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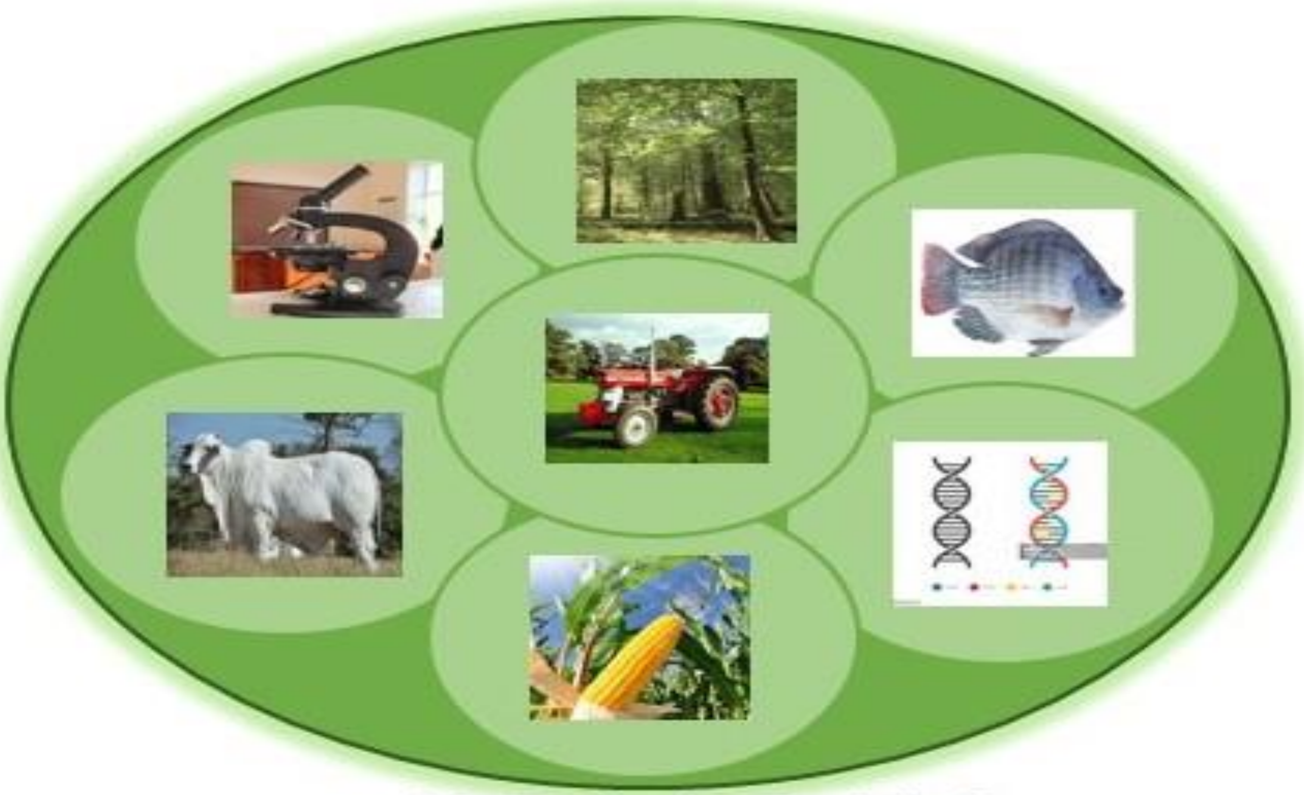

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This official scientific publication of the Faculty of Agriculture, Abdullahi Fodio University of Science and Technology Aliero, is a non-profit, open access, double-blind peer-reviewed Journal publishing four issues (January, April, July and October) per annum. The Journal is a platform open to collaborations with researchers, authors, institutions, research agencies and private companies related to Agriculture. The Mission of the Journal is to disseminate scientific knowledge through the publication of original research articles, research notes, book reviews, letters to the editor and reviews of Literature, representing a contribution to scientific and technological knowledge in respective areas covered by the Journal. The Kebbi Journal of Agriculture and Natural Sciences seeks to validate and disseminate new knowledge, making it public in order to strengthen the human capacity, constitute a link in the scientific community to the society and encouraging the expansion of University and academic researches.

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The Kebbi Journal of Agriculture and Natural Sciences has the sole aim of providing an intellectual platform and ideas for scholars, by promoting interdisciplinary studies related to agriculture and natural science through publishing the latest scientific research findings that are of direct policy implications and beneficial to the research community. Consequently, the journal covers all aspects of Crop Science, Animal Science, Agricultural Economics, Agricultural Extension and Rural Development, Food Science, Fisheries and Aquaculture, Biotechnology, Soil Science and Agricultural Engineering, Forestry and Environment, Wildlife, Agricultural Education, Agro-allied Industries as well as all Natural Science researches related to Agriculture.

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RELATIONSHIP BETWEEN PHENOLOGY, RAINFALL AND TEMPERATURE IN BAKIN TULU AND KWARI KWASA FOREST RESERVES, KEBBI STATE, NIGERIA

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ABSTRACT
This study evaluated the relationship between phenological events and climatic variability in selected forest tree species within Kebbi State, Nigeria, from 2021 to 2023. Monthly observations of key phenophases—leaf shedding, bud burst, leaf flush, flowering, and fruiting—were conducted in two forest reserves and complemented with indigenous knowledge obtained from 120 respondents. Climate data, including monthly rainfall and temperature, were sourced from the Nigerian Meteorological Agency (NIMET). Results indicated that monthly rainfall ranged from 6.4 mm to 330.8 mm, with peak rainfall occurring between August and September, while the dry season extended from November to March. Mean monthly temperature varied between 25°C and 33°C, with the highest temperatures recorded from February to March. Pearson's Product Moment Correlation analysis revealed that temperature exerted a stronger influence on bud burst and early leaf flush, whereas rainfall significantly influenced fruiting and certain leaf flush events. Leaf shedding was strongly associated with the dry season, reflecting adaptive responses to moisture stress. Inter-annual variations in rainfall and temperature significantly affected the timing and intensity of phenological events. The findings underscore the sensitivity of forest tree phenology to climatic fluctuations and highlight the implications of climate variability for forest ecosystem dynamics in the Sudano-Sahelian region.

Keywords: Climate change, Rainfall, Temperature, Tree Phenology and Forest Trees.

Introduction

Changes in climate variables occur as a result of shift in temperature and rainfall patterns, which affect average weather phenomena for long periods. This may lead to drought and increase in extreme climatic phenomena, resulting in adverse effects on biochemical activities (Heba et al., 2023). Temperature and precipitation are the two factors that mostly affect plant phenology. In the same vein, temperature regulate the phenological phases, such as bud formation, the emergence of leaf development and end of leaves development, the flowering of plants, fruiting time. Leaf shedding is affected by environmental temperature. Changes in plant phenology are generally governed by various environmental factors and the influence of temperature on phenological patterns has been ascertained. The seasonal variations in stem water status of trees form a causal link between seasonality and phenology (Nigel, 2019).

The Knowledge of climate change on phenology of forest trees provides relevant information from research in the developed countries in Europe and Asia. The timing of life-cycle events plays an important role in scientific, environmental and socioeconomic disciplines on the usefulness of the phenology and climate change (Kayode et al., 2019). According to Kingsley et al. (2022) phenological studies monitored throughout the year will help in assessing the effects of pollution, human activities, global warning and land cover change on the phenology and productivity of plant species in the ecosystem. It helps to observe changes in the ecosystem and complexities in their vegetation over time and space for proper plantation management and land use.

Phenology is an important tool for monitoring the impact of climate change on plant; some of the imminent effect on vegetation include shift in the growing period, longer growing season, early flowering of species, change in the population density and composition of species. Plants in their life cycle go through a series of phonological life processes, these changes are influenced by different climatic conditions. Abiotic factors like temperature, precipitation and photoperiod effect the onset of particular phenophase in the plant periodic cycle. Phenology observations offer valuable insight into these changes. These can lead to shifts in the start and end of the growing season, the duration of leaf activity, and changes in vegetation density.

Despite the importance of this study, limited research has explored the relationship between phenology and climatic factors in Kebbi State, to guide the researchers on what have been previously achieved. Particular within its forest reserves. This gap justifies the need for the present study.

Materials and Methods

Study area

The research was carried out in Kebbi State Nigeria, which lies within Latitude 11° 00' N to 13° 10' N Longitude 3° 50'E to 5° 00' E and Longitude 3° 50'E to 5° 00 E . It has a total land area of 36,229 square kilometres out of which 12,600 square kilometers is under agriculture (Joseph et al., 2021). The state has a projected population According to the National Population Commission and recent projections by the National Bureau of Statistics (2023), Kebbi State has an estimated population of about 5.2 million people. The study was carried out in the following locations, Maiyama: which lies between Latitude 11° 40' 0 " N- 12° 52' 0" E, Longitude 4° 10' 0" E - 4° 30' 0 " E. Shanga: Latitude 10 0 56'0 "N- 11 32' 0" Longitude 40 26, 0 E' -5° 4' 0" E.

The State is characterized by a distinct wet and dry season. The wet season typically begins in April and ends by October, while the dry season persists from November to March. Annual precipitation varies from approximately 720 mm in the northern part to about 1000 mm in southern areas. Mean monthly temperatures generally range between 25°C and 33°C, with the highest values observed between February and March. (Salisu et al., 2024).

Vegetation in the state falls within two major ecological zones: the Sudan Savanna in the northern part and the Southern Guinea Savanna further south. The vegetation is largely composed of medium-sized trees such as *Parkia biglobosa* (locust bean tree), *Vitellaria paradoxa* (shea butter tree), and various *Combretum* species. Alongside this savanna matrix are open woodlands with scattered trees and grasslands dominating the northern reaches (George et al., 2023).

The drainage system of Kebbi State is dominated by the River Rima and its tributaries, which rise in the Basement Complex of Sokoto State and flow westward to join the Rima River main channel. In the southern parts, additional tributaries such as Dan Zaki, Soda, and Kasanu flow southward to join the River Niger (Daniel et al., 2019).

Sampling Procedure and Sample Size

A multistage sampling procedure was used to obtain the sample of the study. At first stage: The two zones were purposively selected: (Central and Southern zone) because of the significant effect of climate change. At the second stage, one Local Government Area was selected from two of the zone (Southern and Central zone) based on their relative high population density. At the third stage: two forest reserves were selected, which include Kwari-kwasa forest reserve from Maiyama LGA and Bakin tulu forest reserve from Shanga LGA. In the fourth stage: Ten (10) indigenous tree species were selected for phenological phases, including *Azadirachta indica, Detarium microcarpum, Tamarindus indica, Khaya senegalensis, Combretum nigricans, Vitex doniana, Hyphaene thebaica, Acacia nilotica, Vitellaria paradoxa and Piliostigma reticulatum*. Within each forest reserve, six individual trees per species were systematically tagged using durable aluminum labels, giving a total sample of 120 trees (60 individuals per reserve). Phenological monitoring targeted five critical life-cycle events—bud burst, leaf flushing, flowering, fruiting, and leaf shedding. These parameters were recorded at weekly intervals, ensuring high temporal resolution and consistency. Observations were maintained continuously over a two-year period, providing a robust dataset to capture both inter- and intra-annual variability in tree phenology.

Table 1: Data Types and Source of Data

S/N	Data type	Source	Mode of Analysis
1	Phenological and measurement (Rainfall)	Field survey (Nimet)	Mixed method

Annual Variability in Meteorological Conditions

Climate data (annual rainfall and monthly mean temperature) for the study area were acquired from the Nigerian Meteorological Agency (NIMET) station in Sokoto covering verified period [2021–2023]. These records were used to compute mean annual rainfall and mean monthly temperature to support interpretation of vegetation trends and phonological shifts.

Data Analyses

The data were analyzed using Pearson's Product Moment Correlation (r) to examine the strength and direction of the relationship between Phonological variables, rainfall and temperature.

Results and Discussion

Relationship between Phenology and Rainfall

Monthly Mean Rainfall

Rainfall is one of the key climatic factors influencing phenological patterns in vegetation. Analysis of the monthly rainfall data from 2021 to 2023 showed a distinct seasonal pattern, with rainfall occurring mainly between April and October. The least monthly rainfall was recorded in April across the three years (6.4 mm in 2021, 123.1 mm in 2022, and 33.2 mm in 2023), while the highest rainfall occurred in August or September, reaching 315.8 mm in September 2021, 303.2mm in August 2022, and 330.8 mm in August 2023. The dry period, which extended from November to March, coincided with the period of intensive leaf shedding among most tree species, indicating a close association between rainfall availability and vegetative phenological responses (Figure 1). The observed inter-annual variation and shift in peak rainfall from August to September further suggest that rainfall variability influences the timing of phenological events in the study area. These showed a link between rainfall and phenology. A similar finding by Alan and Brown (2021) showed that initial flowering started in February to May, when temperatures began to increase and peaked in September. This is also in line with the finding of Barrett and Brown (2021), who found that completion of leaf development as well as the development of flowers and fruits during the rainy season attests to the importance of a match between phenology and local seasonality, in relation to changing conditions in temperature and water availability.

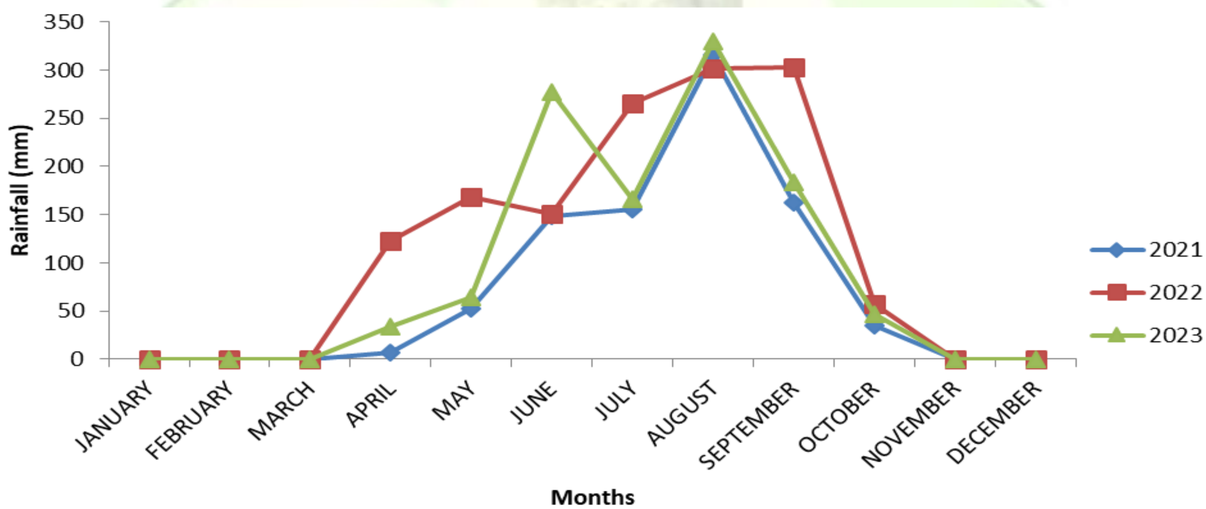

Figure 1: Mean Annual Rainfall from 2021-2023

Implications under climate variability and changes

The graph observed year-to-year variability and shifts in rainfall peaks indicate that rainfall patterns are becoming less predictable. Such changes can disrupt the usual timing and length of key phenological phases such as leaf flushing, flowering, and fruiting. As a result, mismatches may occur between plant growth cycles and optimal environmental conditions, which can reduce photosynthetic efficiency, limit reproductive success, and affect species interactions.

Monthly Mean Temperature

The phenological activities of most tree species showed that bud burst generally began in February and March. This period aligns with the hot dry season, which is normally marked by high temperatures, although the exact timing differed among species. The findings indicate that species adapted to moderate temperatures began bud burst earlier, between January and February, while those that require higher temperatures delayed bud burst until March or April.

The climate data revealed notable temperature variations across the years. In 2021, the highest temperature recorded was 31.5°C, while the lowest was 26.5°C in January. In 2022, March had the highest temperature at 32.7°C, and the lowest temperature was 25.8°C. In 2023, March again recorded the highest temperature (33°C), whereas the lowest temperature, 25°C, occurred in April, with cooler conditions noted from December to January during the harmattan season.

From March to April, temperatures typically rise, coupled with low atmospheric moisture. Vegetation growth is usually stronger during this transition into the rainy season, when moisture levels increase and conditions favor plant development. The results showed a clear temperature shift from April to March, suggesting a relationship between temperature and phenological patterns (Figure 2). This agrees with the finding of Zhang (2023), who reported that the months during which woody plant species contained the most resources coincided with increased rising temperatures and increased rainfall characteristic of the warm wet season. This is also in line with the finding of (Diatta *et al*, 2022) who found that completion of leaf development as well as the development of flowers and fruits during the rainy season, when moisture availability and favorable temperature promote active vegetative and reproductive growth.

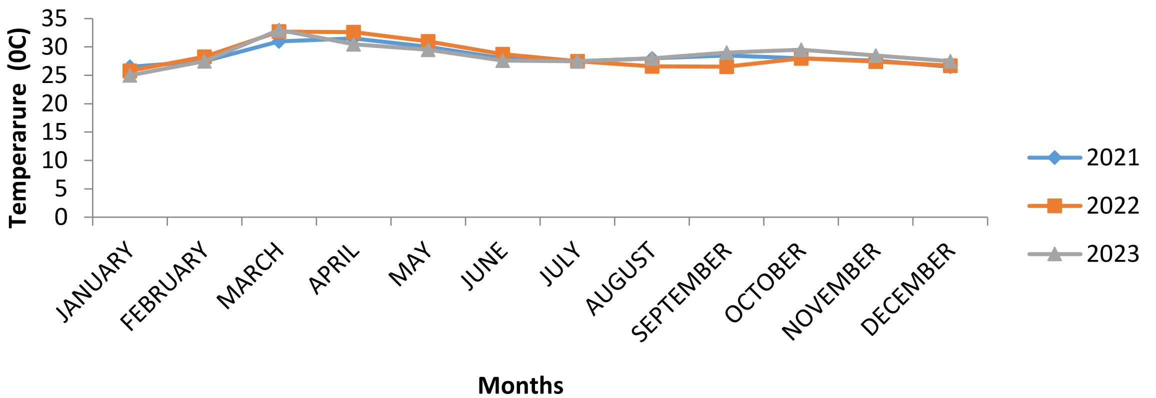

Figure 2: Mean Monthly Temperature for 2021 to 2022

The graph further indicates that increases in temperature toward the end of the dry season trigger key phenological events such as bud burst, leaf flush, and flowering. This early thermal stimulation enables plants to initiate growth before the onset of rainfall, thereby maximizing resource use and ensuring successful development during the forthcoming wet season.

Correlation between Phenology, Rainfall and Temperature

The results in Table 2 show that leaf shedding exhibited variable correlations with rainfall and temperature across the studied species. In general, temperature showed stronger correlations than rainfall, indicating that increased dry-season heat acts as a primary trigger for leaf abscission. Elevated temperatures likely enhance evapotranspiration rates and water stress, leading to adaptive leaf loss as a drought-avoidance strategy. Most species displayed negative correlations with rainfall, suggesting increased leaf shedding during periods of low precipitation. This pattern is typical of deciduous and semi-deciduous savanna trees that shed leaves to reduce water loss during prolonged dry spells. However, *Vitellaria paradoxa* and *Combretum nigricans* showed moderate to strong positive correlations with rainfall, indicating that leaf shedding in these species may be linked to canopy renewal during the early rainy season rather than drought stress alone. This highlights species-specific moisture sensitivity and phenological plasticity.

Table 2: Correlation between Phonology, Rainfalland Temperature (leaf shedding)

Tree Species	Leaf shedding Rainfall	Leaf shedding Temp
Acacia nilotica	-0.34	0.52
Hyphane thebaica	-0.34	0.5
Piliostigma reticulatum	-0.08	0.18
Azadirachta indica	-0.11	-0.39
Detatium microcarpum	-0.08	-0.12
Khaya senegalensis	-0.29	-0.45
Vitellaria paradoxa	0.63	-0.15
Tamarindus indica	-0.33	-0.62
Vitex doniana	0.42	0.21
Combretum nigricans	0.86	-0.18

The results in Table 3 show that bud burst was strongly influenced by temperature, with high positive correlations observed in *Combretum nigricans*, *Acacia nilotica*, and *Vitex doniana*. Rising temperatures toward the end of the dry season act as a critical thermal cue, triggering dormancy release and activating meristematic growth. This early initiation allows trees to prepare for subsequent leaf development before the onset of significant rainfall.

Table 3: Correlation between Phonology, Rainfalland Temperature (Bud burst)

Tree Species	Bud burst Rainfall	Bud burst Temp
Acacia nilotica	0.88	0.92
Hyphane thebaica	0.6	0.75
Piliostigma reticulatum	0.65	0.8
Azadirachta indica	0.26	0.63
Vitellaria paradoxa	0.45	0.7
Khaya senegalensis	0.75	0.7
Detatium microcarpum	-0.7	0.7
Tamarindus indica	0.82	0.88
Vitex doniana	0.85	0.9
Combretum nigricans	0.9	0.92

The results in Table 4 show that flushing was also closely associated with increasing temperature, which promotes leaf emergence, expansion, and early photosynthetic activity. Rainfall played a secondary but supportive role, providing soil moisture that sustains turgor and cell growth. Together, temperature initiates leaf emergence, while moisture ensures successful development, reflecting a coupled climatic control over early vegetative phenophases.

Table 4: Correlation between Phonology, Rainfall and Temperature (leaf flush)

Tree Species	Leaf flush Rainfall	Leaf flush Temp
Acacia nilotica	0.65	0.8
Hyphane thebaica	0.55	0.75
Piliostigma reticulatum	0.6	0.78
Azadirachta indica	0.26	0.63
Vitellaria paradoxa	0.4	0.7
Khaya senegalensis	0.35	0.65
Detatium microcarpum	-0.5	0.6
Tamarindus indica	0.45	0.72
Vitex doniana	0.65	0.8
Combretum ngricans	0.55	0.68

The results in Table 5 indicate that responses varied considerably among species, demonstrating diverse reproductive strategies. *Acacia nilotica and Combretum nigricans* exhibited positive correlations with rainfall, indicating that moisture availability enhances floral initiation and development. *Hyphaene thebaica* showed a moderate positive correlation with rainfall (r = 0.55) and a negative correlation with temperature (r = −0.32), suggesting that flowering in this species is more dependent on moisture availability than thermal conditions. Other species displayed weak or mixed correlations, implying that flowering may be regulated by additional factors such as photoperiod, internal physiological rhythms, or lag effects of prior climatic conditions.

These results underscore the complex and species-specific nature of flowering phenology in tropical savanna ecosystems.

The results in Table 6 show that fruiting was primarily controlled by rainfall, with *Azadirachta indica*, *Vitellaria paradoxa*, and *Tamarindus indica* showing strong positive correlations with precipitation. Adequate rainfall during the fruiting phase enhances photosynthetic activity, promotes effective carbohydrate translocation, supports seed filling, and reduces premature fruit drop. In contrast, temperature exhibited weak or negligible influence on fruiting across most species, with only minor species-specific variations observed. This pattern indicates that following successful flowering, moisture availability becomes the dominant environmental factor regulating fruit development and maturation. The strong dependence on rainfall highlights the vulnerability of reproductive success to rainfall variability in the Sudano-Sahelian environment.

Table 5: Correlation between Phonology, Rainfall and Temperature (Flowering)

Tree Species	Flowering Rainfall	Flowering Temp
Acacia nilotica	0.62	-0.41
Hyphane thebaica	0.55	-0.32
Piliostigma reticulatum	0.5	-0.36
Azadirachta indica	-0.55	0.4
Vitellaria paradoxa	-0.29	-0.45
Khaya senegalensis	0.48	-0.37
Detatium microcarpum	0.7	-0.5
Tamarindus indica	0.53	-0.31
Vitex doniana	0.6	-0.33
Combretum nigricans	0.64	-0.29

Table 6: Correlation between Phonology, Rainfall and Temperature (Fruiting)

Tree Species	Fruiting Rainfall	Fruiting Temp
Acacia nilotica	0.4	0.32
Hyphatne thebaica	0.4	0.32
Piliostigma reticulatum	0.73	-0.18
Azadirachta indica	0.12	0.45
Vitellaria paradoxa	0.72	-0.4
Khaya senegalensis	0.22	-0.05
Detatium microcarpum	0.5	-0.3
Tamarindus indica	0.4	-0.1
Vitex doniana	0.81	-0.17
Combrectum nigricans	0.51	0.19

Conclusion

The study demonstrates that climatic factors, particularly temperature and rainfall, significantly influence the phenology of forest tree species in Kebbi State. Temperature primarily drives early phenophases such as bud burst and leaf flush, whereas rainfall mainly affects fruiting and some leaf flush events. Leaf shedding is closely linked to the dry season, reflecting species-specific adaptations to water availability. Inter-annual variations in climate cause noticeable shifts in the timing and intensity of phenological events, highlighting the sensitivity of tree species to climate variability. The findings also reveal that different species respond differently to the same climatic conditions, emphasizing the importance of considering species-specific responses in ecological studies and forest management. Overall, the study underscores the value of integrating phenological observations with climatic data to understand vegetation dynamics under changing environmental conditions. It is hereby recommended that long-term phenology and climate monitoring in forest reserves be established and use of phenological knowledge to guide forest management and planting schedules should be encouraged. It is hereby recommended that long-term phenology and climate monitoring in forest reserves be established and use of phenological knowledge to guide forest management and planting schedules should be encouraged.

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