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Flowering and fruiting *of Parkia biglobosa* (Jacq.) Benth according to agro climatic zones and land use system in Souhtern Mali

Bokary Allaye Kelly [1,*], Amadou Malé Kouyaté [2] and Sidiki Gabriel Dembélé [3]

[1] *Institute for Rural Economy, Forest Resources Program, Regional Agronomical Research Centre of Sikasso, BP 16 Sikasso, Mali.*

[2] *Institute for Rural Economy, General Direction, Mali.*

[3] *Rural Polytechnic Institute/Institute of Training and Applied Research (RPI/ITAR) of Katibougou, Mali*

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Abstract

Flowering and fruiting of *Parkia biglobosa* were monitored along the north–south climatic gradient in Mali. Three sites (Somasso, Zanzoni and Diou) were concerned. Adult trees were monitored in field and fallow stands. Significant variations of flowering and fruiting were observed according to site and stand. The onset of phenological events started earlier in the south and progressed toward the north. Four to five months of flowering and three to four months of fruiting were observed in all sites. The trend of flowering and fruiting was similar for fields and fallows. The difference between sites like that between stands was not significant for the length of flowering and of fruiting. The number of flowering trees varied according to year and stand in all sites. At Somasso 100% of trees in the fallow stand flowered all years, while in the field stand, it fluctuated from 93% in 2019 and 2020 to 100% in 2021. At Zanzoni, 100% of trees in field stand flowered all years, while in the fallow stands it fluctuated from 93% in 2019 and 2021 to 73% in 2020. At Diou, 60% of trees in the fallow stand flowered all years, while in the fields it fluctuated from 73% in 2019 and 2020 to 77% in 2021. The trend of fruiting was similar to that of flowering. The results indicate that phenological events of *P. biglobosa* are controlled by an intrinsic force and they can be influenced by other factors, such as management practices.

Keywords: Climatic gradient; Fallow; Field; Forest trees; *Parkia biglobosa*; Phenology

1. Introduction

Tree phenology, is how a tree times the different stages of its vegetative and reproductive development [1, 2, 3]. Understanding how tropical trees react to increasing environmental changes is one of the major challenges currently facing tropical ecologists [4, 5]. Phenological studies are thus of crucial interest [6] and are important for the conservation of tree genetic resources and forestry management and for a better understanding of plant species and community level interactions [7].

For many years now, phenological observations have been an important source of data for understanding the functioning of forest ecosystems, and tree growth in particular, as they enrich our knowledge of the autecology of tree species [8]. They are also a necessary tool for improvers regarding the choice of provenances according to early or late budburst (Vernier & Teiser du Cros, 1996 in [9]). Finally, they have recently been used to study vegetation response to climate change. On a time scale, phenological data are also good indicators of the effects of possible climate change on vegetation, as air temperature and water availability have a major influence on phenophase onset dates [10].

* Corresponding author: Bokary Allaye Kelly

Brügger & Vassella (2003) [11] reported that many plants in tropical regions, where the weather is always warm but there is a dry season, only begin to grow when there is sufficient humidity. In these regions, the timing of growth is therefore determined by the rate of rainfall (a limiting factor) and not by temperature. Other authors have pointed out that the phenology of flowering and fruiting in tropical trees is strongly influenced by abiotic factors [12, 13].

While the importance of understanding phenological patterns and variation, particularly in the context of global climatic change has been recognised [4], information on phenological patterns of tropical plants, particularly for woody plants, is still scarce [15]. Also, few studies have compared populations located at sites characterised by marked environmental differences [16] This approach is, however, important since it could help us to understand the extent of phenological variability as a survival strategy in different environments and how abiotic factors influence phenological patterns particularly for agroforestry trees species like *Parkia biglobosa* playing an important role for rural populations.

P. biglobosa is one of agroforestry species of major socio-economic importance in the whole West African region [17]. Its conservation and domestication for the diversification of agricultural production depends on its ability to adapt to climate change [17]. Populations of this species are highly threatened in large parts of its range due to overexploitation and environmental degradation [18].

In Mali, *P. biglobosa* is one of the most important parkland tree species, providing several goods and services (food, medicine and income) to rural populations and contributing to fight poverty. However, very few studies were interested to the state of the resource as well as to its adaptation strategies to climatic changes through the phenological processes. This study was funded by Malian Government in the frame of the Competitive Funds for Research and Technological Innovation (CFRTI) in the objective to contribute to the domestication of the species. The study aims (i) to understand the state of the resource *P. biglobosa* in different agro-climatic zones, (ii) to determine the variation of the phenology of flowering and fruiting of the species according to agro-climatic zones and land use, (iii) to understand the appropriate period of seeds collection according to agro-climatic zones in the frame of the development of strategies for the renewal of *P. biglobosa* parklands.

2. Material and methods

2.1 Study sites

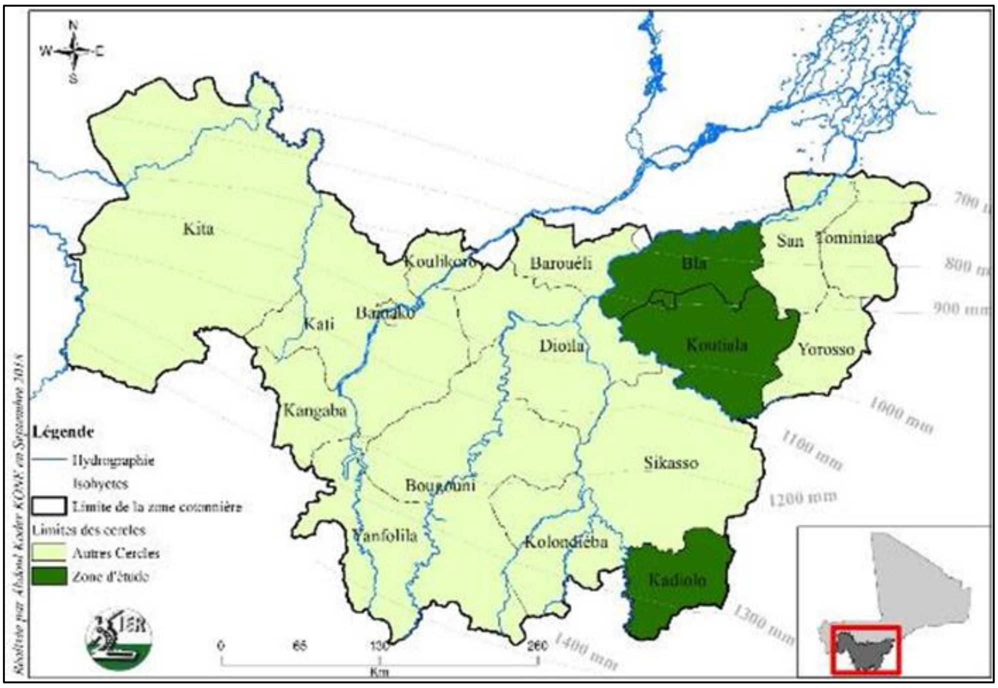

Figure 1 Study zones (green area)

The study was conducted in three agro-climatic zones (the North Sudanian NS, the South Sudanian SS, and the North Guinean NG). Zones were selected based on climatic and environmental conditions as well as management practices (land use system and tree management).

In each zone, one site was selected based on the availability of *P. biglobosa* populations in the fields and fallows, the accessibility in all seasons and the willingness of farmers to collaborate in research activities. Figure 1 shows the three study zones in green colour.

The selected sites were Somasso (district of Bla) in the NS zone, Zanzoni (district of Koutiala) in the SS zone and Diou (district of Kadiolo) in the NG zone.

The site of Somasso (51°31'N, 36°27'W) in the NS zone has a little uneven relief composed of cultivable plains. The climate is North Sudanian, characterized by two seasons (the long dry season from October to May and the short rainy season from June to September). Agriculture is the main activity and the cultivated areas are large, dominated by cereal crops. Cotton and groundnuts are the cash crops. Vegetation is shrubby savannah with some big trees spared in the fields such as *Parkia biglobosa*, *Vitellaria paradoxa*, *Faidherbia albida*.

The site of Zanzoni (36°52'N, 32°05'W) in the SS zone has little hilly relief composed of plains favourable for off-season crops. The climate is South Sudanian, with also two seasons with length similar to those of Somasso. Agriculture concerns food and cash crops such as cotton and peanuts. Vegetal resources are similar to those of Somasso but some protected forests and sacred woods are present.

The site of Diou (35°46'N, 58°33'W) in the NG zone has a slightly uneven relief. The climate is North Guinean with a dry season from November to May and a rainy season from May to October. Agriculture is the main activity and cereal production is mainly composed of Maize, while Cotton is grown as a cash crop. There are important forest resources consisting of natural formations, artificial plantations and sacred forests.

2.2 Experimental design

The experimental design consists of square plots of 50 m x 50 m = 2500 m^2 (0.25 ha). Two factors were studied: the factor agro-climatic zones (ACZ) with three levels (NS, SS and NG) and the factor land use "called stand in the paper" with two levels (fields and fallows). Three plots were installed in each stand within each zone giving six plots per agro-climatic zone. The total number of *P. biglobosa* populations was 18 populations (6 plots x 3 agro-climatic zones). All adult *P. biglobosa* trees, with diameter at 1.30 m above the ground (DBH) superior or equal to 10 cm in the plots, were marked and measured. The geographical position of each tree was recorded using a GARMIN eTrex 10 GPS (accuracy ± 3 m).

2.3 Data collection and analysis

The variables measured or observed concerned adult tree morphological traits i.e. the diameter at 1.30 m above the ground (DBH), the total height (TH) and phenological events.

Two phenological phases were described which are the flowering and the fruiting. The flowering was subdivided in three stages:

- Start of flowering: first flower buds appear;
- Full flowering: capitula are well developed and most of them bear flowers;
- End of flowering: all capitula bear flowers and no more new buds appear.

These observations were used to define a variable called "length of flowering", which is the number of days between stages 1 (start) and 3 (end) of flowering.

The fruiting was also subdivided in three stages:

- Fruit set: appearance of young fruit after fertilization;
- Fruit development: green pod gradually increases in size;
- Fruit maturity: mature pod becomes pink brown to dark brown.

These observations were used to define a variable called "length of fruiting", which is the number of days between stages 1 (fruit set) and 3 (fruit maturity).

Collected data were analysed using SYSTAT9 FOR WINDOWS software. Descriptive statistics and analysis of variance (ANOVA) were used. Multiple comparison of the means was made to distinguish the levels of the factor that were significantly different according to Bonferonni's method.

3. Results

3.1 Morphological traits of *P. biglobosa* adult trees

The global analysis of variance on growth parameters of *P. biglobosa* showed a significant effect of ACZ on the diameter at body height (p = 0.000), the total height (p = 0.001). The effect of stand was not significant for all variables. The means of measured variables were shown in table 1.

Table 1 Mean of morphological variables by agro-climatic zone

Agro-climatic zones (ACZ)	TH (m)	DBH (cm)
North Sudanian (NS)	12.59[a]	65.96[a]
South Sudanian (SS)	12.23[a]	66.26[a]
North Guinean (NG)	10.68[b]	45.46[b]

Means with the same letter were not significantly different

The NG zone showed mean DBH and mean TH significantly lower than those of Sudanian zones which are not significantly different (Table 1).

3.2 Density of populations

The density of *P. biglobosa* by stand in each agro-climatic zone is shown in table 2.

Table 2 Density of *P. biglobosa* populations by agro-climatic zone and stand

	Density (ha^{-1})		
Agro-climatic zones (ACZ)	Fields	Fallows	Mean ACZ
North Sudanian (NS)	13	9	11
South Sudanian (SS)	13	13	13
North Guinean (NG)	17	18	18
Mean stands	14	13	

The mean density of *P. biglobosa* increased from north to south (Table 2). The density was almost the same for the two stands (14 trees ha^{-1} and 13 trees ha^{-1} for fields and fallows respectively). The same density was observed for the fields of the NS and SS zones (13 trees ha^{-1}). Higher density was observed for those of the NG zone (17 trees ha^{-1}). For fallows, the density increased from north to south (Table 2).

3.3 Chronology of flowering and fruiting of *P. biglobosa*

The spread of *P. biglobosa* flowering (start-end) and fruiting (fruit set-full maturation) by stand (field, fallow) in the study sites during the three phenological monitoring campaigns is illustrated in Figure 2.

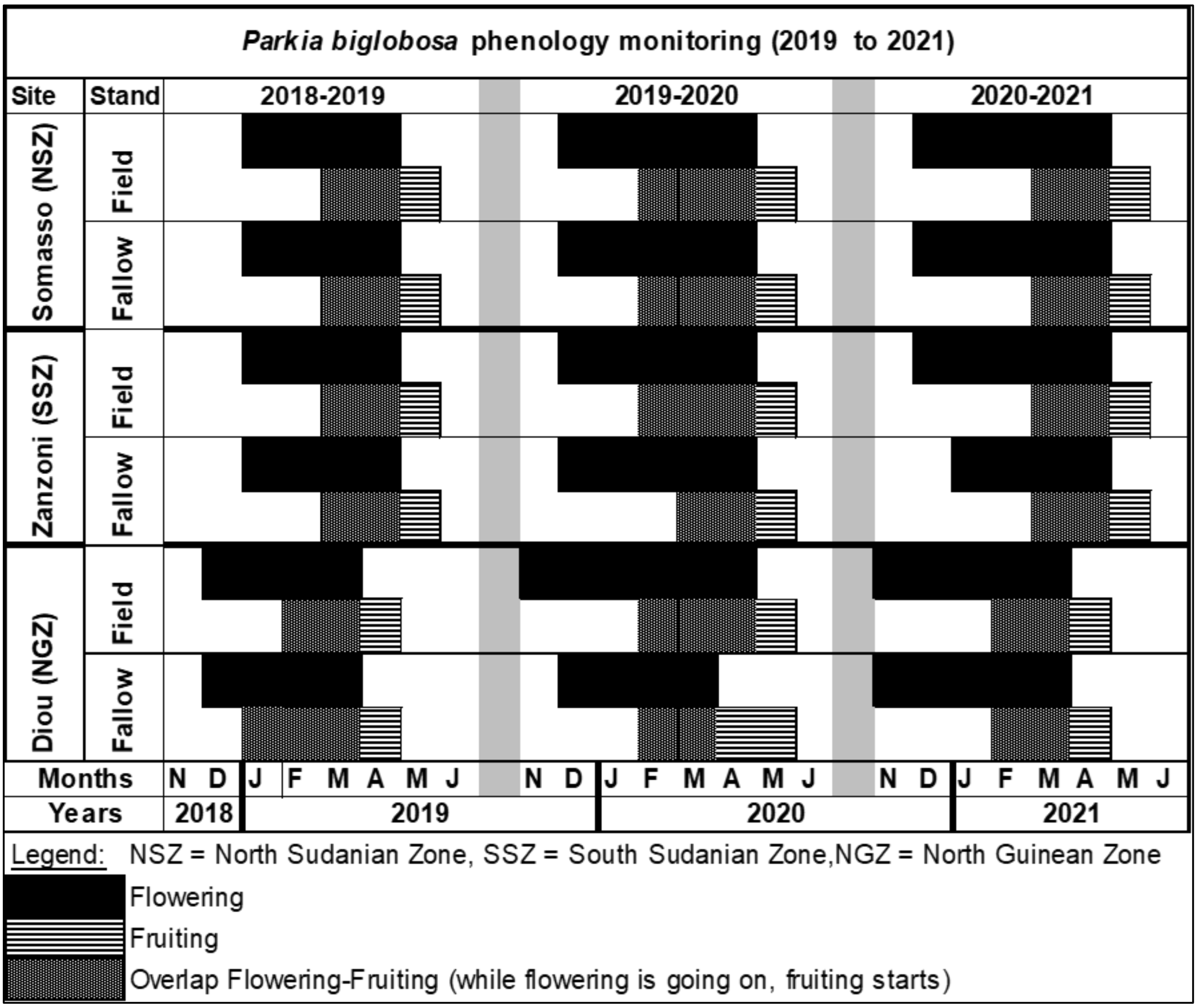

Figure 2 Phenogram of flowering and fruiting of *P. biglobosa* by stand in the study sites

In the North Sudanian Zone (site of Somasso), for the monitoring season 2020-2021, flowering began in both stands in December 2020 and ended in April 2021. Like the season 2019-2020, it was spread over 5 months. Fruiting started in the fallows in mid-March 2021, a month later than in the fields, spread over 3 months in the fallows and over 4 months in the fields like in the season 2019-2020. Pods maturity occurred in both stands at the same time (April 27 to May 12, 2021). Almost the same pods maturity time was observed in the season 2019-2020 (April 25 to May 10, 2020).

In the South Sudanian Zone (site of Zanzoni), for the monitoring season 2020-2021, flowering began in the fields in December 2020 and ended in April 2021, while in fallows it began in January 2021 and ended in May 2021. In both formations, flowering lasted 5 months, as in the season 2019-2020. In both stand, fruiting began in March, spread over 3 months and ended in May. In the fields, the fruiting period was shorter (3 months) compare to the season 2019-2020 (4 months). In the season 2020-2021, pods maturity occurred in both stands at the same time (April 20 to May 06, 2021), slightly earlier compare to 2019-2020 (May 02 to 13, 2020), but at roughly the same time compare to 2018-2019 (mid-April to mid-May).

In North Guinean Zone (site of Diou), for the monitoring season 2020-2021, flowering began in both stands in November 2020 and ended in March 2021. Flowering lasted 5 months, compared to 6 months in the fields and 4 months in the fallows in the season 2019-2020. Like the season 201-2020, in 2020-2021, fruiting began in February 2021 in both stands and spread over 3 months and ended in April. In the season 2020-2021, pods maturity occurred in both stands at almost the same time as in the season 2019-2020 (from March 27 to April 15). The number of months of flowering and fruiting of *P. biglobosa* trees according to site and stand from 2019 to 2021 were shown in table 3.

Table 3 Duration (months) of flowering and fruiting of *P. biglobosa* according to site and stand from 2019 to 2021

Year	Site	Stand	Duration flowering (months)	Duration fruiting (months)
2019	Somasso	Field	4	2
	Somasso	Fallow	4	3
	Zanzoni	Field	4	3
	Zanzoni	Fallow	4	3
	Diou	Field	4	3
	Diou	Fallow	4	4
2020	Somasso	Field	5	4
	Somasso	Fallow	5	4
	Zanzoni	Field	5	4
	Zanzoni	Fallow	5	3
	Diou	Field	6	4
	Diou	Fallow	4	4
2021	Somasso	Field	5	4
	Somasso	Fallow	5	3
	Zanzoni	Field	5	3
	Zanzoni	Fallow	5	3
	Diou	Field	5	3
	Diou	Fallow	5	3

The analysis of variance on the duration of flowering and fruiting showed that for both variables, the interaction between the factors (year, site and stand) was not significant and that among main factors, only year effect was significant (see ANOVA results below).

3.3.1 ANOVA on flowering duration

Source	Sum-of-Squares	df	Mean-Square	F-ratio	p
YEAR	0.219	2	0.110	14.642	0.001
SITE$	0.000	2	0.000	0.004	0.996
STAND$	0.011	1	0.011	1.498	0.244

3.3.2 ANOVA on fruiting duration

Source	Sum-of-Squares	df	Mean-Square	F-ratio	p
YEAR	0.177	2	0.088	3.960	0.048
SITE$	0.024	2	0.012	0.543	0.595
STAND$	0.000	1	0.000	0.006	0.939

Overall, the mean duration of flowering was 4.66 ± 0.594 months and that of fruiting was 3.33 ± 0.594 months. The means of duration of flowering and fruiting by main factor were shown in table 4. Years 2020 and 2021 were not significantly different but both were different to 2019 displaying the lowest number of month of flowering (4 months).

Almost the same trend was observed for fruiting but for this variable year 2019 was not significantly different to year 2021. Year 2020 showed the longest fruiting and flowering and always significantly different to 2019.

Table 4 Mean duration flowering and fruiting according to main factors

Factors	**Mean duration of flowering (months)**	**Mean duration of fruiting (months)**
Year		
2019	4 ± 0.000[b]	3.00 ± 0.632[b]
2020	5 ± 0.632[a]	3. 83 ± 0.408[a]
2021	5 ± 0.000[a]	3.16 ± 0.408[ab]
Site		
Somasso	4.66 ± 0.516	3.33 ± 0.816
Zanzoni	4.66 ± 0.516	3.16 ± 0.408
Diou	4.66 ± 0.816	3.50 ± 0.548
Stand		
Field	4.77 ± 0.667	3.33 ± 0.707
Fallow	4.55 ± 0.527	3.33 ± 0.500

3.4 Ability of flowering and fruiting of *P. biglobosa*

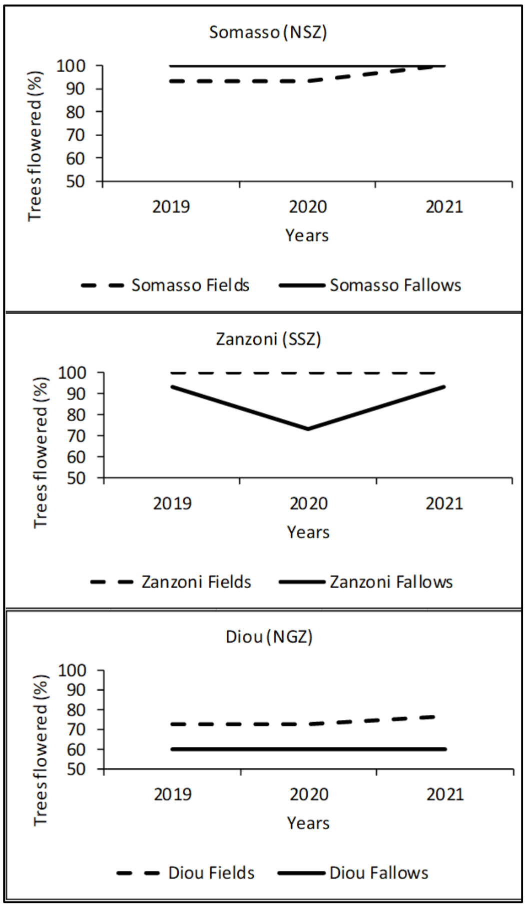

Figure 3 *P. biglobosa* trees having flowered (%) by stand in the three sites from to 2019 to 2021

A total of 90 trees were marked for phenological observations. Four trees died (two due to phytosanitary constraints, one cut down and one burnt). The evolution of the percentage of trees having flowered from 2019 to 2021 by stand in each site was illustrated in figure 3.

At Somasso, the percentage of trees having flowed in fallow stands was 100% in all three years, while in the field stands it fluctuated from 93% in 2019 and 2020 to 100% in 2021. At Zanzoni, the percentage of trees having flowered in the field stands was 100% in all three years, while in the fallow stands it fluctuated (93% in 2019 and 2021 to 73% in 2020). In Diou, the percentage of trees having flowered in fallows stands was 60% in all three years, while in fields it fluctuated from 73% in 2019 and 2020 to 77% in 2021 (Figure 3).

The percentage of trees having fruited in 2021 was 87%. This implies that not all trees having flowered (96%) fruited. The rate of mismatch between flowering and fruiting was 9%. The distribution of the percentage of fruited trees by stand in the sites was very similar to that observed for flowering, illustrated by figure 3.

4. Discussion

In three years of phenological monitoring, 4% of plants died. The causes of mortality were twofold, namely anthropogenic (cutting and burning) and sanitary (desiccation disease). In the areas covered by this study, these two factors are currently the species' main constraints. Other authors have reported these same factors as major constraints for *P. biglobosa* [19, 20, 21, 22].

Phenological monitoring has shown that flowering/fruiting of *P. biglobosa* progresses from south to north. Ouédraogo (1995) [23] reported that *P. biglobosa* flowers and fructifies mainly during the dry season, and that flowering progresses from south to north from November/December in the south to the end of March in the north. This phenomenon has also been observed for this species by [24] and by other authors for agroforestry species such as *V. paradoxa* [25, 26, 27] and *A. digitata* [28].

However, the number of months of flowering was almost the same in all zones. Observations confirmed the existence of different categories of individuals in the *P. biglobosa* population, namely early, late and intermediate flowering individuals. This is also an indication that the flowering phenology of *P. biglobosa* is a character controlled by an intrinsic force (genetic) and that its onset and end can be influenced by other abiotic factors as it is the case for many other tropical species, reported by several authors [27, 29, 30, 31, 32, 33]. Authors [7, 34] have reported that factors such as relative humidity, temperature, wind, fire, rainfall, etc., influence the phenological events of forest species. The results obtained for *P. biglobosa* in this study support this assertion.

The spread of flowering observed in Sudanian zones (4 months) was longer than that reported by [35] who stated that *P. biglobosa* flowered from February to March (2 months). However, the results of the present study agree with those reported by [36] for *P. biglobosa* in Benin. According to this author, the reproductive phenology (flowering and fruiting) of this species shows strong seasonality, with a significant difference between zones. In Benin's Sudano-Guinean zone, flowering extends from December to March (4 months), while in the Sudanian zone it extends from December to April (5 months).

The fruiting showed a similar pattern to the flowering in terms of onset, duration, variation and factors that might have an influence. For example, the progressive onset of *P. biglobosa* fruiting from south to north was reported by [37], who observed fruiting spread over a 4-months period (mid-February to mid-June).

A discrepancy between the rate of flowering and that of fruiting was observed. According to [37], this discrepancy could be due to flower drop, a very frequent phenomenon in the Sudano-Sahelian zone due to winds, or to obedience to a need for natural regulation of flowering and fruiting, as in most plant species. The phenomenon of mismatch between the flowering and fruiting has been observed for other species by [34]. These authors assert that there are multiple instances where flowering events are not followed by those of fruiting.

5. Conclusion

Variations of flowering and fruiting length according to site were observed. The results showed that flowering and fruiting of *P. biglobosa*, like those of many other forest fruit species in agroforestry parks, settled progressively from the south to the north of the distribution area. They also revealed that, like other agroforestry park species such as *V. paradoxa*, the effect of management practices is very important in *P. biglobosa* flowering and fruiting.

Variation in the number of trees having flowered and fruited was observed according to year and stand in all sites. The fluctuation is a result of the biological phenomenon of variation in forest fruit species phenology, reported by several authors. In most of cases, the results of this study confirmed those of previous studies on the *P. biglobosa* and other agroforestry park fruit species.

Phenological results obtained are very important for seed collection according to study zones. For strategy of *P. biglobosa* populations renewing, high quality seeds could be harvested from performant trees to produce seedlings for plantation or to proceed to direct sowing.

Compliance with ethical standards

Acknowledgments

We are very grateful to the Malian government for funding the *Parkia* project through the Competitive Fund for Research and Technological Innovation (CFRTI). Many thanks to Somasso, Zanzoni and Diou villages' authorities and populations for allowing us to conduct this study on their field and fallow parcels and also for cooperating in field activities. We also thank field technicians (Isaïe Dembélé, Younoussa Diarra and Mamadou Diabaté), which achieved an important work of monitoring and data recording.

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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