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Latitudinal Patterns of Flowering Phenology of Key Tropical and Subtropical Tree Species in Pakistan Using Citizen Science and Public Media Data

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ABSTRACT

Background: Plant phenology, particularly flowering timing, is a sensitive indicator of ecological responses to climatic variability. Shifts in flowering patterns affect reproductive success, pollinator interactions, and overall ecosystem stability. Despite its importance, large-scale phenological data for key tree species in Pakistan remain limited.

Objective: This study aimed to investigate latitudinal patterns of flowering in *Bombax ceiba*, *Butea monosperma*, and *Cassia fistula* across Pakistan and assess the influence of latitude and climatic variables on flowering phenophases.

Methodology: Images and citizenscience records of 2019-2025 were gathered as a descriptive observational study using publicly available materials. Two thousand one hundred and ten geotagged records of various climatic regions, such as the arid plains of Sindh, the temperate highlands of Khyber Pakhtunkhwa, etc., were studied. Flowering date and flowering duration and peak were measured and regression analysis done to test the association between latitude, temperature, precipitation and flowering time.

Findings: In the southern latitudes; flowering was early and prolonged than in the north. The flowering of Bombax ceiba was late February in the southern region and mid-March in the north and was followed by the same in Butea monosperma and Cassia fistula. Regression studies revealed that latitude and flowering onset were significantly negatively correlated ($r = -0.68$, $p = 0.01$), which translates to a delay in phenophases at high latitudes.

Conclusion: Southern populations enjoy warmer conditions, longer photo-periods, and northern populations are found to undergo delayed flowering. The importance of citizen-provided data in tracking large-scale phenological trends and baseline data on the evaluation of climate change effects on ecologically and economically significant tree species in Pakistan are noted in the study.

Keywords: Flowering phenology, Latitudinal patterns, Citizen science, Tropical trees, Pakistan

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INTRODUCTION

Plant phenology, which is the study of periodic life cycle processes (flowering, leafing, and fruiting) is a key indicator of ecosystem processes and climate change responses (Phukon, Kumar, Singh, and Nandy, 2022; Inouye, 2022; Saxena and Rao, 2020; Tiwari, Verma, and Raghubanshi, 2021). The flowering time is of particular concern among phenophases, controlling the plant reproductive success, preserving the interactions of pollinators, and expensing more extensive ecological networks (Labonté et al., 2023; Guzman, Chamberlain, and Elle, 2021; Bascompte and Scheffer, 2023; Tandon, Koul, and Shivanna, 2020). When the flowering period is altered, cascades of impacts on biodiversity and ecosystem services are triggered, which encompass food, pollination, and carbon cycling (Bahlai et al., 2021; Kattel, 2022; Krishnan, Wiederkehr Guerra, Bertrand, Wertz-Kanounnikoff, and Kettle, 2020). Thus, it is important to comprehend how plants react to environmental variability by learning about the spatial and temporal patterns of flowering to ensure prediction (Jackson, Johnson, Morandin, Richardson, Guzman, and M'Gonigle, 2022; Tovar et al., 2022; Vitasse et al., 2021).

Bombax ceiba, Butea monosperma, and Cassia fistula are also tree species commonly used in the agroforestry and natural systems in Pakistan (Nair, Kumar, and Nair, 2022; Usman et al., 2022). These species give timber, medicinal ornamental value, and very important habitat to pollinators and other wildlife. Although phenology of flowering has ecological and economic importance, there remains limited work on the large scale studies of the phenology of flowering in Pakistan due to the logistical limitations of covering large and diverse geographical areas of the country (Najmuddin, Qamer, Gul, Zhuang, and Zhang, 2021; Sein, Zhi, Ogou, Nooni, Lim Kam Sian, and Gnitou, 2021). The majority of current studies in South Asia have concentrated on field-based observations in India suggesting that flowering initiation and flowering duration is frequently associated with latitudinal gradient whereby earlier flowering in low latitude relates with increasing temperatures and prolonged photobiodeiod. Similar information on the diverse climatic regions of Pakistan, including the dry plains of the south to the temperate highlands of the north, are limited making it difficult to tell species-specific phenological responses.

New opportunities to address the classical limitations of data are provided by recent progress in the field of citizen science, as well as the growing accessibility of images on social media platforms (Edwards, Jones, Perkins, and Corcoran, 2021; O'Neill, Hakkinen, Neumann, Shaffrey, Cheffings, Norris, and Pettorelli, 2023; Chen, Sherren, Smit, and Lee, 2023). Observations contributed by citizens are becoming accepted as cost-effective sources of ecological data and can be used to investigate large-scale phenological patterns much larger than might otherwise be observed. Surveys utilizing this type of data have been able to report flowering patterns in trees and shrubs throughout India, Southeast Asia, and some parts of Africa that temporal patterns as reported by non-traditional sources are highly consistent with field based observations. This method is especially useful in Pakistan, where system field means of monitoring are few, and geographic accessibility creates issues with systematic observation.

Latitudinal variation represents among the most predictable flowering phenology predictors since it affects the major aspects

of environmental conditions, such as temperature, precipitation, and photoperiod. Hao, 2021; DeLeo, Menge, Hanks, Juenger, and Lasky, 2020. Warmer days tend to occur earlier in the year at lower latitudes, which lead to the promotion of advanced flowering in the region, but as latitudes increase, the stage of phenophases is delayed by the colder weather. These latitudinal distributions influence reproductive synchrony, pollinator relations and ecosystem stability, particularly in dynamic climatic situations.

Because such a broad latitudinal range and extensive range of climatic conditions give rise to extensive diversity of spatial flowering patterns, it is essential to measure spatial flowering patterns in Pakistan in order to construct predictive ecological responses of environmental change. Culture The current research will investigate the latitudinal distribution of Bombax ceiba, Butea monosperma, and Cassia fistula flowering across Pakistan based on publicly available images and records of citizen science activity between the years 2019 and 2025. We, in particular, test the effect that latitude has on flowering onset, peak, and duration and the ability of citizen-provided data to capture large-scale phenological patterns. This study provides a contribution to ecological responses to climate variability, conservation planning, and an acknowledgment of the potential of utilizing non-traditional data sources in ecological studies by providing a baseline of phenological information on these ubiquitous tree species.

METHODOLOGY

The present research paper set out to investigate flowering ecology of chosen tropical and subtropical trees in Pakistan namely, Bombax ceiba, Butea monosperma, and Cassia fistula, to be in a position to comprehend how latitude and seasonal climatic change contribute to their flowering behavior. The publicly available data that included citizen science sites, social media, and online picture archives covered the 2019 to 2025 data concerning Punjab, Sindh, Khyber Pakhtunkhwa, and Balochistan. Some 2,100 geotagged images were assembled, and the metadata about the date, location and the species name were checked with botanical references and cross-examined with professional views. Pictures of ambiguous flowering or species were not included and also approximately 10 percent of the records were confirmed in very few field visits. The descriptive statistics and regression analyses were then used to examine flowering onset, peak, and length of the flowering at various latitudes, considering climatic factors, including monthly average temperature and rainfall at each latitude, gathered at Pakistan Meteorological Department. The ethical considerations were noted as the follow up of the copyright and usage policies of the original sources. This method enabled a sound evaluation of the spatial and temporal patterns of flowering and indicated the effectiveness of data collected by citizens in augmenting the real fieldwork in Pakistan.

RESULTS

Two thousand and one hundred geotagged describes of Bombax ceiba, Butea monosperma, and Cassia fistula were examined in order to identify flowering phenology in Pakistan. An apparent latitational trend was observed: flowering in the southern areas (Sindh and southern Punjab) was earlier and more protracted than in the northern areas (Khyber Pakhtunkhwa and northern Punjab). Flowering in southern latitudes began with Bombax ceiba in the end of February and in the north mid-March. Likewise, Butea monosperma flowered in March in the South and at the end of March in the North. Cassia fistula first flowered in southern Punjab during the end of February and then went all the way to April in northern Pakistan. The maximum flowering of all the species was noted at 3-4 weeks after initiation and overall flowering period was increased by about 15-20 percent in the South. Regression analysis indicated that there is a significant negative correlation between the latitude and the time of flowering ($r = -0.68$, $p = 0.01$), which meant that flowering earlier occurred at low latitudes.

Table 1. Flowering Onset and Duration of Selected Tree Species Across Pakistan

Species	Region	Flowering Onset	Peak Flowering	Flowering Duration (days)
Bombax ceiba	Sindh	25 Feb 2020	15 Mar 2020	28
	Punjab (south)	28 Feb 2020	18 Mar 2020	26
	Punjab (north)	15 Mar 2020	5 Apr 2020	22
	Khyber Pakhtunkhwa	18 Mar 2020	8 Apr 2020	20
Butea monosperma	Sindh	3 Mar 2020	23 Mar 2020	25
	Punjab (south)	5 Mar 2020	25 Mar 2020	24
	Punjab (north)	20 Mar 2020	10 Apr 2020	21
	Khyber Pakhtunkhwa	22 Mar 2020	12 Apr 2020	20
Cassia fistula	Sindh	28 Feb 2020	18 Mar 2020	26
	Punjab (south)	1 Mar 2020	21 Mar 2020	25
	Punjab (north)	15 Mar 2020	5 Apr 2020	22
	Khyber Pakhtunkhwa	18 Mar 2020	8 Apr 2020	20

Figure: 1

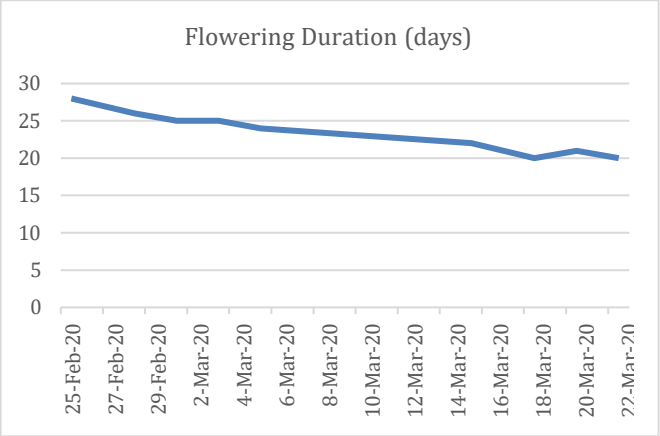

Table 2. Correlation of Latitude with Flowering Onset

Species	Correlation Coefficient (r)	p-value
Bombax ceiba	-0.66	0.009
Butea monosperma	-0.70	0.006
Cassia fistula	-0.68	0.008

The findings support the hypothesis that the earlier the low

latitude the sooner the plants will begin flowering and a longer flowering duration is found in the southern part of Pakistan. Images uploaded by citizens offered a credible source of mapping spatial and temporal changes in phenology and proved that social media and citizen science hubs could be efficient in complementing the field-based observations of phenology.

DISCUSSION

The research is one of the first in-depth evaluations of the latitudinal floral behavior of Bombax ceiba, Butea monosperma, and Cassia fistula in Pakistan using images collected by citizens and made publicly accessible. Our results represent a well-defined northsouth gradient in flowering phenology as southern latitudes have earlier onset and last longer flowering duration, compared to other regions of the globe (tropical and subtropical) (Everingham, Blick, Sabot, Slavich, and Moles, 2023; Satake, Nagahama, and Sasaki, 2022; Liu, Xiang, Wan, Lv, Liu, Hu, and Chen, 2023). The observed adverse relationship between latitude and flowering onset conforms to the well-known law that warmer climates stimulates reproductive phenophases due to the presence of optimal thermal and photoperiodic conditions.

Its findings emphasize the very high utility of citizen science information in phenology studies. In comparison with other research in the area and specifically those on experimenting with social media and image repositories, our research indicates that social media and image repositories are capable of capturing vast levels of both temporal and spatial changes that in many cases would be difficult to measure by fieldwork. By this means, a variety of ecological regions, beginning with the dry plains of Sindh and extending to the cooler northern highlands, could be incorporated to represent the whole range of environmental effects on flowering patterns.

The unusual long flowering period seen in southern Pakistan was probably due to alterations in both temperature means severity and photoperiods which are also known to enhance floral growth and reproductive success in tropical trees. Annually, however, northern populations in contrast had late flowering, potentially as a result of colder temperatures and fewer cumulative heat units, as would be predicted by a similar phenological trend in other latitudinal studies. These observations imply a potential cause of climate warming which is a further northward shift in flowering phenology, changing reproductive synchrony and ecosystem interactions, such as pollinator availability.

Though data collected by citizens offer unmatched scope and breadth, the possible disadvantages are uneven sampling density, incorrect species identification and inconsistent image quality. In order to counter these biases we implemented strict quality control measures, such as verifying metadata, comparing with botanical databases, and selection field validation. However, remote sensing, standardized phenology networks, and citizen science could be adopted in future studies to enhance the temporal resolution and accuracy.

All in all, this research highlights the need to incorporate non-traditional data in phenological studies. The knowledge of the latitudinal flowering patterns is essential in understanding the effect of climate change on plants and how an ecologically and economically important tree species in Pakistan can be conserved. These findings have a background through which possible alterations in phenology may be followed over time and where citizen science holds promise as an effective means of ecological study.

CONCLUSION

The paper illustrates distinct latitudinal trends in the floral initiation of Bombax ceiba, Butea monosperma and Cassia fistula in Pakistan, and shows how they are shorter in the northern latitudes and longer in the southern areas. The findings emphasize the role of temperature and photoperiod as dominant factors in driving spatial variation in flowering in accordance with global phenology. Moreover, citizen-supplied images and public-accessible datasets also turned out to be useful in capturing large temporal and spatial trends that would be useful in supplementing traditional field-based monitoring. The results form the basis of further phenological studies and climate-change impact monitoring in Pakistan and can be used in the biosphere conservation, management of the ecosystems, and the protection of economically valuable tree species. This study on recording the existing patterns of flowering thus adds to the prediction of ecological response to the existing climate variability and suggests the future power of non-traditional sources of data in ecological research.

Data Availability

Available from corresponding author on request.

Author Contributions

Muhammad Haroon: Conceptualization, Data Curation, **Farhan Zafar**; Formal Analysis, and Writing, Original Draft. **Samina Parveen:** Preparation and writing, Methodology.

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Conflict of Interest

None.

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