Trees, Forests and People 8 (2022) 100270

Contents lists available at ScienceDirect

Trees, Forests and People

journal homepage: www.sciencedirect.com/journal/trees-forests-and-people

Distribution and population status of *Adansonia digitata* L. (baobab) and its contribution to livelihood in Makueni County, Kenya

Josephine K. Musyoki, Magrate M. Kaigongi *, Sylvia M. Uchi, Stephen M. Kiama, Joseph Githiomi, George M. Muthike, Albert M. Luvanda

Kenya Forestry Research Institute, Nairobi P. O Box 20412-00200, Kenya

ARTICLE INFO

Key words:
Adansonia digitata
Baobab
Distribution
Populations
Livelihood

ABSTRACT

Adansonia digitata L. commonly known as baobab is a globally known high valued multipurpose tree. The current study was designed to map the distribution and determine the effects of different land use systems (cropland, grazing land and settlement area) on the species population density, composition, health and productivity in Makueni County. Livelihood potential of baobab in the studied area was also assessed. Two sub counties; Kibwezi East and West in Makueni County where baobab populations occur were purposely selected for this study. A reconnaissance study was carried out followed by selection of three contrasting representative land use systems: Namely cropland, grazing land and settlement area/homesteads using Google Map through a desktop study. Plots of 0.5 km long and 0.25 km wide were used to assess the population and health status of baobab trees. Market centers and chiefs' camps were randomly sampled for a household and market survey where a total of 423 informants were interviewed. Baobab growth characteristics across the three land use systems in the two sub counties as well as household and market data were analyzed using GraphPad Prism version 8.4.3. The waypoints were downloaded from the Garmin etrex 10 GPS handset into Arc Map 1.0 of Arc Geographic Information System (GIS) (ESRI, Redlands, CA) where the baobab distribution maps were generated. The findings revealed that the baobab populations occurred in clusters of high to low density. Density and fruit production of baobab trees were statistically different across the three land use systems in the two sub counties while height, DBH and crown diameter did not differ significantly. No saplings were found in the study area. The study revealed that there is a huge potential for baobab fruits in diet especially during food scarcity. Therefore, farmer training is advisable to augment local knowledge and skills for enhanced value addition of baobab products.

1. Introduction

Adansonia digitata L. (Malvaceae), commonly known as baobab occurs in the dry, hot savannah of sub-Saharan Africa. Countries where baobab mainly occurs include but not limited to Kenya, Tanzania, Zimbabwe, Burkina Faso, Sudan and South Africa (Fischer et al., 2020; Sidibe et al., 2002). Baobab trees can grow up to 25m tall with a diameter of 12m (Rahul et al., 2015). The fruits are large and valued for their citrus-like flavor (Gebauer et al., 2002). Local communities across Africa mainly utilize baobab leaves, pulp, and seeds as a source of food and income (Buchmann et al., 2010). Both fresh and dried leaves as well as fruits are a food buffer during the dry season and a valuable source of income (De Caluwé and Van Damme, 2011). The pulp, leaves and seeds are also linked to various health benefits hence they are incorporated into local dishes (Assogbadjo et al., 2012; Cissé et al., 2013; Muthai et al., 2017). Increasing market demand and changing climate puts pressure on baobab natural populations, which may negatively affect their viability and survival. Domestication and sustainable cultivation of the species can be an option to increase tree population and its products, as well as conserve current natural populations (Bell et al., 2015).

In Kenya, baobab has been listed by local communities as a high priority food tree for future domestication due to its multiple uses (Kehlenbeck et al., 2013). The species is distributed in the eastern part of the country in two belts; the inland belt (from the Tanzanian border east of Mount Kilimanjaro towards the North East around Kitui Town) and coastal belt (Gebauer et al., 2016). It occurs in a wide altitudinal range; from sea level up to 1058 m elevation in diverse vegetation types such as deciduous bush land, woodland and grassland, but also thrives in areas with high rainfall at the coast (Gebauer et al., 2016; Wickens, 2008). The counties where baobab grows in Kenya include Kitui, Kilifi, Kwale, Taita

* Corresponding author.
E-mail address: mkaigongi@kefri.org (M.M. Kaigongi).

https://doi.org/10.1016/j.tfp.2022.100270
Received 6 January 2022; Received in revised form 2 May 2022; Accepted 2 May 2022
Available online 5 May 2022

Taveta, Makueni, Tharaka Nithi, and Lamu; which are hotspots of food and nutritional insecurity as well as having high poverty levels (Kiprotich et al., 2019). Several studies on baobab population structure and size classes in other countries in Africa indicate there is a scarcity of young individuals (Fischer et al., 2020; Mpofu et al., 2012; Munyebvu et al., 2018; Omondi et al., 2019; Orina et al., 2021; Venter and Witkowski, 2010). Reports on performance of baobab in different land use systems are limited (Orina et al., 2021). While there is increasing interest from both the government and private stakeholders on possibility of commercialization of baobab products, there still remains a lot of information gaps, particularly in Kenya. These include its distribution, population density, productivity, seasonality, local uses, potential products and markets (Fischer et al., 2020; Meinhold and Darr, 2020; Omondi et al., 2019; Orina et al., 2021). Irrespective of the heightened interest in assessment of baobab in Kenya (Omondi et al., 2019; Orina et al., 2021), little has been done in Kibwezi, Makueni County, which is characterized by the largest population stands of baobab.

Makueni County is characterized by a rapidly growing population, water scarcity, falling food production, and low resilience to climate change. The county is largely arid and semi-arid and usually prone to frequent drought periods (GOK, 2018). Wild fruit trees and particularly baobab have played an important role as a fall back for the communities during such seasons (Jäckering et al., 2019). However, production of baobab has been dwindling over time due to anthropogenic factors hence the need to determine the status of baobab tree population, distribution and productivity of the available trees. The current study was designed to determine how different land uses affect baobab population density, composition and productivity. A hypothesis that cropland, grazing land and settlement area/homesteads have similar baobab population characteristics was used as they were all under similar climatic conditions. The study also aimed at mapping the baobab tree distribution and describing the market structure and how baobab products support the livelihoods of people in Makueni County. The information generated from this study will help in designing the conservation and commercialization strategies required for this valuable tree in Kenya through government- private partnerships.

2. Materials and methods

2.1. Study site

The study was conducted in Makueni County, which lies between latitude -1.516931 dd and -2.991049 dd and longitude 37.141266 dd and 38.519085 dd, covering 8,009 square kilometers. Makueni County is subdivided into six sub-counties namely; Mbooni, Kaiti, Kilome, Makueni, Kibwezi West and East Fig. 1. The study focused on two sub counties; Kibwezi West and East which are known to contain high populations of baobab trees. The other sub counties regularly experience lower temperatures making survival of baobab a challenge.

2.2. Sampling design

A reconnaissance survey was carried out in February, 2020 to identify key areas where baobab grows within Makueni County as well as for the socioeconomic study. It was found that the baobab grew majorly in highest densities in Kibwezi East and West which formed the basis for selecting the two sub counties for this study. Representative sites of three contrasting land use systems, namely cropland, grazing land and settlement area/homesteads in the two sub counties were selected through a desktop study using Google Map which were later verified on the ground to be true.

The sampling was designed according to (Fischer et al., 2020) with slight modification where a plot of 0.5 km long and 0.25 km wide ($0.125 km^2$ equivalent to 12.5 ha) was used. Baobab trees within each

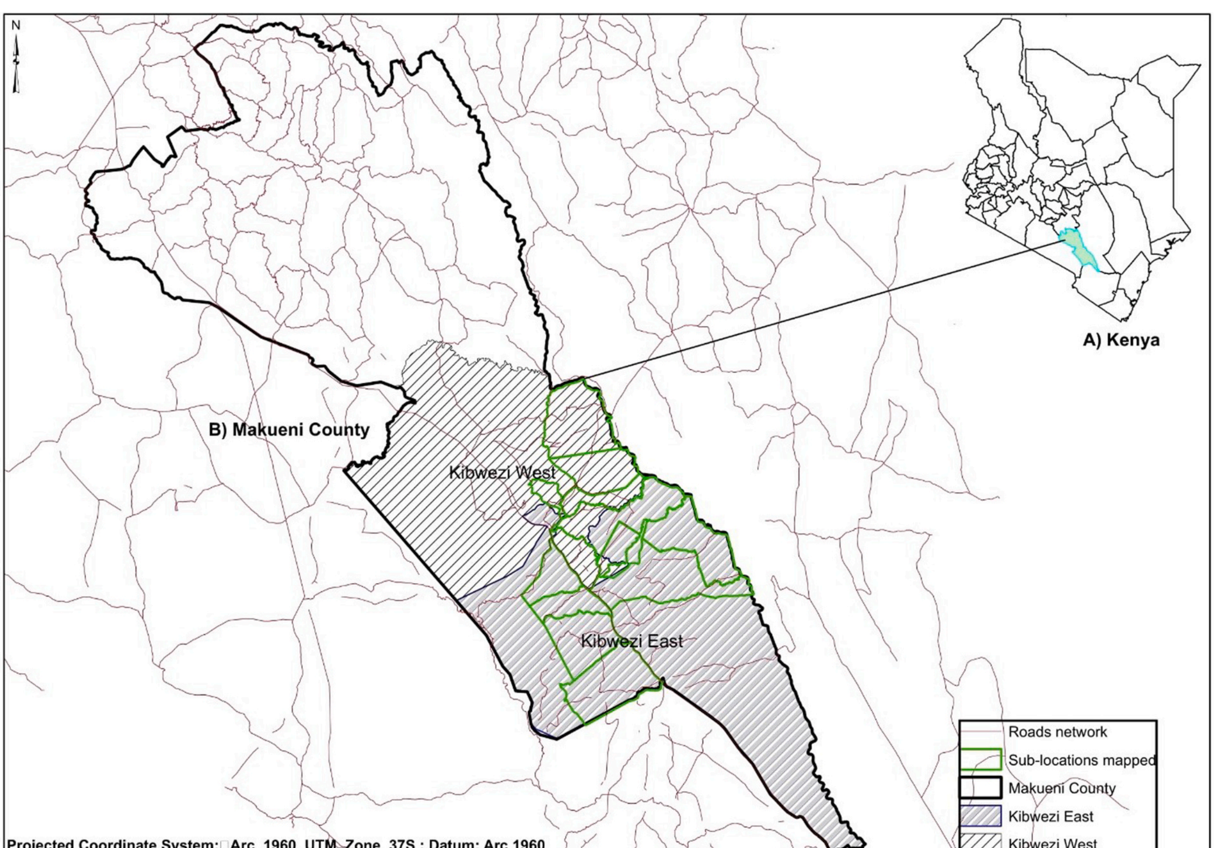

Fig. 1. A) Showing the location of Makueni County in Kenya; B) the two sub counties where the study was conducted.

plot were all sampled and those occurring along plots margins sampled if at least half of the canopy was inside the plot belt transect (Sanchez, 2011). In the field, the first corner of the main plot was established using a Global Positioning System (GPS), and other three corners laid using bearings in the four cardinal directions orientation. A total of 24 and 10 plots respectively, accounting to 425 ha (i.e., 300 ha and 125 ha in Kibwezi East and Kibwezi West respectively) were sampled. In Kibwezi East, 8 plots were sampled in each land use system while in Kibwezi West, 3 plots were each assessed in crop land and grazing areas while 4 plots were assessed in settlement areas. Fewer plots were assessed in Kibwezi West compared to Kibwezi East due to bad terrain which made some plots inaccessible. This study was carried out between May and July 2020. This is usually the peak period for ripening and harvesting of baobab fruits in the study area.

During the reconnaissance survey, the local administration officers (Chiefs and/or their Assistants) of each area were informed of the scheduled socioeconomic survey. The local administration played a critical role in informing the local population of the meetings (locally known as barazas) where focused group discussions were held. These administrators did not have control over the attendance and therefore, those who attended were very random with minimal bias. This was also the case with market survey during the market days, where, the attendance in the market was also random. A total of 423 informants were interviewed in both the socioeconomic and market surveys.

2.3. Estimation of baobab population, size classes and distribution

In every plot, each baobab tree found was isolated as a focal tree and its specific location captured using a hand-held GPS receiver. From the edge of the canopy of each focal tree, a circular plot of 30 m in radius was demarcated following an approach by Selanniemi et al. (2000). This was meant to assist in spotting any sapling or seedlings growing under or near the mother trees. A diameter tape was used to determine the diameter at breast height (dbh) of the stem. Trees that forked below 1.3 m were treated as two separate stems (Thies et al., 2004). The height of each tree was estimated using a suunto clinometer and its crown diameter measured with a linear tape.

Baobab trees were divided into juvenile (<1m DBH) and mature (≥1m DBH) as described by Venter and Witkowski (2010). The extent of debarking or external damage of the stem was assessed as described by Dovie (2003) through assigning the disturbance levels into one of the three different categories; 0-intact (those without any damages), 1- cut branches 2- debarked, 3-debarked with cut branches. The state of health of the tree was also noted on a categorical scale as described by Sharp (1993): 1-healthy and 2-diseased (including trees affected by molds and parasitic plants). Counting of fruits was done on mature trees only by randomly selecting and visually counting the fruits on 50% of crown cover and then multiplying by two to get an estimate of the whole tree. Total number of fruits were considered as the sum of mature and immature fruits that were still attached to the mature tree (Munyebvu et al., 2018). Fruits that had dropped whether mature, immature or eaten by predators such as rodents or other animals were not included in the total number of fruits because they were not available to be counted. For size-class distribution graphs, tree counts were converted to stems/ha to get comparative density data.

2.4. Household socio-economic and market survey

To determine the household socioeconomic status, interviews were conducted for households with or near the baobab trees sampled. The interviews were also conducted in chiefs' barazas as well as the local market places. The interviews involved the use of semi-structured questionnaires highlighting: source of livelihood; whether they had ever planted baobab or not and reasons; factors affecting survival of baobab saplings/planted seedlings; common uses of baobab and parts used; cost of baobab products if they sell; fruiting age of baobab; gender roles in baobab fruit collection; pattern of fruit production over the last five years; any restrictions or taboos associated with baobab and their role in baobab exploitation/protection and reasons for felling baobab trees.

2.5. Data analysis

Data entry was done in Microsoft Excel 2010 and analyzed using GraphPad Prism version 8.4.3. Software. One-way ANOVA test was used to assess any significant differences in tree density, DBH, height, crown diameter in the different land use classes while two tailed t-test was used to compare the parameters between the two sub-counties. The relationship between tree health and productivity was estimated using Pearson's correlation coefficient and a matrix drawn. In-depth analysis of the qualitative information was done to explain the quantitative data outputs using the aforementioned software. Mapping was done by downloading the GPS way points of sampled baobab trees from the Garmin etrex 10 into Arc Map 1.0 of ArcGIS (ESRI, Redlands, CA).

3. Results

3.1. Distribution of baobab in Makueni County

A total of 642 and 242 baobab trees were assessed in Kibwezi East and Kibwezi West sub counties, respectively. In Kibwezi West areas assessed were: Ngulu, Kathyaka, Kalungu, Ngandani, Masimbani and Kinyambu while Kibwezi East included Masongaleni, Ulilinzi, Thange, Mukange, Utithi, Muthingiini and Mangelete. There were more mature trees than juveniles in all land use types in the two sub counties Fig. 2. No seedlings were encountered across the three land use systems investigated, although all sites were sampled during the dry season, when the fields were empty of most herbs and seedlings. A total of 34 sites were sampled and the density of baobab trees was assessed in each of the sites as summarized in Fig. 3.

3.2. Baobab growth characteristics

It was observed that most of the baobab trees in the two sub counties were mainly found in the grazing lands. These grazing lands had the highest stem density (4.07±1.35 stems/ha), where they naturally occurred in the *Acacia* thickets and open woodlands. Crop lands hosted a stem density of 2.17±0.93 stems/ha, while settlement areas had the lowest with 0.18± 0.01 stems/ha. This was observed for both mature (p= 0.037) and juvenile (p= 0.002) size classes. The most common size class category in the three land use systems were mature trees. There was a significant difference in number of fruits per tree, stem density per ha, density of mature and juvenile trees among the land use types (p= 0.05). However, no significant difference (p=0.05) was observed for DBH, tree height and crown diameter across the different land use systems and the two sub counties. The average number of fruits varied substantially (p= 0.028) with crop land having the highest numbers (25.60 ± 5.361 fruits/ tree) while the settlement area had the least (3.2 ± 2.96) refer to Table 1. The two sub counties did not vary significantly in terms of growth characteristics.

3.3. Stem and health conditions of baobab

All the baobab tree populations in the grazing area showed signs of damage with debarked stem being the most prevalent. Baobab trees with cut branches were seldom encountered in the three land uses with farm land recording no cases Fig. 4.

Among the diseased baobab individuals, majority were affected by a sooty baobab disease. It was further observed that a few baobab trees had been attacked by a parasitic plant causing protrusions at the branch ends of the trees which appeared from distance as fruits but were not Fig. 5.

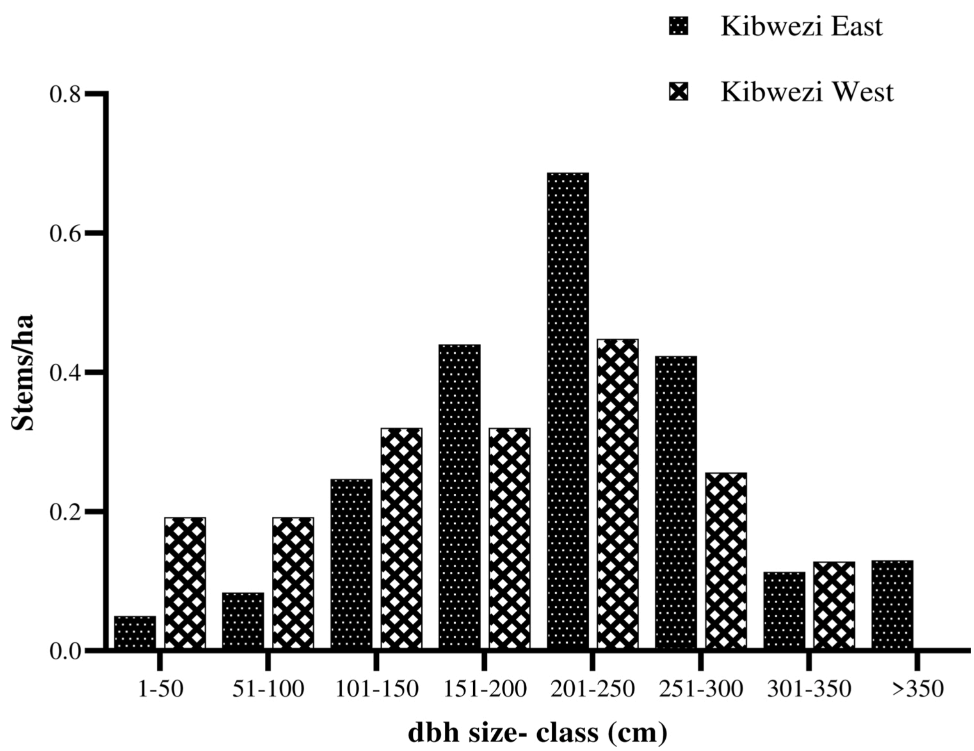

Fig. 2. Density of different dbh categories of baobab trees in Kibwezi East and West in all land use types.

3.4. Influence of baobab tree health conditions on fruit production status

Using pearson's correlation matrix we sought to understand whether disease/damage to trees was more prevalent in mature or juvenile trees and if fruit production was affected. Comparison of the degree of debarking with tree category revealed that most young trees had not been debarked ($r = 0.913$, $p = 0.268$) while the mature trees had higher proportion of debarking ($r = 1$, $p = 0.007$). Although debarking was not quantified, all the adult baobab trees in the studied area had their stems freshly stripped (within a period of 10 years) to some extent. In addition to debarking of adult trees, it was further observed that debarked trees were prone to diseases as there was a significant correlation between debarking and diseased trees ($p = 0.031$, $r = 0.999$). The number of fruits produced in debarked trees with cut branches was also significantly reduced ($p = 0.015$, $r = 1$) as well as those in diseased trees ($p = 0.024$, $r = 0.999$). Bark harvesting on its own did not affect fruit production ($p = 0.402$, $r = 0.807$).

3.4. Livelihood potential of baobab

The analysis showed that across both sub-counties the majority of people (85%) relied on subsistence farming and business operation, while a few (15%) had permanent employment. Fruits (69%), stem bark (20%) and leaves (11%) were reported to be the main baobab products utilized in both sub-counties combined, see Fig. 6 for breakdown between the two areas.Among the identified uses of the different parts of baobab tree showed fruit consumption was the leading followed by making of ropes and hanging of bee hives while use of leaves as vegetables was the least (Fig. 6. Fruit products from baobab are locally utilized when raw (without processing) and also in value added form. One of the processed products is the 'Mabuyu' which in Swahili refers to candy products made out of baobab pulp where seeds are covered with a mixture of sugar, food color and spices such as cinnamon and cardamom (Fischer et al., 2020). This was one of the major products reported from value addition of baobab. Value addition of pulp was done principally to improve quality thereby making it more attractive to customers. Baobab value addition was mainly done by women (68%) and a few men and children at 29% and 3% respectively. Women are more involved in selling of baobab products accounting for 56% followed by men and children at 24% and 20% respectively.

Baobab fruit products' business in the study area commences immediately after the fruits are ready, which happens from April to November. In the rural areas, 95% of farmers sold baobab pulp/seeds to the local wholesalers, mainly at their farm gate at approximately Ksh.300 (3 USD) and Ksh. 500 (5 USD) per bag of fruits and pulp respectively. A few farmers (5%) sold baobab pulp directly to wholesalers based at large markets in Nairobi, Malindi and Mombasa. These farmers either sent their goods via bus to the destination or traveled personally with their produce to the urban centres. Markets for baobab products were well established around Kibwezi town with mabuyu, jam and juices (processed by retailers) being common in supermarkets and grocery stores. One of the wholesalers in the baobab value chain based in Kibwezi Town reported to sell the pulp to export agencies in Kenya. In the rural areas, candies, jam and juices were sold locally during school sports, rallies and other events. Elderly women used baobab fibers which they extract from the stem barks to make the African hand-woven handbags locally known as kyodos. About 65% in the baobab value network indicated that there was no competition while at least 35% reported to face competition in the baobab business.

3.4.3. Cultural perception of baobab and conservation efforts

All the respondents reported that baobab was an important tree that needed to be conserved due to the cultural and economic values attached to the species. About half of the respondents (45%) perceived use of baobab as a source of income and a major reason for its conservation, 32% reported cultural values while 14% emphasized its use as source of food as a reason. The rest of the respondents (9%) valued the baobab tree for hanging bee hives, an important commercial activity in the study area hence the need to conserve it.

Further, the baobab tree was associated with some taboos, which protect it from being cut. Some of the taboos associated with baobab in this study included: people would be cursed to death if they cut down

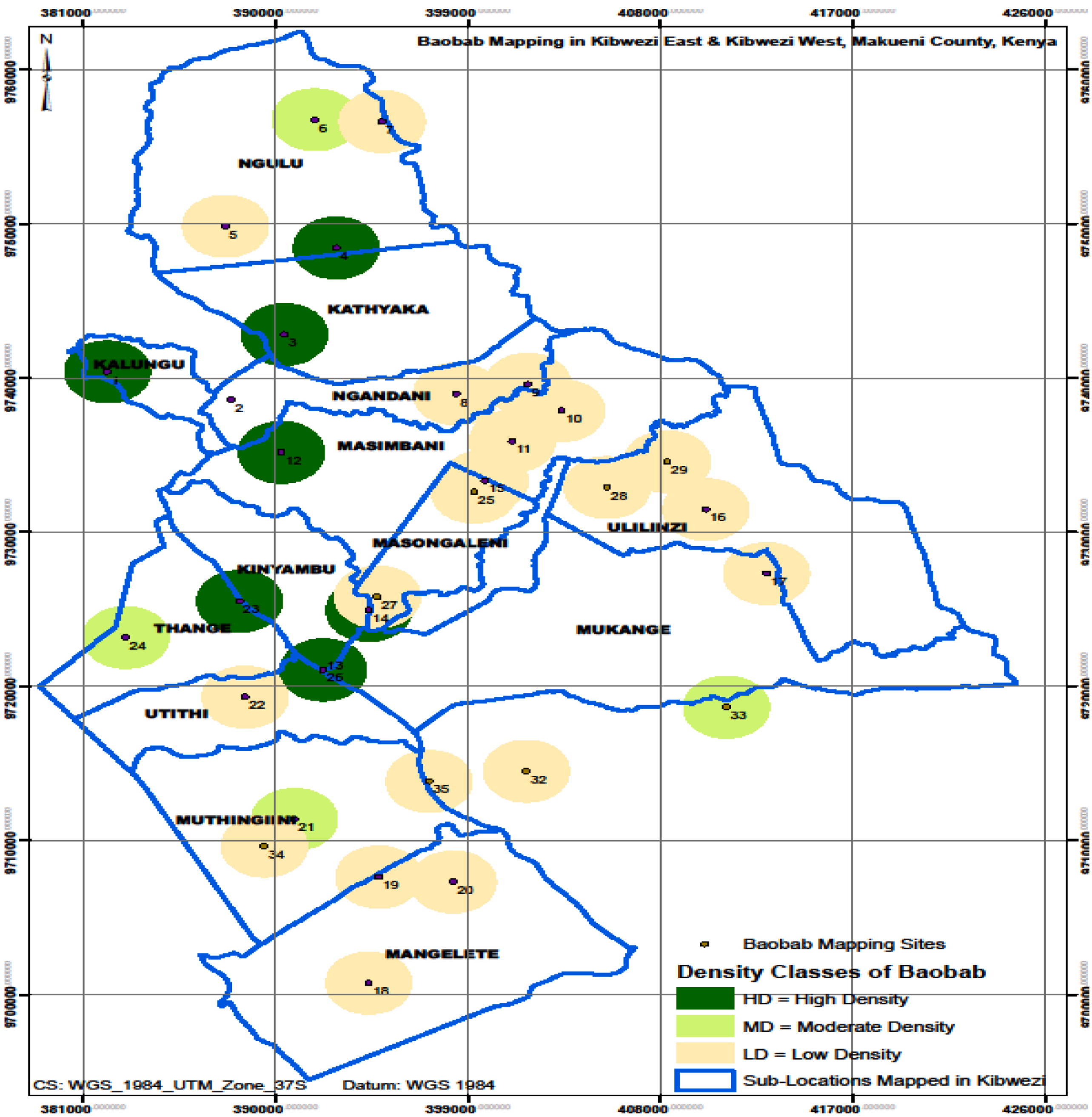

Fig. 3. Distribution and population density of baobab trees in Kibwezi East and West sub-counties in Makueni County.

Table 1
Comparison of growth variables (Mean dbh (cm), Mean height (m) and Mean crown diameter (m), Number of fruits/tree) of baobab in different land uses in the two sub counties of Makueni County. Comparison of results in three land use systems are shown by ANOVA while differences in the two sub counties are shown by t-test and corresponding P values. Corresponding mean and standard error of the mean for each comparison variable is tabulated irrespective of whether the means are significantly different or not.

	Land Use					Sub county			
Variable	F	p	Crop land	Grazing land	Settlement area	t	p	Kibwezi East	Kibwezi West
DBH (cm)	0.52	0.60	224.82 ± 11	212.90 ± 8.30	238.80 ± 49.91	1. 01	0.31	219.81 ±6.569	202.65 ± 21.09
Height (m)	0.41	0.06	25.61 ± 4.78	24.96 ± 2.86	37. 96 ± 16.79	0.070	0.945	25.61 ± 2.63	25.17 ± 6.42
Crown Diameter (m)	0.70	0.09	16.02 ± 0.71	16.98 ± 1.84	16.40 ± 3.89	1.72	0.09	15.59 ± 0.44	20.82 ± 6.13
Number of fruits/mature tree	1.23	0.02	26.34 ± 4.63	21.90 ± 6.72	3.47 ± 7.30	0.35	0.71	21.65 ± 2.28	24.01 ± 15.05
Stem density (Stems/ha)	2.72	0.00	2.17 ± 0.93	4.07 ± 1.35	0.18 ± 0.01	1.562	0.062	2.14 ± 1.00	1.94 ± 0.57
Tree density ≥ DBH 100 cm (trees/ha)	1.52	0.04	1.97 ± 0.78	3.52 ± 1.26	0.153 ± 0.01	1.75	0.07	1.938 ± 0.48	1.58 ± 0.37
Tree density ≤ DBH 100 cm (trees/ha)	2.21	0.00	0.12 ± 0.00	0.55 ± 0.03	0.027 ± 0.02	2.15	0.05	0.20 ± 0.15	0.35 ± 0.20

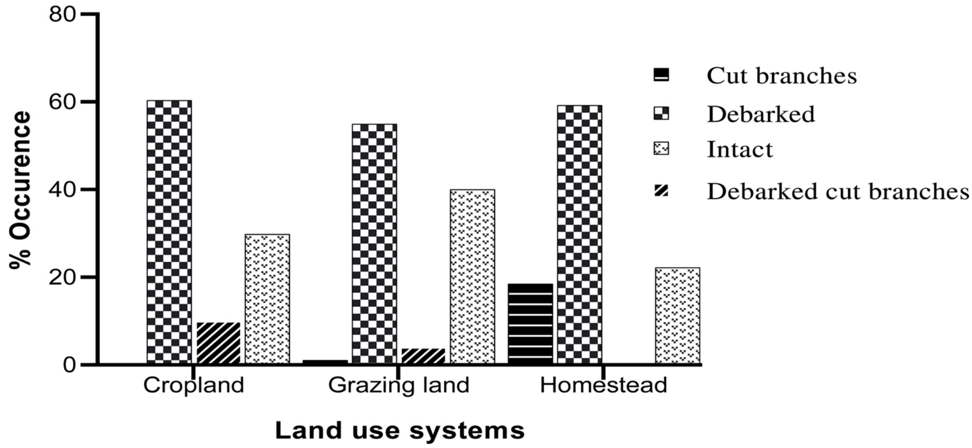

Fig. 4. Stem and health conditions of baobab across different land use systems in Kibwezi East and West Sub counties in Makueni County, Kenya.

Fig. 5. Parasitic plant growing on Baobab tree.

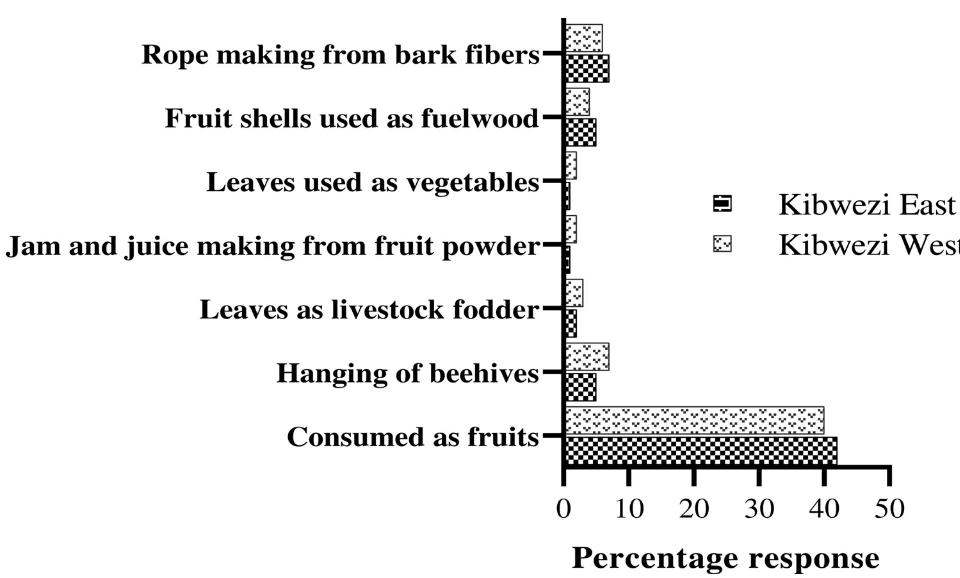

Fig. 6. Reported uses of baobab products in Makueni County in Kenya.

baobab (30%), the tree is not supposed to be cut as it carries bad omen/spirit (30%), baobab trees are not cut during the rainy season as this would stop the rains (27%), unmarried men are not allowed to cut down baobab trees because the gods would curse them and fail to marry (13%).

Majority of the respondents in both sub counties (87%) understood the phenological patterns of baobab which can be used in the conservation of this species. It was indicated that flowering begins at the age of eight to ten years and most of the baobab in the study sites were known to fruit once a year. Essentially, flowering of baobab in the two sub counties fits a particular climatic season; ranging from October-December which is preceded by leaf flushing. The onset of flowering was reported to correspond with the commencement of short rains that occurs around October and sometimes carries on to January the following year. Fruits develop and ripen 5-6 months after flowering, thus fruit harvesting starts from May- September with June-August being the peak period.

It was observed that the respondents had very little information about natural regeneration rates of baobab. However, this could have been caused by the inability of the informants to identify baobab seedlings as they lack the obvious palmate digitate leaves and swollen trunks. Majority of the respondents (96%) stated that there has been no regeneration. The respondents argued that this was due to young seedlings being destroyed by livestock and wild animals hence rarely growing to maturity. Other factors hindering increase of baobab trees was cutting the trees to pave way for farming, house and road construction. Only 4% of the respondents indicated that they propagated baobabs despite the low survival rate of only 33%. Destruction of baobab trees, particularly through fruit predation is known to be caused by wild animals such as baboons, squirrels, monkeys among others, whilst elephants additionally feed on the bark and leaves. Immature fruits are usually consumed by birds whilst domestic animals feed on the leaves and fruits.

4. Discussion

4.1. Baobab population distribution and structure

In this study, baobab trees were found to occur in patches of low and high density clusters. Occurrence of baobab in patches of different density was reported elsewhere in Taita Taveta County in Kenya (Fischer et al., 2020), Mali (Dhillion and Gustad, 2004) and Malawi (Sanchez, 2011). The dry climatic conditions, soil fertility and community perception on baobab could have attributed to high density of mature trees in Kibwezi East and West (Table 1) compared to other African countries (Sidibe et al., 2002). For example, Mpofu et al. (2012), and Gebauer and Luedeling (2013) recorded relatively low density of baobab trees in Zimbabwe (0.005 stems/ha) and Sudan (0.72 stems/ha) respectively. The stem density recorded in different land use systems (Table 1) are comparable to reports from South Africa (Venter and Witkowski, 2010), Namibia (Munyebvu et al., 2018) and Zimbabwe (Mashapa *et al.*, 2014) where baobab density did not differ between different study areas but differed in terms of land use. The insignificant difference in the growth characteristics of the two sub-counties could be attributed to the two areas experiencing almost similar climatic conditions and anthropogenic factors. The high levels of urban development taking place in settlement areas could be the contributing factor to low survival and subsequent low density and distribution pattern of baobab trees. Such human activities have been reported to significantly affect the population structure of baobab stands (Munyebvu et al., 2018). The high density of mature trees and low recruitment Table 1 resulted to a bell shaped curve Fig. 2 which was observed in Zimbabwe (Romero, 2001) and Namibia (Munyebvu et al., 2018). Lack of seedlings in the study areas has been noted in other studies in Kenya (Fischer et al., 2020; Orina et al., 2021), West Africa (Schumann et al., 2010) , South Africa (Venter and Witkowski, 2010) and Malawi (De Smedt et al., 2012) due to herbivory, land clearing by farmers and fires. It is evident that local communities have a role in shaping the baobab population structure as they contribute to lack of regeneration of baobab trees. According to Venter and Witkowski (2010), low recruitment rates and the bell-shaped or positively skewed size-class distributions, are typical characteristics of baobab populations across Africa. This may be of less concern due to the long-lived nature of baobab and extremely low adult mortality rate.

4.2. Fruits production

In both sites, some adult baobab trees were found without fruits either because they did not produce fruits at all or did not produce every year as was observed by Munyebvu et al. (2018). This could be attributed to trees not having enough reserves to produce fruit after leaf flush and bark stripping (Swanepoel, 1993). Fruit production could also be affected by ecological or biological patterns such as insufficient pollination, fruit abortion, predation of the fruits by animals such as baboons and resource limitation such as moisture (Munyebvu et al., 2018). It was observed that cases of cut branches were not common in farm lands while stumps of felled baobab trees were observed. This could be attributed to the belief that farmers have on little productivity for crops growing under baobab trees hence instead of pruning, they cut the whole tree. It was further observed that construction of roads within the two sub counties had resulted in cutting of baobab trees within the road reserves.

The significant difference in fruit production classes within land-use types shows that fruit production is to a certain extent influenced by land-use types. The open pasture areas tend to be more susceptible to fruit predation by animals than the fenced fields and settlements (Munyebvu et al., 2018). Croplands had a high average number of fruits/ tree (25.60 $\pm$ 5.361) compared to grazing (21.68 $\pm$ 5.14) and settlement (3.2 $\pm$ 2.96) areas (Table 1). This suggests that trees within the croplands were protected from animal predation. This is supported by the results of Venter and Witkowski (2011) who found a significant difference in mature fruits between land-use types in Limpopo, South Africa, which was attributed to fruit predation. The low numbers of baobab fruits in settlement areas shows the fruits were already predated or picked by the time the trees were enumerated or could be attributed to biological factors such as fruit abortion and insufficient pollination (Swanepoel, 1993).

4.3. Tree health and productivity

Majority of the debarked trees were mature recording a substantial association between large diameter class and debarking ($p= 0.007$, $r= 1$). This could be ascribed to the fact that debarking for fiber or for climbing to hang traditional bee hives or to collect fruits was majorly done on mature trees. Mature trees are believed to contain high quality fibers and fruits as well as the high height to safeguard beehives from thieves. Hanging of hives in trees with high heights also protects humans and livestock from invasion by bees. Other studies have reported that baobab tree populations are affected by bark harvesting. In southern Malawi 68%, Zimbabwe 97% and Burkina Faso 90% of the sampled baobab trees had been debarked increasing the vulnerability of the trees to sooty disease (Romero et al., 2014; Schumann et al., 2010). Debarking proceeds at a faster rate than the recovery potential of the trees. Slowed bark regeneration causes low quality of fibres. This leads to harvesting from other parts of the tree, leading to increase in the level of injury to the trees (Dovie, 2003). High debarking was experienced in the grazing land followed by crop land and least in the settlement area Fig. 4 this could be due to lack of protection in the grazing land (Munyebvu et al., 2018).

Although the number of diseased trees was significantly less than the healthy ones, results indicated that old trees were more affected by disease than young trees. Fungal induced canker, dieback and sooty baobab diseases, were known to be the main cause of death of baobab trees (Sheillah et al., 2020). The substantive correlation between debarking and diseases in baobab found in this study was an indication that debarking opens the tree trunk for entry of pathogens. Romero (2001) suggested that bark harvesting increased the vulnerability of the trees to the ‘sooty baobab’ disease.

4.4. Uses and community perception on baobab

Baobab has been reported to have the potential to contribute to food security, nutrition, health, income generation and environmental services (Kehlenbeck et al., 2013; Muthai et al., 2017). This was similarly observed in the study area where 55 % of the informants reported that baobab contributed to food security. It is among the tree species with the most valuable food in terms of quantity and quality in Kenyan markets (Schumann et al., 2010).The indigenous plants such as baobabs help to sustain local communities by providing food and income (Sidibe & Williams, 2002). The use of the species is therefore considered as an emergency coping mechanism in averting hunger in the area. This is because ripening of baobab fruits coincides with the dry season (June - November), particularly when inadequate rains are received during the wet season (March-May). Among the respondents interviewed, 76 % indicated direct consumption of baobab fruits as food while 24% indicated use of income from sale of baobab products for buying food. This is in agreement with Fischer et al. (2020) who reported baobab as a valuable source of food in Taita Taveta County in Kenya. Besides the use of this species as source of food, the highest percentage of respondents (45%) reported it as source of income, through selling of fibres and fruits. The different uses of baobab identified in this study Fig. 6 are in agreement with (Buchmann et al. (2010), De Caluwé and Van Damme (2011), Gebauer et al. (2002) and Munyebvu et al. (2018).

In many areas where baobab occurs in Kenya, such as Makueni and Tharaka Nithi Counties, some selected trees culturally serve as prayer and sacrifice places especially to bring rains (Ifejika et al., 2010). Cultural association of baobab has also been reported elsewhere such as in West Africa where the flowering of baobab trees was said to help in determining the rainfall patterns (Zoundji et al., 2017). The phenological pattern explained by the respondents in the current study showed a good understanding of the species, which is in agreement with an earlier study by Venter and Witkowski (2019). The low planting of baobab in the study areas is a clear indication that the local communities could play a role in the conservation of baobab trees through planting and protecting young seedlings.

Conclusion

This study shows that Kibwezi West and East have population status with stem density (stems/ha) of baobab trees occurring in patches of low and high density clusters. Different land use systems were found to influence stem density as well as fruit production in the two sub counties. Stem density (stems/ha) was highest in the grazing land and lowest in settlement areas while number of fruits per tree was highest in the crop land and lowest in the settlement areas.Stem debarking was more predominant in grazing areas which exposed the trees to diseases.The study showed a high livelihood potential of baobab as majority of the informants reported that baobab contributed to food security through direct consumption of fruits as well as selling of baobab products to buy food. Other uses of baobab trees identified were rope making from stem fibres, fruit shells as fuelwood, leaves as vegetables and livestock fodder, jam and juice from fruit pulp and hanging of bee hives.The local inhabitants of the area were aware of lack of regeneration but seemed to apply less effort in the conservation of these trees and only relied on cultural beliefs/taboos. Some of the taboos associated with baobab in the study area included: people would be cursed to death if they cut down baobab, the tree is not supposed to be cut as it carries bad omen/ spirit, baobab are not cut during the rainy season as this would stop the rains, unmarried men are not allowed to cut down baobab trees because the gods would curse them and fail to marry. We recommend that baobab tree propagation training should be made available to augment local knowledge and experience on how to grow the species. Local communities should also be empowered through training on value addition and supported to form cooperative societies for processing and trade in baobab products as a commercialization strategy. The County and the national government should encourage active private sector entry in the baobab products market value chain through establishment of factories/ industries in Makueni County to enhance market competition while offering good prices to the baobab farmers and other stakeholders. Scientific approaches should be explored in the identification and formulation of strategies to control the spread of diseases and the parasitic plants that are reducing fruit production in baobab.

Authors' contributions

JKM, MMK, JK conceptualized the research idea. JKM, SMU and SMK carried out data collection. JKM and MMK did the data analysis and developed the first draft of the manuscript. GMM, JK, AML reviewed the manuscript. All authors read, edited and contributed to the manuscript.

Declaration of Competing Interest

The authors have declared that there is no conflict of interest related to this work.

Acknowledgment

We appreciate the support accorded to us from the Director, Kenya Forestry Research Institute, and the inhabitants of Makueni County during the assessment. Pius O. Matieka and Julius Mwaniki are appreciated for their contribution during the data collection.

References

Assogbadjo, A.E., Chadare, F.J., Kakaï, R.G., Fandohan, B., Baidu-Forson, J.J., 2012. Variation in biochemical composition of baobab (*Adansonia digitata*) pulp, leaves and seeds in relation to soil types and tree provenances. Agric. Ecosyst. Environ. 157, 94–99.

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. R. Soc. open Sci. 2, 150370.

Buchmann, C., Prehsler, S., Hartl, A., Vogl, C.R., 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, 145–172.

Cissé, I., Montet, D., Reynes, M., Danthu, P., Yao, B., Boulanger, R., 2013. Biochemical and nutritional properties of baobab pulp from endemic species of Madagascar and the African mainland.

De Caluwé, E., Van Damme, P., 2011. Market chain analysis of baobab (*Adansonia digitata* L.) and tamarind (*Tamarindus indica* L.) products in Mali and Benin. Afr. Focus 24.

De Smedt, S., Sanchez, A.C., Van den Bilcke, N., Simbo, D., Potters, G., Samson, R., 2012. Functional responses of baobab (*Adansonia digitata* L.) seedlings to drought conditions: differences between western and south-eastern Africa. Environ. Exp. Bot. 75, 181–187.

Dhillion, S.S., Gustad, G., 2004. Local management practices influence the viability of the baobab (*Adansonia digitata* Linn.) in different land use types, Cinzana, Mali. Agric. Ecosyst. Environ 101, 85–103.

Dovie, D.B.K., 2003. Rural economy and livelihoods from the non-timber forest products trade. Compromising sustainability in southern Africa? Int. J. Sustain. Dev. World Ecol. 10, 247–262.

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. Environ. Manage. 66, 305–318.

Gebauer, J., Adam, Y.O., Sanchez, A.C., Darr, D., Eltahir, M.E.S., Fadl, K.E.M., Fernsebner, G., Frei, M., Habte, T.-Y., Hammer, K., 2016. Africa's wooden elephant: the baobab tree (*Adansonia digitata* L.) in Sudan and Kenya: a review. Genet. Resour. Crop Evol. 63, 377–399.

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, 155–160.

Gebauer, J., Luedeling, E., 2013. A note on baobab (*Adansonia digitata* L.) in Kordofan, Sudan. Genet. Resour. Crop Evol. 60, 1587–1596.

Ifejika Speranza, C, Kiteme, B., Ambenje, P, Wiesmann, U, Makali, S, 2010. Indigenous knowledge related to climate variability and change: insights from droughts in semi-arid areas of former Makueni District, Kenya. Clim. Change 100, 295–315.

Jäckering, L., Fischer, S., Kehlenbeck, K., 2019. A value chain analysis of baobab (*Adansonia digitata* L.) products in Eastern and Coastal Kenya. J. Agric. Rural Dev. Trop. Subtrop. 120, 91–104.

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. Divers. food diets Using Agric. Biodivers. to Improv. Nutr. Heal. 257–269.
Kiprotich, C., Kavoi, M.M., Mithöfer, D., 2019. Determinants of intensity of utilization of Baobab products in Kenya. Cogent Food Agric. 5, 1704163.
Mashapa, C., Nyabawa, P., Zisadza-Gandiwa, P., Muvengwi, J., Kativu, S., Gandiwa, E., 2014. Status of African baobab (*Adansonia digitata*) across Gonarezhou National Park, Zimbabwe. J. Appl. Sci. Environ. Manag. 18, 129–133.
Meinhold, K., Darr, D., 2020. Using a multi-stakeholder approach to increase value for traditional agroforestry systems: the case of baobab (Adansonia digitata L.) in Kilifi, Kenya. Agrofor. Syst 1–16.
Mpofu, E., Gandiwa, E., Zisadza-Gandiwa, P., Zinhiva, H., 2012. Abundance, distribution and status of African baobab (*Adansonia digitata* L.) in dry savanna woodlands in southern Gonarezhou National Park, southeast Zimbabwe. Trop. Ecol. 53, 119–124.
Munyebvu, F., Mapaure, I., Kwembeya, E.G., 2018. Abundance, structure and uses of Baobab (*Adansonia digitata* L.) populations in Omusati Region, Namibia. South African J. Bot. 119, 112–118.
Muthai, K.U., Karori, M.S., Muchugi, A., Indieka, A.S., Dembele, C., Mng'omba, S., Jamnadass, R., 2017. Nutritional variation in baobab (*Adansonia digitata* L.) fruit pulp and seeds based on Africa geographical regions. Food Sci. Nutr. 5, 1116–1129.
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. For. Trees Livelihoods 28, 266–280.
Orina, J., Mukundi, J.B., Adimo, A.O., Rimberia, F.K., Omondi, M.A., Gebauer, J., Kehlenbeck, K., 2021. Baobab (*Adansonia digitata* L.) population structure across different agro-ecological zones in Coastal and lower Eastern Kenya. For. Trees Livelihoods 30, 13–27.
Rahul, J., Jain, M.K., Singh, S.P., Kamal, R.K., Naz, A., Gupta, A.K., Mrityunjay, S.K., 2015. *Adansonia digitata* L.(baobab): a review of traditional information and taxonomic description. Asian Pac. J. Trop. Biomed. 5, 79–84.
Romero, C., 2001. Effects of commercial bark harvesting on Adansonia Digitata (Baobab) in the Save Odzi-Valley, Zimbabwe with considerations for its management.
Romero, C., Dovie, D.B.K., Gambiza, J., Luoga, E., Schmitt, S., Grundy, I., 2014. Effects of commercial bark harvesting on *Adansonia digitata* (Baobab) in the Save-Odzi Valley, Zimbabwe, with considerations for its management. Adv. Econ. Bot. 17, 95–114.
Schumann, K., Wittig, R., Thiombiano, A., Becker, U., Hahn, K., 2010. Impact of land-use type and bark-and leaf-harvesting on population structure and fruit production of the baobab tree (*Adansonia digitata* L.) in a semi-arid savanna, West Africa. For. Ecol. Manage. 260, 2035–2044.
Sheillah, C., Jane, N., Alice, M., Japhet, M., Daniel, O., Ignazio, G., Zakayo, K., 2020. Botryosphaeriaceae associated with baobab (*Adansonia digitata* L.) and marula (*Sclerocarya birrea* A. Rich.) in agroforestry systems in Kenya. African J. Plant Sci. 14, 411–419.
Sidibe, M., Williams, J.T., Hughes, A., Haq, N., Smith, R.W., 2002. Baobab. Adansonia digitata, 100.
Swanepoel, C.M., 1993. Baobab phenology and growth in the Zambezi Valley, Zimbabwe. Afr. J. Ecol. 31, 84–86.
Thies, M., Pfeifer, N., Winterhalder, D., Gorte, B.G.H., 2004. Three-dimensional reconstruction of stems for assessment of taper, sweep and lean based on laser scanning of standing trees. Scand. J. For. Res. 19, 571–581.
Venter, S.M., Witkowski, E.T.F., 2019. Phenology, flowering and fruit-set patterns of baobabs, *Adansonia digita*ta, in southern Africa. For. Ecol. Manage. 453, 117593.
Venter, S.M., Witkowski, E.T.F., 2011. Baobab (*Adansonia digitata* L.) fruit production in communal and conservation land-use types in Southern Africa. For. Ecol. Manage. 261, 630–639.
Venter, S.M., Witkowski, E.T.F., 2010. Baobab (*Adansonia digitata* L.) density, size-class distribution and population trends between four land-use types in northern Venda, South Africa. For. Ecol. Manage. 259, 294–300.
Wickens, G.E., 2008. The Baobabs: Pachycauls of Africa, Madagascar and Australia. Springer Science & Business Media.
Zoundji, G.C., Witteveen, L.M., Vodouhe, S., Lie, R., 2017. When baobab flowers and rainmakers define the season: Farmers' perceptions and adaptation strategies to climate change in West Africa. Int. J. Plant, Anim. Environ. Sci. 7, 8–21.