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Effect of climatic zone and land use practices on pod, seed and pulp yield of *Parkia biglobosa* in Southern Mali

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Abstract

Parkia biglobosa parklands, face several constraints such as ageing, mortality and poor natural regeneration. In order to contribute to the domestication of the species, a study was conducted in southern Mali. Three climatic zones and two land use systems referred as stands were concerned. In each zone, three plots of 50 m x 50 m (0.25 ha) each, were installed in each stand. In each plot, adult *P. biglobosa* trees were monitored. The quantity of pods, pulp and seeds was determined each year from 2019 to 2021. The average mean yields were 23.31 kg tree-1, 5.70 kg tree-1 and 5.21 kg tree-1 for pod, seed and pulp respectively. All factors were significant regarding *P. biglobosa* production as well as the interaction between zone and stand. The production was higher in year 2021 (28.15 ± 31.80 kg tree-1 for pod, 7.06 ± 7.50 kg tree-1 for seed and 6.31 ± 7.28 kg tree-1 for pulp). For all products, fields in the north sudanian zone showed the highest mean yields (40.88 ± 39.87 kg tree-1 for pod, 9.03 ± 8.62 kg tree-1 for seed and 8.79 ± 9.30 kg tree-1 for pulp). The results showed that management practices have an influence on growth parameters of *P. biglobosa*. They appeared also to be very important in *P. biglobosa* fruits production. Consequently, any domestication strategy must take this fact into account.

Keywords: Management practices; Fruits production; *Parkia biglobosa*; Stand; Southern Mali

1 Introduction

Parkia biglobosa is a fruit forest tree species common in agroforestry parklands in the sudanian zone. The evidence that forests, trees, and agroforests provide essential nutrients has grown significantly in recent years [1, 2, 3, 4]. However, forest edible products tend to be unaccounted for in official statistics, given the informal nature of markets and consumption ([5]. In addition, a rich diversity of neglected and underutilized species (NUS) including *P. biglobosa*, offers opportunities for more sustainable food production and healthier diets [6, 7, 8].

In Mali, *P. biglobosa* is one of the most important parkland tree species. The species provide several goods and services (food, medicine, and income) to rural populations, contributing to fight poverty. However, populations of this species are highly threatened in large parts of its range due to over-exploitation and environmental degradation [9]. In all study zones, sanitary constraints [10], low density of adult populations in farmed fields as well as in fallows due to several causes like natural mortality, density reduction by farmers in the fields to reduce competition with associated crops (mainly cash crops like cotton which was in expansion in the whole southern Mali) and decreasing production were noticed.

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These constraints, in addition to climate change and other threats like fire and grazing, endangered the sustainability of this species. According to Jacobsen et al. [11], there is a risk of the disappearance of the agro-biodiversity if any action has not taken. A first action would be to have a clear idea about fruiting, which will allow to understand the factors that govern it and to intervene if necessary to increase the yield [12].

However, these last two to three decades, fruit production of agrofrestry tree species like *V. paradoxa* and *P. biglobosa* was characterized by remarkable decrease and a huge fluctuation from year to year. Many attempts were made to explain factors underlying this fluctuation. Thus, authors have hypothesized many combined biotic and abiotic factors underlying the annual variation of fruit production but this process remains still not fully understood. Nevertheless, a better knowledge of the production and the productivity of *P. biglobosa* trees are essential for management and domestication strategies. Ayihouenou et al. [14], reported that the conservation and the domestication of *P. biglobosa* for the diversification of agricultural production depends on its ability to adapt to climate change, while its populations are highly threatened in large parts of its range due to overexploitation and environmental degradation [10].

According to Lompo et al. [10], a sound conservation strategy for *P. biglobosa* and the promotion of its sustainable management should be based on scientific information about threats as well as ecological and genetic processes affecting this species. Assessment of pod, seed and pulp production in relation to climatic zones could contribute to this scientific information needed for conservation strategy. Therefore, this study aims to assess fruit production of *P. biglobosa* trees according to climatic zones and land use system. The specific research questions addressed in this study are:

- How does P. biglobosa pod, seed and pulp yield vary according to climatic zones in Mali?
- How does P. biglobosa pod, seed and pulp yield vary according to land use?
- What is the magnitude of inter-annual variation of pod, seed and pulp yield?

2 Material and methods

2.1 Study zones

The study was conducted in three climatic zones (the North Sudanian NS, the South Sudanian SS, and the North Guinean NG) selected based on climatic and environmental conditions as well as management practices. The NS zone is characterized by a mean annual rainfall varying from 500 to 800 mm. It is a zone of slightly undulated plains, lowlands and depressions with heavy soils quite wet, actively cultivated. It also contains extensive fine-textured plains. The natural vegetation is constantly being degraded, and the existing woody species are those spared by man. In the SS zone, the mean annual rainfall varies from 800 to 1100 mm. Soils are deep alluvial, often the most fertile in the country, used for continuous cultivation and short fallow systems. The soils on rocky foundations are shallow or moderately deep. There are open or moderately dense woody stands on shallow soils. In the NG zone, the rainfall is over 1100 mm per year. The valleys in this area are cultivated in a continuous regime. Fallow system is longer and the density of woody species is higher. It is an excellent zone of timber exploitation.

Land and parkland trees are managed differently in the study zones. In the NG zone, land is less scarce and shifting cultivation still exists whereas in the other two zones, because of land scarcity, the same parcels are used continuously or with short fallow period. Like many West African countries, *P. biglobosa* is officially protected by national legislation in Mali. However, despite this protection, the species is cut for various purposes according to zones. In the NG zone, due to the presence of relative abundant vegetation, *P. biglobosa* trees are less exploited for purposes like fuel wood, charcoal or craft wood in contrary to the Sudanian zones where cases of their exploitation for various purposes were observed. Hence, *P. biglobosa* tree densities in the Sudanian zones are lower compare to the NG zone and because of the use of the same parcels continuously, *P. biglobosa* trees are older and bigger and therefore pruned to favour associated crops.

2.2 Experimental design

In each zone, one site was selected based on the availability of *P. biglobosa* populations in fields and fallows, the accessibility in all seasons and the willingness of farmers to collaborate in research activities. The selected sites were Somasso (51°31'N, 36°27'W) in the NS zone, Zanzoni (36°52’N, 32°05’W) in the SS zone and Diou (35°46'N, 58°33'W) in the NG zone.

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 (DBH ≥ 10 cm) in the plots were marked, measured and monitored for flowering and fruiting phenology. The geographical position of each tree was recorded using a GARMIN eTrex 10 GPS (accuracy ± 3 m).

2.3 Data collection and analyses

Tree variables measured were the diameter at 1.30 m above the ground (DBH) measured with a forest compass, the total height (HT) measured with a 12 m ruler and the crown diameter (CD) measured with a 30 m measuring tape.

The production of monitored tree was assessed for pod, seed and pulp yield from 2019 to 2021. The assessment was done by technicians together with household women owning field and fallow parcels. For each tree, pod, seed and pulp weight was determine using CAMRY DIAL SPRING SCALE (Figures 1, 2 and 3).

Figure 1 Pods **Figure 2** Seed weighing **Figure 3** Pulp weighing

Collected data were analyzed using SYSTAT9 FOR WINDOWS software. Descriptive statistics and analysis of variance were used as analysis methods. For the factors whose effects were significant, multiple comparison of the means was made to distinguish the levels of the factor that were significantly different according to Bonferonni's method. The density of *P. biglobosa* in field and fallow stands in each zone was estimated based on the number of trees in the plots. Correlation coefficients between measured variables were computed and linear regressions were computed to assess the effect of tree variables on pod yield.

3 Results

3.1 Density

The density of *P. biglobosa* by stand in each agro-climatic zone is shown in table 1.

Table 1 Density of *P. biglobosa* by agro-climatic zone and stand

Density (ha-1)			
Climatic zones (CZ)	**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 1). 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 1).

3.2 Summary statistics of measured variables

Table 2 shows statistics of *P. biglobosa* tree variables and products (pod, seed and pulp).

Table 2 Summary statistics over three years monitoring of *P. biglobosa* products

	Mean	Stand dev.	Cv %	Mini	Maxi
Pod weight (kg)	23.31	27.68	118.80	0.25	200
Seed weight (kg)	5.70	6.54	114.70	0.05	43
Pulp weight (kg)	5.21	6.36	122	0.05	46.50
DBH (cm)	62.29	18.34	29.44	31.00	105.00
CD (m)	13.89	3.10	22.32	6.65	18.45
TH (m)	12.24	1.79	14.60	8.55	15.00

DBH= diameter at body height, MCD = mean crown diameter, TH = total height

Production variables showed high coefficients of variation (114 to 122 %)) indicating a huge variability of the data, that reflects an important difference between *P. biglobosa* trees in yield.

3.3 Correlation between variables and regression of tree variables on pod yield

Correlations between tree variables and between tree variables and pod yield were shown in table 3.

Table 3 Correlation matrix between variables

PY	1.000		
DBH	0.185	1.000	
CD	0.228	0.711	1.000
	PW	DBH	MCD

PY = pod yield, DBH= diameter at body height, CD = crown diameter

A high correlation (71 %) was found between tree variables (DBH and CD). The correlation between pod yield and tree variables was weak and pod yield was found to be more related to the CD (23 %) than to the DBH (18 %). Regression analysis showed that both tree crown diameter (MCD) and the diameter at 1.30 m above the ground (DBH) have significant effect on pod yield when they were tested alone each (Table 4). But when tested together, the regression was significant (p = 0.008) but the test of the significance of the coefficient was not significant (p = 0.648, Table 4). The result observed when the two variables were tested together could be explained by the high correlation between tree variables (Table 3).

Table 4 Results of linear regression analysis

Effect	Coefficient	Std Error	T	P (2 Tail)	P (Regression)
MCD	1.835	0.583	3.144	0.002	0.002
DBH	0.260	0.102	2.535	0.012	0.012
MCD	1.564	0.832	1.880	0.062	
+					0.008
DBH	0.066	0.145	0.457	0.648	

3.4 Time zone and stand effects on *P. biglobosa* production

Anova results regarding the effect of the different factors on *P. biglobosa* production variables (pod, seed and pulp) were shown in table 5. For all products, year, zone and stand effect was significant as well as the interaction between zone and stand.

Table 5 Probabilities of the tests of factors effect on production variables of *P. biglobosa*

Probabilities			
Source	**Pod**	**Seed**	**Pulp**
YEAR	0.045	0.010	0.036
ZONE	0.001	0.004	0.005
STAND	0.028	0.028	0.038
ZONE*STAND	0.013	0.033	0.035

3.5 Time (year) effect

The observed yields according to year were illustrated in Figure 4. A similar trend was observed for all products regarding year effect. The difference between years was significant (p = 0.045, 0.010 and 0.036 for pod, seed and pulp respectively). The highest mean yields (28.15 ± 31.80 kg tree^{-1} for pod, 7.06 ± 7.50 kg tree^{-1} for seed and 6.31 ± 7.28 kg tree^{-1} for pulp) were observed in year 2021, which was not significantly different to year 2019. These two years were significantly different to year 2020, which showed the lowest yields (17.45 ± 21.85 kg tree^{-1} for pod, 3.93 ± 4.77 kg tree^{-1} for seed and 3.71 ± 4.88 kg tree^{-1} for pulp.

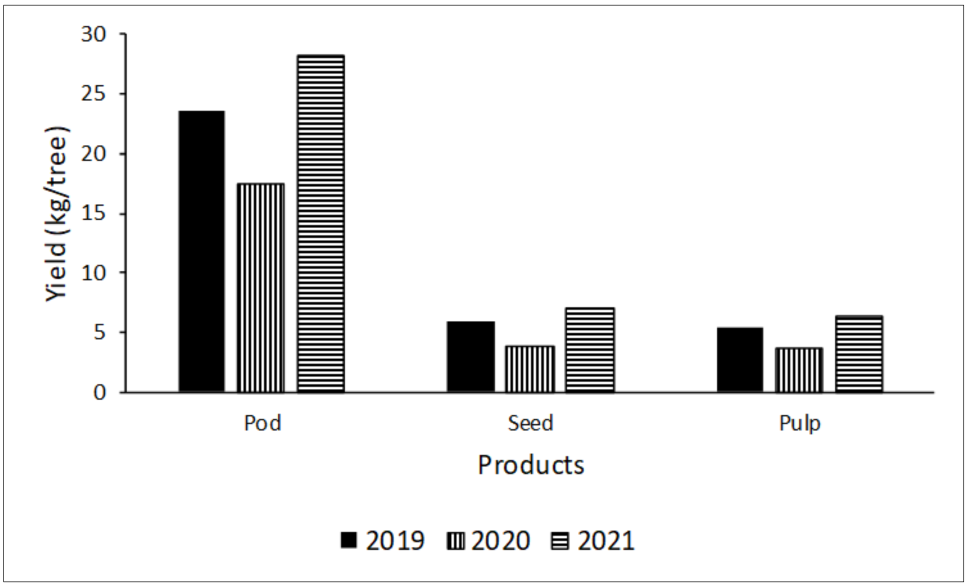

Figure 4 Mean pod, seed and pulp yield of *P. biglobosa* by year

3.6 Climatic zone and land use (stand) effect on *P. biglobosa* pod seed and pulp yields

For all products, climatic zone effect was significant as well as stand effect (Table 4). The interaction between these two factors was also significant (Table 4). Figure 5 illustrates the mean yields by stand within each zone for *P. biglobosa* products (pod, seed and pulp). For all products, fields in the site of Somasso (north sudanian zone) showed the highest mean yields (40.88 ± 39.87 kg tree^{-1} for pod, 9.03 ± 8.62 kg tree^{-1} for seed and 8.79 ± 9.30 kg tree^{-1} for pulp), while fallows in the site of Zanzoni (south sudanian zone) showed the lowest mean yields (7.99 ± 8.78 kg tree^{-1} for pod, 2.12 ± 2.42 kg tree^{-1} for seed and 1.89 ± 2.21 kg tree^{-1} for pulp).

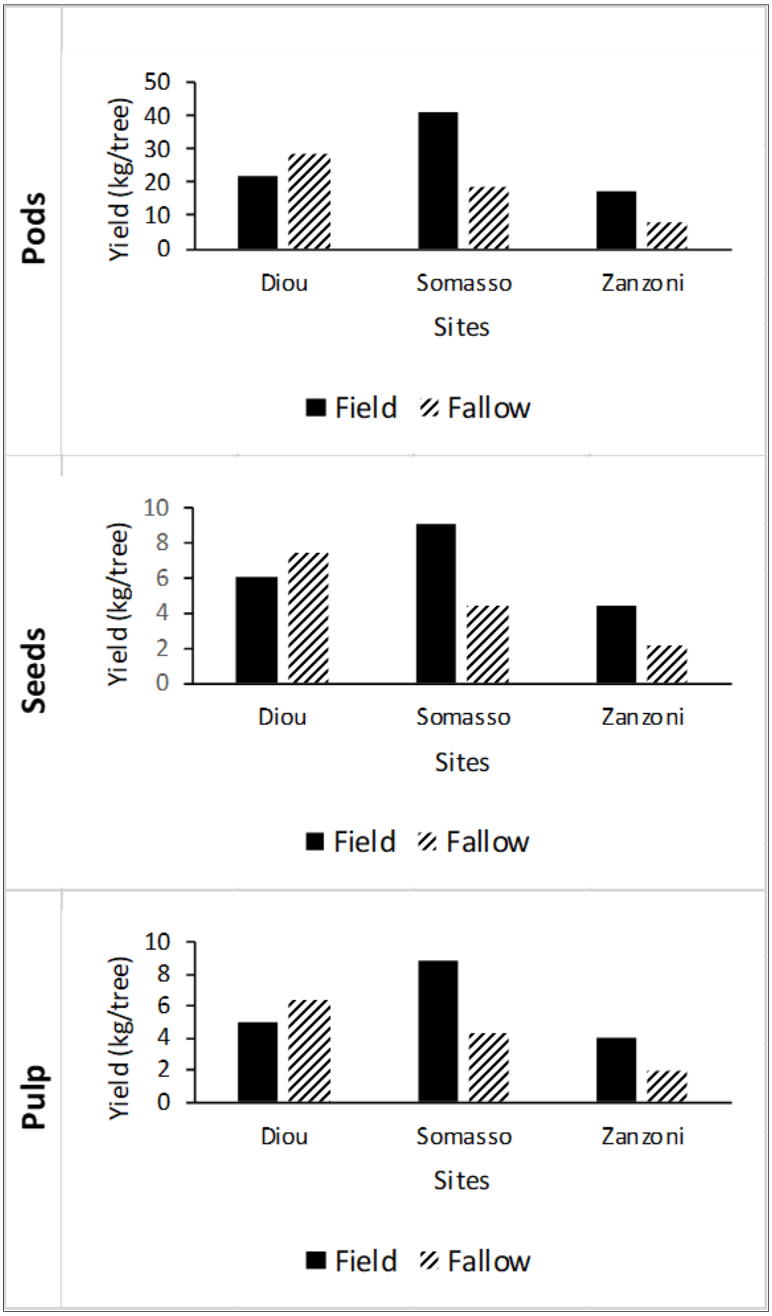

Figure 5 Mean pod, seed and pulp yield of P. biglobosa by stand within site

3.7 Variation in yield according to the year for the stands in the different zones (sites)

The mean yields of *P. biglobosa* products for stands in each site by year were shown in table 6.

The general trend of pod, seed and pulp yield variation over time in the stands for the different site was almost the same. Globally yields were better in year 2021 and fields showed higher mean yields compare to fallows. However, an exception was observed at Diou where mean yields were better in year 2019 and fallows showed higher mean yields compare to fields in many cases (Table 5).

Table 6 Mean pod, seed and pulp yields per stand in each site by year

Mean yield (kg/tree) by year					
Products	**Sites**	**Stands**	**2019**	**2020**	**2021**
Pod	Diou	Field	14.15 ± 17.03	19.92 ± 10.17	29.94 ± 14.82
		Fallow	40.10 ± 39.73	17.00 ± 27.98	32.38 ± 34.59
	Somasso	Field	38.19 ± 33.99	33.61 ± 29.43	50.84 ± 53.28
		Fallow	17.10 ± 28.49	25.33 ± 24.21	17.90 ± 12.07
	Zanzoni	Field	20.06 ± 16.32	6.05 ± 9.44	25.37 ± 20.83
		Fallow	9.83 ± 10.17	4.28 ± 6.83	9.51 ± 8.84
Seed	Diou	Field	3.80 ± 4.53	5.25 ± 2.95	8.72 ± 4.43
		Fallow	10.74 ± 10.56	4.15 ± 7.48	8.24 ± 9.41
	Somasso	Field	8.34 ± 7.16	7.11 ± 5.72	11.65 ± 11.80
		Fallow	4.81 ± 8.32	3.83 ± 3.68	4.29 ± 2.85
	Zanzoni	Field	5.49 ± 4.51	1.41 ± 2.15	6.66 ± 5.42
		Fallow	2.73 ± 2.83	1.10 ± 1.77	2.47 ± 2.46
Pulp	Diou	Field	3.44 ± 3.86	4.40 ± 2.10	7.03 ± 3.41
		Fallow	9.30 ± 9.23	3.75 ± 6.77	6.94 ± 7.57
	Somasso	Field	8.13 ± 7.93	6.84 ± 6.86	11.40 ± 12.33
		Fallow	4.37 ± 7.63	5.66 ± 4.04	3.74 ± 2.93
	Zanzoni	Field	4.87 ± 3.91	1.35 ± 2.18	5.84 ± 4.74
		Fallow	2.56 ± 2.73	0.91 ± 1.47	2.14 ± 2.16

4 Discussion

Over three years of phenological monitoring, 4 % of monitored *P. biglobosa* trees have died. The mortality was caused by two main factors which were the anthropogenic factor (50% of mortality cases) and the sanitary factor (50 %). In the study zones, these two factors are currently the main constraints for *P. biglobosa* species. Other authors have reported the same factors as major constraints for *P. biglobosa* [15, 16, 17, 18].

The density of *P. biglobosa* was higher in the NG zone and a decreasing density was observed from south to north. For field stand, the highest density was observed in the NG (17 trees ha^{-1}) while the SS and NS zones had the same density (13 trees ha^{-1}). In the NG zone, the more abundant vegetal resources implying less pressure on *P. biglobosa trees*, could explain the higher density observed in this zone. The intense cash crop production in the sudanian zones could also imply reduction of tree densities as farmer need to reduce competition in favour of associated crops by cutting trees and/or pruning.

In Benin, Dotchamou et al. [13] reported a significant difference *in P. biglobosa* density between agro-ecological zones and the density was highest in the North (Sudanian zone 13 tree ha^{-1}) compare to the South (Sudano-guinean zone about 10 trees ha^{-1}). This result contrasts with our finding. However, the density they observed for the Sudanian zone in Benin is the same as that we observed for the Sudanian zones in Mali (13 tree ha^{-1}) whereas the density they observed for Sudano-guinean is lower than what we observed for NG zone in Mali (18 trees ha^{-1}). In Tchad, Avana-Tientcheu et al. [19] reported a mean density of *P. biglobosa* varying from 18 ± 12.73 to 28 ± 5.7 trees ha^{-1} for open forest and agricultural field systems respectively. This result corroborates our finding in the NS zone, where the density was higher in field stand compare to fallow (13 trees ha^{-1} vs 9 trees ha^{-1}), but the densities they observed were much higher than ours. The scarcity of wood and land tenure system in the sudanian zones could explain this result. Due to the land tenure system and to the need of craft wood, *P. biglobosa* trees in fallow stands are more exposed to exploitation. Other studies carried out in the NS, SS and NG zones in southern Mali have reported densities of *P. biglobosa* varying from 4 to 16 trees ha^{-1} along the north-south climatic gradient ([20].

Average yields of 23.31 ± 27.68 kg tree^{-1}, 5.70 ± 6.54 kg tree^{-1} and 5.21 ± 63.36 kg tree^{-1} were observed for pod, seed and pulp respectively. Observed yields were low compared to an optimal annual fruit production ranging from 25 to 130 kg tree^{-1} depending on the year, reported in PROTA/database [21]. Year effect of was significant, indicating fluctuation of production according to year. Regarding the three years of monitoring, one year could be considered as good production year (2021; pod yield = 28.15 ± 31.80 kg tree^{-1}), one as medium production year (2019; pod yield = 23.62 ± 27.16 kg tree^{-1}) and in-between a bad production year (2020; pod yield = 7.99 ± 8.78 kg tree^{-1}). This result straightened previous finding stated the fluctuation of the flowering and the fruiting of *P. biglobosa* trees like other agroforestry park fruit tree species. Fruit production fluctuations were reported for *P. biglobosa* by Oni [22], for *V. paradoxa* by Kelly et al. [23, 24] and for *A. digitata* by Oni et al. [25].

Climatic zone effect was found significant like stand effect and also the interaction between these factors. The highest yields were observed in fields of the North Sudanian zone (Somasso) whit mean yields of 40.88 ± 39.87 kg tree^{-1}, 9.03 ± 8.62 kg tree^{-1} and 8.79 ± 9.30 kg tree^{-1} for pod, seed and pulp respectively. This result suggests an important management effect in *P. biglobosa* fruit production, the driest zone being the best for *P. biglobosa* production of pods, seeds and pulp.

Regarding climatic zone effect, Dotchamou et al. [13] Observed for *P. biglobosa*, an average fruits production of 110 ± 19.90 kg tree-1 in the Sudano-Guinean zone and 80.9 ± 20.56 kg tree^{-1} in the Sudanian zone and found that these two climatic zones were not significantly different for the dendrometric and production characteristics. The average fruit yield observed by these authors was widely above our results, but like Dotchamou et al. [13], we did not find significant difference between the North Guienan and North Sudanian zones regarding pod, seed and pulp yield.

P. biglobosa fruit production was influenced by environmental conditions (climatic zone) and management practices (land use considered as stand in the paper). Fruit production was also correlated with tree parameters like diameter at 1.30 m above the ground (weak but positive correlation) and crown diameter (positive and higher correlation). Similar results were observed for *P. biglobosa* and other forest fruit tree species. Dotchamou et al. [13] found significant and positive correlation between dendrometric parameters (diameter at 1.30 m, crown diameter) and production (fruit, seed) of *P. biglobosa*. They stated that their finding corroborates the results of other work carried out on other forest fruit species in Senegal, Benin, Mali, etc. [26, 27, 28, 29]. In the same order, previous studies have shown that parameters like height, trunk and crown diameter have a potential influence on forest tree species fruiting [30, 28]. Lamien et al. [31] also stated that the number and average weight of *Vitellaria paradoxa* fruits were positively correlated with tree size.

5 Conclusion

The results of this study revealed significant effect of climatic zone on growth parameters of *P. biglobosa* which did not display climatic gradient trend. The result suggests that other factors like production systems and management practices have influence on growth parameters of *P. biglobosa* and consequently, any domestication strategy must take this fact into account.

Variation in fruit, seed and pulp yields across zone and stands was observed as well variation according to the year. Like other agroforestry park fruit tree species such as *V. paradoxa*, management practices appeared to be very important in *P. biglobosa* fruits production. While an overall decrease in production was observed in 2020 compared to 2019, an increase in production happened in 2021 compared to 2020. The fluctuation in production would result from the biological phenomenon of variation in the production of fruit tree species, reported by several authors and which is characterized by alternating years of high, medium and low production.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest.

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