World Journal of Agricultural Research, 2022, Vol. 10, No. 3, 82-93
Available online at http://pubs.sciepub.com/wjar/10/3/4
Published by Science and Education Publishing
DOI:10.12691/wjar-10-3-4

Morphological Characterization of Baobab Fruit (*Adansonia Digitata* L.) in Makueni, Taita Taveta, Kilifi and Kwale Counties in Kenya

Molly Murage[1,2], Justus M Onguso[1], Wekesa Remmy[3], Tofick B Wekesa[1,*]

[1]Jomo Kenyatta University of Agriculture and Technology (JKUAT), Institute of Biotechnology Research (IBR), Juja, Kenya
[2]World Agroforestry Centre (ICRAF), Tree Diversity, Domestication and Delivery, Nairobi, Kenya
[3]Louisiana State University, Department of Biological Sciences, Baton Rouge, LA, USA
*Corresponding author: wekesatofick@gmail.com

Received September 17, 2022; Revised October 22, 2022; Accepted November 02, 2022

Abstract Baobab (*Adansonia digitata* L.) is a multipurpose tree with a long lifespan which grows throughout sub-Saharan Africa in the semi-arid and humid regions. The Fruit pulp, which is an important part, is used by locals as a food additive and at times the pulp is consumed directly by children and adults. In Kenya, the fruit pulp is consumed directly in some parts of the country while other parts of the country, mostly coastal regions add value to it and sell to earn an income. Baobab's natural habitat is under threat yet both the morphological and genetic diversity is not well documented. The aim of this study was to determine morphological characteristics of baobab fruit in Makueni, Taita Taveta, Kilifi and Kwale counties. Sixty-four trees (one tree per farm) were randomly selected, and 10 fruits were picked that were used for morphological characterization using 29 qualitative and 15 quantitative descriptors modified from those given for mango by the International Plant Genetic Resources Institute (IPGRI). The results indicated ellipsoid fruit shape was dominant (2.0-3.6) with acute apex (2.8-6.4) and slightly-oblique (4.0-8.4). Baobab fruit had perceptible fruit beak (ranging 4.4-10.0). The results also showed hierarchical clustergram in terms of hair, color, surface, shell hairness and shell surface texture whereby Kilifi and Kwale were clustered together and differed from Makueni and Taita Taveta. In terms of shell hardness to crack, most of the baobab was hard (6.0-8.0) with intermediate adherence of fibre to fruit (6.0-8.0) and intermediate amount of fibre in fruit (2.4-6.0). The seed shape was very reinformed (2.0-9.6), coarse seed testa texture and hard seed testa. The results indicated that fruit length ranged from 12.18-25.06cm, fruit diameter from 7.10-9.08cm. Fruit weight ranged 101.74-319.16g, fibre weight (1.86-5.17G0 and shell weight (46.30-159.68g).

Keywords: *baobab, characterization, conservation, descriptors, domestication, morphological*

Cite This Article: Molly Murage, Justus M Onguso, Wekesa Remmy, and Tofick B Wekesa, "Morphological Characterization of Baobab Fruit (*Adansonia Digitata* L.) in Makueni, Taita Taveta, Kilifi and Kwale Counties in Kenya." *World Journal of Agricultural Research*, vol. 10, no. 3 (2022): 82-93. doi: 10.12691/wjar-10-3-4.

1. Introduction

Baobab *(Adansonia digitata* L.*)* is a tree that belongs to the family Bombacaceae [1]. In Kenya, baobab trees are mainly found in parts of Eastern and Coast Provinces [2]. Baobab is a beneficial tree that provides edible fruit pulp, seeds, and leaves to local communities in Sub Saharan Africa [3]. Baobab fruit pulp is highly nutritious and previous studies have revealed that baobab pulp is a rich source of Vitamin C, with values up to 500 mg/100 g edible portion [4]. According to Rashford, [5], the baobab leaves are used in Africa as food given their nutritiousness. The tree is highly valued in Africa because of its fruit pulp seeds which serves as food [6]. A study conducted by Jäckering et al. [7] in Eastern and coastal parts of Kenya showed very low usage of baobab leaves by households. The study involved a value chain analysis which examined farming, harvesting, and trading of baobab products. It revealed that though most farmers earned additional source of income from selling the baobab products, there was need to increase commercialization of these products in Kenya. However, more baobab products have been found in markets of larger towns such as Mombasa and Kilifi, with traders mostly specializing in the coloured *mabuyu* pellets [8]. Studies have shown that more economic value can be derived from baobab and its products [7,9,10]. They have reported inadequate baobab processors to enable value addition and commercialization of the products.

Ruffo et al. [11] reported that in areas where there is access to refrigeration such as Nairobi and Taita Taveta, water-diluted baobab pulp which has been sweetened is frozen in paper packs and sold as ice lollipops. In addition to using baobab for food, baobab is economically and culturally important to local communities [12]. Baobab products like seed oil and fruit pulp are currently being sold in foreign markets serving as a source of revenue to the local communities where this fruit tree is grown [13]. Recently, baobab has gained international interest following acceptance of the pulp from baobab fruits as a food ingredient by both the United States Food and Drug Administration [14] and the European Union. In their study, address the untapped potential of baobab and the need to increase its exploitation. The increased need for the baobab products in the markets could also result in overexploitation of the baobab resources and consequently also pose a great risk to the nutrition security of the locals [15].

According to Sanchez [16], the decline in baobab populations because of climate change and land use could have negative effects on African livelihoods. Whilst baobab, as an Indigenous Fruit Tree (IFT), can withstand harsh environmental conditions and still produce some yield during times of drought, baobab would face some level of endangerment since they are intensively harvested when other crops fail, leading to the overexploitation. Domestication of baobab trees alongside other IFT species while integrating them into the existing agricultural systems would play a major role in increasing production of these fruits thereby reducing the harvesting pressure on natural stands. Baobab can be conserved as a genetic resource while at the same time promoting nutritional and food security as well as generating income from the harvested fruits [17].

However, not much has been done in Kenya regarding extensive exploitation of baobab as the fruits are commonly sold in informal markets and in most cases considered a secondary means of income generation. However, with the increase in knowledge as well as international interest in baobab products, there has been an increase in commercial scale processing of baobab pulp and seeds. Information regarding molecular and morphological variation within and between baobab populations is still lacking [13]. There are no existing studies to determine the effect of genetic characterization in baobab populations' variation in Kenya [6]. As a result, there is need to further elaborate baobab stands' morphological characterization in. This further elaboration requires employment of coding schemes that promote investigation of variations resulting from trees' shape and sizes, the leaves and fruits, environment, and tree growth habits. Kehlenbeck et al. [18] is one of the major contributors to baobab phonological and morphological variation elaboration through a baobab descriptor development.

2. Materials and Methods

2.1. Study Area

The research was conducted in Makueni, Taita Taveta, Kilifi and Kwale counties in Kenya (Figure 1. In Eastern region, the sample collection areas included the county of Makueni (Kibwezi, Mikuyuni, Manyanga, Kambu, Kinyambu, Mtito Andei and Machinery). These regions are situated on a predominantly semi-arid area and form part of Kenya's Eastern Foreland Plateau. These areas are characterized by mean temperatures that range from a minimum of 11°C to a maximum of 25.9 °C and low precipitation levels (The rainfall pattern is bimodal, with long rains occurring between March and May and short rains from October to December Precipitation ranges from less than 400 mm per annum in the low Eastern plains to more than 2200 mm per annum in the Southeastern windward side of Mt. Kenya. The main altitude ranges in this area are between 2200-2700 m The most widespread natural vegetation type in these areas is Commiphora shrubland and semi-desert grassland and shrubland [19].

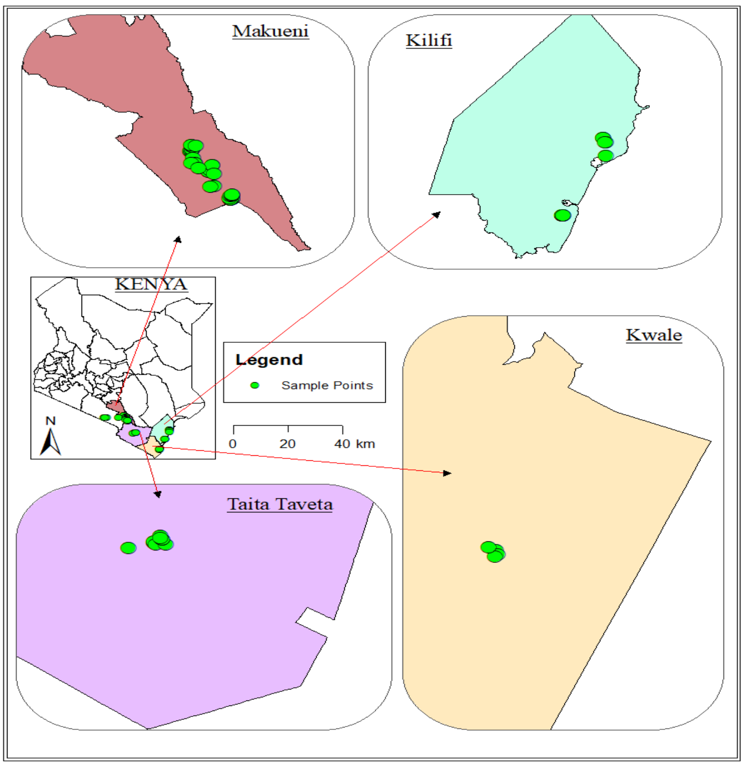

Figure 1. Map of Kenya showing the location of sampling sites for baobab in Makueni, Taita Taveta, Kilifi and Kwale County

The Coast region comprises of Taita Taveta county (Voi kinyeni and Voi Mraru), Kilifi county (Kilifi Mavueni and Malindi Manduguini) and Kwale County (Diani). Most of the soils in the Kenya's coastal region are sandy, free draining and of low inherent soil fertility. The mean annual rainfall along the Kenyan Coast ranges from 500-900 mm at the North Coast to 1000-1500 mm in the areas south of Mombasa. The rainfall pattern is bimodal, with long rains occurring between March and May and short rains from October to December. It is characterized by complex integration of moist and drier forests with coastal thicket, fire-climax savanna woodlands, seasonal and permanent swamps, and littoral habitats Mean minimum and maximum temperatures at the Kenyan coast range between 24℃ and 30℃. Relative humidity is consistently high throughout the year, peaking at 90% during the wet months between April and July

2.2. Sample Collection

Sample collection was done in the frame of an ICRAF-organized baobab collection trip performed by C.G. Waruhiu. A total of 64 farms were purposively selected along the transect from Makueni-Kibwezi to Kwale-Diani where Global Positioning System (GPS) co-ordinates were recorded for a total of 103 trees in the 64 farms. Five farms were selected from each county and one tree per farm was randomly selected and ten baobab fruits picked from each. Agricultural field officers from Kenya Forestry service (KFS) and Kenya Forestry Research Institute (KEFRI) helped in selecting and accessing the individual farms. Farmers or landowners were interviewed using semi-structured questionnaires to collect data on land use, socio-economic information, utilization of baobab etc. (see full questionnaire in Table 1).

The collected fruits of each single tree were put in sacks separately and labeled. Collected samples were transported to the ICRAF seed laboratory in Nairobi, where they were stored in the cold room at 4℃ until morphological characterization was done.

2.3. Baobab Fruit Morphological Characterization

Morphological characterization of the baobab fruits started in May 2013 in the ICRAF seed laboratory using baobab descriptors developed by ICRAF [18] based mainly on the “Descriptors for Mango” developed by Bioversity International (IPGRI 2006). A total of 25 qualitative and 19 quantitative traits were assessed for the baobab fruits.

2.4. Morphological Variations among the Baobab Fruits in Makueni, Taita Taveta, Kilifi and Kwale Counties in Kenya

Morphological characterization of the baobab fruits was done at ICRAF laboratory using baobab descriptors as recently developed by ICRAF (Table 1) based on the Bioversity descriptors for tropical fruits, particularly the mango descriptor list (IPGRI, 2006)

From the samples collected, five farms were randomly selected from each county and 29 qualitative characteristics were determined for variation among the fruits as described in Table 1. The morphological variation of the fruits was assessed based on the outer fruit characteristics such as fruit shape, apex shape, stalk insertion, neck prominence, beak type, among others (Table 1).

Table 1. Bioversity International (IPGRI) Baobab fruit-related descriptors

Fruit Traits	Descriptions							
	1	2	3	4	5	6	7	8	99
Fruit shape	Oblong cylindrical	Oblong irregular	Ellipsoid	Globose	pyriform	reniform	obovate	ovate	other
Shape of fruit apex	Acute	Obtuse	Round	Concave					other
Fruit Stalk insertion	Oblique	Slightly oblique	vertical						
Fruit neck prominence	Absent	Slightly prominent	Prominent	Very prominent					
Fruit Beak type	Absent	perceptible	Pointed	prominent					Other
Fruit shell hairness	Evenly hairy	Not hairy							
Color of hair on the fruit skin	Green	Grey	Yellowish						Other
Fruit ground colour	Black	Green	Grey	Yellowish					Other
Contour	Absent	Shallow contoured	Deeply contoured						
Fruit shell surface texture	Smooth	Wrinkled							
Shell hardness to crack	Easily cracked	Slightly hard	Hard						
Adherence of fibre shell	Weak	Intermediate	Strong						
Amount of fibre in fruit	Low	Intermediate	High						
Texture of fibre in fruit	soft	intermediate	coarse						
Adherence of pulpy seed to fibre	Weak	Intermediate	Strong						
Adherence of fruit pulp seed to fibre	Weak	Intermediate	Strong						
Pulp texture of ripe fruit	Soft	Intermediate	Strong						
Pulp sweetness	Very sweet	Sweet	Slightly sweet						
Pulp sourness	Sour	Slightly sour	Very sour						
Pulp bitterness	Bitter	Slightly bitter	Very bitter						
Pulp aroma	No aroma	mild	Perceptible	Strong					
Pulp colour of ripe fruit	White	Cream	Light yellow	Grey					Other
Seed shape	Oblong	Reniform	Very reniform						Other
Seed testa colour	Dark brown	Reddish black							Others
Seed testa texture	Soft	Coarse							
Testa hardness	Soft	Intermediate	Hard	Very hard					
Colour of endosperm	Use of color chat								

2.5. Evaluation of the Most Discriminant Morphological Quantitative Traits among the Baobab Powdery Pulp from Makueni, Taita Taveta, Kilifi and Kwale Counties in Kenya

After the outer fruit characteristics were assessed, each fruit was opened manually by use of a hacksaw. A transverse section was created in each of the fruits. Representative photos were taken from one of the fruits per accession. The pulp was then separated manually from the seed by use of a knife. The seeds were washed in water to remove any remaining pulp. The seeds were dried on paper towels overnight on bench tops before quantitative measurements were performed

To morphologically characterize the baobab fruits the following traits were measured quantitatively among others: fruit length (cm), fruit weight (g), length of the fruit stalk (cm), total pulp and seed weight (g), number of seeds, fibre weight (g) and shell weight (g). A total of 17 quantitative traits were assessed for the baobab fruits and evaluated to ascertain the most discriminant quantitative trait among the baobab fruit from Makueni, Taita Taveta, Kilifi and Kwale counties.

2.6. Data Analysis

The raw data of the ten fruits was entered and cleaned in Excel and analyzed using SAS for ANOVA analysis, Minitab for pie-chart and Graph pad prism for the graphs. Standard descriptive statistics such as mean, standard error, F-value. P-value, LSD value coefficient of variance (CV) were performed. Discriminant analysis was performed with SAS to identify which variables were the most important quantitative traits (Jieping, 2007). ANOVA and post-hoc Turkey-test were used to test for significant differences of the mean quantitative variables. The differences of qualitative variables were detected

3. Results

3.1. Morphological Variations among the Baobab Fruits Shape

From the results, Oblong-cylindrical fruit shape stood to be dominant traits in Makueni county (6.40±1.91) and Kilifi county (3.40±2.09) compared to Taita Taveta (0.00±0.00) and Kwale county (0.00±0.00). Oblong-irregular was not obtained from any of the county sampled. However, Ellipsoid shape was found in all the four counties with Kilifi (5.80±2.18) recorded highest number compared to Makueni, Kwale and Taita Taveta counties. Globose was only found in two counties Taita Taveta (4.00±2.45) and Kwale county (2.00±2.00). The results (Table 2) indicate that there was no significant difference recorded in pyriform, reniform, obovate, ovate and others from the four counties.

Table 2. Morphological characteristics of baobab fruit shape from Makueni, Taita Taveta, Kilifi and Kwale counties

County	Oblong-Cylindrical	Oblong-Irregular	Ellipsoid	Globose	Pyriform	Reniform	Obovate	Ovate	Other
Makueni	6.40 ± 1.91^{a}	0.00 ± 0.00^{a}	2.00 ± 2.00^{c}	0.00 ± 0.00^{c}	0.20 ± 0.20^{a}	1.20 ± 1.20^{a}	0.00 ± 0.00^{a}	0.20 ± 0.20^{a}	0.00 ± 0.00^{a}
Taita. T	0.00 ± 0.00^{b}	0.00 ± 0.00^{a}	4.00 ± 2.45^{ab}	4.00 ± 2.45^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	2.00 ± 2.00^{a}	0.00 ± 0.00^{a}
Kilifi	3.40 ± 2.09^{ab}	0.00 ± 0.00^{a}	5.80 ± 2.18^{a}	0.00 ± 0.00^{c}	0.20 ± 0.20^{a}	0.60 ± 0.40^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}
Kwale	0.00 ± 0.00^{b}	0.00 ± 0.00^{a}	3.60 ± 2.23^{b}	2.00 ± 2.00^{b}	0.00 ± 0.00^{a}	2.20 ± 1.96^{a}	2.00 ± 2.00^{a}	0.20 ± 0.20^{a}	0.00 ± 0.00^{a}
F-value	4.74	0.00	0.49	1.47	0.67	0.65	1.00	0.86	0.00
P value	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
LSD	4.11	0.00	6.65	4.74	0.42	3.50	3.00	3.03	0.00
CV (%)	2.12	2.12	2.12	2.12	2.12	2.12	2.12	2.12	2.12

Mean values with the same superscript letters within the same column are not significantly different at Fisher's LSD test (P<0.05).

Table 3. Morphological characteristics of baobab fruit Apex and stalk insertion from Makueni, Taita Taveta, Kilifi and Kwale counties

	Apex				Stalk Insertion			
County	Acute Pointed	Obtuse	Round	Concave	Vertical	Slightly-Oblique	Oblique	Very-Oblique
Makueni	2.80 ± 1.96^{b}	5.00 ± 2.14^{a}	1.80 ± 1.80^{a}	0.20 ± 0.20^{a}	2.40 ± 1.94^{a}	6.20 ± 1.91^{ab}	1.20 ± 0.73^{a}	0.00 ± 0.00^{a}
Taita T.	8.00 ± 2.00^{ab}	2.00 ± 2.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	4.00 ± 2.44^{a}	4.00 ± 2.45^{b}	2.00 ± 2.00^{a}	0.00 ± 0.00^{a}
Kilifi	8.60 ± 0.24^{a}	1.40 ± 0.24^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	8.40 ± 0.60^{a}	1.60 ± 0.60^{a}	0.00 ± 0.00^{a}
Kwale	6.40 ± 2.23^{ab}	3.60 ± 2.23^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	5.80 ± 2.06^{ab}	4.20 ± 2.06^{a}	0.00 ± 0.00^{a}
F-value	2.11	0.78	1.00	1.00	1.57	0.92	0.79	0.00
P-value	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
LSD	5.38	5.53	2.67	0.30	4.68	5.65	4.53	0.00
CV (%)	62.16	137.54	447.21	447.21	218.30	69.16	150.23	0.00

Mean values with the same superscript letters within the same column are not significantly different at Fisher's LSD test (P<0.05).

3.2. Morphological Characteristics of Baobab Fruit Apex and Stalk Insertion

From Table 3, the highest number was recorded at acute pointed (8.60±0.24) from Kilifi with the lowest number recorded at concave. In comparison of the counties, most of the acute pointed apex were observed across the whole counties with highest number reported from Kilifi (8.60±0.24) followed by Taita Taveta (8.00±2.00) and least obtained from Makueni (2.80±1.96). Additionally, there was significant difference in terms of the number of acute-pointed baobab fruits obtained from Kilifi compared to the rest of the counties. There was also no significant difference in the number of acute pointed apex baobab fruit for both Taita Taveta and Kwale (Table 3). Makueni county also showed significant difference in the number of acute pointed apex baobab fruit in comparison to the rest of the counties. For the obtuse baobab fruit, the result showed no significant difference across the whole four counties. However, the results indicate that Makueni county (5.00±2.14) had the highest number of obtuse baobab fruit collected followed by Kwale (3.60±2.23) and least number obtained from Kilifi county (1.40±0.24). There were no significant differences in terms of the number of round and concave apex baobab fruits obtained across the four counties. Additionally, only Makueni county reported significant number of both round and concave apex baobab fruits compared to Kwale, Kilifi and Taita Taveta that recorded none.

In terms of stalk insertion, most of the baobab fruits obtained across the counties had slightly oblique stalk insertion. Kilifi county (8.40±0.60) had the highest number. There was no significant difference at $P<0.05$ for Vertical insertion baobab fruit across the four counties. However, the results (Table 3) shows that there was a significant number of baobab fruits with vertical insertion obtained in only Makueni (2.40±1.94) and Taita Taveta counties (4.00±2.44). For slightly oblique, there was significant difference ($P<0.05$) recorded among the four counties. However, there was no significant difference to the number of baobabs with slightly oblique insertion for both Makueni (6.20±1.91) and Kwale counties (5.80±2.06) (Table 3). The results also reported no significant difference in the number of baobab fruits with oblique and very oblique across the four counties. However, there is reported number of baobabs with oblique insertion across the counties with no records on very oblique across the counties (Table 3).

3.3. Morphological Characteristics of Baobab Fruit on Fruit Beak

Table 4 shows the ANOVA results on fruit beak of the baobab fruits from different counties. The results for baobabs with absent fruit beak indicates that there is significant difference between the Makueni with other samples. There was also no significant difference between Taita Taveta and Kwale county. This result is backed up from results on Figure 4. which indicated that Makueni county (66.67%) had the highest percentage of baobabs fruits with absent fruit beak compared to Kilifi (9.5%), Kwale (23.8%) and Taita Taveta (0%). The results also indicated that there were no baobabs with absent fruit beak reported in Taita Taveta county. The results Table 4 indicates that there were significant differences amongst the baobab's fruits with perceptible -slightly seen beak from the four counties. Kilifi county differed significantly (p=0.110) with the rest of the counties. Additionally, there was no significant difference amongst the baobab with fruit beaks obtained from Makueni and Kwale county at P=0.110.

Table 4. Morphological characteristics of baobab fruit on fruit beak from Makueni, Taita Taveta, Kilifi and Kwale counties

Counties	Absent	Perceptible-Slightly seen	Pointed	Prominent
Makueni	5.60±2.16^{a}	4.40±2.16^{b}	0.00±0.00^{a}	0.00±0.00^{a}
Taita T.	0.00±0.00^{b}	10.00±0.00^{a}	0.00±0.00^{a}	0.00±0.00^{a}
Kilifi	0.80±0.49^{b}	4.00±2.07^{b}	3.40±2.09^{a}	1.80±1.80^{a}
Kwale	2.00±2.00^{ab}	5.60±1.96^{ab}	1.40±1.40^{a}	1.00±1.00^{a}
F-value	2.75	2.36	1.64	0.72
P-value	0.077	0.110	0.220	0.556
LSD	4.47	5.37	3.77	3.09
CV (%)	158.83	66.72	234.22	328.88

Mean values with the same superscript letters within the same column are not significantly different at Fisher's LSD test ($P<0.05$).

3.4. Morphological Characteristics of Baobab Fruit Hair Color, Fruit Surface, Fruit Shell Hairness and Fruit Shell Surface Texture

Analysis of the relationship between the selected counties (Taita Taveta, Makueni, Kilifi and Kwale) and the baobab fruit characteristics (fruit hair color, fruit surface, fruit shell hairness and fruit shell surface texture) showed three clusters. Taita Taveta county stood out different from the rest of the counties in the respective of the mean number of the baobab fruits with the selected characteristics. Additionally, there was no significant difference among the Kilifi and Kwale counties since they clustered together in respect to the selected baobab characteristics. In terms of the selected baobab fruit characteristics, hair color (green), fruit shell hairness (not hairy), hair color (brown) and fruit surface (deeply contoured) formed a cluster group since they were the same across the four counties. Hair color (yellow) also formed its own cluster since it was unique and was present in all four counties. Kwale county recorded the highest number of the baobab fruit with wrinkled fruit shell surface texture and shallow contour fruit surface compared to the rest of the counties. Though Makueni county recorded highest in shallow contour fruit surface and evenly hairy fruit shell hairness. The result also indicates that shallow contour fruit surface, wrinkled fruit shell surface texture and evenly hairy fruit shell hairness were the most dominant characteristics across the four selected counties.

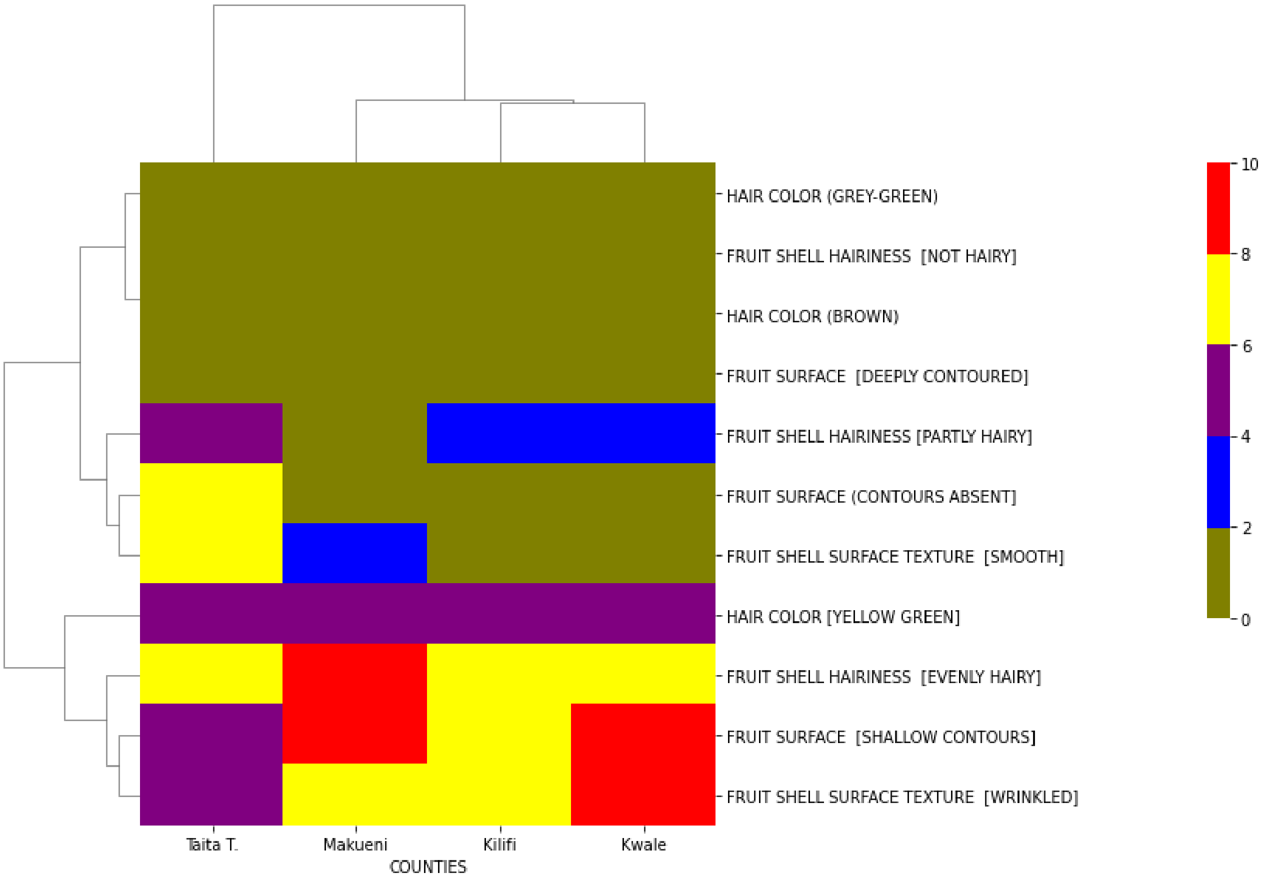

Figure 2. Hierarchical clustergram of assayed counties at varied fruit hair color, fruit surface, fruit shell hairness and fruit shell surface texture

Hierarchical clustergram generated using means of baobab fruit hair color, fruit surface, fruit shell hairness and fruit shell surface texture from Taita Taveta, Makueni, Kilifi and Kwale counties. The heatmap (Euclidean matric) shows the relationship between selected counties at different baobab fruit characteristics. The colored scale bar indicates the significant quantified strength of the baobab fruit characteristics. The red color in the heatmap indicates the highest, and the green color indicates the lowest significance at $P \leq 0.05$.

3.5. Morphological Characteristics of Baobab Fruit on Shell Hardness to Crack, Adherence of Fiber to Fruit and ATTY/AMT of Fibre in Fruit

Baobab fruits are covered with a shell which its role is to protect the flesh part of the fruit. Shell hardness is classified as easily cracked, slightly hard, hard, and very hard. The comparison was therefore assessed if there is variation of shell hardness irrespective to the geographical regions. The result (Table 5) showed that, there was no baobab fruit from the selected counties (Makueni, Taita Taveta, Kilifi and Kwale) that was easy to crack. There was also no significant difference for the baobab fruit from the same counties that were slightly hard to crack despite Taita Taveta recorded (2.00±2.00) some baobabs that were slightly hard to crack. The results (Table 5) indicated majority of the baobab fruits are hard to crack the shell and this was seen across the selected counties. However, there were significant differences irrespective to the regions. Whereby, Makueni county differs significantly from the Taita Taveta, Kwale and Kilifi counties. More so, there were no significant differences to baobabs obtained from Kilifi, Kwale and Taita Taveta counties in relation to the hard the shell is concern. There was also reported number of baobab fruits which were very hard to crack the shell across the counties despite having no significant differences.

In terms of the adherence of fibre to the fruit, this morphological characteristic is categorized into weak, intermediate, and strong adhesion. Most of the baobab's fruits had intermediate adherence and this is reported across the four counties. Despite that, Kilifi and Taita Taveta counties had the highest number of fruits with intermediate adhesion compared to both Makueni and Kwale county. In terms of the comparison per the counties. There was a significant difference between Taita Taveta/Kilifi to Makueni/Kwale counties (Table 5). Weak adherence was reported in Kwale county only. Strong adherence was also reported across the counties where Makueni had the highest number compared to the rest of the counties. Additionally, there was no significant difference in terms of strong adherence of fibre to the fruit across the four selected counties (Table 5).

Table 5. Morphological characteristics of baobab fruit on shell hardness to crack, adherence of fiber to fruit and ATTY/AMT of fibre in fruit from Makueni, Taita Taveta, Kilifi and Kwale counties

	Shell Hardness to crack				Adherence to fibre to fruit			QTTY/ AMT of fibre in fruit		
Counties	**Easily Cracked**	**Slightly Hard**	**Hard**	**Very Hard**	**Weak**	**Intermediate**	**Strong**	**Low**	**Intermediate**	**High**
Makueni	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	8.00 ± 2.00^{a}	2.00 ± 2.00^{a}	0.00 ± 0.00^{a}	6.00 ± 2.45^{b}	4.00 ± 2.45^{a}	2.00 ± 2.00^{a}	4.20 ± 2.37^{a}	3.80 ± 2.33^{a}
Taita T.	0.00 ± 0.00^{a}	2.00 ± 2.00^{a}	6.00 ± 2.45^{b}	2.00 ± 2.00^{a}	0.00 ± 0.00^{a}	8.00 ± 2.00^{a}	2.00 ± 2.00^{a}	3.60 ± 2.23^{a}	2.40 ± 1.94^{a}	4.00 ± 2.45^{a}
Kilifi	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	6.40 ± 2.20^{b}	3.60 ± 2.20^{a}	0.00 ± 0.00^{a}	8.00 ± 2.00^{a}	2.00 ± 2.00^{a}	0.00 ± 0.00^{a}	6.00 ± 2.26^{a}	4.00 ± 2.26^{a}
Kwale	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	6.40 ± 2.23^{b}	3.60 ± 2.23^{a}	2.00 ± 2.00^{a}	6.40 ± 2.23^{b}	1.60 ± 1.60^{a}	0.00 ± 0.00^{a}	4.40 ± 2.32^{a}	5.60 ± 2.32^{a}
F-value	.	1.00	0.16	0.19	1.00	0.23	0.28	1.36	0.44	0.13
P-value	.	0.418	0.923	0.901	0.418	0.872	0.837	0.292	0.730	0.942
LSD	.	3.00	6.67	6.33	3.00	6.53	6.1	4.49	6.68	7.01
CV	.	447.21	74.30	168.56	447.21	68.57	189.57	239.05	117.23	120.28

Mean values with the same superscript letters within the same column are not significantly different at Fisher's LSD test (P<0.05).

The ATTY/AMT of the fibre in fruit, most of the fruits had intermediate QTTY/AMT ranging 2-6. Kilifi county (6.00±2.26) recorded the highest mean number of baobab fruits with intermediate followed by Kwale (4.40±2.32) and Makueni (4.20±2.37) with Taita Taveta (2.40±1.94) recorder the least. Additionally, there was no significant difference among the counties at p<0.05. The result (Table 5) also indicated that baobabs from the selected counties had high QTTY/AMT fibre ranging 3-5 baobabs fruits per county. Kwale recorded the highest mean of 5.60±2.3 followed by both Taita Taveta (4.00±2.45) and Kilifi (4.00±2.26) and lastly Makueni county (3.80±2.33) (Table 5). Despite most of the baobabs recording intermediate and high QTTY/AMT, there was also reported case of low QTTY/AMT from both Taita Taveta (3.60±2.23) and Makueni county (2.00±2.00).

3.6. Morphological Characteristics of Baobab Fruit on Texture of Fibres in Fruits

The texture of fibre in fruit is characterized as soft, intermediate, and coarse. The results (Figure 3) indicate that the texture of fibre in fruit across Makueni, Taita Taveta, Kilifi and Kwale were intermediate and coarse. There was no baobab fruit with soft texture of fibre reported across the selected counties. Intermediate was highest in Makueni than any other county. Additionally, there was no significant difference when comes to intermediate across the counties and coarse texture across the counties. Kilifi county was special in that it had only coarse texture of fibres in fruits (Figure 3).

3.7. Morphological Characteristics of Baobab Fruit on Adherence of Fruit Pulp to Seed

The adherence of fruit pulp to seed has been described as weak, intermediate, and firm/strong. From the results, most of the baobab fruits across the four counties had intermediate adherence of fruit pulp to seed. Makueni county (8.00±2.00) had the highest means on intermediate adherence of the pulp to seed compared to Kilifi (6.20±2.33), Taita Taveta (6.00±2.45) and Kwale being the last (4.00±2.45). Additionally, in terms of significant differences of the intermediate adherence of fruit pulp to seed, Makueni county was significantly different from the rest of the counties (Table 6). There were also reported cases of firm/strong adherence across the counties despite there was no significant difference across the counties. Weak adherence was also reported in Taita Taveta (2.00±2.00), Kilifi (1.80±1.80) and Kwale county (4.00±2.45). Makueni county there was no reported number of baobab fruit with weak adherence of fruit pulp to seed.

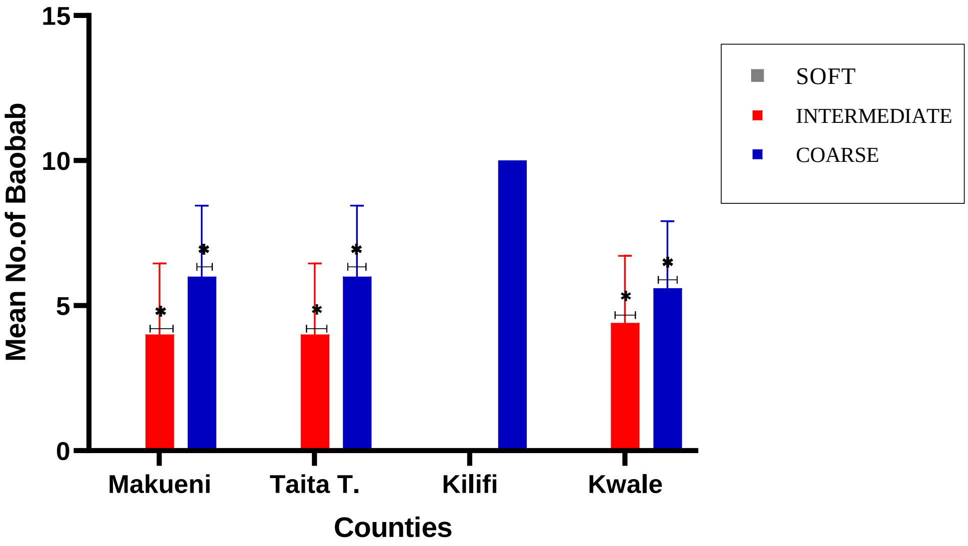

Figure 3. Morphological characteristics of baobab fruit on texture of fibres in fruits from Makueni, Taita Taveta, Kilifi and Kwale counties

Table 6. Morphological characteristics of baobab fruit on adherence of fruit pulp to seed from Makueni, Taita Taveta, Kilifi and Kwale counties

Counties	Weak	Intermediate	Firm/Strong
Makueni	0.00±0.00^{a}	8.00±2.00^{a}	2.00±2.00^{a}
Taita T.	2.00±2.00^{a}	6.00±2.45^{b}	2.00±2.00^{a}
Kilifi	1.80±1.80^{a}	6.20±2.33^{b}	2.00±2.00^{a}
Kwale	4.00±2.45^{a}	4.00±2.45^{b}	2.00±2.00^{a}
F-value	0.81	0.50	0.00
P-value	0.507	0.688	1.00
LSD	5.45	6.94	5.99
CV	208.62	85.57	223.61

Mean values with the same superscript letters within the same column are not significantly different at Fisher's LSD test (P<0.05).

3.8. Morphological Characteristics of Baobab Fruit on Seed Shape, Seed Testa Texture and Seed Testa Hardness

The seed morphology of the baobab fruit is classified into seed shape where oblong shape was not recorded in any of the selected counties. Taita Taveta (8.00±2.00) recorded the highest mean number of baobab fruits with reniform shape. The reniform shape among the seeds were significantly different across the counties. On other hand, very reniform seed shape was reported highest in Kwale County (9.60±0.40) compared to the rest of the counties. Significantly, very reniform seed shape was different across the counties despite Taita Taveta and Kilifi having no significant difference. In terms of the Seed Testa texture, Taita Taveta county (4.00±2.45) reported the highest number of soft/smooth texture compared to the rest of the counties. There was no significant difference across the counties for the soft/smooth seed Testa texture. Most of the baobab seeds across the counties had coarse/rough texture with no significant differences across the counties. In terms of the seed Testa hardness, most of the seeds were hard with Makueni and Taita Taveta recording the highest the number of seeds. There were also several seeds with intermediate and very hard seed Testa texture (Table 7).

3.9. Evaluation of the Most Discriminant Morphological Quantitative Traits among the Baobab Powdery Pulp from Makueni, Taita Taveta, Kilifi and Kwale Counties in Kenya

3.9.1. Baobab Fruit Length and Diameter (cm)

In fruit length, Kilifi county differed significantly (P<0.05) from the rest of the counties. Kwale also differed significantly (P<0.05) from rest of the county but there was no significant difference (P<0.05) among Makueni and Taita Taveta counties. Additionally, Kilifi (25.06±1.44cm) reported the highest fruit length which was followed by Kwale (18.98±1.91cm) and Makueni (12.18±0.66 cm) was the last. In terms of fruit diameter (longitudinal), ANOVA analysis revealed significant (P<0.05) variation in longitudinal and at 90° diameter of baobab fruits across the selected counties. The highest longitudinal diameter was recorded in Kilifi county (9.08±0.57cm) followed by Kwale (8.83±0.55cm), Taita Taveta (7.42±0.52cm) and lastly Makueni (7.10±0.25cm). At 90°, Kilifi (8.73±0.50cm) still had the highest diameter followed by Kwale (8.47±0.46cm) and Makueni (6.73±0.23cm) was the last.

Table 7. Morphological characteristics of baobab fruit on seed shape, seed Testa texture and seed Testa hardness from Makueni, Taita Taveta, Kilifi and Kwale counties

	Seed shape			Seed Testa Texture		Seed Testa Hardness			
Counties	**Oblong**	**Reniform**	**Very Reniform**	**Soft/Smooth**	**Coarse/Rough**	**Soft**	**Intermediate**	**Hard**	**Very Hard**
Makueni	0.00±0.00^{a}	4.00±2.45^{ab}	5.80±2.37^{ab}	1.80±1.80^{a}	8.00±2.00^{a}	0.00±0.00^{a}	2.00±2.00^{a}	6.00±2.45^{a}	1.80±1.80^{a}
Taita T.	0.00±0.00^{a}	8.00±2.00^{a}	2.00±2.00^{b}	4.00±2.45^{a}	6.00±2.45^{a}	0.00±0.00^{a}	2.00±2.00^{a}	6.00±2.45^{a}	2.00±2.00^{a}
Kilifi	2.00±2.00^{a}	3.80±2.33^{ab}	3.60±2.20^{b}	1.80±1.80^{a}	7.60±1.91^{a}	0.00±0.00^{a}	3.80±2.33^{a}	1.80±1.80^{a}	3.80±2.33^{a}
Kwale	0.00±0.00^{a}	0.00±0.00^{b}	9.60±0.40^{a}	1.60±1.60^{a}	8.00±2.00^{a}	0.00±0.00^{a}	2.00±2.00^{a}	4.00±2.45^{a}	3.60±2.23^{a}
F-value	1.00	2.77	2.96	0.34	0.21	.	0.19	0.76	0.25
P-value	0.418	0.075	0.063	0.794	0.891	.	0.905	0.535	0.862
LSD	3.00	5.89	5.73	5.81	6.30	.	6.26	6.91	6.30
CV	447.21	111.22	81.54	188.52	63.49	.	190.57	115.79	167.71

Mean values with the same superscript letters within the same column are not significantly different at Fisher's LSD test (P<0.05).

Table 8. Morphological characteristics of baobab fruit length and diameter from Makueni, Taita Taveta, Kilifi and Kwale counties

Counties	Fruit Length (cm)	Fruit diameter (Longitudinal cm)	Fruit diameter (At 90° cm)
Makueni	12.18±0.66^{c}	7.10±0.25^{c}	6.73±0.23^{c}
Taita T.	13.32±0.70^{c}	7.42±0.52^{bc}	7.17±0.52^{bc}
Kilifi	25.06±1.44^{a}	9.08±0.57^{a}	8.73±0.50^{a}
Kwale	18.98±1.91^{b}	8.83±0.55^{ab}	8.47±0.46^{ab}
F-value	21.07	4.09	4.84
P-value	<.0001	0.0248	0.0139
LSD	3.86	1.48	1.33
CV	16.57	13.57	12.73

Mean values with the same superscript letters within the same column are not significantly different at Fisher's LSD test (P<0.05).

3.10. Morphological Characteristics of Baobab Fruit Weight, Pulp+ Seed Weight, Pulp Weight, Total Seed Weight, Fibre Weight and Shell Weight

In fruit weight Kilifi county and Kwale county differed significantly (p<0.05) from Makueni and Taita Taveta county. There was no significant difference (P<0.05) between Makueni and Taita Taveta county (Table 9). Additionally, Kilifi county (319.16± 45.89g) reported the highest fruit weight followed by Kwale (240.84±62.78g), Taita Taveta (114.16±19.57g) and lastly Makueni county (101.74±6.18g). For pulp +seed weight, ANOVA analysis revealed significant (P<0.05) variation across the selected counties. Kilifi county (152.16±18.20g) recorded the highest pulp+ seed weight followed by Kwale (110.06±29.22g), Taita Taveta (59.53±12.12g) and lastly Makueni (51.87±3.52g).

In pulp weight, ANOVA analysis revealed there is no significant difference between the Makueni and Taita Taveta county (Table 9). Additionally, Kilifi county differs significantly (p<0.05) against all the selected counties. Kilifi county (60.12±11.47g) had the highest weight, followed by Kwale (35.65±16.91g), Taita Taveta (19.22±3.97g) and lastly Makueni county (17.42±1.70g). For total seed weight, ANOVA analysis showed significant (P<0.05) variation across the selected counties. Kilifi county (92.06±11.84g) had the highest total seed weight followed by Kwale (71.58±16.48g), Taita Taveta (39.26±8.04g) and Makueni county (34.59±2.41g). For fibre weight and shell weight, Kilifi county and Kwale county differed significantly (p<0.05) from Makueni and Taita Taveta county (Table 9). There was no significant difference (P<0.05) between Makueni and Taita Taveta county. Kilifi county recorded the highest fibre weight (5.17±0.44g) and shell weight (159.68±31.97g). Makueni county on other hand reported the least fibre weight (1.86±0.29g) and shell weight (46.30±2.63g).

3.11. Morphological Characteristics of Baobab Fruit on Seed Length and Shell Thickness

The results (Figure 4) show that Kilifi county had the highest seed length (11.45mm) followed by Kwale (11.26mm). Makueni county (10.08mm) had the lowest seed length recorded. In terms of shell thickness, Kilifi county (6.78mm) recorded the highest shell thickness, followed by Kwale (6.48mm), Taita Taveta (6.36mm) and Makueni (5.46mm) was last.

Table 9. Morphological characteristics of Baobab fruit weight, Pulp+ Seed weight, Pulp Weight, Total seed weight, fibre weight and shell weight from Makueni, Taita Taveta, Kilifi and Kwale counties

Counties	Fruit Weight	Pulp+ Seed Weight	Pulp Weight	Total seed weight	Fibre Weight	Shell Weight.
Makueni	$101.74±6.18^{b}$	$51.87±3.52^{c}$	$17.42±1.70^{b}$	$34.59±2.41^{c}$	$1.86±0.29^{b}$	$46.30±2.63^{b}$
Taita T	$114.16±19.57^{b}$	$59.53±12.12^{bc}$	$19.22±3.97^{b}$	$39.26±8.04^{bc}$	$2.53±0.51^{b}$	$53.78±8.07^{b}$
Kilifi	$319.16± 45.89^{a}$	$152.16±18.20^{a}$	$60.12±11.47^{a}$	$92.06±11.84^{a}$	$5.17±0.44^{a}$	$159.68±31.97^{a}$
Kwale	$240.84±62.78^{a}$	$110.06±29.22^{ab}$	$35.65±16.91^{ab}$	$71.58±16.48^{ab}$	$4.61±0.74^{a}$	$127.36±33.75^{a}$
F-value	6.75	6.55	3.59	6.18	9.49	5.55
P-value	0.0037	0.0043	0.0371	0.0054	0.0008	0.0084
LSD	120.56	54.97	31.31	32.93	1.55	70.83
CV	46.35	43.89	70.54	41.36	32.72	54.59

Mean values with the same superscript letters within the same column are not significantly different at Fisher's LSD test (P<0.05).

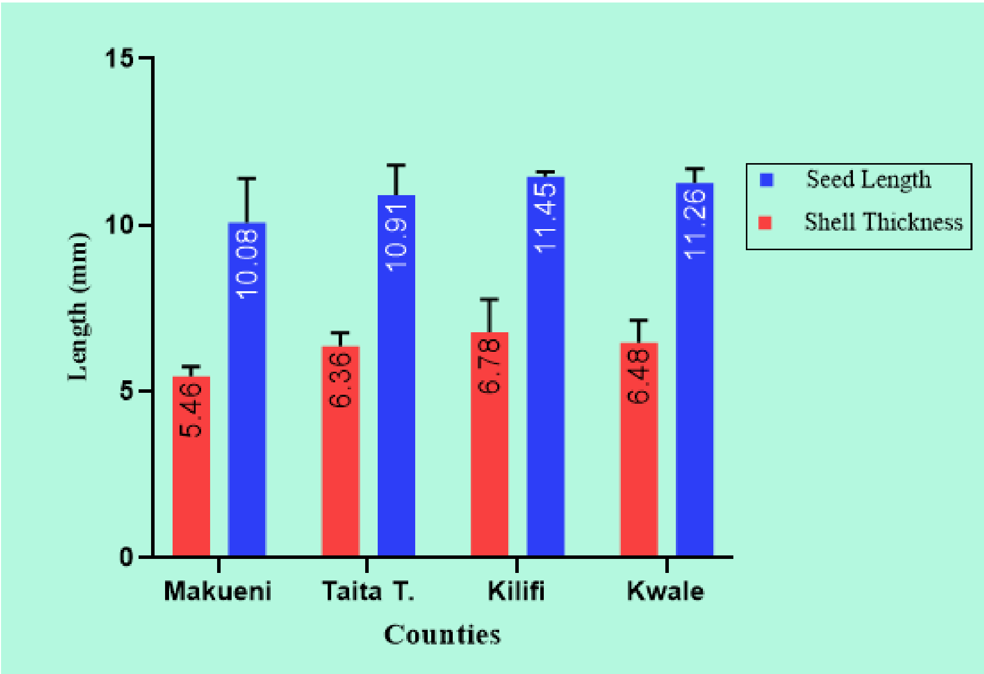

Figure 4. Morphological characteristics of baobab fruit on seed length and shell thickness from Makueni, Taita Taveta, Kilifi and Kwale counties

4. Discussion

There was variation of the evaluated morphological trait of the Baobab fruit characteristics in the four-study area. Fruit shape is one of the important activities in the morphological characterization of intraspecific diversity in fruits that are not only used for quality assessment of fruits, but also for clone description and selection as well as for studying trait heritability [23].Fruit shape variation in baobab may be a result of genetic, but also climatic and other environmental factors [16] There was a high tree-to-tree variability regarding fruit shapes of baobab fruit from Makueni, Taita Taveta, Kilifi and Kwale County with Oblong-cylindrical fruit shape stood to be dominant traits in Makueni and Kilifi counties compared to Taita Taveta and Kwale county. Oblong-irregular was not obtained from any of the county sampled. However, Ellipsoid shape was found in all the four counties with Kilifi recorded highest number compared to Makueni, Kwale and Taita Taveta counties. Despite that, globose fruit shape was only found in Taita Taveta and Kwale counties. The results concur with the previous findings reported by Gurashi and Kordofani [20], whose findings indicate ellipsoid was the most frequent fruit shape [23,24,25]. Among the two-region sampled in Sudan. Additionally, the results differ from baobab fruit from Mali which according to [23], they were mostly elongated shape. According to [20], most of the baobab fruits from Kilifi and kitui had ellipsoid shape.

Fruit apex and stalk insertion are one of the characteristics that differentiate different types of baobab fruits. The fruit apex according to IGRAF descriptors ranges from acute pointed to concave while stalk insertion ranges from vertical to very oblique. Different baobab fruits have been characteristic depending on the type of apex and stalk insertion they have. From the study, acute pointed apex was dominant trait across the four counties with others having obtuse apex. Few of the samples were round and concave and were only obtained from Makueni county. On stalk insertion, slightly-oblique was dominant across the study areas. The findings agree with [20] who reported obtuse apex and slightly oblique stalk insertion as the dominant characteristics across Kilifi and Kitui baobab fruits. However, the study disagrees with the findings from Sachez et al., [16] who reported Malawi baobab fruis having round apex. This can be because of different geographical region with genetic variation hence different in fruit apex of Kenyan and Malawian baobab fruits.

According to ICRAF, fruit beak is one of the characteristics used in classifying fruits. These characteristics have been used for baobab fruits. From the study, perceptible was dominant across the study area.Despite that Makueni baobab fruits most had absent fruit beak. The results also indicate variation among the study areas in terms of the level of perceptible fruit beak.This can be due to geographical regions in that they belong in coastal and easter region which have different climate hence, variation. Similar results have also been reported by [20]. There was relationship between the fruit color, surface, shell hairness and shell surface texture where the results grouped Kilifi and Kwale in one cluster differencing them from Makueni and Taita Taveta county. The result agrees with the findings from [23,27]. Additionally, according to [28] there is a close relationship amongst fruit color, surface, hairness of the shell and shell texture. Despite the above characteristics not mapped to the genetic diversity among the baobab fruits.

According to the literature, shell hardness to crack across baobab fruits have been hard. The findings have also been reported from various study. For instance, [28] indicated that just like coconut, baobab fruits have hard shell with intermediate adherence of fibre to fruit and with high quantity of the fibre in fruit. The fruit from our study shows that most of the baobab fruit across Makueni, Taita Taveta, Kilifi and Kwale had hard shell hardness to crack, intermediate adherence of fibre to fruit and high quantity/amount of fibre in fruit. The study also reported fruit texture of fibre in fruit which showed most of them were coarse. The texture of fibre in fruit also correlates to fibre adherence and quantity/ amount of fibre in the fruit [29]

The present study showed a correlation on adherence of the fruit pulp seed and seed shape, texture and testa hardness. Fruit pulp seed recorded intermediate across the Makueni, Taita Taveta, Kilifi and Kwale. This was also seen when comes to general seed characteristics whereby, seed shape varied from county to county with rough seed testa texture and hard seed testa. The results agree with the previous findings as reported by [30] who reported that climatic and environmental factors are the major contributor of different attributes among the baobab fruits. In fact, by the fact that they are found in semi-desert regions makes their seeds to have rough and hard testa as a way of surviving against harsh conditions [30].

The present study found significant differences in fruit length and fruit thickness, fruit weight, pulp +seed weight, pulp weight, total seed weight, fibre weight and shell weight between the Makueni, Taita Taveta, Kilifi and Kwale counties in Kenya. Baobab fruits from Kilifi and Kwale Counties with their slightly more humid climate were longer, wider, and heavier as compared to the fruits from Makueni and Taita Taveta Counties, which have a transitional to semi-arid climate [21,22] Similar differences were also found in studies from other parts of Africa. In Mali, for example, where 10 regions were surveyed, mean fruit weight and pulp weight were significantly higher in the wettest than the driest areas [32]. Contrarily, fruit weight was either slightly negatively correlated with annual precipitation in Malawi [16] or did not show any clear trend [10]. Most probably, both genetic factors and environmental variables such as precipitation and soil characteristics influence fruit quantitative traits [10,16] together with genotype x environment interactions [32]. Due to the high variation that was found in the present study, further research needs to be done focusing particularly on environmental and genetic factors as agents causing variation on different traits. However, as the above-described tree-to-tree variation usually follows a pattern of continuous variation, such trials may not be efficient in short time and it might be better to use a decentralized, local participatory domestication approach on a village level [12,17,18,19], which may also help to minimize the effect of the 'genetic bottleneck' during the domestication process [14]

According to Assogbadjo et al. [1] study baobab morphological traits assessed showed diverse variability in fruit length, fruit weight, shell thickness and pulp amount between fruits from the Inland and Coastal regions. The significant differences observed agree to baobab studies by Gurashi et al. [20], who also observed significant differences in fruit length, shape, and weight within and between studied sites in Sudan.

Mean seed weight (0.639 g), seed length (11.24 mm), seed width (8.69 mm) and seed thickness (7.1 mm) reported in this study was higher than those obtained by Munthali et al. [10] in baobab accessions from Malawi. Similarly, the present study reported lower seed weight (0.639 g) compared to Omondi et al.'s mean seed weight (132.5g). This could be attributed to different climatic zones of the study areas. Baobab located in harsh climate characterized by high temperatures and long water stress tend to preserve substrates hence are larger and heavier compared to its counterparts found in wetter climatic zones [10]. Fruit characteristics observed in the current study varied with previous studies. Fruit length (15.44cm) and fruit width (7.58cm) was lower than 30cm and 10cm attained by Gebauer, El-Siddig & Ebert [21] study in Sudan and then 22.1 cm and 10.4 cm by Omondi et al. [6] in Kilifi, Kitui and Makueni countries, Kenya. Mean fruit weight ranged from 108-453g which was higher than Munthali et al. [10] but within the range of Omondi's et al [6] fruit weight at 376.1 g. Differences in baobab fruit morphological traits across different climatic zones have also been revealed in studies conducted in areas of Benin [22]. The study established a correlation between environmental conditions and morphological characteristics. On the other hand, high values of Carbon / Nitrogen ratio are negatively associated with pulp and kernel production as well as with the development of baobab fruit trees. However, other baobab fruit morphology traits presented low difference. The difference in the morphological traits observed could therefore be attributed to the difference in the environmental effects between the two regions (Coastal and Inland). The coastal regions tend to have higher values of the morphological traits compared to the inland areas. These differences are reflected in Omondi et al.'s findings on the morphological traits between Kilifi county and Kitui/Makueni County with the latter being lower. The selection of the superior trees in the present study was only based on three traits, the fruit weight (as a proxy for yield), pulp proportion and the sweet taste of the fruit pulp. These traits have been reported as useful by Sanchez et al. [16] in their studies on baobab elite tree selection performed in Malawi and Mali. However, further traits should be assessed and considered for the final selection of the elite trees, including possible annual variability of yield regarding fruit numbers and weights or of fruit pulp quality parameters such as nutrient contents, particularly of sugar, vitamin C, calcium, and iron. [23] suggested consideration of the primary and secondary products of a tree species during the selection process of elitetrees. In the case of baobab, the focus should therefore not only be on the fruit pulp, but also on seed oil content (for oil production) or on leaf traits (for vegetable production).

The 'ideotype' concept, developed by [23] could help in the selection of the respective elite baobab trees. This concept refers to the systematic characterization of the tree to-tree variation for different traits such as fruit, seed, leaf or timber traits, then selecting those with specific demands, drawing multi-trait spider-web graphs and finally developing the ideotype (or several ideotypes) of elite trees for domestication that meet most of the demands. In the case of baobab, different ideotypes can be developed such as (i) a 'fruit pulp ideotype' with high weight, proportion, and nutrient contents of its pulp, (ii) a 'seed ideotype' with low pulp, but high seed proportion and with seeds of high oil content, and (iii) a 'vegetable ideotype' with high and continuous production of most nutrient-rich and tasty leaves. This should all be done in a participatory tree domestication process, so that farmers and other stakeholders along the value chain (processors and traders) are empowered to create their own cultivars in the selection of the elite tree for domestication [21,32]. The present study represents a first step towards baobab domestication, and future efforts should include more stakeholders, larger parts of the baobab growing area and more desired traits for the selection of elite trees.

5. Conclusion

The morphological characteristics of baobab fruit in Makueni, Taita Taveta, Kilifi and Kwale counties was achieved using different descriptor. Additionally, molecular work should be carried out to quantify the diversity of baobab fruits from Makueni, Taita Taveta, Kilifi and Kwale counties.

Declaration of Interest Statement

The authors declare that they have no conflict of interest.

Acknowledgements

I am grateful to the World Agroforestry Centre (ICRAF) and Biosciences eastern and central Africa (BecA - ILRI Hub) for the molecular work). This study was funded by the International Fund for Agricultural Development (IFAD) and the European Commission under the project 'Tree crops development in Africa to benefit the poor' and by the CGIAR research program A4NH (Agriculture for Nutrition and Health).

References

[1] Assogbadjo AE, Kyndt T, Sinsin B, Gheysen G, Van Damme P. 2006. Patterns of genetic and morphometric diversity in baobab (Adansonia digitata) populations across different climatic zones of Benin (West Africa). Ann. Bot. 97(5):819-30.

[2] Maundu P, Tengnas B. 2005. *Useful trees and shrubs for Kenya*, World Agroforestry Centre, Nairobi, Kenya.

[3] Chadare FJ, Linnemann AR, Hounhouigan JD, Nout MJ, Van Boekel MA. (2009). Baobab food products: a review on their composition and nutritional value. Critical Reviews in Food SciNutr. 49(3):254-74.

[4] Stadlmayr B, Charrondiere UR, Eisenwagen S, Jamnadass R, Kehlenbeck K. 2013. Nutrient composition of selected indigenous fruits from sub‐Saharan Africa. JSci Food Agr. 93(11):2627-36.

[5] Rashford, J. (2018). The use of Baobab leaves (Adansonia digitata L.) for food in Africa: A review. *Economic Botany*, *72*(4), 478-495.

[6] Omondi, M., Rimberia, F. K., Wainaina, C. M., Mukundi, J. B. N., Orina, J., Gebauer, J., & Kehlenbeck, K. (2019). Fruit morphological diversity and productivity of baobab (Adansonia digitata L.) in coastal and lower eastern Kenya. *Forests, Trees and Livelihoods*, *28*(4), 266-280.

[7] Jäckering, L., Fischer, S., & Kehlenbeck, K. (2019). A value chain analysis of baobab (Adansonia digitata L.) products in Eastern and Coastal Kenya. *Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS)*, *120*(1), 91-104.

[8] Fischer, S., Jäckering, L., & Kehlenbeck, K. (2020). The Baobab (Adansonia digitata L.) in Southern Kenya–A Study on Status, Distribution, Use and Importance in Taita–Taveta County. *Environmental management*, *66*(3), 305-318.

[9] Kirui, K. C. (2020). *Consumer Awareness, Purchases and Attitudes towards Baobab (Adansonia digitata L.) Products in Urban and Rural Markets of Kenya* (Doctoral dissertation, JKUAT-AGRICULTURE).

[10] Munthali, C. R. Y., Chirwa, P. W., & Akinnifesi, F. K. (2012). Phenotypic variation in fruit and seed morphology of Adansonia digitata L.(baobab) in five selected wild populations in Malawi. *Agroforestry systems*, *85*(2), 279-290.

[11] Ruffo CK, Birnie A, Tengna’s B.2002. Edible wild plants of Tanzania. Regional Land Management Unit (RELMA). English Press, Kenya.

[12] Kyndt T, Assogbadjo AE, Hardy OJ, GleleKakaïR, Sinsin B, Van Damme P, Gheysen G. 2009. Spatial genetic structuring of baobab (Adansonia digitata, Malvaceae) in the traditional agroforestry systems of West Africa. Am. J. Bot. 96(5): 950-7.

[13] Sibibe M, Williams JT. 2002. Baobab–Adansonia digitata Fruits for the future. Int Centre Underutil Crops. University of Southampton, UK.

[14] FDA, U., 2009. Agency Response Letter GRAS Notice No. GRN 000274 [Subject: Branching glycosyltransferase enzyme preparation from Bacillus subtilis expressing a branching glycosyltransferase gene from Rhodothermus obamensis]. Washington (DC): US Food and Drug Administration (US FDA). *Center for Food Safety and Applied Nutrition (CFSAN), Office of Food Additive Safety. Available at: http://www. fda. qov/Food/FoodInqredientsPackaging/GenerallyRecognizedasSafe GR AS/GRASListings/ucm185687. htrn [June 25, 2009].*

[15] Buchmann C, Prehsler S, Hartl A, Vogl CR. 2010. The importance of baobab (Adansonia digitata L.) in rural West African subsistence—suggestion of a cautionary approach to international market export of baobab fruits. Ecol Food Nutr. 49(3): 145-72.

[16] Sanchez AC, Osborne PE, Haq N. 2011. Climate change and the African baobab (Adansonia digitata L.): the need for better conservation strategies. Afr. J. Ecol. 49(2): 234-45.

[17] Kehlenbeck K, Asaah E, Jamnadass R. 2013. Diversity of indigenous fruit trees and their contribution to nutrition and livelihoods in sub-Saharan Africa: examples from Kenya and Cameroon. Diversifying food and diets: Using agricultural biodiversity to improve nutrition and health. 257-69.

[18] Kehlenbeck K. Padulosi S,AlerciaA. 2015. Descriptors for baobab (*Adansonia digitata* L.). Bioversity International, Rome, Italy and World Agroforestry Centre, Nairobi, Kenya.

[19] Kindt R, Lillesø JP, van Breugel P, Bingham M, Sebsebe D, Dudley C, Friis I, Gachathi F, Kalema J, Mbago F, Minani V. 2011. Potential natural vegetation of eastern Africa, Description and tree species composition for other potential natural vegetation types. Forest and Landscape Working paper. 5:65-2011.

[20] Gurashi NA, KordofaniMAY. 2014. Morphological Variation in Fruit shapes of *Adansonia digitata* L. From Blue Nile and North Kordofan States, Sudan. JFPI.3: 2325-4513.

[21] Gebauer, J., El-Siddig, K., & Ebert, G. (2002). Baobab (Adansonia digitata L.): a review on a multipurpose tree with promising future in the Sudan. *Gartenbauwissenschaft*, *67*(4), 155-160.

[22] Assogbadjo AE, KAKAI RG, Kyndt T, Sinsin B. 2010. Conservation genetics of baobab (Adansonia digitata L.) in the parklands agroforestry systems of Benin (West Africa). Not Bot *Horti* Agrobot *Cluj Napoca*. 38(2):136-40.

[23] Bell, K. L., Rangan, H., Kull, C. A., & Murphy, D. J. (2015). The history of introduction of the African baobab (Adansonia digitata, Malvaceae: Bombacoideae) in the Indian subcontinent. *Royal Society open science*, *2*(9), 150370.

[24] Chikamai B,ChatatT. 2009. Forest management for non-wood forest products and services in Africa. KeFRI, Nairobi, Kenya.

[25] Chládová, A., Kalousová, M., Mandák, B., Kehlenbeck, K., Prinz, K., Šmíd, J., ... & Lojka, B. (2019). Genetic diversity and structure of baobab (Adansonia digitata L.) in southeastern Kenya. *Royal Society open science*, *6*(9), 190854.

[26] Gebauer J, Adam YO, Sanchez AC, Darr D, Eltahir ME, Fadl KE, Fernsebner G, Frei M, Habte TY, Hammer K, Hunsche M.2016. Africa’s wooden elephant: the baobab tree (Adansonia digitata L.) in Sudan and Kenya: a review. Genet Resour Crop Ev. 63(3): 377-99.

[27] Gurashi, N. A., Kordofani, M. A., & Elkhalifa, K. F. (2019). Variations in fruit and seed characteristics of baobab (Adansonia digitata L) in wild stands in the Sudan. *Agriculture and Forestry Journal*, *3*(2), 64-73.

[28] Kamau, C. (2016). *Genetic Diversity and Phylogenetic Analysis of Adansonia Spp. In the Kenya/Tanzania Transect* (Doctoral dissertation, University of Nairobi).

[29] Li YC, Korol AB, Fahima T, Beiles A, Nevo E. 2002. Microsatellites: genomic distribution, putative functions and mutational mechanisms: a review. Mol. Ecol. 11(12): 2453-65.

[30] Muriungi, M. K., Kavoi, M. M., Majiwa, E., & Mithöfer, D. (2021). Characterization and Determinants of Baobab Processing in Kenya. *International Journal of Food and Agricultural Economics (IJFAEC)*, *9*(1128-2021-1287), 215-228.

[31] National Drought Management Authority. 2021. Long and Short Rains Assessment Reports. https://www.ndma.go.ke/index.php/resource-center/category/28-long-short-rains-assessment-reports.

[32] Odoom, D.A., 2021. Characterization of Baobab (Adansonia digitata L.) in the Builsa District of Ghana.