh and Nanda 2021), and other locations (McLaren and McDonald 2005, Patrícia et al. 2000) also showed comparable patterns in leaf fall. In both TWH and BGK, leaf initiation was in March, which was significantly seasonal (Rayleigh Z = S, $p < 0.001$). In dry forests, leaf initiation generally occurs during the dryer months, as observed in Mudumalai and Bhadra Wildlife Sanctuary (Nanda et al. 2015; Suresh and Nanda 2021).

Flower initiation peaked in March at TWH and BGK. Flower initiation occurred before leaf initiation in both locations. This is because some species flowered before the leaf initiation, such as *Phyllanthus polyphyllus, Ixora arborea*, and *Butea monosperma*. In contrast to Bhadra and Mudumalai (Nanda et al. 2011, Suresh and Nanda 2021), it was found that TWH and BGK had earlier leaf and flower initiations. Fruit initiations were significantly seasonal (Rayleigh's Z = S, $p < 0.001$ in both TWH and BGK).

Compared to the reproductive phenophases (flowering and fruiting), the leafing phenophases had a comparatively higher seasonality strength. Among the leafing phenophases, leaflessness (r = 0.688 for TWH and r = 0.686 for BGK) or deciduous condition was the highest compared with either senescence (r = 0.484 for TWH and r = 0.482 for BGK) or leaf initiation (r = 0.341 for TWH and r = 0.343 for BGK). A similar trend was observed in other dry forests in southern India (Nanda et al. 2020) and Brazil (Patrícia et al. 2000).

Synchrony

Leafing synchrony was very high compared to flowering and fruiting synchrony. *Polyalthia cerasoides, Pterocarpus marsupium,* and *Vitex altissima* had very high synchrony among the canopy species in TWH, whereas it was *Vitex altissima, Acacia chundra,* and *Polyalthia cerasoides* in BGK transects. In the case of understorey species, *Ixora arborea, Maytenus emarginata,* and *Phyllanthus polyphyllus* were synchronous in TWH; *Ixora arborea, Maytenus emarginata,* and *Erythroxylum monogynum* were synchronous in BGK. In the case of leaf fall, canopy species *Dalbergia paniculata, Terminalia bellirica,* and *Anogeissus latifolia* showed high synchrony in both TWH and BGK transects. Understorey species *Ixora arborea, Phyllanthus polyphyllus,* and *Ochna obtusata* were synchronous for leaf fall in both TWH and BGK.

Synchrony in leafing could be a defence mechanism; greater leaf turnover may prevent herbivory-related losses and improve growth (Lamarre et al. 2014). Plants that maintain synchrony in leafing could avoid herbivory, or the effect of herbivory is minimal, whereas asynchronous species are affected by herbivory (Murali and Sukumar 1993). The same is seen among TWH and the BGK community species, implying that synchrony is paramount to avoid herbivory.

Flowering synchrony was moderate, with the majority of the species being asynchronous. Flower initiations in *Polyalthia cerasoides, Vitex altissima,* and *Pterocarpus marsupium* among the canopy species showed moderate synchrony in TWH. In contrast, it was *Polyalthia cerasoides, Vitex altissima,* and *Acacia chundra* in the BGK transect. In understorey species *Erythroxylum monogynum, Phyllanthus polyphyllus,* and *Maytenus emarginata* were synchronous in both TWH and BGK.

Synchrony in flowering is essential, as many insects rely on flowers, and cross-pollination is better achieved with synchronous flowering. Synchrony in canopy species was low compared to understorey species in both TWH and BGK transects. Most species in BNP are insect-pollinated. Asynchrony in flowering phenology would have evolved to avoid competition for pollinators.

Asynchronous flowering in many species may be the reason for the low fruiting synchrony observed in both TWH and BGK transects. Since environmental factors also affect synchrony, climatic change may cause changes in the timing of leafing, flowering, and fruiting, which may further cause mismatches across different dependent species.

CONCLUSIONS

Our observations on the vegetative and reproductive phenophases of woody species in the two transects of BNP confirm that a dry winter is favourable for leaf fall. We also confirm that the maximum temperature during the summer triggers the flowering in these dry tropical forests. During January, when the minimum temperature and rainfall are at their lowest, the greatest number of species (88% in TWH and 85% in BGK) experience leaf fall. During February, when there are the fewest wet days, the lowest soil moisture content in transects, and the most sunshine hours, the greatest number of species are leafless (91% of species in TWH and 77% in BGK). During April, when temperatures are at their highest, the greatest number of species begins to produce leaves (84% in TWH and 80% in BGK) and flowers (56% in TWH and 49% in BGK). Based on our studies, we conclude that maximum temperatures and distinct increases in sunshine hours during a dry period trigger leaf initiations and flower initiations. In addition to the drier air and soil conditions, tropical woody plants, like those in temperate regions, require temperature increases and extended daylight periods to initiate leaves and flowers.

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REFERENCES

Abernethy, K., Bush, E.R., Forget, P., Mendoza, I. and Morellato, L.P.C. 2018. Current issues in tropical phenology: A synthesis. Biotropica, 50(3), 477-482. https://doi.org/10.1111/btp.12558

Adole, T., Dash, J., Rodriguez-Galiano, V. and Atkinson, P.M. 2019. Photoperiod controls vegetation phenology across Africa. Communications Biology, 2(1), 391. https://doi.org/10.1038/s42003-019-0636-7

Alberton, B., Da Silva Torres, R., Sanna Freire Silva, T., Rocha, H.S.B., Moura, M. and Morellato, L. 2019. Leafing patterns and drivers across seasonally dry tropical communities. Remote Sensing, 11(19), 2267. https://doi.org/10.3390/rs11192267

Alsubhi, N.H., and Alzahrani, S.M. 2023. Plant phenology: Definition, history, and response to environmental factors. Egyptian Journal of Botany, 64(4), 49-58. https://doi.org/10.21608/ejbo.2023.209652.2323

Anonymous. 1973. IS 2720-2: Methods of Test of Soils, Part 2: Determination of Water Content. Bureau of Indian Standards (BIS), New Delhi, India.

Balasubramanian, S., Sureshkumar, S., Lempe, J. and Weigel, D. 2006. Potent induction of *Arabidopsis thaliana* flowering by elevated growth temperature. PLoS Genetics, 2(7), e106. https://doi.org/10.1371/journal.pgen.0020106

Borchert, R. 1994. Soil and stem water storage determine phenology and distribution of tropical dry forest trees. Ecology, 75(5), 1437-1449. https://doi.org/10.2307/1937467

Borchert, R., Meyer, S.A., Felger, R.S. and Porter Bolland, L. 2004. Environmental control of flowering periodicity in Costa Rican and Mexican tropical dry forests. Global Ecology and Biogeography, 13(5), 409-425. https://doi.org/10.1111/j.1466-822X.2004.00111.x

Borchert, R., Renner, S.S., Calle, Z., Navarrete, D., Tye, A., Gautier, L., Spichiger, R. and von Hildebrand, P. 2005. Photoperiodic induction of synchronous flowering near the Equator. Nature, 433(7026), 627-629. https://doi.org/10.1038/nature03259

Chen, Y., Collins, S.L., Zhao, Y., Zhang, T., Yang, X., An, H., Hu, G., Xin, C., Zhou, J., Sheng, X., He, M., Zhang, P., Guo, Z., Zhang, H., Li, L. and Ma, M. 2023. Warming reduced flowering synchrony and extended community flowering season in an alpine meadow on the Tibetan Plateau. Ecology, 104(1), e3862. https://doi.org/10.1002/ecy.3862

Cortés-Flores, J., Cornejo-Tenorio, G., Urrea-Galeano, L.A., Andresen, E., González-Rodríguez, A. and Ibarra-Manríquez, G. 2019. Phylogeny, fruit traits, and ecological correlates of fruiting phenology in a Neotropical dry forest. Oecologia, 189(1), 159-169. https://doi.org/10.1007/s00442-018-4295-z

Daubenmire, R. 1972. Phenology and Other Characteristics of Tropical Semi-Deciduous Forest in North-Western Costa Rica. The Journal of Ecology, 60(1), 147. https://doi.org/10.2307/2258048

Devi, N.L., Brearley, F.Q. and Tripathi, S.K. 2023. Phenological diversity among sub-tropical moist forest trees of north-eastern India. Journal of Tropical Ecology, 39, e29. https://doi.org/10.1017/S0266467423000184

Devineau, J.-L. 1999. Seasonal rhythms and phenological plasticity of savanna woody species in a fallow farming system (south-west Burkina Faso). Journal of Tropical Ecology, 15(4), 497-513. https://doi.org/10.1017/S0266467499000978

Dore, J. 1959. Response of rice to small differences in length of day. Nature, 183(4658), 413-414. https://doi.org/10.1038/183413a0

Dunham, A.E., Razafindratsima, O.H., Rakotonirina, P. and Wright, P.C. 2018. Fruiting phenology is linked to rainfall variability in a tropical rain forest. Biotropica, 50(3), 396-404. https://doi.org/10.1111/btp.12564

Elliott, S., Baker, P.J. and Borchert, R. 2006. Leaf flushing during the dry season: The paradox of Asian monsoon forests: Dry season leaf flushing. Global Ecology and Biogeography, 15(3), 248-257. https://doi.org/10.1111/j.1466-8238.2006.00213.x

Fenner, M. 1998. The phenology of growth and reproduction in plants. Perspectives in Plant Ecology, Evolution and Systematics, 1(1), 78-91. https://doi.org/10.1078/1433-8319-00053

Frankie, G.W., Baker, H.G. and Opler, P.A. 1974. Comparative phenological studies of trees in tropical wet and dry forests in the lowlands of Costa Rica. The Journal of Ecology, 62(3), 881. https://doi.org/10.2307/2258961

Gopalakrishna, S.P., Kaonga, M.L., Somashekar, R.K., Suresh, H.S. and Suresh, R. 2015. Tree diversity in the tropical dry forest of Bannerghatta National Park in Eastern Ghats, Southern India. European Journal of Ecology, 1(2), 12-27. https://doi.org/10.1515/eje-2015-0013

Griz, L.M.S. and Machado, I.C.S. 2001. Fruiting phenology and seed dispersal syndromes in caatinga, a tropical dry forest in the northeast of Brazil. Journal of Tropical Ecology, 17(2), 303-321. https://doi.org/10.1017/S0266467401001201

Hammer, O., Harper, D.A.T. and Ryan, P.D. 2001. PAST: Paleontological Statistics Software Package for Education and Data Analysis. Palaeontologia Electronica, 4(1), 9. https://palaeo-electronica.org/2001_1/past/past.pdf

Hopkins, A.D. 1920. The bioclimatic law. Journal of the Washington Academy of Sciences, 10(2), 34-40. https://www.jstor.org/stable/24521154

Hudson, I.L., Kim, S.W. and Keatley, M.R. 2010. Climatic influences on the flowering phenology of four Eucalypts: A GAMLSS approach. pp. 209-228. In: Hudson, I.L. and Keatley, M.R. (Eds.), Phenological Research. Springer, Netherlands. https://doi.org/10.1007/978-90-481-3335-2_10

Jackson, J.F. 1978. Seasonality of flowering and leaf-fall in a Brazilian subtropical lower montane moist forest. Biotropica, 10(1), 38. https://doi.org/10.2307/2388103

Janzen, D.H. 1967. Synchronization of sexual reproduction of trees within the dry season in Central America. Evolution, 21(3), 620-637. https://doi.org/10.1111/j.1558-5646.1967.tb03416.x

Kakkar, R., Kumar, K.H.V., Remadevi, O.K., Manjunatha, M., Saritha, B., Sharma, B., Kiranraddi, M., Dattaraja, H.S. and Suresh, H.S. 2021. Patterns of woody species diversity and structure in Thalewood House permanent preservation plot in Bannerghatta National Park, Bangalore, India. Tropical Ecology, 62(4), 626-643. https://doi.org/10.1007/s42965-021-00169-y

Kakkar, R., Kumar, K.H.V., Remadevi, O.K., Manjunatha, M., Saritha, B., Sharma, B., Kiranraddi, M., Dattaraja, H.S. and Suresh, H.S. 2018. Establishing permanent preservation plots in Bannerghatta National Park for long-term ecological studies to monitor climate change. My Forest, 54(2), 19-34.

Koelmeyer, K.O. 1960. The periodicity of leaf change and flowering in the principal forest communities of Ceylon. Part II. Phenology of the tropical dry mixed evergreen forest. Ceylon Forester, 4, 308-364.

Kushwaha, C.P. and Singh, K.P. 2005. Diversity of leaf phenology in a tropical deciduous forest in India. Journal of Tropical Ecology, 21(1), 47-56. https://doi.org/10.1017/S0266467404002032

Kushwaha, C.P., Tripathi, S.K., Tripathi, B.D. and Singh, K.P. 2011. Patterns of tree phenological diversity in dry tropics. Acta Ecologica Sinica, 31(4), 179-185. https://doi.org/10.1016/j.chnaes.2011.04.003

Lamarre, G.P.A., Mendoza, I., Fine, P.V.A. and Baraloto, C. 2014. Leaf synchrony and insect herbivory among tropical tree habitat specialists. Plant Ecology, 215(2), 209-220. https://doi.org/10.1007/s11258-013-0290-y

Li, N., Xiao, J., Bai, R., Wang, J., Wu, L., Gao, W., Li, W., Chen, M. and Li, Q. 2023. Preseason sunshine duration determines the start of growing season of natural rubber forests. International Journal of Applied Earth Observation and Geoinformation, 124, 103513. https://doi.org/10.1016/j.jag.2023.103513

Liang, L. 2016. Beyond the bioclimatic law: Geographic adaptation patterns of temperate plant phenology. Progress in Physical Geography: Earth and Environment, 40(6), 811-834. https://doi.org/10.1177/0309133316656558

Liu, L., Zhang, Y., and Yu, H. (2020). Florigen trafficking integrates photoperiod and temperature signals in Arabidopsis. *Journal of Integrative Plant Biology*, *62*(9), 1385–1398. https://doi.org/10.1111/jipb.13000

Lobo, J.A., Quesada, M., Stoner, K.E., Fuchs, E.J., Herrerías-Diego, Y., Rojas, J. and Saborío, G. 2003. Factors affecting phenological patterns of Bombacaceous trees in seasonal forests in Costa Rica and Mexico. American Journal of Botany, 90(7), 1054-1063. https://doi.org/10.3732/ajb.90.7.1054

McLaren, K.P. and McDonald, M.A. 2005. Seasonal patterns of flowering and fruiting in a dry tropical forest in Jamaica. Biotropica, 37(4), 584-590. https://doi.org/10.1111/j.1744-7429.2005.00075.x

Murali, K.S. and Sukumar, R. 1993. Leaf flushing phenology and herbivory in a tropical dry deciduous forest, southern India. Oecologia, 94(1), 114-119. https://doi.org/10.1007/BF00317311

Murali, K.S. and Sukumar, R. 1994. Reproductive phenology of a tropical dry forest in Mudumalai, Southern India. The Journal of Ecology, 82(4), 759. https://doi.org/10.2307/2261441

Murphy, P.G. and Lugo, A.E. 1986. Ecology of tropical dry forest. Annual Review of Ecology and Systematics, 17(1), 67-88. https://doi.org/10.1146/annurev.es.17.110186.000435

Nanda, A., Prakasha, H.M. and Krishnamurthy, Y.L. 2011. Leafing patterns and seasonality at community level in a tropical dry deciduous forest of Bhadra wildlife sanctuary, Karnataka, India. Tree and Forestry Science and Biotechnology, 5(1), 82-87. http://www.globalsciencebooks.info/Online/GSBOnline/images/2011/TFSB_5(SI1)/TFSB_5(SI1)82-87o.pdf

Nanda, A., Prakasha, H.M., Murthy, Y.L.K. and Suresh, H.S. 2011. Phenology of leaf flushing, flower initiation and fruit maturation in dry deciduous and evergreen forests of Bhadra Wildlife Sanctuary, Karnataka, Southern India. Our Nature, 9, 89-99. https://www.academia.edu/7451720/phenology_of_leaf_flushing_flower_initiation_and_fruit_maturation_bhadra_wildlife_ sanctuary_2011

Nanda, A., Prakasha, H.M., Suresh, H.S. and Krishnamurthy, Y.L. 2015. Leafing phenology of tropical forests of Bhadra wildlife sanctuary, Karnataka, India. Applied Science Reports, 12(1), 3340. https://doi.org/10.15192/PSCP.ASR.2015.12.1.3340

Nanda, A., Suresh, H.S. and Krishnamurthy, Y.L. 2014. Phenology of a tropical dry deciduous forest of Bhadra wildlife sanctuary, southern India. Ecological Processes, 3(1), 1. https://doi.org/10.1186/2192-1709-3-1

Nanda, A., Suresh, H.S. and Murthy, Y.L.K. 2020. Community, dominant tree species leaf phenology and seasonality in a tropical dry forest, India. International Journal of Environment and Climate Change, 10(11), 34-49. https://doi.org/10.9734/ijecc/2020/v10i1130265

Obando Guzmán, J.K., Beltrán, L.C., Rodríguez-León, C.H. and Roa-Fuentes, L.L. 2023. Pattern of litterfall production throughout a tropical humid forest chronosequence. Ecosystems, 26(8), 1753-1765. https://doi.org/10.1007/s10021-023-00862-0

Patrícia, L., Morellato, C., Talora, D.C., Takahasi, A., Bencke, C.C., Romera, E.C. and Zipparro, V.B. 2000. Phenology of Atlantic rain forest trees: A comparative study. Biotropica, 32(4), 811. https://doi.org/10.1646/0006-3606(2000)032[0811:POARFT]2.0.CO;2

Pau, S., Wolkovich, E.M., Cook, B.I., Nytch, C.J., Regetz, J., Zimmerman, J.K. and Wright, S.J. 2013. Clouds and temperature drive dynamic changes in tropical flower production. Nature Climate Change, 3(9), 838-842. https://doi.org/10.1038/nclimate1934

Prasad, S.N. and Hegde, M. 1986. Phenology and seasonality in the tropical deciduous forest of Bandipur, South India. Proceedings / Indian Academy of Sciences, 96(2), 121-133. https://doi.org/10.1007/BF03053328

Ramaswami, G., Datta, A., Reddy, A. and Quader, S. 2018. Tracking phenology in the tropics and in India: The impacts of climate change. pp. 45-69. In: Bhatt, J.R., Das, A. and Shanker. K. (Eds.). Biodiversity and Climate Change: An Indian Perspective. Ministry of Environment, Forest and Climate Change, New Delhi.

Revelle, W. 2024. psych: Procedures for Psychological, Psychometric, and Personality Research [Computer software]. Northwestern University. Evanston. https://CRAN.R-project.org/package=psych.

Richardson, A.D., Hufkens, K., Li, X. and Ault, T.R. 2019. Testing Hopkins' Bioclimatic Law with PhenoCam data. Applications in Plant Sciences, 7(3), e01228. https://doi.org/10.1002/aps3.1228

Rivera, G., Elliott, S., Caldas, L.S., Nicolossi, G., Coradin, V.T.R. and Borchert, R. 2002. Increasing day-length induces spring flushing of tropical dry forest trees in the absence of rain. Trees, 16(7), 445-456. https://doi.org/10.1007/s00468-002-0185-3

Saha, D. and Sundriyal, R. 2010. Stand structure, phenology and fruit yield of *Illicium griffithii* in western Arunachal Pradesh, North-East India. Indian Journal of Forestry, 33(4), 475-488. https://doi.org/10.54207/bsmps1000-2010-K45G7Z

Shukla, R.P. and Ramakrishnan, P.S. 1982. Phenology of trees in a sub-tropical humid forest in north-eastern India. Vegetatio, 49(2), 103-109. https://doi.org/10.1007/BF00052764

Singh, K.P. and Kushwaha, C.P. 2006. Diversity of flowering and fruiting phenology of trees in a tropical deciduous forest in India. Annals of Botany, 97(2), 265-276. https://doi.org/10.1093/aob/mcj028

Singh, L.J., Dey, B.C., Mitra, P.K., Sharma, G.P. and Kushwaha, C.P. 2024. Diversity of reproductive phenology of trees in the tropical evergreen forest of Andaman and Nicobar Islands, India. Tropical Ecology, 65, 201-211. https://doi.org/10.1007/s42965-024-00326-z

Singh, S.L. and Sahoo U.K. 2019. Shift in phenology of some dominant tree species due to climate change in Mizoram, North-East India. Indian Journal of Ecology, 46(1), 132-136.

Stucky, B.J., Guralnick, R., Deck, J., Denny, E.G., Bolmgren, K. and Walls, R. 2018. The plant phenology ontology: A new informatics resource for large-scale integration of plant phenology data. Frontiers in Plant Science, 9, 517. https://doi.org/10.3389/fpls.2018.00517

Sundarapandian, S.M, Chandrasekaran, S. and Swamy, P.S. 2005. Phenological behaviour of selected tree species in tropical forests at Kodayar in the Western Ghats, Tamil Nadu, India. Current Science, 88(5), 805-810. https://www.jstor.org/stable/24111271

Suresh, H.S. and Nanda, A. 2021. Comparative phenologies of two tropical dry forests in Southern India. Journal of Global Ecology and Environment, 13(1), 36-57.

Susila, H., Juriæ, S., Liu, L., Gawarecka, K., Chung, K.S., Jin, S., Kim, S.-J., Nasim, Z., Youn, G., Suh, M.C., Yu, H. and Ahn, J.H. 2021. Florigen sequestration in cellular membranes modulates temperature-responsive flowering. Science, 373(6559), 1137-1142. https://doi.org/10.1126/science.abh4054

van der Laken, P. 2021. Ppsr: An R implementation of the predictive power score. https://paulvanderlaken.com/2021/01/12/ppsr-r-package-predictive-power-score/

Wang, C., Tang, Y. and Chen, J. 2016. Plant phenological synchrony increases under rapid within-spring warming. Scientific Reports, 6(1), 25460. https://doi.org/10.1038/srep25460

Wang, S.-L., An, H.R., Tong, C.-G. and Jang, S. 2021. Flowering and flowering genes: From model plants to orchids. Horticulture, Environment, and Biotechnology, 62(2), 135-148. https://doi.org/10.1007/s13580-020-00309-8

Wright, S.J. 1996. Phenological responses to seasonality in tropical forest plants. pp. 440-460. In: Mulkey, S.S., Chazdon, R.L. and Smith, A.P. (Eds.), Tropical Forest Plant Ecophysiology. Springer, US. https://doi.org/10.1007/978-1-4613-1163-8_15

Wright, S.J. and Cornejo, F.H. 1990. Seasonal drought and leaf fall in a tropical forest. Ecology, 71(3), 1165-1175. https://doi.org/10.2307/1937384

Xuan, L., Jiang, Y. and Liu, L. 2022. New insights into temperature-dependent regulation of flowering. Molecular Plant, 15(11), 1656-1658. https://doi.org/10.1016/j.molp.2022.10.002

Yadav, R.K. and Yadav, A. 2008. Phenology of selected woody species in a tropical dry deciduous forest in Rajasthan, India. Tropical Ecology, 49, 25-34.

Zohner, C.M., Mo, L. and Renner, S.S. 2018. Global warming reduces leaf-out and flowering synchrony among individuals. eLife, 7, 1-15. https://doi.org/10.7554/eLife.40214

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Supplimentary information

Impact of Weather on the Leafing, Flowering, and Fruiting Patterns of Woody Plant Communities in the Tropical Dry Forests of Bannerghatta National Park, India

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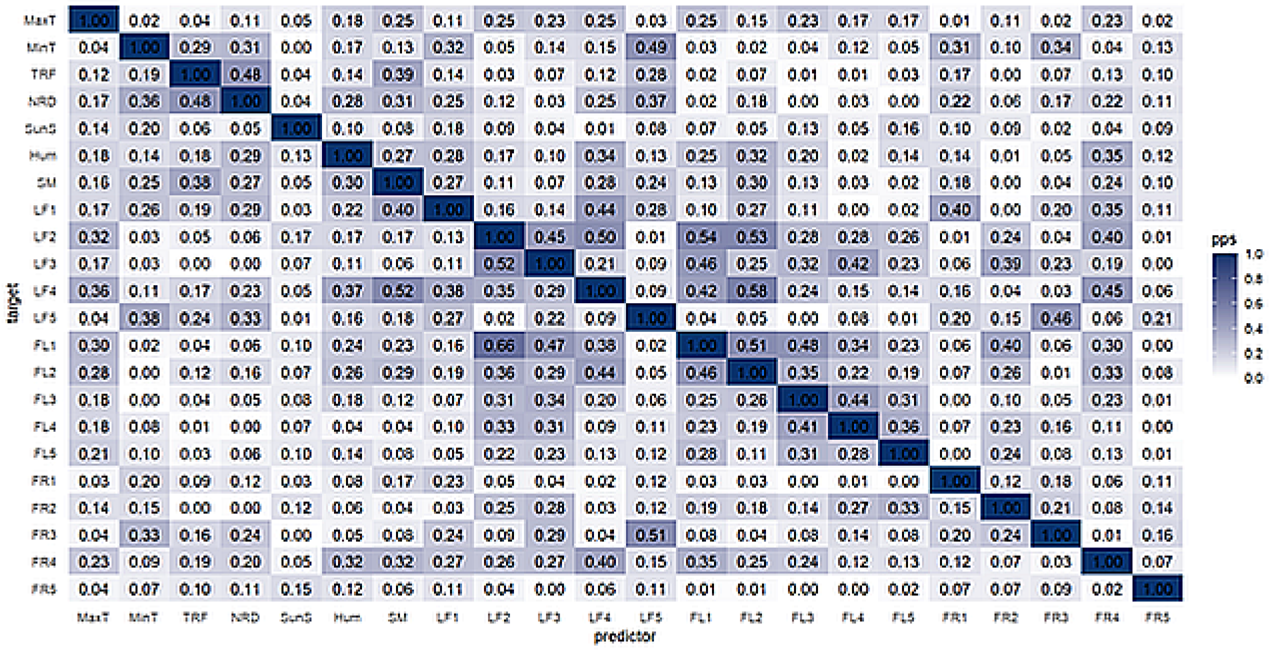
Annexure 1. List of species monitored in Thalewood House (TWH) and Bugarikallu (BGK) transects

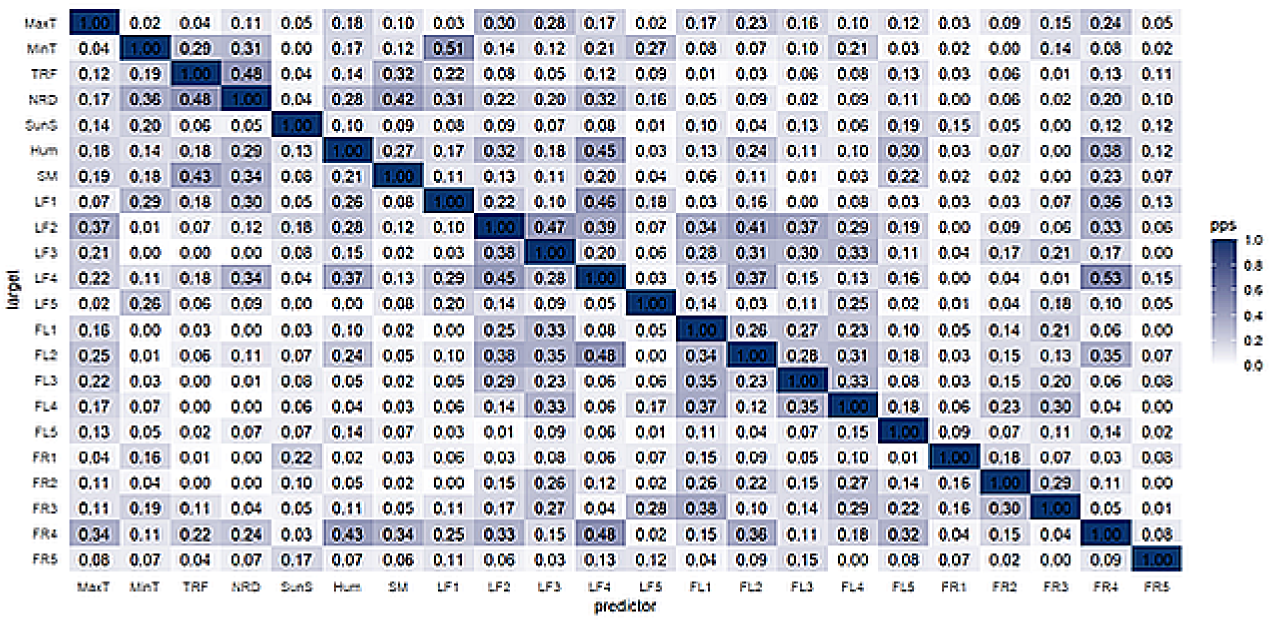
Species	Family	Number of individuals	
		TWH	BGK
Acacia chundra	Fabaceae	5	14
Acacia leucophloea	Fabaceae	0	1
Albizzia odoratissima	Fabaceae	1	0
Anogeissus latifolia	Combretaceae	7	22
Antidesma ghaesembilla	Euphorbiaceae	1	1
Azadirachta indica	Meliaceae	1	5
Balanites aegyptica	Balanitaceae	0	2
Bauhinia racemosa	Fabaceae	6	5
Bridelia retusa	Euphorbiaceae	0	2
Buchanania axillaris	Anacardiaceae	5	3
Butea monosperma	Fabaceae	3	2
Canthium dicoccum	Rubiaceae	1	5
Canthium parviflorum	Rubiaceae	6	2
Capparis grandis	Capparaceae	1	0
Careya arborea	Lecythidaceae	2	1
Cassia fistula	Fabaceae	7	3
Cassia siamea	Fabaceae	0	1
Cassine glauca	Celastraceae	0	3
Chloroxylon swietenia	Rutaceae	2	2
Cordia wallichii	Boraginaceae	2	1
Dalbergia lanceolaria	Fabaceae	6	5
Dalbergia sissoo	Fabaceae	0	2
Dichrostachys cinerea	Fabaceae	0	1
Diospyros melanoxylon	Ebenaceae	7	7
Diospyros montana	Ebenaceae	5	2
Dolichondrone atrovirens	Bignoniaceae	2	0
Erythroxylon monogynum	Erythroxylaceae	6	18
Eucalyptus tereticornis	Myrtaceae	0	1
Ficus benghalensis	Moraceae	3	1
Ficus microcarpa	Moraceae	1	0
Firmiana colorata	Sterculiaceae	1	0

Species	Family	Number of individuals	
		TWH	BGK
Flacourtia indica	Flacourtiaceae	0	1
Garuga pinnata	Burseraceae	1	0
Givotia moluccana	Euphorbiaceae	2	1
Glochidion velutinum	Myrsinaceae	5	0
Glochidion zeylanicum	Myrsinaceae	1	0
Gmelina arborea	Verbenaceae	1	0
Gmelina asiatica	Verbenaceae	3	2
Grewia orbiculata	Tiliaceae	2	10
Holarrhena antidysenterica	Apocynaceae	5	4
Ixora arborea	Rubiaceae	23	20
Lagerstroemia parviflora	Lythraceae	3	4
Limonia acidissima	Rutaceae	1	2
Madhuca longifolia var. latifolia	Sapotaceae	1	3
Mangifera indica	Anacardiaceae	2	0
Maytenus emarginata	Celastraceae	6	17
Melia dubia	Meliaceae	0	1
Memecylon umbellatum	Melastomataceae	2	0
Miliusa tomentosa	Annonaceae	0	1
Mitragyna parvifolia	Rubiaceae	0	1
Morinda citrifolia	Rubiaceae	0	2
Naringi crenulata	Rutaceae	3	2
Ochna obtusata	Ochnaceae	6	3
Olea dioica	Oleaceae	3	0
Phyllanthus emblica	Euphorbiaceae	2	1
Phyllanthus polyphyllus	Euphorbiaceae	12	6
Polyalthia cerasoides	Annonaceae	12	9
Pongamia pinnata	Fabaceae	3	2
Premna tomentosa	Verbenaceae	2	2
Pterocarpus marsupium	Fabaceae	5	3
Randia dumetorum	Rubiaceae	6	2
Randia uliginosa	Rubiaceae	1	0
Santalum album	Santalaceae	0	1
Schleichera oleosa	Sapindaceae	1	2
Schrebera swietenioides	Oleaceae	1	0
Semecarpus anacardium	Anacardiaceae	0	1
Shorea roxburghii	Dipterocarpaceae	4	1
Soymida febrifuga	Meliaceae	3	3
Stereospermum suaveolens	Bignoniaceae	2	3
Strychnos potatorum	Loganaceae	5	4
Syzygium alternifolium	Myrtaceae	1	0
Syzygium cumini	Myrtaceae	6	1
Tamarindus indica	Fabaceae	1	1
Terminalia alata	Combretaceae	1	3
Terminalia arjuna	Combretaceae	6	2
Terminalia bellirica	Combretaceae	7	3
Terminalia chebula	Combretaceae	2	4
Terminalia paniculata	Combretaceae	6	3
Vitex altissima	Verbenaceae	8	3
Wrightia arborea	Apocynaceae	0	1
Wrightia tinctoria	Apocynaceae	1	0
Ximenia americana	Olacaceae	2	1
Ziziphus mauritiana	Rhamnaceae	2	0
Ziziphus xylopyrus	Rhamnaceae	1	2

Annexure 2. Predictive power score matric for Thalewood House locality



Annexure 3. Predictive power score matrix for Bugarikallu locality



Annexure 4. Spearman's correlations in Thalewood House and Bugarikallu transects

Parameter	Corresonding months (df=46)		One-month lag (df=45)		Two-months lag (df=44)	
	Spearman's rs	*p-value*	Spearman's rs	*p-value*	Spearman's rs	*p-value*
Thalewood House (TWH) transect						
Leafing						
No leaves (LF1)						
Maximum temperature (°C)	0.360	*0.014*	0.090	*0.559*	-0.332	*0.028*
Minimum temperature (°C)	-0.612	*0.000*	-0.777	*0.000*	-0.686	*0.000*
Total rainfall (mm)	-0.506	*0.000*	-0.532	*0.000*	-0.309	*0.041*
Number of rainy days	-0.623	*0.000*	-0.620	*0.000*	-0.364	*0.015*
Sun shine (hrs)	-0.169	*0.262*	-0.309	*0.039*	-0.463	*0.002*
Humidity (%)	-0.497	*0.000*	-0.355	*0.017*	0.024	*0.875*
Soil moisture (%)	-0.531	*0.000*	-0.297	*0.047*	0.027	*0.858*
Leaf initiation (LF2)						
Maximum temperature (°C)	0.627	*0.000*	0.729	*0.000*	0.478	*0.001*
Minimum temperature (°C)	0.096	*0.524*	-0.217	*0.151*	-0.515	*0.000*
Total rainfall (mm)	-0.102	*0.499*	-0.440	*0.002*	-0.776	*0.000*
Number of rainy days	-0.196	*0.191*	-0.515	*0.000*	-0.761	*0.000*
Sun shine (hrs)	0.221	*0.140*	0.226	*0.136*	0.126	*0.414*
Humidity (%)	-0.327	*0.027*	-0.596	*0.000*	-0.656	*0.000*
Soil moisture (%)	-0.387	*0.007*	-0.623	*0.000*	-0.764	*0.000*
Leaf expansion (LF3)						
Maximum temperature (°C)	0.481	*0.001*	0.655	*0.000*	0.644	*0.000*
Minimum temperature (°C)	0.348	*0.018*	0.013	*0.930*	-0.343	*0.023*
Total rainfall (mm)	0.127	*0.400*	-0.263	*0.081*	-0.591	*0.000*
Number of rainy days	0.080	*0.599*	-0.309	*0.039*	-0.614	*0.000*
Sun shine (hrs)	0.165	*0.274*	0.257	*0.088*	0.226	*0.140*
Humidity (%)	-0.094	*0.535*	-0.424	*0.004*	-0.632	*0.000*
Soil moisture (%)	-0.169	*0.260*	-0.519	*0.000*	-0.711	*0.000*
Mature leaves (LF4)						
Maximum temperature (°C)	-0.600	*0.000*	-0.407	*0.006*	-0.023	*0.881*
Minimum temperature (°C)	0.440	*0.002*	0.735	*0.000*	0.833	*0.000*
Total rainfall (mm)	0.513	*0.000*	0.681	*0.000*	0.602	*0.000*
Number of rainy days	0.630	*0.000*	0.780	*0.000*	0.674	*0.000*
Sun shine (hrs)	-0.025	*0.867*	0.078	*0.611*	0.255	*0.095*
Humidity (%)	0.551	*0.000*	0.595	*0.000*	0.385	*0.010*
Soil moisture (%)	0.638	*0.000*	0.600	*0.000*	0.381	*0.010*
Leaf fall/Falling leaves (LF5)						
Maximum temperature (°C)	0.085	*0.573*	-0.362	*0.014*	-0.655	*0.000*
Minimum temperature (°C)	-0.814	*0.000*	-0.626	*0.000*	-0.232	*0.129*
Total rainfall (mm)	-0.632	*0.000*	-0.348	*0.019*	0.125	*0.420*
Number of rainy days	-0.703	*0.000*	-0.386	*0.009*	0.116	*0.455*
Sun shine (hrs)	-0.022	*0.885*	-0.223	*0.142*	-0.321	*0.034*
Humidity (%)	-0.512	*0.000*	-0.089	*0.559*	0.347	*0.021*
Soil moisture (%)	-0.477	*0.000*	-0.020	*0.892*	0.499	*0.000*
Flowering						
No Flowers (FL1)						
Maximum temperature (°C)	-0.685	*0.000*	-0.605	*0.000*	-0.418	*0.005*
Minimum temperature (°C)	0.010	*0.948*	0.409	*0.005*	0.690	*0.000*
Total rainfall (mm)	0.228	*0.127*	0.551	*0.000*	0.733	*0.000*
Number of rainy days	0.281	*0.058*	0.629	*0.000*	0.775	*0.000*
Sun shine (hrs)	-0.102	*0.499*	-0.105	*0.491*	0.024	*0.875*
Humidity (%)	0.356	*0.015*	0.564	*0.000*	0.600	*0.000*
Soil moisture (%)	0.482	*0.000*	0.719	*0.000*	0.658	*0.000*

Parameter	Corresonding months (df=46)		One-month lag (df=45)		Two-months lag (df=44)	
	Spearman's rs	*p-value*	Spearman's rs	*p-value*	Spearman's rs	*p-value*
Flower initiation (FL2)						
Maximum temperature (°C)	0.605	*0.000*	0.516	*0.000*	0.290	*0.056*
Minimum temperature (°C)	-0.220	*0.143*	-0.534	*0.000*	-0.781	*0.000*
Total rainfall (mm)	-0.333	*0.024*	-0.560	*0.000*	-0.696	*0.000*
Number of rainy days	-0.449	*0.002*	-0.623	*0.000*	-0.765	*0.000*
Sun shine (hrs)	0.058	*0.703*	-0.034	*0.824*	-0.166	*0.281*
Humidity (%)	-0.458	*0.001*	-0.577	*0.000*	-0.533	*0.000*
Soil moisture (%)	-0.501	*0.000*	-0.632	*0.000*	-0.568	*0.000*
Flower opening (FL3)						
Maximum temperature (°C)	0.686	*0.000*	0.789	*0.000*	0.461	*0.002*
Minimum temperature (°C)	0.254	*0.089*	-0.191	*0.209*	-0.521	*0.000*
Total rainfall (mm)	-0.198	*0.188*	-0.649	*0.000*	-0.738	*0.000*
Number of rainy days	-0.176	*0.243*	-0.653	*0.000*	-0.761	*0.000*
Sun shine (hrs)	0.435	*0.003*	0.423	*0.004*	0.308	*0.042*
Humidity (%)	-0.403	*0.005*	-0.711	*0.000*	-0.706	*0.000*
Soil moisture (%)	-0.529	*0.000*	-0.859	*0.000*	-0.728	*0.000*
Pollinated/Mature flowers (FL4)						
Maximum temperature (°C)	0.631	*0.000*	0.677	*0.000*	0.540	*0.000*
Minimum temperature (°C)	0.381	*0.009*	-0.010	*0.950*	-0.321	*0.034*
Total rainfall (mm)	0.062	*0.681*	-0.424	*0.004*	-0.695	*0.000*
Number of rainy days	0.047	*0.757*	-0.382	*0.010*	-0.688	*0.000*
Sun shine (hrs)	0.248	*0.096*	0.371	*0.012*	0.304	*0.045*
Humidity (%)	-0.184	*0.221*	-0.509	*0.000*	-0.606	*0.000*
Soil moisture (%)	-0.274	*0.064*	-0.649	*0.000*	-0.758	*0.000*
Falling flowers (FL5)						
Maximum temperature (°C)	0.658	*0.000*	0.639	*0.000*	0.477	*0.001*
Minimum temperature (°C)	0.403	*0.006*	-0.082	*0.594*	-0.436	*0.003*
Total rainfall (mm)	-0.130	*0.388*	-0.553	*0.000*	-0.749	*0.000*
Number of rainy days	-0.087	*0.566*	-0.506	*0.000*	-0.749	*0.000*
Sun shine (hrs)	0.415	*0.004*	0.499	*0.000*	0.433	*0.003*
Humidity (%)	-0.343	*0.020*	-0.678	*0.000*	-0.693	*0.000*
Soil moisture (%)	-0.378	*0.009*	-0.721	*0.000*	-0.769	*0.000*
Fruiting						
No Fruits (FR1)						
Maximum temperature (°C)	0.270	*0.070*	-0.087	*0.569*	-0.340	*0.024*
Minimum temperature (°C)	-0.495	*0.000*	-0.545	*0.000*	-0.421	*0.004*
Total rainfall (mm)	-0.588	*0.000*	-0.484	*0.001*	-0.167	*0.280*
Number of rainy days	-0.594	*0.000*	-0.454	*0.002*	-0.174	*0.258*
Sun shine (hrs)	0.353	*0.016*	0.189	*0.215*	-0.070	*0.652*
Humidity (%)	-0.629	*0.000*	-0.431	*0.003*	-0.048	*0.755*
Soil moisture (%)	-0.589	*0.000*	-0.250	*0.096*	0.156	*0.310*
Fruit initiation (FR2)						
Maximum temperature (°C)	0.355	*0.016*	0.480	*0.001*	0.583	*0.000*
Minimum temperature (°C)	0.314	*0.033*	-0.005	*0.975*	-0.392	*0.008*
Total rainfall (mm)	0.097	*0.520*	-0.183	*0.228*	-0.410	*0.006*
Number of rainy days	0.099	*0.514*	-0.226	*0.135*	-0.504	*0.000*
Sun shine (hrs)	0.006	*0.970*	0.058	*0.706*	0.060	*0.700*
Humidity (%)	0.010	*0.948*	-0.263	*0.081*	-0.509	*0.000*
Soil moisture (%)	-0.028	*0.853*	-0.406	*0.005*	-0.580	*0.000*

Parameter	Corresonding months (df=46)		One-month lag (df=45)		Two-months lag (df=44)	
	Spearman's rs	***p-value***	**Spearman's rs**	***p-value***	**Spearman's rs**	***p-value***
Fruit elongation (FR3)						
Maximum temperature (°C)	0.093	*0.538*	0.466	*0.001*	0.717	*0.000*
Minimum temperature (°C)	0.779	*0.000*	0.566	*0.000*	0.106	*0.495*
Total rainfall (mm)	0.461	*0.001*	0.156	*0.307*	-0.287	*0.059*
Number of rainy days	0.542	*0.000*	0.208	*0.169*	-0.281	*0.065*
Sun shine (hrs)	0.179	*0.233*	0.253	*0.094*	0.333	*0.027*
Humidity (%)	0.285	*0.054*	-0.046	*0.764*	-0.447	*0.002*
Soil moisture (%)	0.255	*0.087*	-0.165	*0.276*	-0.630	*0.000*
Mature fruits (FR4)						
Maximum temperature (°C)	-0.605	*0.000*	-0.358	*0.016*	-0.005	*0.976*
Minimum temperature (°C)	0.412	*0.004*	0.714	*0.000*	0.806	*0.000*
Total rainfall (mm)	0.580	*0.000*	0.721	*0.000*	0.546	*0.000*
Number of rainy days	0.621	*0.000*	0.805	*0.000*	0.644	*0.000*
Sun shine (hrs)	-0.150	*0.320*	0.029	*0.851*	0.219	*0.153*
Humidity (%)	0.692	*0.000*	0.665	*0.000*	0.413	*0.005*
Soil moisture (%)	0.736	*0.000*	0.646	*0.000*	0.306	*0.043*
Falling fruits (FR5)						
Maximum temperature (°C)	0.194	*0.196*	-0.010	*0.946*	-0.201	*0.192*
Minimum temperature (°C)	-0.207	*0.167*	-0.129	*0.397*	0.050	*0.747*
Total rainfall (mm)	-0.474	*0.001*	-0.353	*0.018*	-0.087	*0.575*
Number of rainy days	-0.465	*0.001*	-0.341	*0.022*	-0.040	*0.797*
Sun shine (hrs)	0.467	*0.001*	0.387	*0.009*	0.318	*0.036*
Humidity (%)	-0.423	*0.003*	-0.188	*0.216*	0.046	*0.766*
Soil moisture (%)	-0.480	*0.000*	-0.188	*0.216*	0.093	*0.043*
Bugarikallu (BGK) transect						
Leafing						
No leaves (LF1)						
Maximum temperature (°C)	0.314	*0.034*	-0.060	*0.696*	-0.413	*0.005*
Minimum temperature (°C)	-0.735	*0.000*	-0.824	*0.000*	-0.687	*0.000*
Total rainfall (mm)	-0.637	*0.000*	-0.534	*0.000*	-0.205	*0.181*
Number of rainy days	-0.723	*0.000*	-0.616	*0.000*	-0.292	*0.055*
Sun shine (hrs)	-0.143	*0.343*	-0.352	*0.018*	-0.487	*0.001*
Humidity (%)	-0.531	*0.000*	-0.313	*0.036*	0.072	*0.643*
Soil moisture (%)	-0.529	*0.000*	-0.378	*0.010*	-0.066	*0.670*
Leaf initiation (LF2)						
Maximum temperature (°C)	0.620	*0.000*	0.682	*0.000*	0.365	*0.015*
Minimum temperature (°C)	0.020	*0.893*	-0.297	*0.048*	-0.598	*0.000*
Total rainfall (mm)	-0.143	*0.343*	-0.512	*0.000*	-0.769	*0.000*
Number of rainy days	-0.220	*0.142*	-0.561	*0.000*	-0.736	*0.000*
Sun shine (hrs)	0.236	*0.115*	0.253	*0.093*	0.013	*0.933*
Humidity (%)	-0.429	*0.003*	-0.646	*0.000*	-0.631	*0.000*
Soil moisture (%)	-0.244	*0.103*	-0.502	*0.000*	-0.695	*0.000*
Leaf expansion (LF3)						
Maximum temperature (°C)	0.557	*0.000*	0.668	*0.000*	0.545	*0.000*
Minimum temperature (°C)	0.204	*0.173*	-0.150	*0.324*	-0.507	*0.000*
Total rainfall (mm)	-0.011	*0.944*	-0.341	*0.022*	-0.687	*0.000*
Number of rainy days	-0.054	*0.721*	-0.380	*0.010*	-0.685	*0.000*
Sun shine (hrs)	0.189	*0.210*	0.233	*0.124*	0.100	*0.517*
Humidity (%)	-0.249	*0.095*	-0.542	*0.000*	-0.671	*0.000*
Soil moisture (%)	-0.142	*0.348*	-0.374	*0.011*	-0.622	*0.000*

Parameter	Corresonding months (df=46)		One-month lag (df=45)		Two-months lag (df=44)	
	Spearman's rs	*p-value*	Spearman's rs	*p-value*	Spearman's rs	*p-value*
Mature leaves (LF4)						
Maximum temperature (°C)	-0.607	*0.000*	-0.330	*0.027*	0.039	*0.799*
Minimum temperature (°C)	0.480	*0.001*	0.742	*0.000*	0.875	*0.000*
Total rainfall (mm)	0.569	*0.000*	0.734	*0.000*	0.590	*0.000*
Number of rainy days	0.652	*0.000*	0.793	*0.000*	0.681	*0.000*
Sun shine (hrs)	-0.050	*0.742*	0.068	*0.657*	0.280	*0.066*
Humidity (%)	0.608	*0.000*	0.578	*0.000*	0.389	*0.009*
Soil moisture (%)	0.581	*0.000*	0.630	*0.000*	0.440	*0.003*
Leaf fall/Falling leaves (LF5)						
Maximum temperature (°C)	-0.066	*0.665*	-0.530	*0.000*	-0.737	*0.000*
Minimum temperature (°C)	-0.792	*0.000*	-0.576	*0.000*	-0.211	*0.169*
Total rainfall (mm)	-0.601	*0.000*	-0.209	*0.168*	0.249	*0.104*
Number of rainy days	-0.649	*0.000*	-0.245	*0.105*	0.208	*0.176*
Sun shine (hrs)	-0.222	*0.139*	-0.368	*0.013*	-0.426	*0.004*
Humidity (%)	-0.330	*0.025*	0.074	*0.628*	0.478	*0.001*
Soil moisture (%)	-0.431	*0.003*	-0.023	*0.881*	0.364	*0.015*
Flowering						
No Flowers (FL1)						
Maximum temperature (°C)	-0.618	*0.000*	-0.661	*0.000*	-0.481	*0.001*
Minimum temperature (°C)	-0.252	*0.091*	0.140	*0.359*	0.461	*0.002*
Total rainfall (mm)	0.011	*0.940*	0.437	*0.003*	0.707	*0.000*
Number of rainy days	0.024	*0.876*	0.442	*0.002*	0.665	*0.000*
Sun shine (hrs)	-0.208	*0.166*	-0.280	*0.062*	-0.106	*0.494*
Humidity (%)	0.248	*0.096*	0.586	*0.000*	0.608	*0.000*
Soil moisture (%)	0.175	*0.244*	0.434	*0.003*	0.637	*0.000*
Flower initiation (FL2)						
Maximum temperature (°C)	0.604	*0.000*	0.546	*0.000*	0.157	*0.309*
Minimum temperature (°C)	-0.206	*0.169*	-0.490	*0.001*	-0.737	*0.000*
Total rainfall (mm)	-0.259	*0.082*	-0.602	*0.000*	-0.756	*0.000*
Number of rainy days	-0.345	*0.019*	-0.647	*0.000*	-0.749	*0.000*
Sun shine (hrs)	0.081	*0.592*	0.011	*0.943*	-0.151	*0.327*
Humidity (%)	-0.452	*0.002*	-0.632	*0.000*	-0.601	*0.000*
Soil moisture (%)	-0.306	*0.038*	-0.577	*0.000*	-0.596	*0.000*
Flower opening (FL3)						
Maximum temperature (°C)	0.669	*0.000*	0.695	*0.000*	0.487	*0.001*
Minimum temperature (°C)	0.252	*0.091*	-0.113	*0.461*	-0.383	*0.010*
Total rainfall (mm)	-0.079	*0.603*	-0.478	*0.001*	-0.711	*0.000*
Number of rainy days	-0.096	*0.527*	-0.471	*0.001*	-0.661	*0.000*
Sun shine (hrs)	0.366	*0.012*	0.428	*0.003*	0.417	*0.005*
Humidity (%)	-0.252	*0.091*	-0.577	*0.000*	-0.661	*0.000*
Soil moisture (%)	-0.273	*0.066*	-0.509	*0.000*	-0.640	*0.000*
Pollinated/Mature flowers (FL4)						
Maximum temperature (°C)	0.574	*0.000*	0.634	*0.000*	0.586	*0.000*
Minimum temperature (°C)	0.354	*0.016*	0.020	*0.895*	-0.309	*0.041*
Total rainfall (mm)	0.036	*0.815*	-0.374	*0.011*	-0.570	*0.000*
Number of rainy days	0.028	*0.855*	-0.351	*0.018*	-0.577	*0.000*
Sun shine (hrs)	0.300	*0.043*	0.424	*0.004*	0.326	*0.031*
Humidity (%)	-0.166	*0.271*	-0.547	*0.000*	-0.619	*0.000*
Soil moisture (%)	-0.185	*0.218*	-0.386	*0.009*	-0.527	*0.000*

Parameter	Corresonding months (df=46)		One-month lag (df=45)		Two-months lag (df=44)	
	Spearman's rs	*p-value*	Spearman's rs	*p-value*	Spearman's rs	*p-value*
Falling flowers (FL5)						
Maximum temperature (°C)	0.588	*0.000*	0.460	*0.001*	0.245	*0.109*
Minimum temperature (°C)	0.200	*0.182*	-0.280	*0.062*	-0.529	*0.000*
Total rainfall (mm)	-0.390	*0.007*	-0.673	*0.000*	-0.631	*0.000*
Number of rainy days	-0.327	*0.026*	-0.594	*0.000*	-0.668	*0.000*
Sun shine (hrs)	0.478	*0.001*	0.437	*0.003*	0.151	*0.327*
Humidity (%)	-0.540	*0.000*	-0.677	*0.000*	-0.556	*0.000*
Soil moisture (%)	-0.523	*0.000*	-0.606	*0.000*	-0.588	*0.000*
Fruiting						
No Fruits (FR1)						
Maximum temperature (°C)	0.019	*0.898*	-0.092	*0.547*	-0.241	*0.116*
Minimum temperature (°C)	0.059	*0.698*	0.062	*0.685*	0.124	*0.422*
Total rainfall (mm)	-0.196	*0.192*	-0.148	*0.332*	0.030	*0.845*
Number of rainy days	-0.127	*0.401*	-0.041	*0.787*	0.079	*0.611*
Sun shine (hrs)	0.541	*0.000*	0.501	*0.000*	0.428	*0.004*
Humidity (%)	-0.233	*0.119*	-0.149	*0.328*	0.016	*0.918*
Soil moisture (%)	-0.239	*0.110*	-0.211	*0.163*	-0.022	*0.886*
Fruit initiation (FR2)						
Maximum temperature (°C)	0.394	*0.007*	0.505	*0.000*	0.509	*0.000*
Minimum temperature (°C)	0.090	*0.551*	-0.244	*0.107*	-0.552	*0.000*
Total rainfall (mm)	-0.024	*0.873*	-0.196	*0.197*	-0.472	*0.001*
Number of rainy days	-0.063	*0.675*	-0.283	*0.060*	-0.506	*0.000*
Sun shine (hrs)	0.012	*0.938*	0.000	*0.999*	-0.079	*0.611*
Humidity (%)	-0.194	*0.197*	-0.388	*0.008*	-0.533	*0.000*
Soil moisture (%)	-0.157	*0.298*	-0.227	*0.133*	-0.406	*0.006*
Fruit elongation (FR3)						
Maximum temperature (°C)	0.391	*0.007*	0.561	*0.000*	0.666	*0.000*
Minimum temperature (°C)	0.510	*0.000*	0.175	*0.249*	-0.201	*0.191*
Total rainfall (mm)	0.217	*0.147*	-0.090	*0.555*	-0.418	*0.005*
Number of rainy days	0.218	*0.146*	-0.050	*0.746*	-0.457	*0.002*
Sun shine (hrs)	0.140	*0.353*	0.214	*0.159*	0.155	*0.315*
Humidity (%)	0.017	*0.909*	-0.355	*0.017*	-0.567	*0.000*
Soil moisture (%)	0.086	*0.571*	-0.215	*0.157*	-0.455	*0.002*
Mature fruits (FR4)						
Maximum temperature (°C)	-0.621	*0.000*	-0.382	*0.010*	-0.012	*0.937*
Minimum temperature (°C)	0.355	*0.015*	0.721	*0.000*	0.866	*0.000*
Total rainfall (mm)	0.608	*0.000*	0.684	*0.000*	0.577	*0.000*
Number of rainy days	0.638	*0.000*	0.792	*0.000*	0.647	*0.000*
Sun shine (hrs)	-0.275	*0.064*	-0.043	*0.780*	0.219	*0.154*
Humidity (%)	0.757	*0.000*	0.715	*0.000*	0.441	*0.003*
Soil moisture (%)	0.719	*0.000*	0.662	*0.000*	0.452	*0.002*
Falling fruits (FR5)						
Maximum temperature (°C)	0.462	*0.001*	0.236	*0.119*	0.044	*0.775*
Minimum temperature (°C)	-0.053	*0.726*	-0.202	*0.184*	-0.211	*0.170*
Total rainfall (mm)	-0.503	*0.000*	-0.575	*0.000*	-0.386	*0.010*
Number of rainy days	-0.479	*0.001*	-0.514	*0.000*	-0.403	*0.007*
Sun shine (hrs)	0.543	*0.000*	0.505	*0.000*	0.280	*0.065*
Humidity (%)	-0.441	*0.002*	-0.423	*0.004*	-0.244	*0.111*
Soil moisture (%)	-0.459	*0.001*	-0.516	*0.000*	-0.362	*0.016*

Annexure 5. Multiple regressions of Principal components with phenophase intensities

Description	**Locality**	**Multiple R:**	**p-value**	**Variance inflation factor (VIF)**	**Description**	**Intercept (constant)**	**PC1**	**PC2**	**PC3**
Leaf initiation (LF2)	TWH	0.671	< 0.01	1.821	Coeff	10.96	-1.82	1.47	4.02
					p-value	*< 0.01*	*< 0.01*	*0.05*	*< 0.01*
	BGK	0.791	< 0.01	2.672	Coeff	11.18	-2.16	1.12	4.20
					p-value	*< 0.01*	*< 0.01*	*0.12*	*< 0.01*
Flower initiation (FL2)	TWH	0.724	< 0.01	2.102	Coeff	18.60	-3.42	0.64	5.15
					p-value	*< 0.01*	*< 0.01*	*0.51*	*< 0.01*
	BGK	0.726	< 0.01	2.117	Coeff	17.56	-2.18	0.73	4.70
					p-value	*< 0.01*	*< 0.01*	*0.339*	*< 0.01*
Fruit elongation (FR3)	TWH	0.727	< 0.01	2.122	Coeff	12.35	1.31	3.82	-0.90
					p-value	*< 0.01*	*< 0.01*	*<0.01*	*0.35*
	BGK	0.705	< 0.01	1.991	Coeff	9.62	0.26	2.84	0.76
					p-value	*< 0.01*	*0.55*	*<0.01*	*0.47*
Fruit maturation (FR4)	TWH	0.810	<0.01	2.911	Coeff	20.56	3.25	0.186	-3.70
					p-value	*<0.01*	*<0.01*	*0.77*	*<0.01*
	BGK	0.794	<0.01	2.700	Coeff	21.08	3.77	-0.34	-2.44
					p-value	*<0.01*	*<0.01*	*0.645*	*0.03*