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# Investigating the patterns of *Gmelina arborea* populations in diverse environmental conditions of Madhya Pradesh, India

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**Abstract**

*Gmelina arborea*, a deciduous tree native to India, exhibits intriguing variations in events under different environmental influences. This study delves into the species' events, flowering, fruiting, leaf initiatiin, and leaf fall which are crucial life cycle stages, influenced by climate and environmental factors. Despite its significance, there is lack of comprehensive research on *Gmelina arborea's* phenology in Madhya Pradesh which represents central India. This study addresses this gap, exploring the impact of seasonal rainfall, temperature fluctuations, and site-specific conditions on the species' events. The research area, characterized by tropical and sub-tropical climates, offers a unique setting to analyse the intricate interplay between environmental variables and Gmelina's life cycle events. Observations were recorded from different populations spreading across 4 agroclimatic zones of Madhya Pradesh and composed of natural distribution as well as plantations. On the basis of observations recorded for different phases among different population, it is observed that maximum number of trees in natural populations showed flowering in January-February whereas most trees in plantations extended its flowering period up to March. At Jabalpur, Mandla, Betul locations most of the Gmelina tree sheds its leaves late up to March while a greater number of trees in plantation found to be regular in case of leaf shedding. Fruiting of Gmelina starts from mid-April to June in most of the populations but some trees of Sonaghati and Saraswahi populations fruits till mid-July. Leaf initiation was found to be the most consistent traits in all locations. Leaf fall showed considerable variation in its timing in natural populations while planted populations shed their leaves as per the cycle.

**Keywords:** Phenology, population genetics, reproductive biology, plantation

## Introduction

*Gmelina arborea* is a deciduous tree native to several South Asian countries, including India, Myanmar, Thailand, Laos, and southern China. Since the 1960s, it has also been introduced extensively as a fast-growing timber species in tropical regions of Brazil, Honduras, Malaysia, and Nigeria, among others (Orwa *et al.*, 2009 [27]). This tree adapts well to various climatic conditions, thriving in tropical and subtropical environments with red sandy loam soils (pH 5-8) and altitudes up to 1200 m above sea level (Tewari, 1995) [38]. Its utility spans from timber and pulp production to medicinal use, making it a preferred species in forestry and agriculture sectors. Its timber is used for products such as chipboards, plywood, and packaging, while the leaves serve as animal feed and for silkworm cultivation (Rojas-Rodríguez *et al*., 2004) [33].

*Gmelina arborea* grows naturally throughout India, Myanmar, Thailand, Laos, Cambodia, Vietnam and in southern parts of China. Since the 1960s, it has been introduced considerably as fast-growing timber tree in Brazil, Gambia, Honduras, Ivory Coast, Malaysia, Malawi, Nigeria, Philippines and Sierra Leone. *Gmelina arborea* adapts well to different climatic conditions. This hardy tree can be grown in tropical and subtropical conditions. It grows very well in red sandy loam soils with a pH of 5 to 8 and high soil depth. It grows at altitudes from 0 to 1200 m above mean sea level. It adapts very well to humid climates with optimal temperatures ranging from $20^0$c to $38^0$c. The annual rainfall requirement is 750 to 4,500 mm. It is a medium to large-sized deciduous tree that can reach up to the height of 40 meters and a diameter of 140 centimeters. It grows very well in full sun with little shade.

The tree has great potential for timber and medicinal value. It is the preferred species of farmers, forestry sector and Ayurvedic industries due to its versatile utility, fast growth rate and maximum economic returns. The wood of *Gmelina arborea* is used for pulp, chipboard, plywood, matches, carpentry and packaging. It is also used to build panels, sculptures, and musical instruments. The leaves and fruits of Gmelina are used as animal feed and for raising silkworms. This species is also grown in the Taungya system with short-term rotation crops, and as a shade tree for coffee and cocoa.

**Phenology**

Phenology is the study of periodic biological events in plants under the influence of the environment (Schwartz, 2003) [34]. Global climate change can induce changes in the timing of morphological events in tropical forests (Reich, 1995) [32]. Variation in flowering time, caused by various factors like heavy winter, summer, rainfall, decreased or increased photoperiod, or defoliation due to drought leads to certain flowering patterns in tropical plants (Borchert *et al*., 1996) [7]. changes in tree species are mainly caused by seasonal rainfall (Daubenmire, 1972 [12]; Borchert, 1983[6]; Bullock and Solis-Magallanes, 1990 [8]; Eamus and Prior, 2010 [13] and the duration and intensity of seasonal drought (Mooney *et al.,* 1995 [22]). Plant growth and its response to biotic and abiotic factors reflect different morphological strategies in tropical tree species (Dalling *et al.,* 2004) [11]. Information of pattern and how these are affected by natural components is imperative for the forecast of the potential impacts of climate alter on vegetation. Record of long-term response on trees, such as the dates of leaf unfurling, blooming, leaf discoloration and leaf drop, gives chronicled data to demonstrate how plants have reacted to varieties in climatic conditions.

Comprehensive studies on reproductive phenology of plants in relation to environment were reported by several authors. The results revealed that climate acts as the triggering and synchronizing master control factor of cycles in tropical rain forests (Newstrom *et al*., 1994) [26].

Flowering phenology is well studied in most temperate and sub-temperate conifers and eucalypts (Griffin, 1984[15]; Askew, 1986[3]; Matziris, 1994 [20]; Verma *et al.,* 1989[39]), however, it is relatively rarely recorded among tropical species (Corlett, 1998) [9]. But the impact of climate, and altitude factors on flowering is still unclear. Research information on flowering expression, and fruit sets in *Gmelina arborea* under Indian conditions is still lacking. Therefore, it is important to understand phenology of Gmelina which will be helpful in establishing Seed Production Areas (SPAs) in suitable locations.

**Site characteristics**

Madhya Pradesh has tropical and sub-tropical types of climates with the average mean temperature of the region recorded as $24.63^0$c while the region receives an annual mean average rainfall of 1259.93 mm. The climate in Madhya Pradesh is governed by a monsoon weather pattern. The distinct seasons are summer (March through May), winter (November through February), and the intervening rainy months of the southwest monsoon (June through September). The summer is hot, dry, and windy. Soils in Madhya Pradesh can be classified into two major groups. Fertile black soils are found in the Malwa Plateau, Narmada valley, and parts of the Satpura Range. Less-fertile red-to-yellow soils are spread over much of eastern Madhya Pradesh. The average annual rainfall is about 44 inches (1,100 mm). In general, precipitation decreases westward and northward, from 60 inches (1,500 mm) or more in the east to about 32 inches (800 mm) in the west. Most parts of Madhya Pradesh receive almost all of their precipitation in the monsoon months; however, there is considerable rainfall over the northern part of the state in December and January.

**Methodology**

The study was conducted in 10 geographical locations (Figure1) stretching over the four agroclimatic zones viz; Kymore plateau and Satpura hills, northern hill zones of Chhattisgarh, Satpura plateau and Vidhya plateau (Table 1). The elevation of these locations ranges from 1236 to 2227 feet. Soil types vary significantly, including mixed red and black soils, shallow black soils, and skeletal soils, indicating diverse agricultural potential and challenges. The rainfall

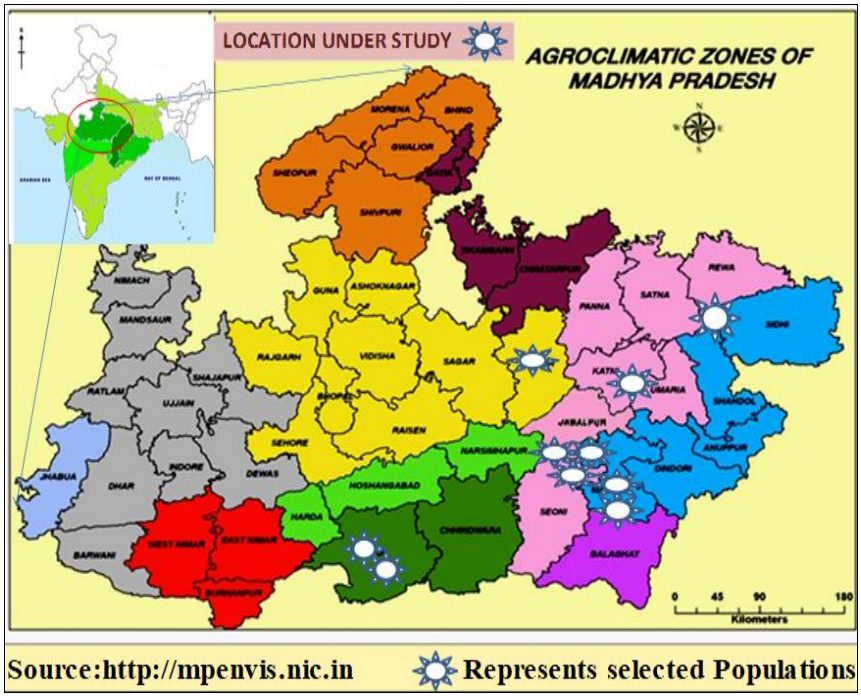



**Fig 1:** Location of the population projected on maps of agroclimatic zones of Madhya Pradesh

**Table 1:** GPS Range, Elevation, Rainfall, and Agroclimatic Zones of the selected populations of Madhya Pradesh.

| Sr No | Location | Latitude | Longitude | Elevation (Ft) | Agroclimatic Zone/ Soil Type | Rainfall (Range in mm) |
|---|---|---|---|---|---|---|
| 1 | Jabalpur | N23°05'55" | E79°59'26" | 1322 | Kymore Plateau and Satpura Hills/ Mixed red and black soils (Medium) | 1000 to 1400 |
| 2 | Barha | N23°01'30" | E79°59'40" | 1374 | | |
| 3 | Saraswahi | N23°48'59" | E80°27'43" | 1269 | | |
| 4 | Neemkheda | N23°00'61" | E79°57'45" | 1315 | | |
| 5 | Badhaura | N24°24'47" | E81°44'30" | 1456 | | |
| 6 | Moiyanala | N23°01'20" | E80°41'46" | 1692 | Northern Hills Zone of Chhattisgarh/ Red & Yellow Medium black & Skeltal (medium/ light) | 1200 to 1600 |
| 7 | Mandla | N23°01'20" | E80°41'46" | 1476 | | |
| 8 | Betul | N21°54'13" | E77°54'12" | 2092 | Satpura Plateau/ Shallow black (Medium) | 1000 to 1200 |
| 9 | Sonaghati | N22°05'45" | E78°52'29" | 2227 | | |
| 10 | Nohta | N23°38'13" | E79°37'43" | 1236 | Vindhyan Plateau / Medium black &deep black (Medium/Heavy) & Skeltal | 1200 to 1400 |

***Source*:** http://jnkvv.org/Departments/Dep_DRS_AgroClimaticZones.aspx

Range also varies across sites, reflecting variation in precipitation. Out of 10 location Jabalpur, Mandla and Betul represents natural forests while remaining locations are composed of plantations. 27 Reproductive trees from each location were chosen, marked, and observed regularly throughout the study period (January 2019-March 2022) to record various phases according to the methods outlined by Koch *et al*. (2007) [17] for perennial plants. Referential time to record Regular or irregular phenology of an individual tree was decided on the basis of monograph of Khamer (Tewari, 1995) [38]. In India the flowering of Gmelina is observed during February to march, fruiting during mid-April to June (Tewari, 1995). Gmelina sheds its leaves in January and February and leaf sprouting observed in March to April (Tewari, 1995). This time period was taken as standard to record regularity of events and observation recorded outside these months were recorded irregular for the given traits. When 50% of each trees' developmental stages are complete, all of the corresponding phases are regarded as having begun. While leaf fall is defined as more than half of the leaves of the observed plant having fallen, leaf initiation is defined as the first regular surface of the leaves becoming apparent.

## Results

Most consistent flowering has been observed at Jabalpur location while most irregular population recorded in case of flowering is Sonaghati (Figure 2). As far as fruiting is concerned most of the populations are consistent in fruiting except Sonaghati and Saraswahi (Figure 3). Badhaura location showed irregularity in case of leaf initiation while rest of the populations were found to be more regular (Figure 4). Considerable variation has been observed in leaf fall of Gmelina across different locations (Figure 5). At Jabalpur, Mandla, Betul locations Gmelina sheds its leaves late up to March (Table 2) while remaining locations which are plantation are found to be regular in case of leaf fall.

Flowering in Gmelina is observed from last week of January to March (Table 2). Maximum regularity in flowering is observed in Jabalpur followed by Nohta while maximum irregularity is observed in Sonaghati followed by Barha. Jabalpur represents the natural population while Nohta is plantation (Figure 2).

Fruiting in Gmelina has observed from April to July (Table 2). Regular fruiting was observed in Barha followed by Neemkheda while most irregularity is observed in Saraswahi followed by Sonaghati (Figure 3). With slight variation in the fruiting pattern natural population showed more consistency compared to planted populations (Figure 6).

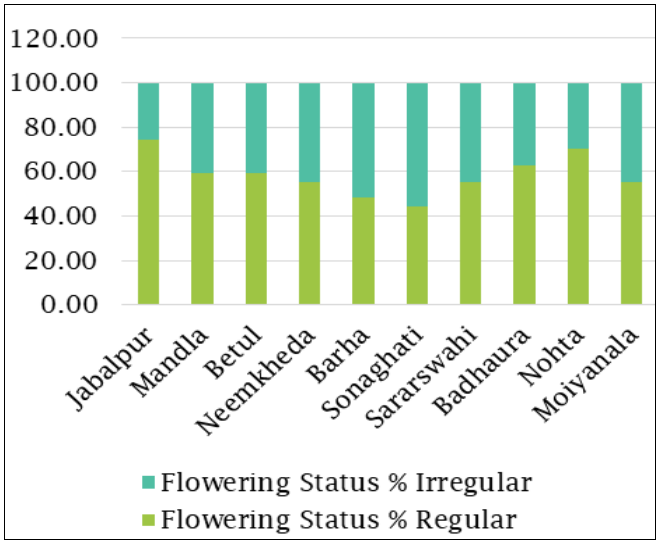



**Fig 2:** Flowering status across different population in *Gmelina arborea*

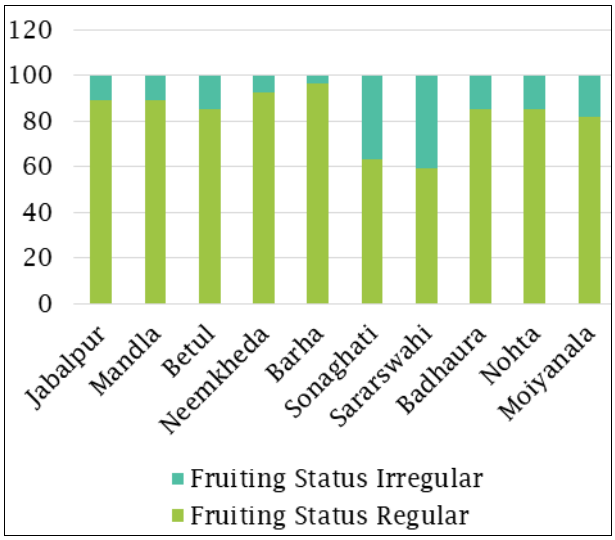



**Fig 3:** Fruiting pattern across different populations in *Gmelina arborea*

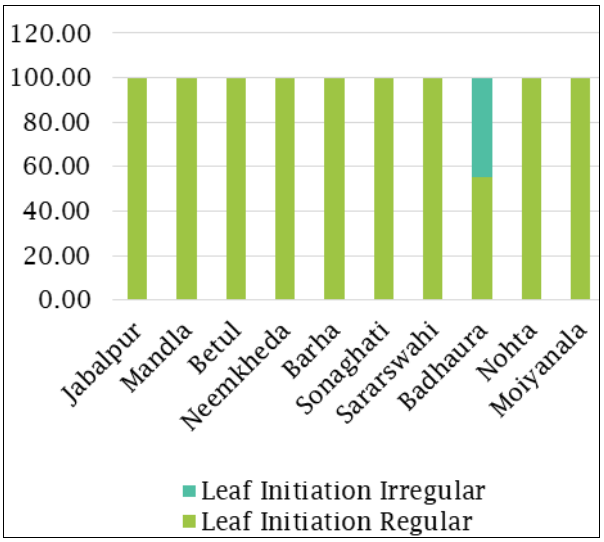



**Fig 4:** Leaf initiation pattern across different populations in *Gmelina arborea*

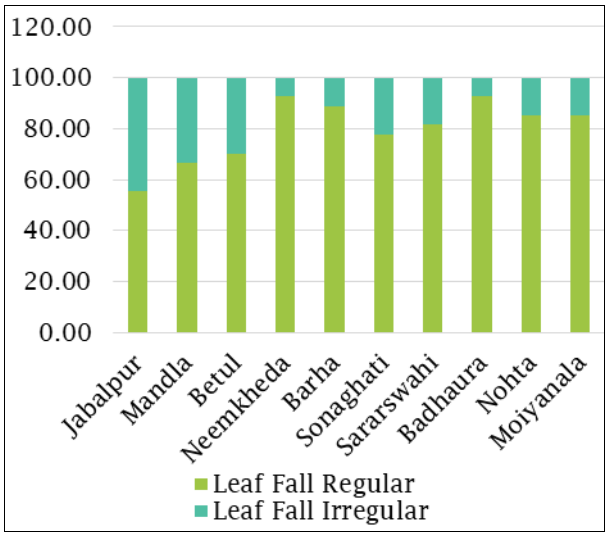



**Fig 5:** Leaf fall pattern across different population in *Gmelina arborea*

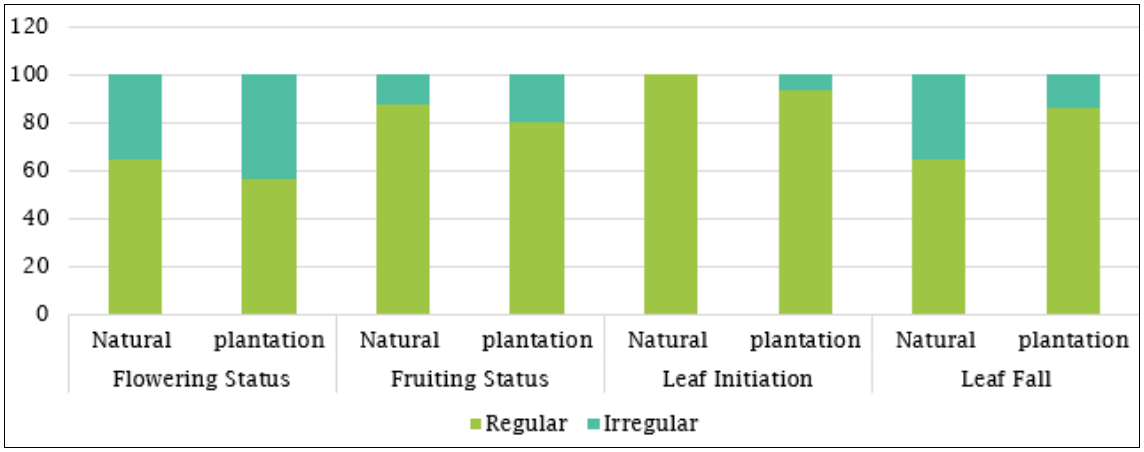
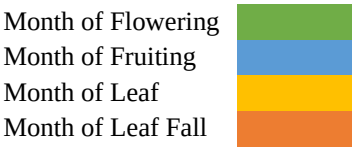



**Fig 6:** Comparison of phenophases among natural and plantation

**Table 2:** Phenophases of *Gmelina arborea* in months for different populations of Madhya Pradesh

| Populations | | Phenophases of *Gmelina arborea* | January | February | March | April | May | June | July | August | September | October | November | December |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Natural | Jabalpur | Month of flowering | | | | | | | | | | | | |
| | | Month of fruiting | | | | | | | | | | | | |
| | | Month of leaf initiation | | | | | | | | | | | | |
| | | Month of leaf fall | | | | | | | | | | | | |
| | Mandla | Month of flowering | | | | | | | | | | | | |
| | | Month of fruiting | | | | | | | | | | | | |
| | | Month of leaf initiation | | | | | | | | | | | | |
| | | Month of leaf fall | | | | | | | | | | | | |
| | Betul | Month of flowering | | | | | | | | | | | | |
| | | Month of fruiting | | | | | | | | | | | | |
| | | Month of leaf initiation | | | | | | | | | | | | |
| | | Month of leaf fall | | | | | | | | | | | | |
| Plantation | Neemkheda | Month of flowering | | | | | | | | | | | | |
| | | Month of fruiting | | | | | | | | | | | | |
| | | Month of leaf initiation | | | | | | | | | | | | |
| | | Month of leaf fall | | | | | | | | | | | | |
| | Barha | Month of flowering | | | | | | | | | | | | |
| | | Month of fruiting | | | | | | | | | | | | |
| | | Month of leaf initiation | | | | | | | | | | | | |
| | | Month of leaf fall | | | | | | | | | | | | |
| | Sonaghati | Month of flowering | | | | | | | | | | | | |
| | | Month of fruiting | | | | | | | | | | | | |
| | | Month of leaf initiation | | | | | | | | | | | | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Month of leaf fall | | | | | | | | | | | | |
| | Sararswahi | Month of flowering | | | | | | | | | | | | |
| | | Month of fruiting | | | | | | | | | | | | |
| | | Month of leaf initiation | | | | | | | | | | | | |
| | | Month of leaf fall | | | | | | | | | | | | |
| | Badhaura | Month of flowering | | | | | | | | | | | | |
| | | Month of fruiting | | | | | | | | | | | | |
| | | Month of leaf initiation | | | | | | | | | | | | |
| | | Month of leaf fall | | | | | | | | | | | | |
| | Nohta | Month of flowering | | | | | | | | | | | | |
| | | Month of fruiting | | | | | | | | | | | | |
| | | Month of leaf initiation | | | | | | | | | | | | |
| | | Month of leaf fall | | | | | | | | | | | | |
| | Moiyanala | Month of flowering | | | | | | | | | | | | |
| | | Month of fruiting | | | | | | | | | | | | |
| | | Month of leaf initiation | | | | | | | | | | | | |
| | | Month of leaf fall | | | | | | | | | | | | |



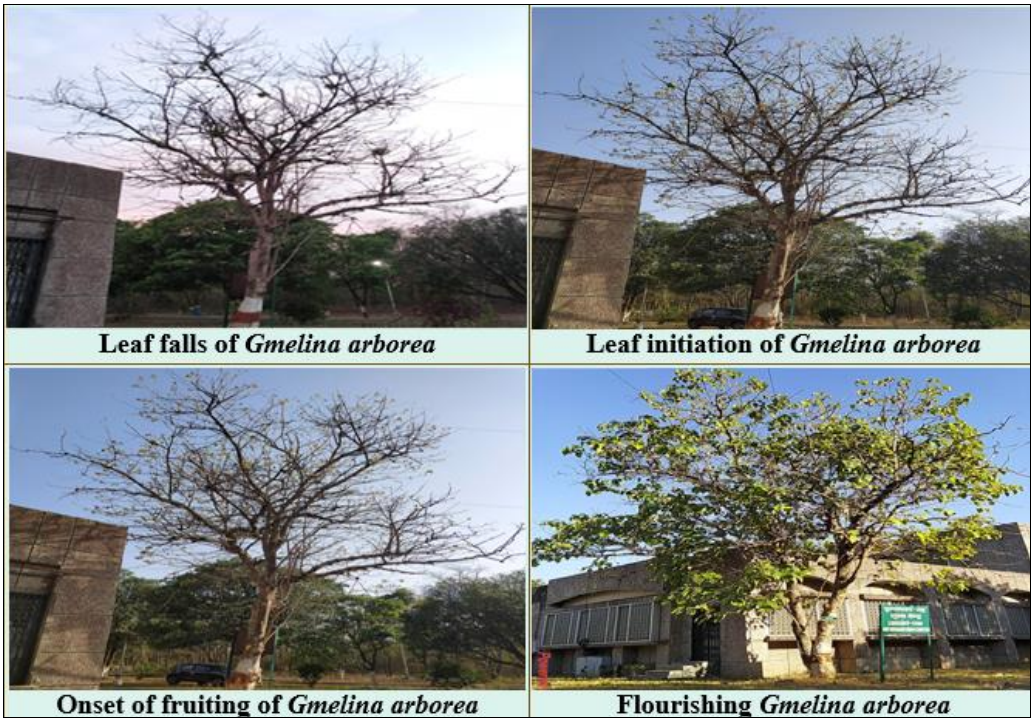




**Fig 7:** Phenophases of *Gmelina arborea*

Leaf initiation has started in the month of march and lasted up to April except for the location Badhaura (Table 2). Most of the population under study showed the regularity in case of leaf initiation except Badhaura where 15 trees were regular while 12 trees showed irregularity. All population whether planted or natural showed regularity in leaf initiation (Figure 6) except Badhaura population which represent the Kymore plateau agroclimatic zones (Figure 4)
Gmelina's leaf fall starts from January to March (Table 2). Leaf fall was regular in Neemkheda and Badhaura population followed by Barha, Nohta and Moiyanala (Figure 5). Maximum irregularity is observed in Jabalpur, Mandla and Betul population (Figure 5). Natural population showed irregularity in leaf fall as compared to plantation (Figure 6). These natural population represents Kymore Plateau and Satpura Hills, Northern Hills Zone of Chhattisgarh, Satpura Plateau agroclimatic zones.

**Discussion**

Troup (1921) reported that earlier to blooming, Gmelina tree regularly sheds its leaves. This shedding happens at the early period of the dry season. Blossoming begins within the dry season after the process of leaf shedding has been completed. The length of the blooming season is shorter when one flush happens. Blossoming was begun from February to March and leaf flushing begun after the blooming within the month of march and reached its peak in the months of June-July. The leaf fall was recorded amid

dry periods in December-January. The fruit maturity was reported in the months of June-July. Deciduous species varies with regard to the timing of leaf flushing and leaf drop, often broadly shifting timing and term of deciduousness. It is reported that, by and large, Gmelina drops leaves from January to march, it blossoms towards the end of this period or with the leaf initiation starting off in the month of April (Akachuku, 1984) [1]. The mean leafless periods in Gmelina are 56.02 days. The ranges of leafless period in Gmelina are between 54-58 days. Fruiting term of Gmelina is 30-60 days. (Raju and Rao, 2006) [31].

In Indian condition Gmelina flower in February and March, and from the end of April to June, the fruits start to ripen with 1408 stones per kg, fruiting is abundant and regular. Although trees planted in plantations blossom when they are between 3 and 4 years old, the tree doesn't start producing flowers and fruit until it is between 6 and 8 years old (Rojas-Rodriguez *et al.*, 2004; Orwa *et al.*, 2009) [33, 27]. While the leaves start to fall around the months of January and February, the new leaves start to appear around March and April. The first six years of the tree's life are marked by rapid growth, which is followed by a slowdown in the seventh year. The tree's lifespan is influenced by the site (Zabala,1990) [42]. No correlation was detected between flowering time and fruit maturity by latitude or forest type (Lauridsen, 1977) [18].

studies are useful for planning conservation strategies as well as developing measures to cultivate species on a large scale. Zobel and Talbert (1984) [43] stated that an understanding of the biology of tropical plants is essential before starting any plant breeding program. Reproductive knowledge is an important aspect that requires a lot of attention. It is also useful to know the degree of genetic variation in a species (Costich, 1995) [10]. Considering the distribution of *Gmelina arborea* in large geographical areas throughout the world considerable variation has been recorded in its events like leaf fall, leaf initiation, flowering, and fruiting.

**Flowering**

In *Gmelina arborea*, yearly flowers and fruiting are typically profuse for the stand as a whole but sporadic for individual trees. In the natural distribution of *Gmelina arborea* in Asia, flowering typically begins in February or earlier. In China, flowering occurs from April to May (Flora of China; 2016). In Central America, flowering of *Gmelina arborea* occurs from December to March. Flowering lasts for nine months in the Amazon basin. In India flowering is observed from February to March (Orwa *et al.* 2009; Tewari, 1995) [27, 38]. In the present study, it was observed that *Gmelina arborea* flowers from January to March, Soosai (2019) [35] reported same period of year, for flowering with slight variation in the deciduous period in the Western Ghat and Eastern Ghat populations of southern India. Flowering in the Eastern Ghat started a month earlier (January-February) than in the Western Ghat in the month of February and March (Soosai, 2019) [35].

**Fruiting**

According to Woessner (1983) [40], fruit ripening begins in November and reaches its peak in January or February. In Asia, during the dry season, when trees have no leaves, Fruits begin to ripen in April and continue until well into July. In China, fruiting occurs from May to July (Flora of China; 2016) [14] Fruit harvesting season in the Philippines runs from May to September. In India, fruiting occurs from April to June or July (Orwa *et al*. 2009; Tiwari, 1995) [27]. In Uttar Pradesh, fruit ripens in late June while in Bengal same event is noticed earlier. In the present study, similar findings were recorded, However Soosai (2019) [35] reported same for fruiting with slight variation in eastern and western ghat populations of *Gmelina arborea* in southern India.

**Leaf initiation**

leaf initiation was reported from March to April by (Tewari, 1995) [38]. In Chambal eco-region of Madhya Pradesh Leaf flushing in Gmelina was observed in April and May by Bhat and Jain (2013) [4]. Panda *et al*., (2021) [29] observed leaf bud emergence in the last week of May and full development in the first week of June in northwestern mid-Himalayan region; and

**Leaf fall**

In India Gmelina start shedding its leaves in January to February (Orwa *et al.* 2009 [27]; Tewari, 1995) [38]. Leaf maturation occurs from September to October and defoliation occurs from November to December in the northwestern mid-Himalayan ecosystem Panda *et al*., (2021) [29]. Gmelina sheds its leaves in January and February (Tewari, 1995) [38]. Large amount of variation is observed considering the vast geographic stretch of *Gmelina arborea*. Soosai (2019) [35] observed very small variation in defoliation timing between Western and Eastern Ghats populations in South India, which may be due to differences in humidity and temperature across locations.

Soosai (2019) [35] reported that in both plantations as well as natural populations, tree began flowering from the fourth week of February and peaked in March. However, there are very few reports on seasonality research in India (Prasad and Hegde, 1986; Bhat, 1992; Murali and Sukumar, 1993 and 1994) [30, 5, 24, 25]. In the present study, observations were made on the phenology of *Gmelina arborea* associated with natural forests and plantations, which showed least significant variation for flowering and fruit set. Looking at the variation in events among various populations of *Gmelina arborea*, it is observed that all the natural populations showed maximum regularity in flowering of trees, while comparatively less regularity have been observed among planted populations.

Surendra (2013) [37] observed that defoliation periods were more frequent in low rainfall areas with high temperatures than in high rainfall areas with low temperatures in natural teak populations in Karnataka. Palanisamy *et al.* (2005) [28] reported that the leaf shedding period is very short, when teak grows under constant moisture conditions. These trees retain their leaves for long and a short period of leaf shedding is observed in February.

Wright (1996) [41] believes that seasonal changes in abiotic and biotic factors may have a continuous impact on tropical forest phenology. studies in tropical forest ecosystems have shown that the rainy season is the main abiotic factor controlling the timing, intensity, and duration of flowering and fruiting cyclicity (Newstrom *et al.*, 1994; Sun *et al.*, 1996; Borchert, 1996) [26, 36 7]. In the Atlantic tropical

forests, flowering occurs during the warmer, rainier months, when days are longer, while defoliation is observed more frequently during the driest and coldest months when days are shorter (Marques and Oliveira, 2004 [19]; Morellato *et al.*, 2000) [23]

studies in tropical forest ecosystems indicated that rainfall season being the major abiotic factor controlling the timing, intensity and duration of flowering and fruiting periodicities (Newstrom *et al.*, 1994 [26]; Sun *et al.*, 1996 [36]; Borchert, 1996 [7]). In dry forests, leaf flushing attains peak during late dry season and ends in rainy season (Anderson *et al.*, 2005; Justiniano and Fredericksen, 2000; McLaren and McDonald, 2005) [2, ,16, 21]. In the Atlantic rainforest, defoliation and flowering occur during the warmer, wetter seasons with longer days, whereas defoliation is more frequent during the shorter days and drier, cooler seasons (Marques and Oliveira, 2004; Morellato *et al.*, 2000) [19, 23].

## Conclusion

The study sheds light on the intricate patterns and reproductive biology of this significant deciduous tree species. The study observed variations in flowering, fruiting, leaf initiation, and leaf shedding across different populations and locations. Natural populations showed more regularity in events compared to planted populations, indicating the influence of environmental factors on the species' life cycle stages.

This research not only fills a crucial gap in the understanding of *Gmelina arborea's* phenology in the Madhya Pradesh region but also contributes valuable information for conservation and sustainable management practices. The detailed documentation of events and site conditions will help to understand the reproductive biology and patterns of *Gmelina arborea* in the region.

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