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ESTIMATION OF SHEA TREES (*Vitellaria paradoxa* C.F. GAERTN.) FRUIT PRODUCTION BY ASSESSING THE CORRELATION BETWEEN YIELD PARAMETERS AND DENDROMETRIC FEATURES IN NORTHERN OF CÔTE D'IVOIRE

Diarrassouba Nafan, Dago Dougba Noel, Yao Saraka Didier Martial*

UFR of Biological Sciences, Department of Biochemistry-Genetics, Pedagogical and Research Unit (UPR) of Genetics, University of Peleforo GON COULIBALY (UPGC), BP 1328 Korhogo, Côte d'Ivoire

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Yield feature

Côte d'Ivoire

ABSTRACT

Vitellaria paradoxa, commonly known as the shea tree, is a tree of the family Sapotaceae and represents a traditional African food plant. It has been claimed to have the potential to improve nutrition, boost food supply, foster rural development, and support sustainable land care. Despite its multiple potentials, statistical data relating to its production are non-existent and/or unexploited in several African communities. To contrast this tendency, the present study aims to assess the intra-seasonal variation in fruit production of a sample of 115 shea trees and then to establish a correlation between yield parameters and several dendrometric features. Dendrometric (i.e. tree height, trunk girth, and crown basal area) and pomological (i.e. fruit and nut length and width) parameters, as well as yield parameters by monitoring daily fallen fruit from each sampled shea tree, carried out for five years consecutively, were considered for this study. The results showed inter-year fluctuation of shea fruit/nut number and shea fruit/nut weight. In addition, the results showed a significant increase in the annual average of shea fruit/nut yield per tree and as well per girth and/or crown basal area interval class, randomly generated by Sturge and Yule's formula. Interestingly, potentially high producing trees emerged within each considered interval class. Then, observed intraclass variation between trees determining shea yield can be exploited in selecting elite shea trees.

* Corresponding author

E-mail: didiers@yahoo.fr (Yao Saraka Didier Martial)

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1 Introduction

In the African Sudanese savannas community, shea (*Vitellaria paradoxa* C.F. Gaertn.) represents a multipurpose as well as a highly solicited plant and an important source of income for local people (Bup et al., 2014). *V. paradoxa* species ranges from Eastern Senegal to Ethiopia via Nigeria, Mali, Burkina Faso, Ghana, and Côte d'Ivoire. Geographic Information Systems (GIS) showed that shea tree suitability area is spread of 3.41 million km² across 23 countries (Naughton et al., 2015). The species *V. paradoxa* is subdivided into two subspecies that are *ssp. paradoxa* and *ssp. nilotica*. Among these subspecies, *paradoxa* are significantly reported between Senegal and Nigeria. In addition, Cameroon, Ethiopia, and Uganda territories are strongly dominated by subspecies *nilotica*. Further, among these two *ssp. paradoxa* usually grow at lower elevations (100 to 600 m) than *nilotica* (650 to 1600 m) (Hall et al., 1996).

According to Global Shea Alliance, shea processing activities directly and/or indirectly employ around 16 million Africans, mostly women (Zacharie et al., 2011). Considered as a second-class woody product, shea tree is now perceived as one of the flagship commodities of Côte d'Ivoire since European directives authorize the use of vegetal butter such as shea butter in confectioning chocolate (Madieng, 2003). Moreover, in Côte d'Ivoire, *V. paradoxa* species significantly contributes to rural subsistence as well as to local and national economic activities. Of note, shea products represent between 12 and 15% of export earnings in Côte d'Ivoire. Shea activity sector is mainly dominated by the feminine gender since more than 42,000 women, in Northern Côte d'Ivoire are involved in this dynamic production sector. In addition, the purchase price has quadrupled in just a few years, amounting to between 1,000 and 2000 CFA francs/kg, depending on shea production area (Bup et al., 2014). In Côte d'Ivoire shea production rank between 150,000 and 200,000 tonnes/year generating between 120 and 160 billion CFA francs (Bup et al., 20014). A reason for shea yielding increasing interest in Côte d'Ivoire is because of the adoption of a new European directive authorizing 5% of vegetal fat other than cocoa butter in chocolate manufacture (Madieng, 2003).

Despite the strategic importance of shea products and derivate, little is known about that tree potential production, as well as about factors involved in its seasonal fluctuation in terms of raw fruit yield. Sanon (2009) has pointed out the difficulty in assessing shea production that results to be an undomesticated species. Few studies have been performed for the estimation of shea production in Western Africa, with special reference to Burkina Faso. Among these some common are focused on (i) evaluating shea population production (Lamien et al., 2007), (ii) assessing shea fruit

productivity in traditional agroforestry parks (Lamien et al., 2005), and (iii) measuring annual incision effect on shea reproduction (Lamien et al., 2007). In the same tendency, Bondé et al. (2019a) and Bondé et al. (2019b) investigated the impact of environmental conditions on shea tree fruit production. Some allometric equations for estimating fruit production in shea trees were developed. To reduce the effect of environmental factors on the performance of allometric models, the use of specific zone equations (Sudanian, Sudano-Sahelian, and Sahelian) is recommended. According to Dorthe (2000), the shea tree fruit production rate ranks between 4.66-22.22 kg depending on yearly plants (shea trees) yielding performances. Lamien et al. (2005) estimated shea adult kernel average yield of trees located in parklands agroforestry and it was reported between 1.5 to 4 kg tree⁻¹ yearly. Exceptionally, some individual shea trees can produce up to 200 kg of fruit per year (Dorthe, 2000). Very few shea tree features studies were performed in Côte d'Ivoire and Cameroon focused on evaluating and identifying quantitative descriptors and as well morphological parameters performances (Diarrassouba et al., 2007a; Diarrassouba et al., 2007b; Diarrassouba et al., 2009). Subsequently, potentially higher fruit-producing shea trees were selected and characterized in Côte d'Ivoire (Yao et al., 2020). Along with this, previous studies highlighted the influence of the agrarian system on the natural regeneration of shea trees (Diarrassouba et al., 2009; Diarrassouba et al., 2020). With the purpose of *V. paradoxa* species domestication, the effect of some abiotic factors influencing seed germination performances quality has been evaluated (Alui et al., 2019; Yao et al., 2021). Although the local shea community estimated that shea fruit collection rate (27%) represents the lowest production as compared to the other sub-region of Western Africa. Further previous studies conducted in Côte d'Ivoire to this purpose do not provide any potential shea production data. Moreover, estimated exports (62%) appear to exceed local shea consumption (Holtzman, 2004). Furthermore, studies conducted by Soro et al. (2011) exhibiting shea production rate meanly focused on the effect of rainfall and temperature.

Very little information is available in terms of shea tree potential production per hectare in Côte d'Ivoire Sudanian, Sudano-Guinean, and Guinean savannahs where the shea parkland are found. Therefore, this study was carried out for five years consecutively to estimate the shea fruit and as well kernel production data based on the dendrometric, pomological, and yield. Because the study has been conducted in a wild environment, the shea average production will be estimated according to shea tree diameter and as well crown basal surface structured classes. We believed that the data of the present study will be useful in helping the local community and agro-industrialists as well as producers in predicting shea fruit rate per tree and hectare.

2 Material and methods

2.1 Study area

Shea tree morphometric and yield data from the monospecific shea parkland of Tengrela, in Northern Côte d'Ivoire was collected from the tropical Sudanese climate between 2016 to 2020. This climate includes a (i) dry season characterized by high temperatures and low humidity running from June to October and (ii) a rainy season running from July to September. Annual rainfall in this area spanning from May to September ranks between 800 - 1200 mm. The rainy season in Tengrela is oppressive and mostly cloudy, while the dry season is humid and partly cloudy as well as hot. The estimated yearly temperature in this area was reported between 18 - 37°C while sometimes it was reported between 15 - 40°C. Further, Tengrela shea parkland is located 850 km north of Abidjan and includes 627 mature shea trees representing an average density of 26 trees per hectare.

2.2 Plant material

For this study, 115 shea trees at the full fruit production at three different times were randomly selected. The basic focus is on selecting different shea trees diameter classes free to human exploitation as well as parasitical aggression (Gaoue & Ticktin, 2008; Boussim et al., 2012). The 115 randomly selected shea trees goodly fit with 10 - 25 minimal interval range. Even a random sampling was performed, 20 m distance has been kept between sampled shea trees with the purpose to estimate the shea trees fruit production without any ambiguity. In this study, five descriptors parameters such as trunk circumference, tree height, crown base circumference, shea fruit yield, and shape have been analyzed. Shea tree girth at 1.30 m from the ground has been measured by using a tape measure tool.

2.3 Collected data

In the current study, various important shea tree features such as trunk girth at 1.30 m from the ground, tree total height, and crown base girth were measured. The girth was measured by using a graduated ribbon. Trees age classes were attributed as follows: (i) shea trees exhibiting a girth \leq of 76 cm were defined as young trees corresponding to class K1; (ii) shea tree with girth ranging between 76 - 120 cm interval corresponding to adult class K2; (iii) old shea trees display a girth measure ranging between 120-200 cm, referring to class K3 and shea trees with girth > 200 cm are part of the K4 class that corresponds to the senescent trees category. Shea tree height parameter that includes trunk length from tree foot at ground level to the crown top has been measured by the Blume-Leiss tool. Crown base area was estimated by applying the formula given by Diarrassouba et al. (2007a):

$$\text{Crown base area} = \pi * \left(\frac{DH}{200}\right)^2$$

Where DH is referred to crown diameter.

Regarding shea tree production monitoring, a warning fence was placed around sampled trees with the purpose to deter itinerant collectors. The ground was cleared to speed up fruit picking. Shea tree total production includes daily harvested fruits. This production data was linked to sampled shea trees morphology by assessing the latter's production features. The fruit counting method includes periodically fallen fruit count under each sampled shea trees (Lamien et al., 2007). Application of this method involving sampled shea trees required setting of the suitable device in collecting fruits as they fall. Fruit production was estimated by counting the total number of fallen harvested fruits (Kouyate et al., 2006). Harvesting was done and organized in several pools, in correspondence to each sampled shea tree. Next, counting and pulping to determine the quantity of nuts corresponding to the fruits was also estimated. Nuts were dried by the sun and weighed every other day until reaching constant weight. Next, almonds/kernel weight was estimated by the extraction of shelling nuts and estimated the dry almond/kernel weight per tree.

2.4 Statistical data analysis

Statistical analysis was based on a developed computational statistical pipeline (Dago et al., 2019). Indeed, data were analyzed in the R (statistical package) programming environment by integrating several packages and/or scripts of the descriptive and analytical statistical tests at statistically significant levels ($p < 0.05$). Shea tree girth and crown basal area dendrometric parameters interval class have been generated by applying Sturge and/or Yule's formula (Scott, 2009) as follows:

$$\text{Sturges' reule } k \approx 1 + 3.32 \log n \quad (\text{i})$$

$$\text{Sturges' reule } k \approx 2.5 \sqrt[4]{n} \quad (\text{ii})$$

Where n represents the analyzed sample size. For this investigation n (total number of sampling shea tree) is 115. Next, class intervals have been adjusted by our self.

3 Results and Discussion

3.1 Yearly shea fruit production distribution in Tengrela mono-specific shea parkland

Yearly distribution and variability of shea fruit production were calculated by performing both Shapiro normality and Bartlett variance homogeneity statistical tests. Averages yearly shea fruit production was recorded and presented in Table 1, as per the results given in table annual shea fruit production for five successive years are 5045.61 kg (first year), 4088.25 kg (second

year), 2386.39 kg (third year), 3473.53 kg (fourth year) and 6287.41 kg (fifth year). Bartlett's test of homogeneity of variances assessing yearly shea fruit production dynamism during the five consecutive years exhibited Bartlett's K-squared = 192.68, df = 4, and p-value <0.05. In the other words, from these results, it can be observed that $p < 0.05$ means that there is evidence suggesting yearly yielded fruit variance is statistically significantly different for the five-year harvesting groups. Next, the Shapiro Wilk normality test was admitted as the null hypothesis, shea fruit production is normally distributed during the five considered consecutive years. The result of the normality test implies that the distribution of shea production during the five considered consecutive years is significantly different from a normal distribution ($p < 0.05$). The present study showed inter-year fluctuation of shea fruit/nut number and/or shea fruit/nut weight. Shea fruit harvesting rate data variability during the five consecutive experimental years has been supported by several descriptive and analytical statistic surveys. Similar results about inter-year fluctuation of shea fruit/nut number and/or shea fruit/nut weight were reported by Soro et al. (2011), and Lamien et al (2005). In other words, normal distribution regarding shea production in the five analyzed years cannot be assumed. The normality regarding intra-year shea fruit production for each year was also studied in the current study and reported that intra-year shea fruit production distribution is different from a normal

distribution (Table 1). The same results suggested a relative normal distribution of shea production respectively for first ($p = 1.05e-06$) and third ($p = 1.16e-07$) harvesting years as oppose to second ($p = 3.22e-10$), fourth ($p = 3.98e-09$) and fifth ($p = 7.74e-16$) shea fruit harvesting years (Table 1).

3.2 Multiple comparison analysis assessing shea fruit yield variability by ANOVA and Turkey tests

Even if the global Turkey test supported significant difference ($p < 0.05$) by comparing all shea fruit production during the five consecutive years, partial Turkey test exhibited no significant difference in terms of harvested shea fruit production average between (i) first and second harvesting year, (ii) first and fifth harvesting year, (iii) second and fourth harvesting year and (iv) third and fourth year harvesting (Table 2). Multivariate statistical analysis showed high shea production data variability for year 5, while weak shea fruit harvesting data was recorded in the third harvesting year (Figure 1A). Findings supported the highest data variability regarding fifth-year shea fruit production harvesting as opposed to third-year shea fruit harvesting data (Figure 1B). The same analysis suggested the highest shea fruit production for the fifth harvesting year, while minimum shea fruit production was recorded in the third harvesting year. This result is in agreement with Turkey multiple comparison tests that suggested a significant

Table 1 Descriptive statistic and assessment of shea fruit production normality in Tengrela shea mono-specific parkland during five consecutive years by Shapiro normality test

Parameters	Shea fruit harvesting				
	Year 1	Year 2	Year 3	Year 4	Year 5
Mean of shea fruit production weight (kg)	5045.61	4088.25	2386.39	3473.53	6287.41
W (Shapiro normality test coefficient)	0.91	0.83	0.89	0.86	0.62
Shapiro normality test p-value	$1.05e^{-06}$	$3.22e^{-10}$	$1.16e^{-07}$	$3.98e^{-09}$	$7.74e^{-16}$

Table 2 Turkey test comparing multiple shea fruit production weight mean (kg) during five consecutive years

Durations	Difference	Lower r	Upperr	p-adjusted value
Year 2 - Year 1	-957.36	-2525.13	610.41	0.45
Year 3 - Year 1	2659.22	-4227	-1091.45	<0.001
Year 4 - Year 1	1572.07	-3139.85	-4.30	0.04
Year 5 - Year 1	1241.8	-325.97	2809.58	0.19
Year 3 - Year 2	-1701.86	-3269.63	-134.09	0.03
Year 4 - Year 2	-614.71	-2182.49	953.05	0.82
Year 5 - Year 2	2199.17	631.39	3766.94	<0.001
Year 4 - Year 3	1087.15	-480.62	2654.91	0.32
Year 5 - Year 3	3901.03	2333.26	5468.8	<0.001
Year 5 - Year 4	2813.88	1246.11	4381.65	<0.001

difference in terms of shea fruit production rate between (i) third and fifth year harvesting ($p < 0.001$), (ii) first and third year harvesting ($p < 0.001$), (iii) second and fifth year harvesting ($p < 0.001$), (iv) second and third year harvesting ($p = 0.03$) and (v) first and fourth year harvesting ($p = 0.04$) respectively (Table 2). Further, performed ANOVA test assessing shea fruit production variability in these five consecutive years by exhibiting the following results: $F = 13.54$; $p = 1.51e^{-10}$, supported Turkey multiple comparison test by suggesting highly significant shea fruit production rate variability during the five considered harvest years (Table 2). Parallel Principal Component Analysis (PCA) exhibited second and fifth harvesting years of shea fruit as the highest sources of shea fruit yield data variability. Whole shea production data variability and/or shea yield data heterogeneity during the five consecutive experimental years has been supported by (i) Bartlett variance homogeneity test and as well as by performed integrative survey between ANOVA and Turkey multi-comparison statistical tests. The above mentioned shea yield rate heterogeneity/variability is in agreement with Soro et al. (2011) and Lamien et al. (2005) those who reported high shea fruit production dispersion in the shea tree population. It is noteworthy to underline that observed shea fruit heterogeneous dispersion agree with wild-type phenotype and/or genotype of shea trees (Fontaine et al., 2004; Lovett & Haq, 2002). In the same tendency, several studies have been carried out in Mali and Burkina Faso suggested significant irregularity in the fruit rate fluctuation regarding *Detarium microcarpum* and *V. paradoxa* species (Kouyate et al., 2006).

3.3 Hierarchical clustering analysis linking shea tree fruit yield and dendrometric features

Findings by processing shea quantitative features showed a

significant relationship between shea yields and dendrometric parameters. Z-score clustering survey based on Pearson correlation analysis suggested two clustering groups by assessing the interaction between shea tree fruit and dendrometric features (Figure 2A). Indeed, while the first group exhibited a high correlation value between fruit crown, nut width, fruit shape, and fruit length parameters, while the second one suggested a high relationship between (i) nut weight, (ii) nut number (iii) tree girth, (iv) tree high, and (v) tree basal area (Figure 2A). In other words, the second clustering group suggested shea tree dendrometric parameters as influencing shea fruit yield. Similar results were found by Bondé et al. (2019a) in the shea tree. The highest fruit production observed in large trees is probably related to their greater capacity to capture sunlight (crown volume) and correspondingly larger root biomass, which allow these trees to have access to groundwater and therefore, to reduce the moisture stress.

In addition, findings revealed strong heterogeneity concerning shea fruit pomological and production parameters. Shea tree dendrometric features (tree height, tree trunk, and/or basal girth) and shea fruit qualitative traits (fruit shape, crown shape) exhibited the highest variability than shea fruits/nuts traits (fruit/nut width and fruit/nut length) (Figure 2B). P-value clustering analysis by considering an unbiased probability \geq of 95% suggested a strong correlation between shea fruit/nut weight and shea fruit/nut number parameters ($p\text{-value} = 100\%$). Of note, p-value clustering analysis has shown a drastic reduction in standard error data considering unbiased probability \geq 95% and suggested two distinct clustering groups; (i) shea fruit yield features (fruits/nuts weight and fruits/nuts number) and (ii) shea fruit and/or tree dendrometric parameters (shea tree trunk/basal area girth, shea fruit/nut length) (Figure 2B and Figure 3).

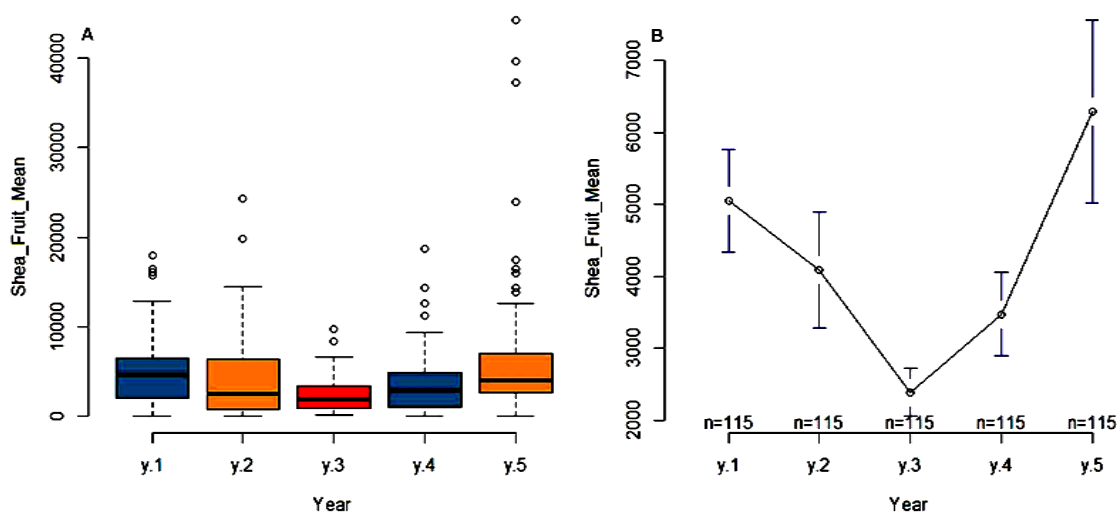


Figure 1 Yearly variability of the means of shea fruit production here (A) assessing shea fruit production average variability (B) in five consecutive analyzed years by Turkey and ANOVA test. Of note, y.1, 2, 3, 4, and 5 acronyms are respectively for first, second, third, the fourth, and fifth year of shea fruit harvesting.

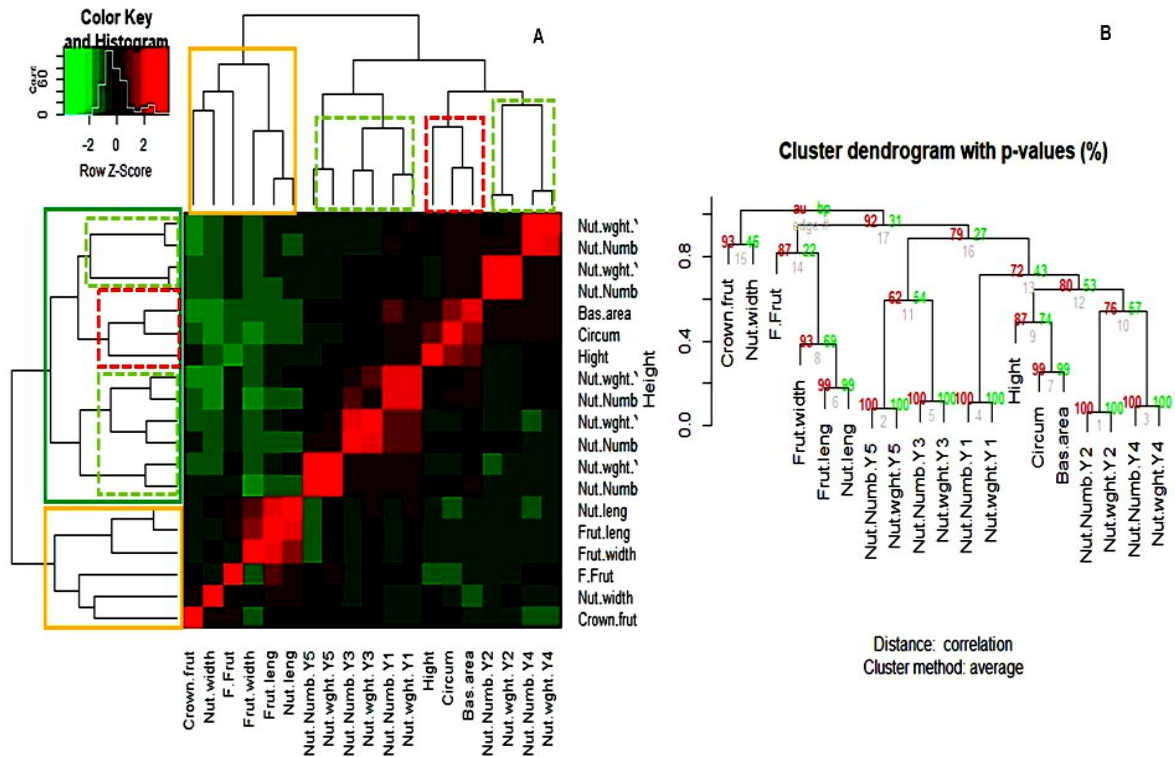


Figure 2 Correlations between fruit traits assessed yearly and tree dendrometric parameters here (A) Pearson and p-value distance correlation clustering (B) survey in assessing the yearly relationship between shea fruit (fruit/nut weight, fruit/nut number, fruit/nut length, width, and fruit crown and shape) and tree morphometric (tree height, tree trunk and/or basal area girth) traits.

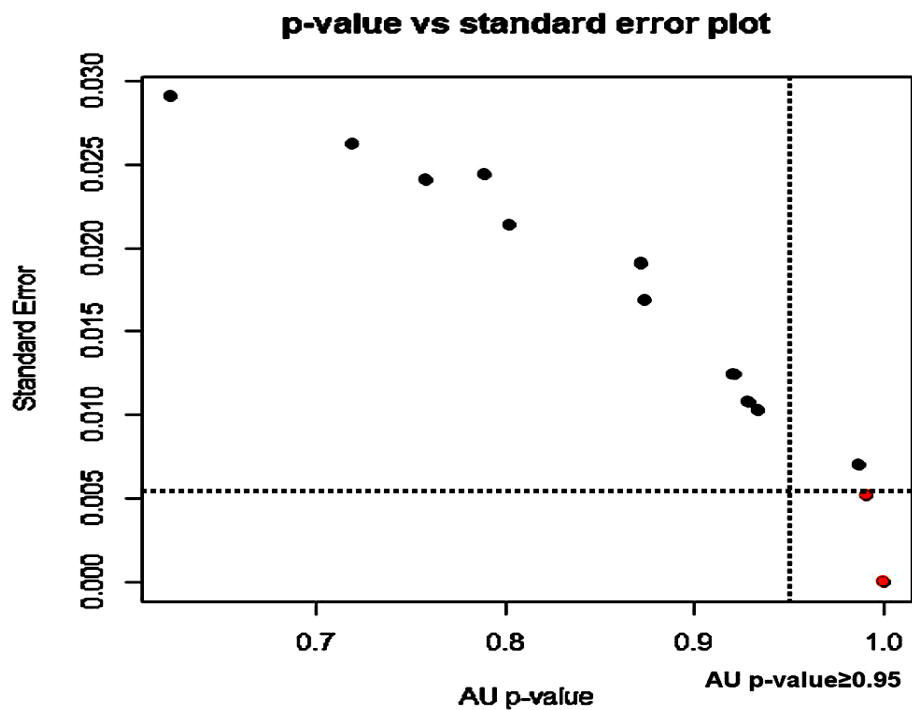


Figure 3 The plot of p-value and standard error assessing group features in p-value clustering survey by setting AU p-value ≥ 0.95 parameters.

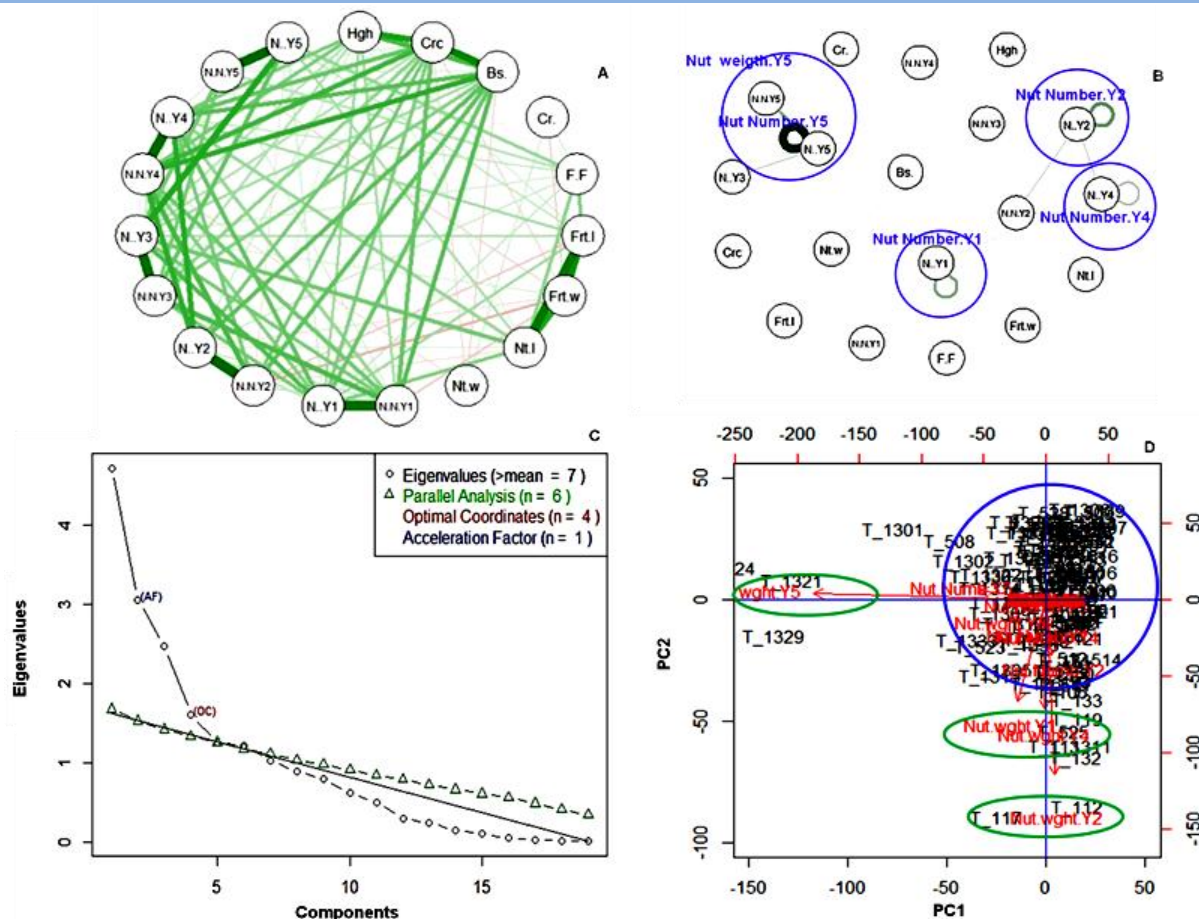


Figure 4 Evaluating shea fruits and/or trees yield and/or morphometric relationship and as well data variability sources. Here Wght.Y1, Wght.Y2, Wght.Y3, Wght.Y4 and Wght.Y5 acronyms are respectively for shea nut weight for first, second third, the fourth, and fifth year. N.Y1, N.Y2, N.Y3, N.Y4, and N.Y5 acronyms are respectively for nut number for first, second third, the fourth and fifth experimental year. Acronyms Hgh, Crc, Bs, Cr, FF, Frl, Frlw, Ntl, Nlw are respectively for shea tree height, circumference, basal area and shea fruit crown basal area, shea fruit shape, shea fruit longer and weight.

(A-B) Integrative multivariate principal component network analysis (PCA) and (C) parallel PCA survey and (D) PCA bi-plot graphic.

3.4 Assessment of shea tree fruits yield and dendrometric data variability by multivariate statistical survey

An integrative multivariate PCA survey confirmed the link between nut weight and nut number traits during experimentation years (Figure 4A). Interestingly, the same analysis exhibited relatively high concordance between the aforementioned nut traits (nut weight and number) and tree (i) girth, (ii) trunk basal area, and (iii) height features respectively by contrast to fruit shape and/or crown parameters (Figure 4A). The variability of nut production (number and biomass) related to the dendrometric characteristics in the shea tree were also reported by Bondé et al. (2019a) and Bondé et al. (2019b). PCA network analysis reported in Figure 4B, by assessing the interaction between all analyzed shea fruit parameters suggested nut weight and/or number at 2 and 5 years (four shea yield harvesting year data) as a source of data variability (Figure 4B and Table 3). Shea fruit production data exhibited high stability

for the third harvesting year, which may be due to the low rate of the shea fruit harvest, while the highest shea fruit number and/or weight data variability has been observed during the fifth harvesting year, and this might be because of high harvesting rate (Figure 4B, Table 3). Parallel Principal Component Analysis (PCA) suggested seven fruit and/or nut traits as exhibiting Eigenvalues higher than the estimated data mean value (Figure 4C). Four parameters out of the above-mentioned shea fruit/nut yield features were selected as optimal coordinates explaining that data variability (Figure 4C). In addition, PCA bi-plot analysis by their first and second components and by linking factors and variables parameters supported third and fifth fruits/nuts harvesting data as the main source of data variability during the five experimental years (Figure 4D). Also, the findings of this study suggested that the fourth harvesting year as displaying relatively higher shea harvest rate data variability than the first and third shea fruit harvesting rate data (Table 3).

Table 3 Descriptive statistic assessing shea fruits and/or nuts number and weight data in the five experimental years.

Parameters	Year 1		Year 2		Year 3		Year 4		Year 5	
	Weight	Number	Weight	Number	Weight	Number	Weight	Number	Weight	Number
Mean	5045.61	1667.37	4088.25	1418.83	2386.39	791.36	3473.53	1129.1	6287.41	2117.64
Standard Deviation	3877.72	1234.46	4337.79	1580.64	1826.37	559.42	3134.75	915.95	6880.98	2159.92
CV	0.76	0.74	1.06	1.11	0.76	0.71	0.90	0.81	1.09	1.02

Table 4 ANOVA interdependence test table by linking shea fruits/nuts weight (response variable) to shea tree dendrometric features (explicative variables)

Weight year	Shea tree height		Shea trunk girth		Shea tree crown basal area		ANOVA interdependence test	
	F	Pr >F	F	Pr >F	F	Pr >F	R adjusted	F statistic
Year 1	9.30	0.002***	5.83	0.02***	4.93	0.02***	0.13	0.00***
Year 2	3.53	0.06	12.40	0.00***	4.93	0.03***	0.14	0.00***
Year 3	5.00	0.02***	1.68	0.20	1.77	0.19	0.05	0.04
Year 4	16.05	0.000***	7.64	0.006**	5.72	0.02***	0.19	0.00***
Year 5	0.01	0.92	0.37	0.55	0.58	0.45	-0.02	0.82 ^{NS}

*** $p \leq 0.05$ and ^{NS} $p > 0.05$.

3.5 ANOVA in evaluating the relationship between shea tree fruit rate and dendrometric parameters

Our previous results suggested a correlation between shea fruit/nut shape, weight, and/or a number and (i) shea tree girth and crown basal area and (ii) height (Figure 2). Based on these observations we embarked here in linking that parameters aiming to predict harvested shea fruit rate (response variable) by shea tree dendrometric feature (explicative variable). These findings suggested a strong positive correlation between nut weight and nut number. Pearson correlation test between these two parameters exhibited significantly high positive correlation ($R > 0.9$; $p \ll 0.05$) between shea fruits/nuts number and shea fruits/nuts weight for the first (Figure 5A), second (Figure 5B), third (Figure 5C), fourth (Figure 5D) and fifth (Figure 5E) consecutive experimental year. Based on these evidences, we selected one of these parameters (Fruits/Nuts weight) as the response variable in developing a multiple linear regression model by assuming tree height, trunk girth, and crown basal area as explicative because of their heterogeneous attitude. Performed ANOVA interdependence statistical test (Table 4). Weak determinant coefficient ($R: -0.02-0.19$) of performed ANOVA test suggested multiple linear regression model limits by commenting high residual error, in predicting shea fruit rate by multiple shea tree features variables (Table 4).

fruit harvesting year (Table 4). Similar results were reported by Bondé et al. (2019a) in their study on the evaluation of shea fruit production in three climatic zones (Sudanian zone, Sudano-Sahelian zone, and the Sahelian zone) in Burkina Faso, West Africa. For these authors the relationship between fruit production and tree diameter is relatively strong. Therefore, to reduce the effect of environmental factors on the performance of developed allometric models, the use of specific zone equations is recommended. The equations developed are valid for parkland trees with diameters ranging from 10.50 to 65.89 cm for the Sudanian zone, 10.50 to 92.93 cm for the Sudano-Sahelian zone, and 16.23 to 96.13 m for the Sahelian zone (Bondé et al., 2019a). Although shea tree dendrometric parameters exhibited heterogeneous statistically significant ($p \leq 0.05$) and/or nonsignificant ($p > 0.05$) aptitude in predicting shea nut weight and/or number rate, it is noteworthy to underline the significant statistical ($p = 0.00-0.04$) aptitude of the latter's in predicting shea fruits/nuts weight and/or shea fruits/nuts number rate variability for harvesting year 1, 2, 3 and 4 by processing ANOVA interdependence statistical test (Table 4). Weak determinant coefficient ($R: -0.02-0.19$) of performed ANOVA test suggested multiple linear regression model limits by commenting high residual error, in predicting shea fruit rate by multiple shea tree features variables (Table 4).

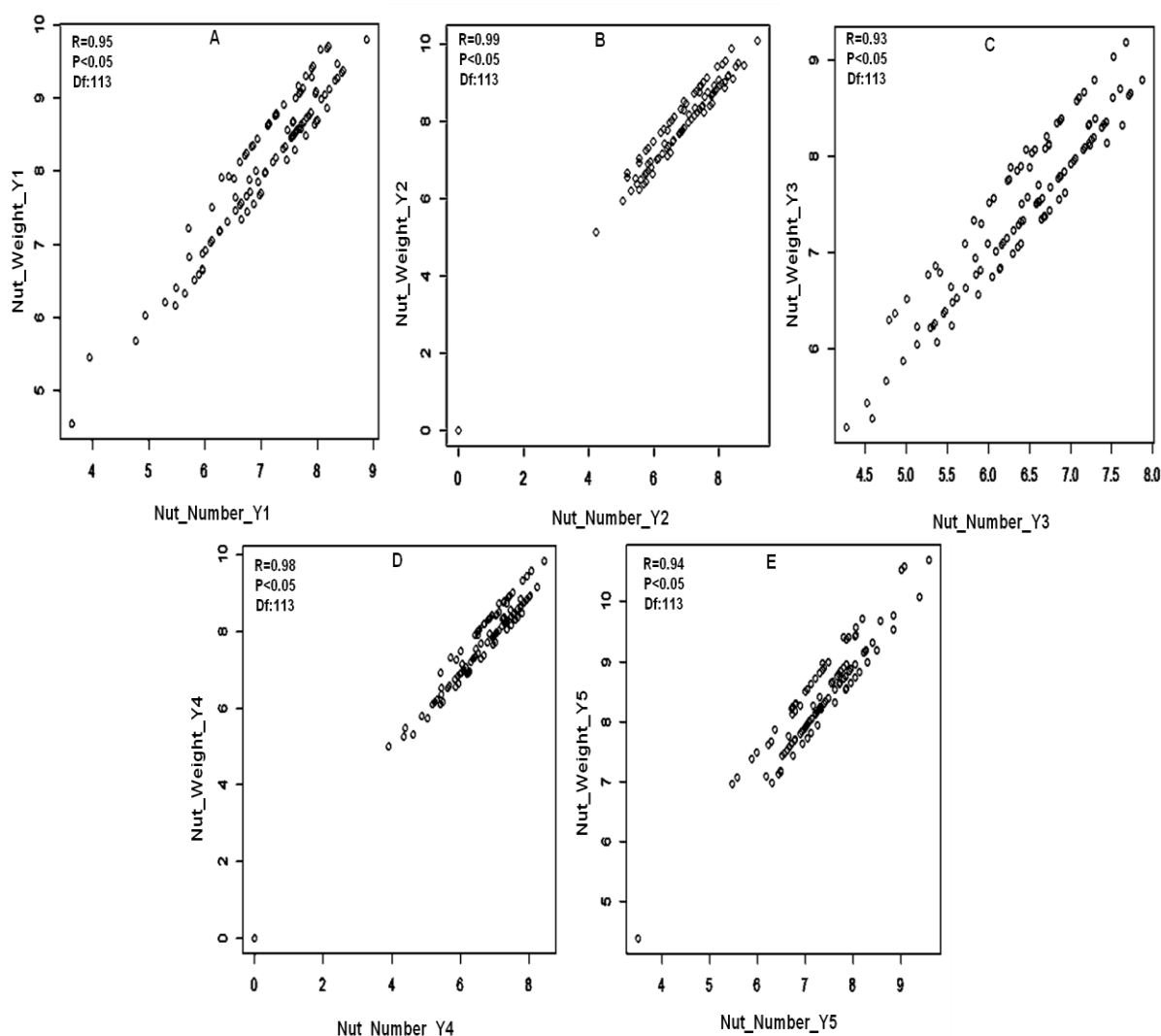


Figure 5 Pearson correlation survey between fruit/nut weight and shea fruit/nut number during five experimental years. Nut number and weight values have been transformed by the logarithm function. Here (A), (B), (C), (D), and (E): Pearson correlation test and dot-plot representation between both shea nut number and weight parameters respectively for first, second, third, fourth, and fifth experimental consecutive year.

3.6 Relationship between shea tree crown basal area interval class and harvested shea fruits and/or nuts rate

Because of shea tree girth and crown basal area parameters explaining and/or predicting shea fruits yield rate variability, we embarked here on evaluating the link between shea fruits number rate dynamism and shea tree dendrometric parameter class. For this purpose, six interval classes of shea tree crown basal surface parameters were identified by Yules and Sturge formula (Scott, 2009). The average of shea fruit/nut increases with the increase of the shea tree crown surface (Figure 6A). Results showed that 38-60% of shea trees in each obtained crown area interval class displayed a nut rate higher than the nut mean value (Table 5).

Shea nut crown surface interval class impact on yearly fruit/nut data variability by combining ANOVA and Turkey tests was assessed in this study. ANOVA test supported significant nut data variability by processing shea crown basal area interval class ($p = 0.01$) (Figure 6B). By establishing a relationship between shea tree dendrometric and production features, this study showed a statistically significant positive correlation between (i) shea tree crown basal area and (ii) shea fruit production rate. Indeed, shea nut numbers range from 7261.35 for shea trees associated with a small crown area class interval ($10\text{-}26\text{m}^2$) to 40815.1 for shea trees with a high crown area class interval ($90\text{-}152\text{m}^2$).

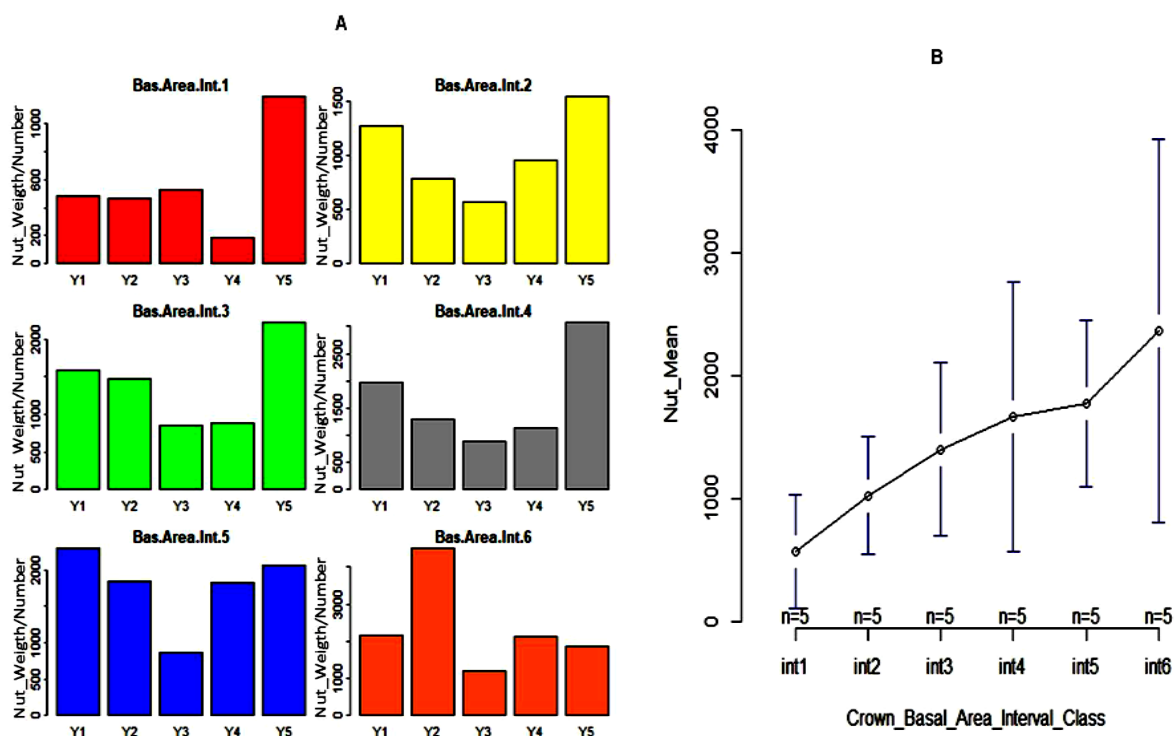


Figure 6 Impact of shea tree crown interval class on intra-annual variability of shea nut number average here (A) descriptive analysis and (B) Turkey test analysis. Int: acronym is for crown basal area interval classes. Int1: (10-29cm); Int2: (26-42cm); Int3:(42-58cm); Int4: (58-74cm); Int5: (74-90cm) and Int6: (90-152cm).

Table 5 Shea nut number dynamism by crown basal surface parameter interval class

Parameters	Interval 1: (10cm-26cm)	Interval 2: (26cm-42cm)	Interval 3: (42cm-58cm)	Interval 4: (58cm-74cm)	Interval 5: (74cm-90cm)	Interval 6: (90cm-152cm)
Tree number	10	23	31	23	23	5
Nut weightmean(kg)	570.6	1027.53	1403.16	1666.24	1777.68	2362.36
Tree number with nut>nut mean	5	9	12	9	10	3

3.7 Relationship between shea tree girth interval class and harvested shea fruits and/or nuts rate

In the current study, shea tree trunk girth interval class impact on shea nut number dynamism was also checked. In total, eight shea trunk girth interval classes have been discriminated for this analysis revealing an increase of nut weight and/or number rate by increasing shea trunk girth (Table 6). Shea tree performance was analyzed by comparing shea nut rate production with girth interval class estimated shea nut means (Table 6). ANOVA and Turkey integrative analysis assessing shea trunk girth interval class impact on shea tree yield performance and exhibited the following results: freedom degree (df) = 7, F = 2.79 et Pr(>F) = 0.02, revealing trunk girth dynamism influencing significantly shea yield rate (p = 0.02) (Figure 7A and 7B). Shea fruit rate increases from 1403.24 (kg) to 6062.87 (kg) for shea trunk girth interval classes (0.73m-

0.86m) and (1.64m-2m) respectively (Figure 7A and 7B). Next, we performed the Shapiro normality test aiming to assess shea trees yield performance distribution by setting the shea trunk girth interval class. The results of the Shapiro normality test is as follows: w = 0.91 with a p-value = 0.004, suggesting a relatively normal distribution of the yield of shea trees performances (Figure 7A and 7B). The same surveys based on shea tree trunk girth class interval, as expected supported a strong significant positive correlation between shea nut weight and shea tree trunk girth. Considering as a whole, shea production rate increases with the increasing of shea trees age and/or trunk girth. In other words, this study suggested the height and/or the dimension of shea tree trunk girth as a valid feature influencing significantly shea production rate as reported by Bondé et al. (2018). This study established a link between shea tree girth and shea tree age is not completed, these two parameters are based on several observations that would

be correlated. Also, based on shea tree girth features, findings by an integrative statistical survey between ANOVA and Turkey multi-comparison test supported a relatively normal distribution of shea trees targeted as high producers. This observed a significant and positive correlation between dendrometric parameters and parameters of shea fruit production corroborate with the results of other works carried out on Sudano-Sahelian forest fruit species (Kouyate et al., 2006; Bondé et al., 2018). Taking together, findings of this study strongly supported that in shea stand, good producer trees have larger girth and as well large crown basal area. In the other words, the results of this study reported that older trees have large girth and/ diameter and therefore large crown basal area as the best shea producer. These findings are in agreement with the conclusions of Lamien et al.

(2007) those who suggested that *V.paradoxa* fruit/nut weight and/or number exhibits a positive correlation with tree size. By contrast to this evidence, a negative correlation by processing *V. paradoxa* tree diameter and yield parameters suggests size normalization concerning the high producer shea tree diameter parameter. Interestingly this evidence seems to be supported by the present analysis that suggested a relatively normal distribution of shea tree targeted as a high producer by processing shea tree girth class interval. In the other words, shea tree girth interval class 125-138 cm exhibited the highest number of shea trees with a high producer attitude. These findings emphasized the hypothesis that in addition to shea tree girth features other dendrometric and/or hexogen parameters could contribute to improving shea tree production performances.

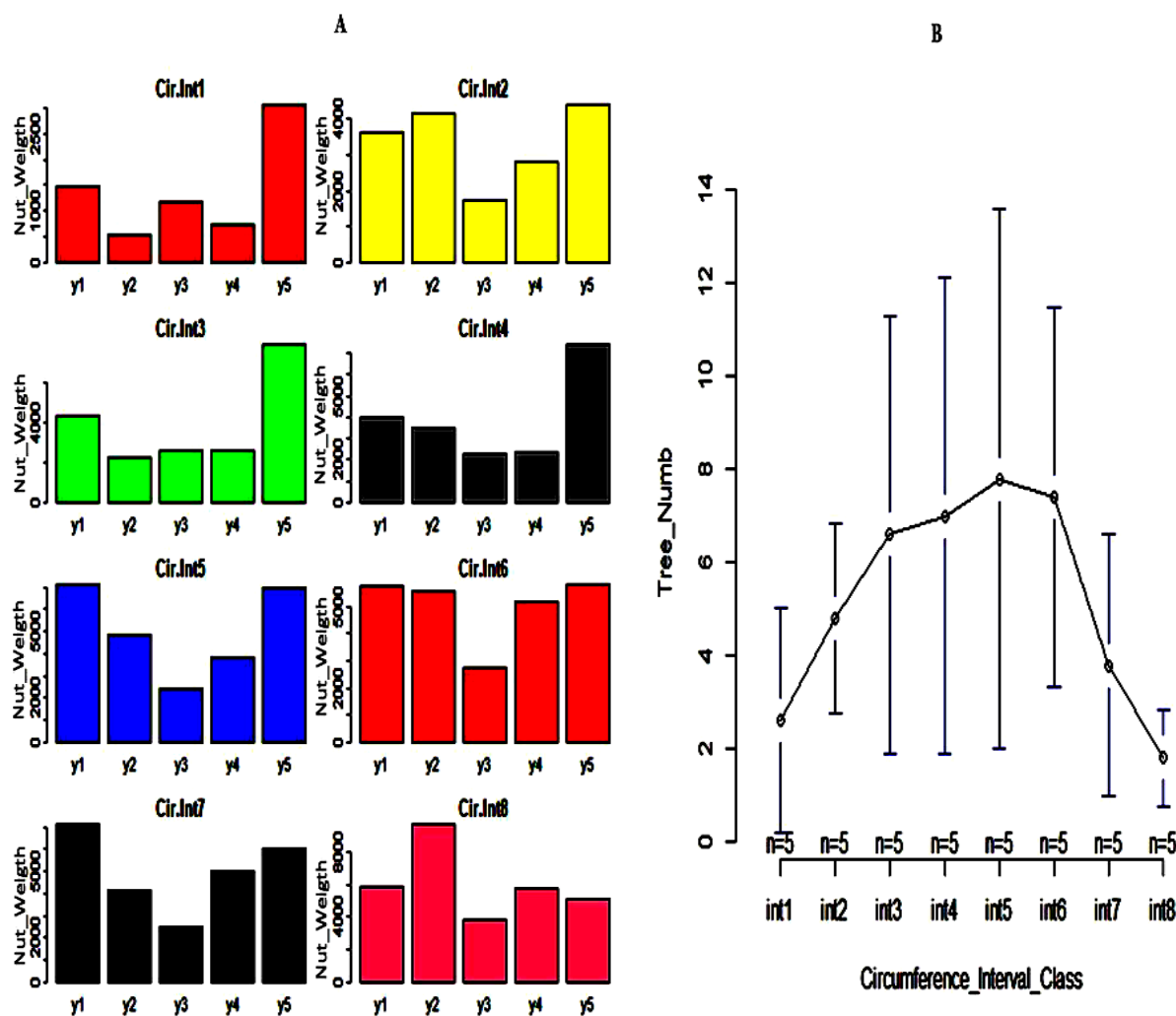


Figure 7 Shea trees yielding distribution performances by processing shea trunk girth interval class. Here (A) Descriptive and ANOVA and Turkey integrative analysis. (B) Cir.Int = Circumference interval class. Cir.Int 1: (73cm-86cm); Cir.Int 2: (86cm-99cm); Cir.Int 3: (99cm-112cm); Cir.Int 4: (112cm-125cm); Cir.Int 5: (125cm-138cm); Cir.Int 6: (138cm-151cm); Cir.Int 7: (151cm-164cm); Cir.Int 8: (164cm-200cm).

Table 6 Shea nut number dynamism/ shea tree production performance by trunk girth interval class

Girth (cm)	Interval class 1 (73cm-86cm)					Interval class 2 (86cm-99cm)					Interval class 3 (99cm-112cm)					Interval class 4 (112cm-125cm)				
Shea tree number	7					14					18					21				
Nut weight mean (kg)	1403.24					3345.44					3933.42					3912.83				
Yearly tree number rate with nut weight > nut mean	y1	y2	y3	y4	y5	y1	y2	y3	y4	y5	y1	y2	y3	y4	y5	y1	y2	y3	y4	y5
	2	2	2	1	6	6	6	3	3	6	7	4	4	5	13	10	7	2	4	12
Girth (m)	Interval class 5 (125 cm-138cm)					Interval class 6 (138cm-151cm)					Interval class 7 (151cm-164cm)					Interval class 8 (164cm-200 cm)				
Shea tree number	20					21					10					4				
Nut weight mean (kg)	5036.75					5004.24					4976.18					6062.87				
Yearly tree number rate with nut weight > nut mean	y1	y2	y3	y4	y5	y1	y2	y3	y4	y5	y1	y2	y3	y4	y5	y1	y2	y3	y4	y5
	14	9	1	7	8	8	8	3	6	12	7	3	1	5	3	2	3	1	2	1

yi: acronym is for year

Conclusion

The analysis of shea production rate performance during five consecutive years in Northern Côte d'Ivoire showed a significant positive correlation between shea yield parameters and some dendrometric features (i.e. shea tree trunk girth, crown basal area). In addition, there is a significant increase in the annual average of shea fruit/nut yield per tree and as well per girth and/or crown basal area interval class, randomly generated. This study discovered significant positive correlations between shea production and dendrometric features that are shea tree trunk girth and crown basal area. Furthermore, based on the shea tree girth interval class, findings suggested an almost normal distribution of potential higher producer shea trees. These results will help the shea breeding program of Côte d'Ivoire to refine shea elite producer trees selecting for the production of high-yielding grafted plants for farmers. This demarche can help select shea elite producer trees helping in the improvement of future breeding and genetic improvement programs on shea.

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Conflict of Interest

The authors have declared that no competing interest exists.

Author's contribution

Prof. DIARRASSOUBA Nafan and Dr. YAO Saraka Didier Martial set up the experiment. Prof. DIARRASSOUBA Nafan and Dr. DAGO Dougba Noel wrote the paper draft. Dr. DAGO Dougba Noel performed statistical analysis. Dr. YAO Saraka Didier Martial managed the literature searches. Prof. DIARRASSOUBA Nafan, Dr. YAO Saraka Didier Martial and Dr. Dago Dougba Noel revised manuscript. All Co-Authors read and approved the final version of the paper.

References

- Alui KA, Diarrassouba N, Yao SDM (2019) Germination Test of Shea Seeds (*Vitellaria paradoxa* C.F. Gaertn.) in Nursery on Substrates of Northern Côte d'Ivoire. *Asian Plant Research Journal* 3 (2):1-13.
- Bondé L, Ouédraogo O, Ouédraogo I, Thiombiano AA, Boussim IJ (2019a) Variability and estimating in fruiting of shea tree (*Vitellaria paradoxa* C.F. Gaertn.) associated to climatic conditions in West Africa: implications for sustainable management and development. *Plant Production Science* 22 (2): 143-158.
- Bondé L, Ouédraogo O, Traoré S, Thiombiano A, Boussim IJ (2019b) Impact of environmental conditions on fruit production patterns of shea tree (*Vitellaria paradoxa* C.F. Gaertn.) in West Africa. *African Journal of Ecology* 57 (3): 353-362.
- Bup DN, Mohagir AA, Kapseu C, Mouloungui Z (2014) Production zones and systems, markets, benefits and constraints of shea (*Vitellaria paradoxa* Gaertn) butter processing. *OCL* 21 (2) : D206.

- Boussim IJ, Yonli D, Medah NM, Guinko S, Sallé G (2012) Prospects for an integrated of Loranthaceae species parasitizing *Vitellaria paradoxa* C.F. Gaertn. in Burkina Faso. *International Journal of Biological and Chemical Sciences* 6: 355-364.
- Dago DN, Inza JF, Nafan D, Mohamed LB, Jean-Luc AM, Olefongo D, Loukou N, Martial DSY, Souleymane S, Giovanni M (2019) A Quick Computational Statistical Pipeline Developed in R Programming Environment for Agronomic Metric Data Analysis. *American Journal of Bioinformatics Research* 9 (1):22-44. .
- Diarrassouba N, Koffi KE, N'Guessan KA, Sangare A (2007a) Évaluation de la performance de quelques descripteurs quantitatifs et structuration de la population d'un parc naturel de karité en Côte d'Ivoire. *Plant Genetic Resource Newsletter* (152) : 65-72. Retrieve from <https://dialnet.unirioja.es/servlet/articulo?codigo=2721490>.
- Diarrassouba N, Bup ND, Kapseu C, Kouame C, Sangare A (2007b) Phenotypic Diversity of Shea (*Vitellaria Paradoxa* C.F. Gaertn.) Populations across Four Agro-Ecological Zones of Cameroon. *Journal of Crop Science and Biotechnology* 10 (4) : 223- 230. Retrieve from <https://www.koreascience.or.kr/article/JAKO200716637994327.page>.
- Diarrassouba N, Fofana IJ, Bakayoko A, N'Guessan KA, Sangare A (2009) Influence des systèmes agraires sur la dynamique de régénération naturelle du karité : *Vitellaria paradoxa* C.F. Gaertn. (Sapotaceae) en Côte d'Ivoire. *Agronomie Africaine* 21 (1): 49-58. Retrieve from <https://www.ajol.info/index.php/aga/article/view/46204>.
- Diarrassouba N, Yao SDM, Alui KA, Ble PA, Kouame NMT (2020) How to restore degraded shea agroforestry parks using the Assisted Natural Regeneration (ANR) technique ? *Afrique SCIENCE* 16(1):307 – 314. Retrieve from <http://www.afriquescience.net/PDF/16/1/26.pdf>.
- Dorthe J (2000) *Vitellaria paradoxa* Gaertn. F. Seed Leaflet. N°50. Technical report, Danida Forest Seed Centre. pp.2. Retrieve from <https://sl.ku.dk/rapporter/seed-leaflets/filer/vitellaria-paradoxa-50.pdf>.
- Fontaine C, Lovett PN, Sanou H, Maley J, Bouvet JM (2004) Genetic diversity of the shea tree (*Vitellaria paradoxa* C.F. Gaertn.) detected by RAPD and chloroplast microsatellite markers. *Heredity* 93 (6):639–648. DOI:10.1038/sj.hdy.6800591.
- Gaoue OG, Ticktin T (2008) Impacts of bark and foliage harvest on *Khayasenegalensis* (Meliaceae) reproductive performance in Benin. *Journal of Applied Ecology* 45: 34-40. doi:<https://doi.org/10.1111/j.1365-2664.2007.01381.x>.
- Hall JB, Aebischer DP, Tomlinson HF, Osei-Amaning E, Hindle JR (1996). *Vitel/aria paradoxa: a monograph*. Bangor, U. K. : School of Agricultural and Forest Sciences, University of Wales, Bangor.
- Holtzman J (2004) la chaine de valeur du beurre du karité synthèse d'étude et recommandations pour le West Africa Trade Hub (Centre pour le commerce en Afrique de l'Ouest). Rapport technique WATH no. 1.
- Kouyate AMP, Van D, Diawara H (2006) Evaluation of fruit production of *Detarium microcarpum* Guill. & Perr. in Mali. Technical report. *Fruits* 61: 1-13. DOI: <https://doi.org/10.1051/fruits:2006024>.
- Lovett PN, Haq N (2002) Diversity of the Shea nut tree (*Vitellaria paradoxa* C.F. Gaertn.) in Ghana. *Genetic Resources and Crop Evolution* 47 (3):293–304. DOI: 10.1023/A:1008710331325.
- Lamien N, Ouédraogo SJ, Diallo OB, Guinko S (2005) Fruit production of sheanut tree (*Vitellaria paradoxa* Gaertn. C.F., Sapotaceae), in traditional agroforestry parklands in Burkina Faso. *Fruits* (59) : 423–429. DOI: 10.1051/fruits:2005004.
- Lamien N, Tigabu M, Guinko S, Oden PC (2007) Variations in dendrometric and fruiting characters of *Vitellaria paradoxa* populations and multivariate models for estimation of fruit yield. *Agroforestry Systems* 69: 1-11. doi:<https://doi.org/10.1007/s10457-006-9013-x>.
- Madieng S (2003) Le Karité. L'arbre à beurre. Nourritures inconnues d'Afrique. Jade. Sénégal.
- Naughton CC., Lovett PN, Mihelcic JR (2015) Land suitability modeling of shea (*Vitellaria paradoxa*) distribution across sub-Saharan Africa. *Applied Geography* 58:217-22.
- Sanon Z (2009) Physiological functioning of shea (*Vitellaria paradoxa* Gaertn. F. Hepper, Sapotaceae) under different water regimes. Master thesis submitted to the Polytechnic University of Bobo-Dioulasso, Burkina Faso, Pp.76.
- Scott DW (2009) Sturges' rule, *WIREs Computational Statistics* 1 : 303-306.
- Soro D, Traore K, Kassi NJ (2011) Variabilité des caractères morphologiques chez le karité (*Vitellaria paradoxa*) dans le Nord de la Côte d'Ivoire. *International Journal of Biological and Chemical Sciences* 5(3):1201-1214. DOI: <http://dx.doi.org/10.4314/ijbcs.v5i3.72263>.
- Yao SDM, Diarrassouba N, Attikora AJP, Fofana IJ, Dago DN, Silué S (2020) Morphological diversity patterns among selected elite Shea trees (*Vitellaria paradoxa* C.F. Gaertn.) from Tchologo

- and Bagoué districts in Northern Côte d'Ivoire. *International Journal of Genetics and Molecular Biology* 12(1): 1-10. doi: <https://doi.org/10.5897/IJGMB2019.0189>.
- Yao SDM, Diarrassouba N, Diallo R., Koffi EBZ, Dago DN, Fofana IJ (2021) Effects of Sowing Depth and Seed Orientation on the Germination and Seedling Growth in Shea Tree (*Vitellaria paradoxa* C.F. Gaertn.) for Rootstock Production in Nursery. *Research in Plant Sciences* 9 (1): 13-22. doi: 10.12691/plant-9-1-3.
- Zacharie B, Kaboré M, Van J, Vellema S (2011) Historique de la filière karité au Burkina Faso et des services offerts par les partenaires techniques et financiers aux acteurs. VC4PD Research Paper, No. 11.