**Research Article**

# Variations in Morphmetrics of Fruits. Seed and Dendrometric Measurements of *Adansonia digitata* L. in Sudan

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**Abstract**

Though Baobab (*Adansonia digitata* L**)** tree is one of the important multi-purpose species, its fruits characteristics, have rarely been researched and hence remain underutilized or not domesticated yet. With the aim of helping domestication and consequently improvement of baobab fruits, morphological variations in relation to locations of baobab tree have been studied in two genetically isolated different populations, namely Blue Nile and Kordofan states each state having three sites were selected where random sampling was carried. For morphometric measurements, 30-78 individual trees were randomly sampled within each baobab population. Baobab fruit traits were correlated with fruit pulp. The Analysis of variance of the parameters was performed following F-variance test. Analysis of variance for different characters showed significant differences in fruit traits between study sites. The dendrometic results were also significantly different ($P \leq 0.05$) between studied population/locations. Trees from ElGerri site were smallest and shortest in DBH and height, respectively. Fruits from Elroseies site were have the largest values (long; 18.29 cm±5.72, width; 9.40 cm ±2.13 and heavy; 264.17g ±99.23). There was a trend that the heavier the fruit, the greater the number of seeds. The pulp weight percentage was found to be significantly higher both at El Mansora site and KourTaggat than others study sites. In general, trend at Blue Nile state study sites were found to be superior to others regarding fruit weight, fruit length, pulp percent. The variability in these characters' present valuable information that might be used for choice of close relative for advance baobab high quality planting material.

***Keywords**:* Baobab tree, Dendrometric, Diversity, Fruits traits, Climatic zone

## 1. Introduction

Africa has rich wild plants and cultivated indigenous species with great commercial and agronomic potential as food crops. However, many of these species, particularly the fruits and nuts, have not been promoted or researched and thus remain underutilized. Furthermore, many of these species face the danger of loss due to increasing human impact on ecosystems (Gebauer et al. 2002). Worldwide, only about 50 fruit tree species have been highly domesticated so far and are produced on a commercial scale (Leakey and Tomich 1999). Compared to tropical America and Asia, Paull and Duarte (2011) reported that Africa has the highest number of wild edible fruit species that amount to about 1200 species. One of the African wild edible fruit species is the African baobab (*Adansonia digitata* L.) belonging to the Family *Malvaceae* (Baum et al. 2004)
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Baobab has massive size, the trunk is swollen and stout, Branches are distributed irregularly and large primary, branches are well distributed along the trunk or limited to the apex (Cuni Sanchez 2010). *A. digitata is* a deciduous, massive, royal tree that measures up to 25 m high. It has thick, angular, wide spreading branches and a short, stout trunk, which reaches 10-14 m in girth and often becomes deeply fluted. The form of the trunk varies; in young trees it is conical while in mature trees it may be cylindrical, bottle shaped or tapering with branching near the base.

Baobab is one of the most importance trees of the world (Pakenham 2002, Bynum and Bynum 2014). It is an important indigenous fruit trees (IFTs) throughout the dry lands especially in savanna regions of Africa (Jama et al. 2008). As example, CEC (2008) reported that the European Union acceptance of baobab fruit pulp as a food ingredient in July 2008, and its acceptance in the USA in July 2009 (FDA 2009) have raised concerns in the popular press that baobab commercialization may lead to over-exploitation of natural stands of this species. The baobab tree is being commercialized as a food ingredient due to the high nutritional content of its fruit pulp (Gruenwald and Galizia 2005). According to Diop et al. (2006) baobab fruits are used locally to treat more than 20 diseases. In addition, its roots, bark, wood, leaves, flowers, capsules, gum, seeds, and fruits are used for over 300 different purposes (e. g. Buchmann et al. 2010). Its bark fibers are used for a variety of applications (De Caluwe´ et al. 2009a; Wickens and Lowe 2008).

The Baobab tree is well-known as multipurpose tree species of sub-Saharan Africa, with substantial socioeconomic importance (Sidibe and Williams 2002; Wiehle et al. 2014). Dhillion and Gustad, (2004) reported that the NTFPs of baobab are harvested from different land-use types (e.g., croplands, fallows, forests) and even in protected areas. Although their widely accepted potential and importance, product quality could be greatly improved through more intensive domestication programs. Wickens and Lowe (2008) urged that baobab trees sustainability is endangered in their natural savannah ecosystem due to cattle overgrazing, intensive agricultural practices, and pronounced drought situations. Before loss of baobab tree domestication, understanding of its morphological characterization and propagation can help to protect the species. The development of management and conservation strategies requires a detailed investigation of morphological variation and genetic resources in the selected populations. Little information is available on baobab tree fruits and dendromeric variation in the study area, that provide information, help towards the effective domestication of this species. As reported by Gebauer *et al*., (2002), within the species there is evidence indicating the existence of a number of local types, differing inhabit, vigour, size, quality of the fruits. Therefore, the present study aimed to analyze variation of baobab tree and fruits traits, in relation to ecological variations between and within locations.

## 2. Materials and Methods

### 2.1. Study area

The present study was conducted in two states (Blue Nile and North Kordofan) in the Sudan, across six study sites (Table 1, Fig. 1). Blue Nile state is located in the semi wet zone (Blue Nile Investment Map, 2004) between latitude 10˚ and 13˚ North and longitude 33˚ and 36˚ East, and occupies a total area of 38500 km². The soil is dominantly characterized by clayey soils while others are sandy. The temperature varies from 14-40˚C during the rainy season and increasing to 46˚C in the dry season (April - June). The annual rainfall ranges from 650 - 750 mm and the mean annual rainfall is about 700 mm from May to October. The tree species dominant in the study area include, among others, *A. digitata*, *Anogeissus leiocarpus* DC, *Balanites aegyptiaca* L, *Boswellia papyrifera* Delile ex Caill. and *Terminalia brownii* Fres.

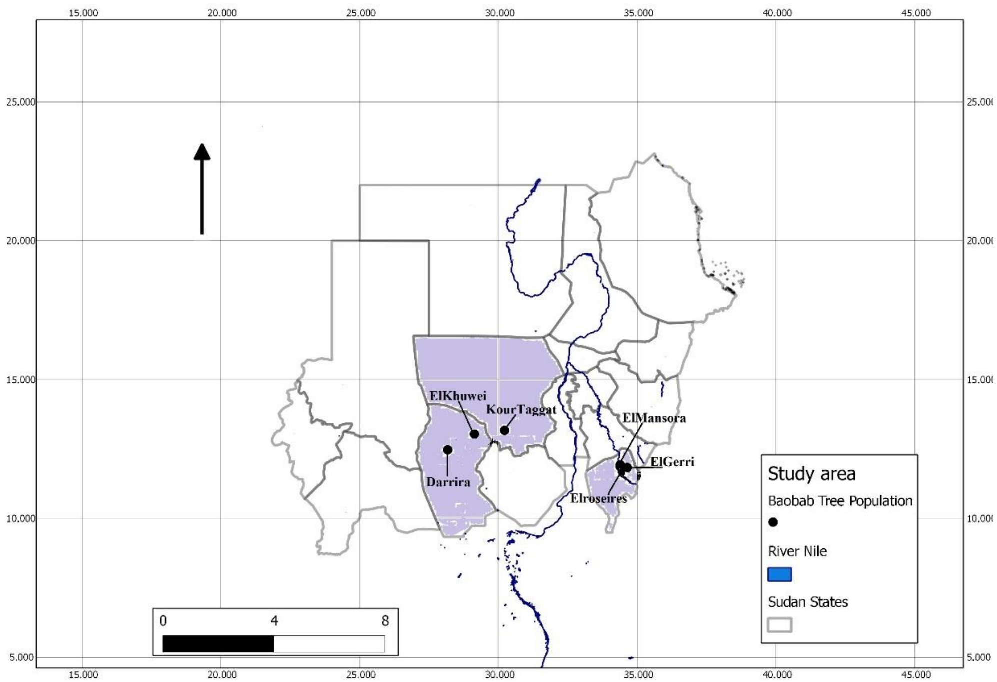


Figure. 1: Sudan Map presenting location of six sampled populations of Baobab

North Kordofan State lies in the semi-arid zone (khairelseid, 1998). It located between latitude 10.5˚ and 15˚ North and longitude 27.5˚ and 32˚ East. It occupies a total area of 185302 km². The soil where baobab population occurs is characterized by its brown color and more fine particles. This kind of soil may be originated from alluvial sediments deposited by streams which widely varies in particle size and surface characteristics with a hard surface layer when dry (Muneer, 2011). the mean annual temperature ranges from 28˚-30˚C with January being the coldest month, and May the hottest. The mean annual rainfall ranges from less than 200 mm in the north to about 450 mm in the southern parts. The dominant trees are *Acacia* spp. such as *Acacia senegal*, *Acacia millefera* and *Acacia orofota*. Other species include *Balanites eagyptiaca*, *Faidherbia albida*, *Ziziphus spp* and *Tamaridus indica*

Table 1: Sampled locations of *A. digitata*: areas, attitudes, geographical locations

| Silvicultural Zone | Study sites | Latitude (N) | Longitude (E) | Altitude (m) | Mean annual Precipitation, mm |
|---|---|---|---|---|---|
| Blue Nile | Elroseires-taloba | 11° 94´0″ | 34° 23´0″ | 467 | 700 |
| | El Gerri | 11º84′ 10″ | 34º63′3 67″ | 538 | 700 |
| | El Mansora | 11º94´ 00″ | 34º38´ 33″ | 465 | 700 |
| Kordofan | ElKhuwei | 13° 04´122 ″ | 29° 13´098 ″ | 530 | 450 |
| | Kour Taggat | 13° 18´010 ″ | 30° 21´272 ″ | 560 | 350 |
| | Darrira | 12° 47´20″ | 28° 16´99″ | 565 | 450 |

## 2.2. Tree sampling

Trees were sampled at two states from December 2018 to February 2019. At each state, three study sites were selected following a latitudinal and climatic gradient (Cuni, 2010) with the main criterion being the existence of a well-established baobab tree population, and fruit-bearing as well as the abundance of the species (Table 1, Fig.2). Elamin (1990) also used similar approach to collect data on knowledge and distribution of baobab trees. Within baobab population for the morphometric measurements a total 318 individuals were collected. As shown in Table 2 a total of 198 and 120 individual trees were from Blue Nile and Kordofan, respectively. A baobab individual was selected at a minimum distance of 100 m from one another tree in order to avoid the genetically related individuals sampling following approach of (Assogbadjo *et al*. 2006; Kouyate´ 2005). All the trees encountered during the survey were counted and measured for their diameter at breast height (dbh) and total height using a diameter tape and Sunnto clinometer, respectively. The crown diameter was measured depending on the crown boundaries marked on the ground at mid-day.

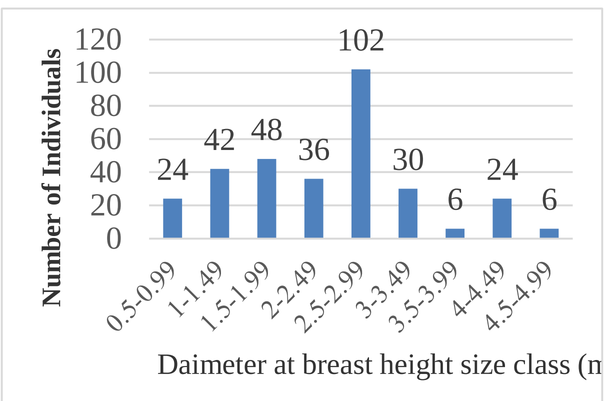


Figure. 2: Diameter at breast height range of 318 baobabs (A. digitata) trees of study area, Sudan. Sizes classes are in 0.25 m intervals

At each site, from each tree, five ripe fruits without any damage or malformation were collected from different positions in the crown and put in labeled plastic bags. Fruits were harvested by climbing the tree and picking, or by throwing wooden sticks and catching the falling fruits with a tarpaulin to avoid cracking of the fruit shell (De Smedt et al., 2011). For each fruit capsule length and diameters at the widest part were measured in cm using a measuring tape and then the average was calculated. Capsules shape ratio was calculated by dividing capsule length by capsule diameter which is thickness. Total weights were measured using a Dial Scale to determine the pulp productivity. The capsule shell was opened and separated from shell content (pulp plus seeds) and weighted. Fruits pulp and seeds were separated by dissolving the dry powdery pulp in water for five minutes and then the seeds were weighted and the pulp weight was calculated by subtraction (pulp + seed - seeds weight). The individual seeds were weighted and seed length was measured, according to the method described by De Smedt *et al*. (2011).

Statistical Package for the Social Sciences was used to analysis differences in fruit traits between study sites. Study site was ranked by means of Tukey's. Honest Significance Difference method. Correlations between pulp weight, fruit weight, and other fruit characteristics means were tested using Spearman's rank correlation coefficients. The significance level was 0.05 for the F-ratios and Tukey tests. Throughout this article, the reported values are denoted as means ± SD.

## 3. Results

The mean diameter at breast height (DBH), Bole height and Crown diameter of the six different baobab stands were similar (Table 2). Mean height of trees at Elroseirs- taloba, El mansora, El khuwei and Darrira were longer ($P < 0.05$) than those at El gerri and Kour Taggat (Table 3). Mean height of trees at Kour Taggat was longer ($P < 0.05$) than mean trees height at El Gerri. The mean diameter at breast height of trees at El Gerri site is shorter ($P < 0.05$) than mean trees DBH of trees from all sites. The diameter at breast height sizes classes based on 0.5 m diameter intervals (Eltahir et al. 2015) was 0.5-

0.99 m; 1 – 1.49 m; 1.5 – 1.99 m. etc...). The overall tree diameter ranges from 0.78 m to 4.55m (Table 3). The largest tree DHH sizes was recorded for Elroseires population (1.75 -4.28 m), while the smaller tree was documented for El Mansora population (0.79-1.64 m). Overall, about 102 trees was recorded within 2.5–2.99 m DBH classes. Only six trees were recorded within DBH class range of 4.5- 4.99 m.

Mean fruit width of tree at Elroseires-taloba, El Mansora and Kour Taggat are larger ($P \leq 0.05$) than mean width tree at El Gerri. ElKhuwei and Darrira (Table 4). In terms of mean fruit length, trees at Kour Taggat and Darrira have shorter length than tree trees from other sites. The least shortest fruit length was recorded at Darrira site. As shown in table 4 there is significant variation ($P \leq 0.05$) in mean fruit weight in the order of: Elroseires-taloba > El Gerri, El Mansora and Kour Taggat > ElKhuwei > Darrira. The pulp weight percent of trees population at Kour Taggat and El Mansora was higher ($P \leq 0.05$) than pulp weight percent of trees in other sites. Mean number of seeds per fruit of tree population at Elroseires- taloba, El Gerri and El Mansora higher ($P \leq 0.05$) than tree population at El Khuwei, Kour Taggat and Darrira.

Mean variation in seeds weight per fruit, dry one seed weight, seed length and seed width of *Adansonia digitata* population from six study sites is shown in Table 5. Highest ($P \leq 0.05$) mean seeds weight per fruit was from tree population at Elroseires- taloba and the lowest ($P \leq 0.05$) mean value was from tree population at Darrira site. In terms of mean dry one seed weight, tree population Elroseires- taloba and Darrira showed higher ($P \leq 0.05$) values than population at other sites. Tree population at El Gerri and El Khuwei showed shorter ($P \leq 0.05$) mean seed length than values from tree population at remaining four sites. Mean seed width tree population at Elroseires- taloba, El Gerri and Darrira was higher than values at other tree population at other sites.

As shown in table 6, pulp weight and weight of fruit was positively correlated with most measured fruit characteristics over each study area. For all study sites, correlations between weight of pulp, weight of fruits and other fruit characteristics, except for trees DBH and were found to be similar. In addition, there was no significant correlations between pulp weight and weight fruit with tree height from Kordofan. Pulp weight and weight of fruit was positively correlated with most measured fruit characteristics over each study area.

Table 2: Dendrometric tree (mean) of baobab stands of different Baobab stands in study sites of Blue Nile and Kordofan States

| Study sites | Dendrometric characters | | | | |
|---|---|---|---|---|---|
| | DBH (m) | Girth (m) | Height (m) | Bole height (m) | Crown diameter (m) |
| Elroseires | 2.90 $^{a}$ ±0.73 | 9.11 $^{a}$ ±0.8 | 21.63 $^{a}$ ±3.55 | 3.21 $^{a}$ ±1.12 | 16.09 $^{a}$ ±6.42 |
| El Gerri. | 1.15 $^{b}$ ±0.23 | 3.61 $^{b}$ ±0.22 | 13.05 $^{c}$ ±1.89 | 3.21 $^{a}$ ±0.75 | 12.22 $^{a}$ ±2.16 |
| El Mansora | 2.61 $^{a}$ ±0.48 | 8.19 $^{a}$ ±0.51 | 22.15 $^{a}$ ±1.19 | 2.95 $^{a}$ ±0.33 | 13.83 $^{a}$ ±1.60 |
| ElKhuwei | 2.90 $^{a}$ ±0.78 | 9.11 $^{a}$ ±0.65 | 19.42 $^{a}$ ±3.25 | 3.53 $^{a}$ ±1.03 | 13.92 $^{a}$ ±3.63 |
| Kour Taggat | 2.27 $^{a}$ ±1.28 | 7.13 $^{a}$ ±1.33 | 16.38 $^{b}$ ±5.21 | 1.66 $^{b}$ ±0.61 | 14.44 $^{a}$ ±7.33 |
| Darrira | 2.18 $^{a}$ ±0.47 | 6.84 $^{a}$ ±0.35 | 17.60 $^{a}$ ±3.91 | 3.50 $^{a}$ ±0.93 | 10.40 $^{a}$ ±1.67 |
| **Total** | **2.40** | **7.33** | **18.42** | **3.02** | **13.83** |

Means charted by standard deviation. Parameter means charted by a same letter are not significantly different between both sites at $P < 0.05$ (ANOVA)

Table 3: Diameters at Breast Height class range across Baobab population

| States | Sites | Daimeter at breast height range | Number of individual |
| --- | --- | --- | --- |
| Blue Nile | Elroseirs | 1.75 – 4.28 | 78 |
| | ElGerri | 1.6 – 4.55 | 66 |
| | El Mansora | 0.79 – 1.64 | 54 |
| North Kordofan | ElKhuwei | 0.78 – 4.19 | 54 |
| | Kour Taggat | 2.03 – 3.41 | 36 |
| | Darrira | 1.62 – 2.77 | 30 |

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## 4. Discussion

The study results contribute to baobab tree conservation and domestication in Sudan as an important resource for the future. Regarding morphological characters. El Amin (1990) stated that the baobab is deciduous trees up to 20 m high, girth up to 13 or more. Gebauer et al. (2002) also reported that baobab is a massive and majestic tree which reaches a maximum height of 25 m. The mean height of the six stands found in this study match up to the height range of earlier work done by El Amin, (1990) and Gebauer et al. (2002). This might probably be due to the fact that the studies were conducted at the same ecological areas or the earlier works might have dealt with similar ages group population.

The diameter (girth values) was also in the range of other observations in western (Assogbadjo et al. 2010; Duvall 2007) and southern Africa (Venter and Witkowski 2010; Cuni Sanchez 2011). Based on assessment 306 baobabs trees in the Nuba Mountains, Sudan, Wiehle et al., (2014) reported that Kordofan baobabs daimeter can reach an impressive size of up to 8.93 m. Patrut et al. (2007) reported the largest DBH (9.74 m) of African baobab from north-eastern Namibia. According to Gebauer *et al.*, (2002) the baobab tree has a short and a stout trunk which attains 3.18 m to 4.45 m or more in DBH. The present findings showed that the DBH of baobab trees at the study sites agree with the earlier studies showed by Baum, (1995) and Gebauer et al. (2002) in Sudan.

The current study reported that fruit size was found to be within the range (13.24-18.29 cm length, 7.27-9.4 cm wide). The result is inconsistent Munthali et al. (2012) fruits from Malawi who reported (11.9 - 16.5 cm length and 6.8 -7.6 cm width) and Assogbadjo et al. (2006) in Benin (16.8-20.7 cm length, 6.2 -8.3 width). Variances in fruit morphology influence be connected to differences in ecological sites between baobabs from Blue Nile and Kordofan states, as suggested by Cuni Sanchez et al. (2010) in Malawi.

Table 4: Mean (±Std. Deviation) morphological characteristics (Fruits, width; length; weight, pulp weight and seed weight) of baobab populations in six study sites

| Study sites | Fruits width (cm) | Fruit Length (cm) | Fruit weight (g) | Pulp weight % (g) | Number of seeds per fruit |
|---|---|---|---|---|---|
| Elroseires- taloba | $9.40^{a} \pm 2.13$ | $18.29^{a} \pm 5.72$ | $264.17^{a} \pm 99.23$ | $14.21^{b} \pm 2.99$ | $224.71^{a} \pm 106.61$ |
| El Gerri. | $8.27^{b} \pm 1.29$ | $17.65^{a} \pm 4.96$ | $179.85^{b} \pm 58.69$ | $16.88^{b} \pm 3.92$ | $184.93^{a} \pm 88.79$ |
| El Mansora | $8.91^{a} \pm 1.03$ | $16.11^{a} \pm 5.27$ | $206.8^{b} \pm 59.87$ | $19.95^{a} \pm 5.27$ | $178.97^{a} \pm 85.61$ |
| ElKhuwei | $7.49^{c} \pm 1.56$ | $16.17^{a} \pm 3.86$ | $158.24^{c} \pm 75.5$ | $16.01^{b} \pm 3.70$ | $139.65^{b} \pm 77.95$ |
| Kour Taggat | $8.53^{a} \pm 1.84$ | $14.78^{b} \pm 3.10$ | $178.21^{b} \pm 93.16$ | $20.12^{a} \pm 8.31$ | $150.68^{b} \pm 84.16$ |
| Darrira | $7.27^{d} \pm 1.78$ | $13.24^{c} \pm 4.46$ | $125.15^{d} \pm 94.52$ | $16.64^{b} \pm 4.77$ | $111.80^{c} \pm 107.61$ |
| **Total** | **8.33** | **16.33** | **189.43** | **17.00** | **168.51** |

Mean numbers with the same letter are not significantly different within column at ($P \leq 0.05$)

Table 5: Mean (±Std. Deviation), variation in seeds weight per fruit and single seed parameters among six study site of *Adansonia digitata* L

| Study sites | Seeds weight (g) Per fruit | Dry one seed weight (g) | Seed length (cm) | Seed width (cm) |
|---|---|---|---|---|
| Elroseires- taloba | $117.58^{a} \pm 52.38$ | $0.53^{a} \pm 0.10$ | $1.22^{a} \pm 0.12$ | $0.72^{a} \pm 0.05$ |
| El Gerri. | $78.22^{b} \pm 35.53$ | $0.43^{b} \pm 0.08$ | $1.12^{b} \pm 0.08$ | $0.68^{a} \pm 0.09$ |
| El Mansora | $72.87^{b} \pm 34.84$ | $0.41^{c} \pm 0.11$ | $1.15^{a} \pm 0.11$ | $0.65^{b} \pm 0.04$ |
| ElKhuwei | $63.74^{b} \pm 36.94$ | $0.45^{b} \pm 0.06$ | $1.11^{b} \pm 0.18$ | $0.66^{b} \pm 0.07$ |
| Kour Taggat | $66.97^{b} \pm 43.91$ | $0.42^{c} \pm 0.09$ | $1.14^{a} \pm 0.11$ | $0.67^{b} \pm 0.06$ |
| Darrira | $52.71^{c} \pm 46.64$ | $0.48^{a} \pm 0.05$ | $1.17^{a} \pm 0.09$ | $0.69^{a} \pm 0.09$ |
| **Total** | **77.79** | **0.46** | **1.15** | **0.68** |

Mean numbers with the same letter are not significantly different within column at ($P \leq 0.05$)

Table 6: Coefficients of correlation between pulp weight, fruit weight, and other fruit characteristics

| Characters | Weight of Pulp | | Weight of Fruit | |
|---|---|---|---|---|
| | Blue Nile | Kordofan | Blue Nile | Kordofan |
| Weight of Pulp g | 1.000 | 1.000 | $0.829^{**}$ | $0.807^{**}$ |
| Weight of Fruit_ | $0.829^{**}$ | $0.807^{**}$ | 1.000 | 1.000 |
| DBH | 0.157 | 0.068 | 0.205 | 0.056 |
| Height | $0.418^{*}$ | 0.006 | $0.449^{*}$ | 0.009 |
| Fruit width | $0.781^{**}$ | $0.768^{**}$ | $0.839^{**}$ | $0.882^{**}$ |
| Fruit Length | 0.030 | $0.421^{**}$ | $0.220^{**}$ | $0.492^{**}$ |
| Fruit shape | $-0.267^{**}$ | $-0.260^{**}$ | -0.139 | $-0.240^{**}$ |
| Fruit thickness | $0.431^{**}$ | 0.132 | $0.452^{**}$ | $0.336^{**}$ |
| Weight of seed | $0.679^{**}$ | $0.765^{**}$ | $0.925^{**}$ | $0.966^{**}$ |
| Number of valves | $0.197^{*}$ | $0.461^{**}$ | 0.106 | $0.453^{**}$ |
| Number of Seed /Fruit | $0.614^{**}$ | $0.770^{**}$ | $0.794^{**}$ | $0.925^{**}$ |
| Weight of seed | 0.121 | 0.144 | $0.311^{**}$ | $0.322^{**}$ |

** and * Correlation is significant at the 0.01 and 0.05 level, Across study sites in the present study, mean seed weight is 77.79 g per fruit, which close to fruit seed weight (71 g per) from Mali (De Smedt et al 2011). As far as seed weight concerned, the finding of study disagrees with the findings of Cuni Sanchez (2010) indicating a value of 87 g in Mali. The means of seed size found in the present study seeds traits (length, 1.15 cm and width of seed, 0.68 cm), is in line with those reported by Msanga (1998) with seed dimensions of 1.2cm in length and 0.8 mm width in Tanzania and by Owen (1999) indicating mean seed size of 0.5 cm width, in Niger. The differences in recorded results showed importance of studying variation at regional scale**,** as seed characteristics may also strongly depict species adaptability Chapman *et al* (2000).

In terms of the correlations between pulp and fruit weight, and measured characters, the study results agreed with those of Assogbadjo *et al*. (2005), who reported a similar relationship in Mali, Malawi and Benin. De Smedt *et al*, (2011). commented that it is interesting to mention that the selection of pulp weight according to fruit weight may end up with a large error because some fruits with high weight are not significantly different from fruit pulp that relatively smaller due to heavy shell weight (De Smedt *et al*, 2011). Nevertheless, the study results contrast the argument of Smedt and his colleagues (2011). This may be due to the fact that environmental variables have an important role in phenotypic expression of fruit characteristics in the study areas.

## 5. Conclusion

The present work revealed that diversity in morphometric traits of baobab fruits and dendrometric tree exist in the six studied baobab population in Blue Nile and Kordofan states, Sudan. The results of this study are useful for great for future domestication and improvement programs of fruits traits. The study recommends further selection of trees with improved fruit characteristics might increase the productivity for getting more variability in respect of desired traits.

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**Competing interests**: The authors declare that they have no competing interests.

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