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Reproductive phenophases of *Uvariodendron angustifolium* (Engl. & Diels) R. E. Fries in West Africa: seasonal dynamics and conservation challenges

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Abstract

Understanding the reproductive phenophases of a species is essential for shedding light on its reproductive ecology and defining appropriate conservation strategies. *Uvariodendron angustifolium* (Engl. & Diels) R. E. Fries is a versatile aromatic forest species that is threatened in the Ewè-Adakplamè forest (southern Benin). This study describes the reproductive phenophases of the species in the Ewè Adakplamè forest and assesses their seasonal dynamics over three years. The data collected were analysed to characterise the seasonal calendar and assess variations between years and between individuals of the species. The evolution of quantitative data and the variation in the flowering and fruiting stages of *U. angustifolium* were established for the three years of observations. The

species has four flowering stages and four fruiting stages, aligned with seasonal windows linked to the major local climatic seasons. Interannual variability in the duration of the stages is observed, reflecting the species' sensitivity to climatic fluctuations and the microclimatic heterogeneity of the forest environment. Flowering is mainly associated with the dry season and the beginning of the rainy season, while fruiting occurs mainly during the rainy season. Fruit productivity is low (approximately 4% of flowers initiated result in mature fruit), suggesting that regeneration may be vulnerable to rainfall variations and anthropogenic pressures, particularly local exploitation and medicinal uses. These results highlight the importance of integrating local phenological knowledge into conservation and management plans for West African tropical forests, particularly in the face of climate change and anthropogenic pressure.

Keywords: *Uvariodendron angustifolium*, flowering, fruiting, climate, tropical forests.

Introduction

Phenology studies the seasonal phases of the reproductive cycle of plants. It is a key tool for understanding the reproductive ecology of tropical angiosperms and for informing conservation strategies for threatened species (Allemann, 2023; Etou *et al*., 2024). In the tropical forests of West Africa, climatic variations (seasonal rainfall and humidity patterns) modulate flowering and fruiting schedules, with direct consequences on population demographics and interactions with pollinators and dispersers. Habitat loss and anthropogenic pressures exacerbate these issues by increasing the risk of local extinction for many forest species (IPBES, 2023).

In Benin, the ecological context is characterised by a mosaic of terrestrial ecosystems and the existence of large forest islands, such as Ewè-Adakplamè, which are home to a significant proportion of regional biodiversity and provide refuges for threatened species (Adomou *et al*., 2006; Adomou *et al*., 2011; Bada Amouzoun *et al*., 2019). The Ewè-Adakplamè forest island, in particular, remains vulnerable to intensifying human pressures (deforestation, fires, overexploitation) and climate change, while hosting rare or endemic species and plant genetic resources of cultural and socio-economic importance (Adomou, 2006; Akoègninou *et al*., 2006; Bada Amouzoun., 2022). Among these species is *Uvariodendron angustifolium* (Engl. & Diels) R. E. Fries.

U. angustifolium is a cauliflorous shrub whose fruits and essential oils are used locally and have significant ecological value (Akoègninou *et al*., 2006; Bada Amouzoun *et al*., 2019). It grows in the dense forests of West Africa, including Cameroon, and is characterised by shrubby to tree-like growth, with cauliflorous flowers and fruits that have a strong lemon scent (Akoègninou *et al*., 2006; Bada Amouzoun *et al*., 2019). Despite its regional distribution, pressures related to extraction, habitat fragmentation and cultural exploitation accentuate its conservation priority status (Adomou *et al*., 2006; Bada Amouzoun, 2022). In Benin, the available phenological data remain fragmentary, and studies specific to *U. angustifolium* are rare, which limits the ability to develop appropriate, empirically based conservation strategies (Bada Amouzoun., 2022). In this context, a careful description of reproductive phenophases and their seasonal dynamics is essential to understand reproductive mechanisms, estimate reproductive yields, and guide conservation and management actions. This study aims to characterise the reproductive phenophases of *U. angustifolium* and assess the implications for conservation. More specifically, it sought to: (1) describe the different reproductive phenophases (flowering and fruiting) of *U. angustifolium*; (2) establish the annual calendar of phenophases according to the seasons (3) and assess the rate of loss of reproductive organs in individuals of *U. angustifolium*.

Materials and Methods

Study area

The study was conducted in southern Benin, West Africa, where the species is endangered, specifically in the Ewè-Adakplamè community forest (Figure 1). This forest belongs to the Plateau phytogeographic district, characterised by dense semi-deciduous vegetation (Adomou, 2005).The Ewè-Adakplamè community forest, with an estimated area of 738 ha (MEHU, 2012), is located between 7°25'–7°30' N and 2°32'–2°35' E. It is the largest area of sacred forest in the commune of Kétou in Benin and is bordered by several villages including Adakplamè, Ewè, Gbèdji and Igbo-Owolo.

The climate of the area is sub-equatorial or Guinean, with two rainy seasons (March–July, September–October) and two dry seasons (November–February, August). The average annual temperature is 28°C, with peak temperatures during the dry season and minimum temperatures in August. Annual rainfall varies between 1,100 and 1,300 mm depending on the location (Yabi and Afouda, 2012).The soils are mainly ferralitic in Ewè-Adakplamè (Igué *et al*., 2013). The hydrographic network includes permanent and temporary watercourses originating in the Ouémé basins.

From a human perspective, the population density is relatively high around the forest (163 to 247 inhabitants/km² in Ewè-Adakplamè, between 2013 and 2023) (INSAE, 2016). The dominant ethnic groups are the Fon, Mahi, Holli and Nagot, who live mainly from agriculture, hunting, small-scale trade and the exploitation of forest resources (Codjia *et al*., 2000; INSAE, 2016).

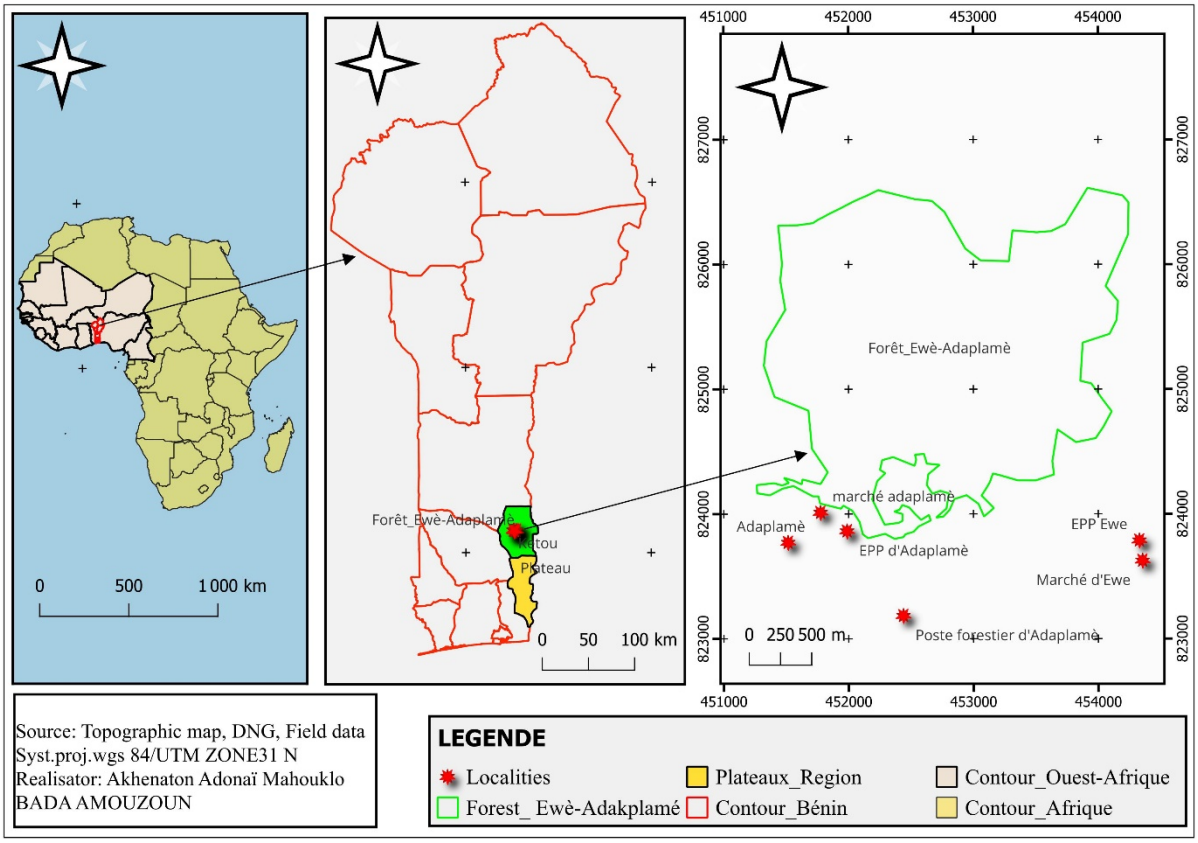

Figure 1: Geographical location of the study area (Ewè-Adakplamè Forest)

Data collection

❖ *Data collection and observation protocol*

Data on the reproductive phenology of *Uvariodendron angustifolium* were collected over a period of three consecutive years: 2017–2018, 2018-2019 and 2019-2020 in the Ewè-Adakplamè community forest. The study was conducted on a sample of ten identified shrubs, to which ten inflorescences per shrub were added for more detailed observation of phenophases.

❖ *Determination of phenophases*

The phenological stages of *U. angustifolium* were identified based on the external morphological characteristics of the reproductive organs, using qualitative criteria such as: the formation and appearance of flower buds; the colour, size and development of flowers; the appearance of inflorescences, flowering, fertilisation and the onset of fruiting; the characteristics of mature fruit and fruit fall. These qualitative characteristics were supplemented by quantitative measurements to better characterise the stages: counting the number of flowers and fruits per inflorescence; dimensional measurements (diameter and length) of flowers and fruits where possible and relevant. The approximate duration between stages was noted.

❖ *Frequency and method of observation*

Phenological observations of *U. angustifolium* were made on a weekly basis from the start of flowering until the fruit ripened. To ensure data traceability, each shrub was geolocated and the inflorescences observed were linked to their shrub in a centralised database.

❖ *Sampling and collection*

For each stage identified, 20 flowers and 20 fruits of *U. angustifolium* were collected from unmarked inflorescences. The samples were collected with the agreement of local managers and in accordance with current ethical and regulatory practices. The specimens collected were used solely for the morphological and quantitative analyses planned as part of the study.

❖ *Controls and data quality*

The floral analysis of *U. angustifolium* was carried out in the field and, in cases of doubt, confirmed by comparison with monographic descriptions and, where possible, by consultation with the National Herbarium of Benin. Data cross-checks were carried out periodically to avoid recording errors (double counting, scale inconsistencies).

Data analysis

The data collected on the reproductive phenophases of *U. angustifolium* were analysed to characterise the seasonal calendar and assess variations between years and between individuals of the species. The different stages of the reproductive phenophases of *U. angustifolium* were identified based on Ewédjè *et al*. (2015) and Badou *et al*. (2017). The characteristics of these stages were presented on the basis of qualitative morphological characteristics (colour, appearance of flower buds, condition of flowers and fruits, presence or absence) and quantitative characteristics (length and diameter of flowers and fruits, number of flowers and fruits per inflorescence) relating to the species. The evolution of quantitative data and the variation in the flowering and fruiting stages of *U. angustifolium* were established for the three years of observations. Analysis of variance (ANOVA) was used to verify the variability of these quantitative characteristics from one shrub to another and between years.

Results

Morphological description of reproductive phenophases in *U. angustifolium*

Two main reproductive phenophases have been identified in *U. angustifolium*: flowering and fruiting. A total of eight phenological stages have been recorded: four for flowering (fl1 to fl4) and four for fruiting (fr1 to fr4).

Flowering

Stage 1: Flowers initiated (fl1)

- In *Uvariodendron angustifolium*, the first stage is characterised by small, globular cauliflorous buds, initiated and assembled directly on the stem.

Stage 2: Developed flower buds (fl2)

- The second stage is marked by a much more pronounced development of the flower buds, which are solitary, cauliflorous and closed. The sepals and outer petals are visible (Figure 2.a).
- The flower buds (fl2) become individual flowers with the differentiation of the perianth parts during the third stage.

Stage 3: Flowers in bloom (fl3)

- The third stage is characterised by the opening of the flowers. There are 3 sepals and 6 petals (3 internal and 3 external) (Figure 2.b).
- The 3 sepals are fused at the base and imbricate in the middle.
- The petals are free and oval: the 3 outer petals are contiguous from the base to the tip, while the 3 inner petals are contiguous only at the tip, revealing numerous stamens at the base.
- The carpels are free.

Stage 4: Senescent flowers (fl4)

- Stage fl4 is characterised by the withering of the calyx, corolla and androecium.
- The flowers are bisexual or hermaphroditic.

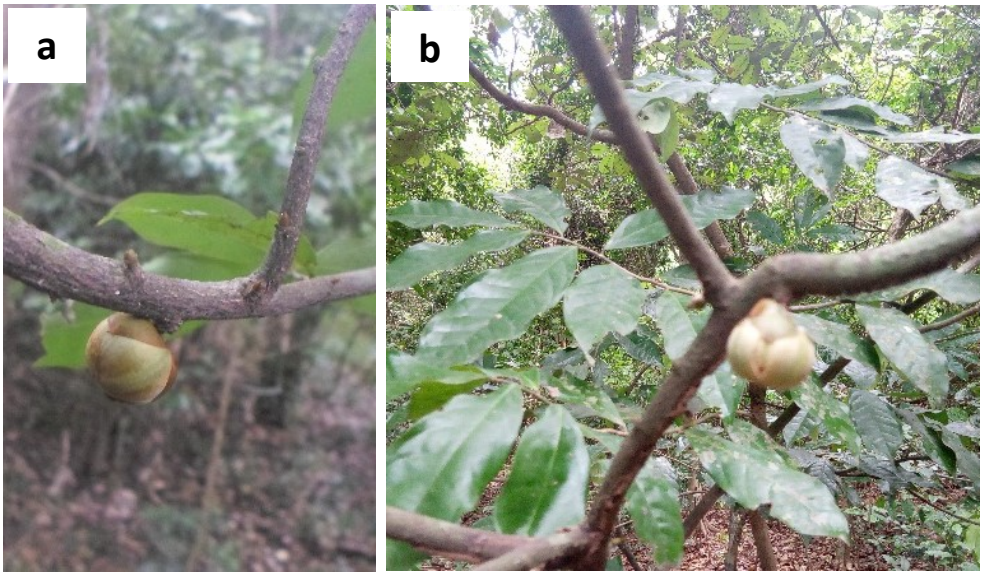

Figure 2: Photos of *Uvariodendron angustifolium*: a) developed flower buds; b) open flowers

Fruiting

Stage 1: fruit initiation (fr1) / fruit set

- This stage is marked by the swelling of the fertilised ovary. The carpels remain free in each flower, resulting in sessile mericarp fruits (Figure 3.c).

Stage 2: young fruits (fr2)

- Characteristics: increased swelling and more pronounced elongation of the fertilised ovary.
- Consequence: disappearance of the petals (Figure 3.c).

Stage 3: developed fruits (fr3)

- The shape of the fruit becomes distinct, with very marked swelling and elongation.
- Colour: green (Figure 3.d).

Stage 4: mature fruits (fr4)

- Cylindrical shape and pericarp that turns yellow when mature (Figure 3.e).

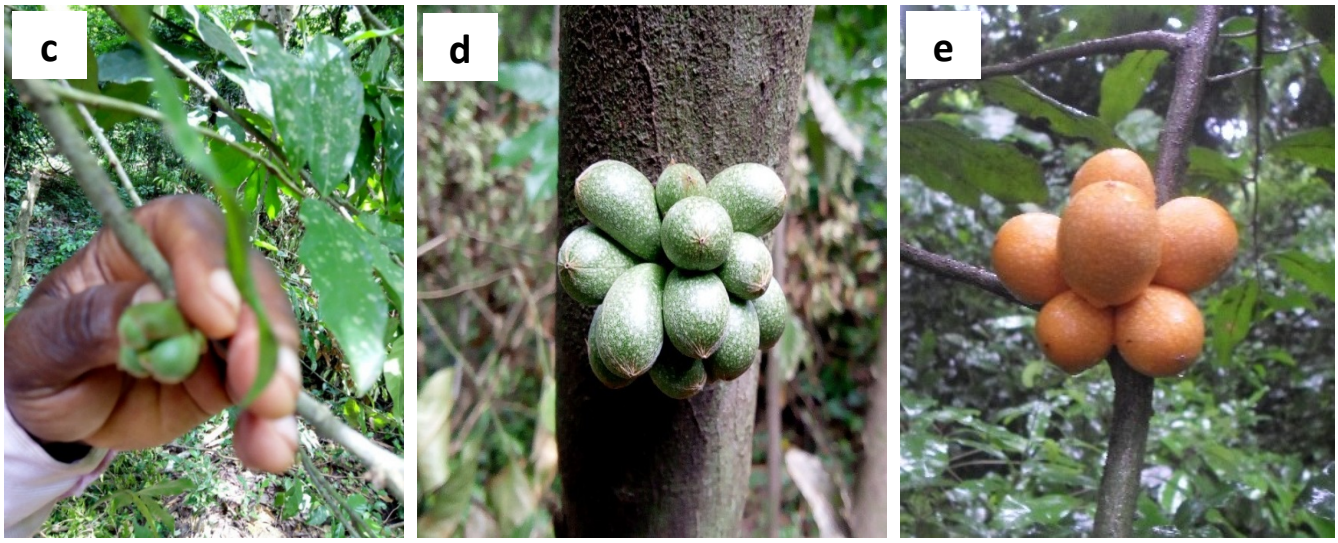

Figure 3: Photos of *Uvariodendron angustifolium* on different shrubs: c) multiple fruit initiation, d) young fruit, e) mature fruit

Variation in the timing of reproductive phenophases in *Uvariodendron angustifolium* over three years of observation

The flowering of *U. angustifolium* lasted from 1st December 2017 to 15 April 2018, a period of 136 days for the first year of observation. In the second year, it lasted from 9 December 2018 to 27 April 2019, a period of 139 days. In the third year, it lasted from 3 January 2020 to 20 May 2020, a period of 139 days (Table 1). Considering the different stages of floral phenophases, their duration is similar for all three years. However, the flower initiation stage has a higher and longer duration, ranging from 42 to 50 days. It appears that in southern Benin, the species flowers during the long dry season and at the beginning of the long rainy season. It flowers only once a year, with full flowering occurring between February and April.

Table 1: Variation in the flowering stage calendar for *Uvariodendron angustifolium*

Flowering stages	Seasons	Year 2017-2018		Year 2018-2019		Year 2019-2020	
		Date	**Duration (days)**	**Date**	**Duration (days)**	**Date**	**Duration (days)**
Flowers initiated (fl1)	Long dry season	1st/12/2017 to 15/01/2018	46	09/12/2018 to 20/01/2019	43	03/01/2020 to 21/02/2020	50
Developed floral buds (fl2)	Long dry season + start of long rainy season	16/01/2018 to 16/02/2018	32	21/01/2019 to 20/02/2019	31	22/02/2020 to 22/03/2020	30
Flowers in bloom(fl_3)	Long dry season + Long rainy season	17/02/2018 to 14/03/2018	26	21/02/2019 to 23/03/2019	31	23/03/2020 to 20/04/2020	29
Senescent flowers (fl4)	Long rainyseason	15/03/2018 to 15/04/2018	32	24/03/2019 to 27/04/2019	34	21/04/2020 to 20/05/2020	30

The fruiting of *Uvariodendron angustifolium* took place from 16 April 2018 to 20 June 2018 in the first year, lasting 65 days. In the second year, it took place from 28 April 2019 to 12 July 2019, lasting 76 days. In the third year, it lasted from 31 May to 31 July 2020, for a total of 65 days (Table 2). However, there is a slight difference in the duration of the various stages of fruiting between the three years. It appears that in southern Benin, the species fruits during the main rainy season and only once a year.

In total, *Uvariodendron angustifolium* flowers during the main dry season and at the beginning of the main rainy season. It fruits during the main rainy season in southern Benin. The duration of the phenophases of flowering and fruiting of *Uvariodendron angustifolium* was 211 days (7 months) in 2017-2018, 215 days (7 months) in 2018-2019 and 204 days (7 months) in 2019-2020.

Table 2: Variation in the timing of fruiting stages in *Uvariodendron angustifolium*

Fruiting stages	Seasons	Year 2017-2018		Year 2018-2019		Year 2019-2020	
		Date	**Duration (Hours)**	**Date**	**Duration (Hours)**	**Date**	**Duration (Hours)**
Initiated fruit (fr1)	Long rainy season	16/04/2018 to 30/04/2018	15	28/04/2019 to 11/05/2019	14	21/05/2020 to 11/06/2020	15
Young fruit (fr2)	Long rainy season	1st/05/2018 to 16/05/2018	16	12/05/2019 to 31/05/2019	20	12/06/2020 to 02/07/2020	21
Developed fruit (fr3)	Long rainy season	17/05/2018 to 30/05/2018	14	1er/06/2019 to 20/06/2019	20	03/07/2020 au 17/07/2020	15
Mature fruit (fr4)	Long rainy season	1st/06/2018 to 20/06/2018	20	21/06/2019 to 12/07/2019	22	18/07/2020 to 31/07/2020	14

Changes in quantitative data recorded for *Uvariodendron angustifolium*

Changes in the quantitative values of reproductive organs at each stage of *Uvariodendron angustifolium* are summarised in Table 3. The values changed from one phenological stage to another. The highest values were recorded at the mature fruit stage: 30.29 ± 1.85 mm for length and 22.33 ± 1.22 mm for diameter. The number of organs per shrub decreased considerably from one phenological stage to another, from flower initiation to mature fruit. The highest values were recorded at the flower initiation stage (271 ± 94 flowers), while the lowest values were recorded at the mature fruit stage (12 ± 5 fruits).

Table 3: Variations in the quantitative values of reproductive organs according to the phenological stages identified in *Uvariodendron angustifolium*

Stages	Flower/fruit length (mm)	Flower/fruit diameter (mm)	Number of flowers/fruits per shrub
Initiated flowers (fl1)	3.96 ± 0.32	1.57 ± 0.54	271 ± 94
Developed floral buds (fl2)	8.24 ± 1.12	5.17 ± 0.67	178 ± 67
Flowers in bloom (fl3)	16.08 ± 1.32	5.95 ± 0.75	147 ± 54
Senescent flowers (fl4)	8.39 ± 0.74	6.18 ± 0.69	145 ± 51
Initiated fruits (fr1)	14.09 ± 1.09	10.22 ± 0.83	77 ± 28
Developed fruits (fr3)	20.64 ± 1.75	14.16 ± 1.32	35 ± 12
Fruits développés (fr_3)	24.73 ± 2.02	16.28 ± 1.43	20 ± 7
Mature fruits (fr4)	30.29 ± 1.85	22.33 ± 1.22	12 ± 5

The average cumulative loss of reproductive organs per individual of *U. angustifolium* was measured from the flower initiation stage to the mature fruit stage (Figure 4). The resulting curve follows an almost logarithmic progression: the average cumulative rate of reproductive organ loss increases from 34% at the developed flower bud stage to 96% at the mature fruit stage. As a result, only 4% of flowers initiated per individual manage to develop into mature fruit at the end of reproductive organ development.

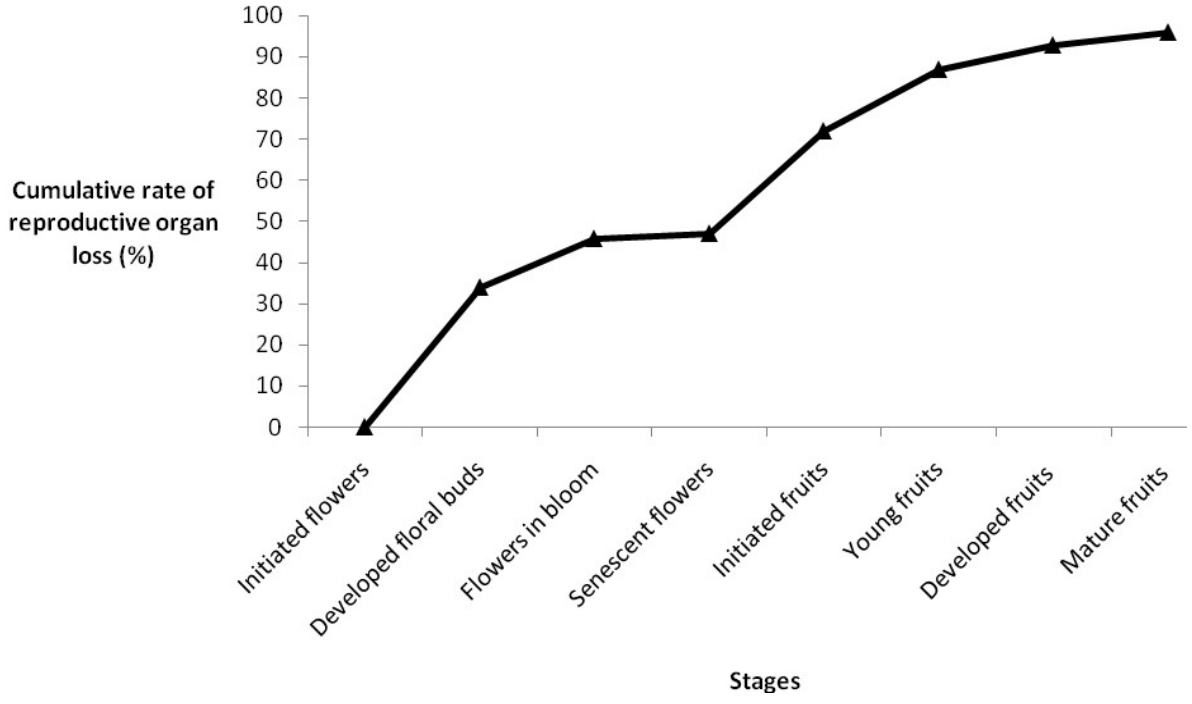

Figure 4: Evolution of the average cumulative loss rate of flowers and fruits on individuals of *Uvariodendron angustifolium*

Discussion

The reproductive phenology of *Uvariodendron angustifolium* (Engl. & Diels) R. E. Fries is a key marker for understanding the functioning of forest ecosystems in the region and for evaluating the mechanisms underlying its regeneration. In this study, phenology is described by four floral stages and four fruiting stages, each occurring within seasonal windows specific to southern Benin. Observations over three years reveal interannual variability in the duration of the stages, while showing consistency in the phenological sequence: flowering precedes fruiting, with transition periods associated with climatic seasons. The flowering of *U. angustifolium* occurs during the long dry season and at the beginning of the long rainy season. These results are consistent with previous observations indicating that the flowering of woody species tends to start in the dry season and then extend into the wetter periods (Yédomonhan 2009; Jaouadi *et al*. 2012; Badou *et al*. 2017; Lawin *et al*., 2021; Azalou-Tingbé *et al*. 2022; Etou *et al*., 2024). This variability can be explained by fluctuations in climatic and environmental conditions specific to the Ewè Adakplamè forest. In plants, climate directly influences their phenology through fundamental processes such as photosynthesis, CO2 absorption and transpiration (Diallo *et al*., 2016; Helman, 2018). Differences between intermediate stages of the same species may also reflect sources of variation related to the demography of individuals (different sizes and ages) and the microclimatic heterogeneity of the forest environment (Depommier, 1998; Azalou-Tingbé *et al*., 2022).

U. angustifolium fruits during the heavy rainy season in southern Benin. The results related to the fruiting periods of *U. angustifolium* corroborate those of Vayssières *et al*. (2010), Badou *et al*. (2017), Lawin *et al*. (2021) and Azalou-Tingbé *et al*., (2022), who showed that tropical woody fruit species have fruiting periods ranging from March to October in Benin. The fruit productivity of *U. angustifolium* is low, with approximately 4% of flowers initiated resulting in mature fruit, highlighting a potential reproductive vulnerability to variable rainfall conditions and local anthropogenic pressure.

The low fruit production can also be explained by attacks from mould, fungi, anthropogenic pressures and competition from animals (squirrels, monkeys, birds, insects, worms) and humans (hunters) consuming the fruits of *U. angustifolium* in the Ewè-Adakplamè forest. The fruit is edible, sweet, peppery, rich in vitamins and thirst-quenching (Bada Amouzoun *et al*., 2019).

U. angustifolium is a cauliflorous species with multiple uses. Cutting its stems for the 'Oro' cult and medicinal uses could have a long-term impact on its regeneration capacity and demographic structure (Bada Amouzoun *et al*., 2019). This can have direct effects on the flowering, fruiting, growth, survival and reproduction of the individuals exploited. And consequently, on the structure and dynamics of their population and on the distribution of areas favourable to the conservation of this species. Thus, phenology is not limited to describing biological cycles, but also serves as an indicator of plant responses to climate change and anthropogenic pressures, while informing conservation strategies adapted to the local and regional scale.

Observation carried out with the naked eye, without binoculars, has major methodological limitations, particularly in terms of subjectivity, temporal precision and spatial coverage, as access, density and height of the stand influence the reliability of ratings and the quantification of phenological stages (Jean *et al*., 2017). Nevertheless, the results provide robust evidence of the link between phenology and regional seasonality. This study did not include the potential effect of shrub diameter and soil type, which are known determinants of phenology in many species (Depommier, 1998; Azalou-Tingbé *et al*., 2022). These variables could explain some of the variability observed between individuals and years.

The low fruit productivity associated with the region's climate suggests that *in situ* and *ex situ* conservation strategies are necessary to maintain populations of the species and ensure their regeneration. Protecting Ewè Adakplamè forest habitats from anthropogenic pressures (illegal logging, vegetation fires, poaching) is crucial, as is the development of protected areas and sustainable management practices that maintain or restore water resources and microclimatic regimes favourable to reproductive phenology. Given the vulnerability of flowers and fruits during sensitive periods, the implementation of firebreaks and fire management during or before these periods can limit reproductive losses and preserve local genetic stocks. Participatory phenological monitoring involving local communities and forest managers should be established, using simple and reproducible protocols, in order to inform adaptive management plans that respond to climatic and anthropogenic variations. Ways of propagation and reintroduction (seeds, cuttings) in protected areas and agroforestry systems should also be explored, with enhanced monitoring to avoid reproductive disturbances. Future prospects include strengthening collaborations with local communities, forest managers and policy makers in order to translate phenological results into effective and sustainable conservation actions in the West African region.

At the same time, *ex situ* initiatives (botanical gardens, nurseries, community plantations) could contribute to the conservation and resilience of *U. angustifolium* by ensuring the reproduction and maintenance of populations in the absence of optimal conditions on site. These *ex situ* actions would be synchronised with the observed phenological windows to optimise germination, propagation and eventual reintroduction into the natural habitat, while strengthening local capacities for managing and utilising phenological resources by communities.

Conclusion

This study shows that the reproductive phenophases of *Uvariodendron angustifolium* are part of a seasonal dynamic marked by a systematic alternation between flowering and fruiting, with four distinct stages for each phenological stage and time windows closely linked to the major climatic seasons of southern Benin. This phenological structure, observed over three years, reveals interannual variability in the duration of the stages, reflecting the species' sensitivity to climatic fluctuations and the microclimatic heterogeneity of the Ewè-Adakplamè forest. Flowering is concentrated during the dry season and the beginning of the rainy season, while fruiting occurs mainly during the rainy season. This operational synchronisation between available water resources and reproductive phases highlights *U. angustifolium*'s adaptation to its environment, but also its potential vulnerability to increasing climatic shifts and local anthropogenic pressures.

As fruit productivity is low (approximately 4% of flowers initiated result in mature fruit), the species' regenerative success depends heavily on annual water conditions and disturbances related to human exploitation (logging, medicinal harvesting and local rituals). These results highlight a twofold conservation challenge: (i) preserving and restoring the region's forest habitats in order to maintain the ecological windows that promote reproduction and regeneration, and (ii) developing *in situ* and *ex situ* conservation strategies that strengthen the species' demographic and genetic resilience.

Methodologically, the study highlights the need to integrate complementary approaches for a robust assessment: observing phenophases with instruments (binoculars, camera traps, drones for difficult access), quantifying stages more accurately, and taking into account variations in the age and size of individuals. These improvements would make it possible to better describe the mechanisms of phenological regulation and anticipate the species' responses to climate change.

In summary, this study provides original insights into the reproductive phenophases of *Uvariodendron angustifolium* in West Africa and

offers concrete implications for its conservation. It calls for adaptive management of forest resources, based on continuous phenological monitoring, the promotion of responsible local uses, and the integration of climatic and ecological data into the conservation and management plans for the tropical forests of the region.

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