CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Tropical AgriSciences

The use and silvicultural management of baobab (*Adansonia digitata*) in East Africa

MASTER'S THESIS

Prague 2019

Author:

Bc. Tomáš Čemák

Supervisor:

doc. Ing. Bohdan Lojka, Ph.D.

Co-supervisors:

Ing. Iva Viehmannová, Ph.D.

Ing. Anna Chládová

Declaration

I Tomáš Čermák declare that I have worked on my diploma thesis titled " The use and silvicultural managment of baobab (*Adansonia digitata*) in East Africa" by myself and I have used only the sources mentioned at the end of the thesis. As the author of the diploma thesis, I declare that the thesis does not break copyrights of any third person.

In Prague 20.04.2019

....

Tomáš Čermák

Acknowledgements

I would like express my sincere gratitude to the people who devoted their time to help me during the elaboration of this master thesis.

First and foremost I would like to extend special thanks to my thesis supervisor doc. Ing. Bohdan Lojka, Ph.D. for his unconditional and continuous support and guidanceduring the elaboration of my research.

I extent my gratitude to my second supervisor Ing. Iva Viehmannová, Ph.D. for her help and patience with the parts of the thesis involving callogenesis and micropropagation.

My big thanks to Anna Chládová for her helping with collecting data in Kenya and supporting during my diploma thesis writing, thank you!

I would like to thank Ing. Zdeněk Hlaváč and Marie Hlaváčová from the Botanical Garden of the Faculty of Tropical AgriSciences of CULS Prague for helping with *ex vitro* transfer of plants as well.

Also, my family, especially my parents Dana and Jakub, deserve my thanks for their moral and financial support during my entire studies.

Last but not least, I would like to extend my sincere gratitude to Faculty of Tropical AgriSciences and to "Nadání Josefa, Marie a Zdenky Hlávkových" for their financial support.

NADACE
Nadání Josefa, Marie a Zdeňky Hlávkových

Abstract

Adansonia digitata L. (Malvaceae) is a huge multipurpose tree of the savannahs of sub-Saharan Africa, with high economic potential for local communities which can help for conservation of this majestic specie. This study aimed to found out suitable ways of *Adansonia digitata* L. propagation and silviculture management in Kenya. This study was divided in three section. In first we carried out three pre-treatment methods for speed up germination of seeds, by counting of germinated seeds on the end of experiment. Second was experiment with indirect morpohogenesis, we used embryonic axes on different types of media and third was farmers survey in done by semi-structured questionnaire in three location in Kenya. The best result was achieved in treatment with acid 81.9% but best method for people living in rural areas of Kenya, boiling method was chosen as the most suitable treatment. We were also testing indirect morpohogenesis in baobab; this method of propagation was not fully successful; protocol for induction and proliferation of callus was successfully developed, the best growth regulator concentrations were (MS + 2.4-D + BAP 0.1 mg/l) and (MS + 2.4 D 1 mg/l) chosen based on the growth intensity of callus, however plant regeneration process from callus needs more time to be optimized. Results from survey showed that the biggest challenge in management of baobab is increasing drought due climatic change which seedlings of baobab cannot survive. Result of this study showed that natural regeneration can be supported by artificial methods, but aftercare is crucial. Future research should be conducted to broaden the knowledge attained during this research.

Key words: germination, callogenesis, management, Pre-treatment, indirect morphogenesis, local uses

Contents

List of figures

List of tables

List of the abbreviations used in the thesis

2.4 D – Dichlorophenoxyacetic acid

AC – Active charcoal

BAP – 6-benzylaminopurine

CULS – Czech University of Life Sciences

DAP – Days after planting

DBH – Diameter at breast height

IBA – Indole-3-butyric acid

KIN – Kinetin

MS – Murashige and Skoog (1962) medium

NNA – 1-Naphthaleneacetic acid

PGR – Plant growth regulator

WPM – Woody Plant Medium (McCown & Lloyd 1981)

1. Introduction

The baobab (*Adansonia digitata* L.) is an important multipurpose indigenous fruit tree in sub-Saharan Africa, it is used for subsistence production and commercial purposes. The baobab is one of the most remarkable trees of Africa and representative of the wooden ‘‘Big Five’’ (Gebauer et al. 2016). It was first described by Michel Adanson in 1761, and in 1762 Linneaus did the tree´s namesake for memorialized him. Even Darwin and Livingstone documented baobab trees. Darwin was writing about their size and longevity on St Jago in the Cape Verde Islands in 1832 and Livingstone on his travels in southern Africa notices baobab several times during the 1840s and 1850s (Pettigrew et al. 2012).

For many people from rural areas of Africa, baobab represent inviable resource, since this tree can be utilized for many products such food, fibre and medicine (Sidibe & Williams 2002; Wickens & Lowe 2008). However, low recruitment of this important specie is reported across Africa (Dhillion & Gustad 2004; Assogbadjo et al. 2005). Poor regeneration is influenced by the lack of consistent rainfall and also by livestock browsing and trampling, change of land use significant factors are deforestation, fires (Dhillion & Gustad 2004; Venter & Witkowski 2013a).

Conservation is important from different views such as aesthetic, scientific or historic but mainly is essential for people from rural areas of Kenya. For them it is a source of tender root, tubers, twigs, fruit, seeds, leaves and flowers which are edible (Wickens & Lowe 2008). Leaves, seeds and pulp from fruit are nutritious rich and in rural areas presenting a part of diet (Wickens 1982). Nutritious seed oil and fruit pulp attracts international trade for cosmetic and food industry (Buchmann et al. 2010). For these purposes, increasing of regeneration is required. However, natural germination is less than 20 percent (Danthu et al. 1995) and for mass production treatment of seeds is essential. Knowledge of *A. digitata* silviculture is also important but knowledge about silviculture management is still low.

Therefore, the main purpose of the study was to define suitable ways of *Adansonia digitata* L. propagation and silviculture management in Kenya. For determination of suitable way of propagation three pre-treatment methods (manual scarification, boiling in water, soaking in acid) were tried and indirect morphogenesis. To found out the effective ways how to manage this species in the future, surveys with Kenyan farmers was done.

2. Literature Review

2.1. Nomenclature and taxonomy of genus *Adansonia*

The baobab trees belong to the family Malvaceae, subfamily Bombacoideae, genus *Adansonia*. Previously, the genus *Adansonia* was assigned to Bombacaceae family, however it was re-classified to Malvaceae based on APG taxonomy classification (Baum 2004). Malvaceaefamily covers about 30 genera, 6 tribes and about 250 species, which are used for leaves, wood, fruits, seeds or gum (Rahul et al. 2015).

Genus *Adansonia* can by divided into three sections according to floral morphology (Figure 1). Sect. *Adansonia* (*A. digitata* L.) African species, sect. *Brevitubae* (*A. grandidieri, A. suarezensis*) Malagasy species, and sect. Longitubae (*A. perrieri, A. madagascariensis, A. za, A. rubrostipa, A. gregorii*) Malagasy and Australian species (Baum 1995). Madagascar is a centre of diversity, can be found six species which are endemic to this island. *A. grandidieri* Baill., *A. suarezensis* H. Perrier, *A. rubrostipa* Jum. and H. Perrier, *A. za* Baill., *A. madagascariensis* Baill., *A. perrieri* Capuron (Pettigrew et al. 2012). The only Australian endemic species is *A. gregorii* F. Muell., from north-western Australia, Kimberley region. *A. digitata* L. is native species in semi-arid sub-Saharan Africa, extending from Angola, through southern Africa to East Africa, as far north as southern Sudan and Ethiopia (Kotina 2017). From mainland Africa it has been widespread throughout the tropics by humans (Wickens & Lowe 2008). To separate Adansonia digitata from the other species of the genus can be used a pendulous flower, the globose buds, broad petals, rounded crown and irregularly distributed branching as clear and useful diagnostic characters (Sidibe & Williams 2002).

Pettigrew et al. (2012) found and described new species *Adansonia kilima* in eastern and southern Africa. *A. kilima* has diploid nature, different floral morphology, pollen and appeared at elevations between 650 and 1500 m, while *A. digitata* is a tetraploid and occurred primarily at elevations below 800 m (Pettigrew et al. 2012). At first, Dourie et al. (2015), done study for support the two species by morphological study and they confirm the presence of *A. kilima* in Zimbabwe. However, speculations about the newly describe species occurred. Cron et al. (2016) showed in the study that *A. kilima* is neither cytologically, nor morphologically, distinct from the *A. digitata* and described it as synonym to *A. digitata*.

The name baobab is probably derived from the Arabic words ‘bu hibab’ meaning ‘fruits with many seeds’ and coming from the 16th century, when the Venetian herbalist and physician Alpino described fruits with medicinal properties (Wickens 1982; Gebauer 2016). Linnaeus used the name *Adansonia*, in honour of Michel Adanson, botanist who had been to Senegal and firstly described *A. digitata* in detail, in the mid-18th century. The species name digitata (hand-like) is connected to the shape of the leaves (Baum 1995; Sidibe &Williams, 2002).

According to wide geographical distribution we can find multitude of vernacular names, in English language are used names like Baobab, dead-rat tree (from the appearance of the fruits), upside down tree (the bare branches looked like roots), cream of tartar tree (the acidic taste of the fruits) or monkey-bread tree this name comes from the fact that monkeys eat the baobab´s fruits (Rahul et al. 2015). For greyish wrinkled bark at the massive trunk one of the common names is wooden or vegetative elephant (Gebauer 2016). In the Swahili language, which is the second official language in Kenya, are used names mbuyu and majoni (Kehlenbeck et al. 2015).

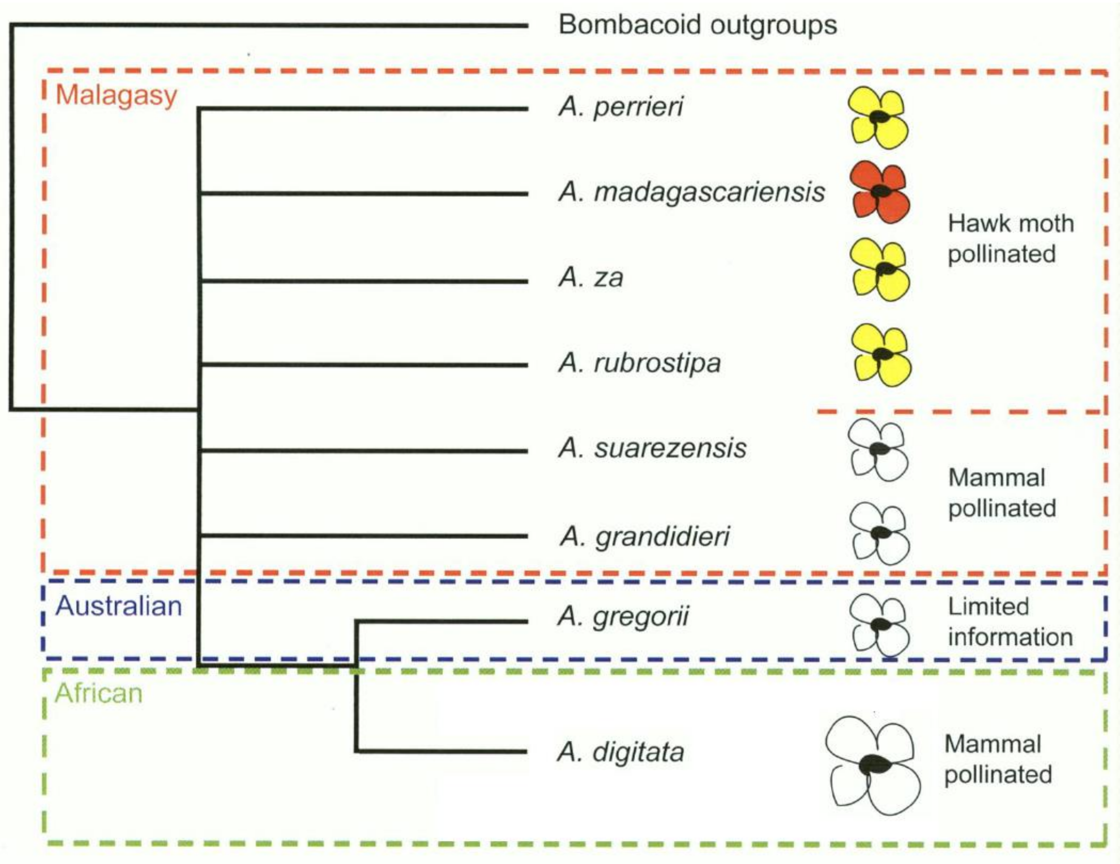

Figure 1. List of *Adansonia species* with basic flower characteristics and pollination, adopted from (Pettigrew et al. 2012)

2.2. Origin and distribution

According to Pock Tsy et al. (2009) centre of origin of *Adansonia digitata* is probably from West Africa, based on chloroplast DNA of 344 individuals across Africa. Pettigrew et al. (2012) suggest two hypotheses about origin of this species based on ploidy, because *A. digitata* is tetraploid and all the other species are diploids. The first hypothesis, which also correspond with Pock Tsy et al. (2009), is that the origin is in Africa and tetraploidy was evolved after the differentiation of the Australian and Malagasy lineages. The second hypothesis describes that *A. digitata* ancestors are not from Africa and tetraploidy was evolving during or after segregation to Africa. The distribution of A. digitata in Africa ranges from very arid regions of the Sahel to sub-humid, humid regions in north and south of the equator (Figure 2), (Wickens & Lowe, 2008). This including countries in Western Africa (e.g. Senegal, Mali, Niger, Benin), Southern Africa (e.g. Namibia, South Africa, Mozambique, Zambia, Malawi) and Eastern

Africa (e.g. Sudan, Ethiopia, Kenya, Tanzania) (Kehlenbeck et al. 2015). However, it is absent in Liberia, Uganda, Djibouti and Burundi (Wickens 1982).

Main dispersal agents are animals, rivers or sea, state that baobabs were only dispersed by men is wrong (Wickens & Lowe 2008). However, introduction to Zanzibar, Madagascar, India, Sri Lanka, Penang, Java and the Philippines was done by Arab traders or their slaves because there is strong correlation between their settlement, mosques and trade roads (Wickens & Lowe 2008). Bell et al. (2015) did a genetic analysis of baobabs from Mascarenes, southeast India and Malaysia and confirm that *A. digitata* was introduce there due to the slave trade from West Africa by European colonial networks.

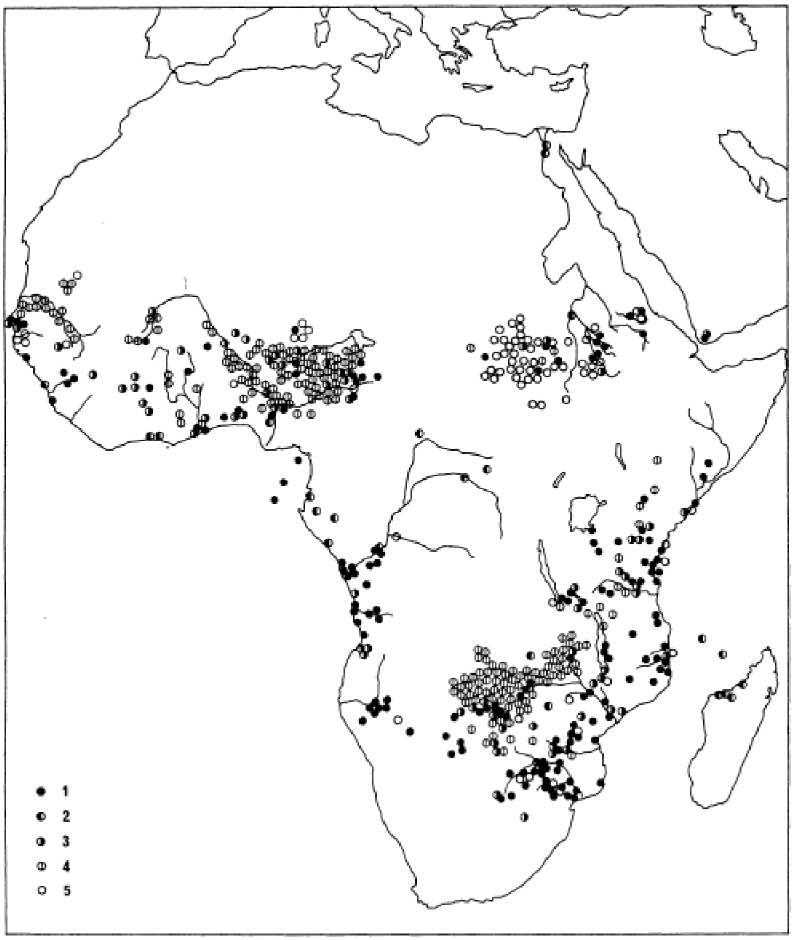

Figure 2. Distribution of *Adansonia digitata* in Africa and neighboring areas. 1 Distribution based on Herbarium and flora records; 2 Specimens known to be cultivated or introduced; 3 Distribution based on published and unpublished photographs; 4 Distribution base on the Kew 'Baobab Survey' information 5; Records obtained from travel literature, maps. (Wickens 1982)

2.3. Ecology

Baobab survives well in dry climates, is resistant to fire and prefers a high-water table. However, seedlings and small trees are susceptible to fire and drought, two of the main hazards in dry areas of Africa (FAO 1993; Gebauer et al. 2002; Sidibe & Williams 2002). Baobab is widespread throughout the hot, drier regions of tropical Africa. It can survive in a wide range of vegetation types including scrub, wooded savannah, hot dry areas, and semiarid to sub-humid tropics. The baobabs are usually found in an arid area, between 450 and 600 m.a.s.l. and with a rainfall of 300 to 500 mm. However, we can find it grow from the coast up to 1250 m.a.s.l, e.g. in Tanzania (Figure 3) (FAO 1993), or in 1500 m.a.s.l in Ethiopia (Sidibe & Williams 2002). Baobab can occur in arid areas with precipitations 90 mm where is growth very marginal to sub-humid areas 800-1200 mm in with occasional growth (Sidibe & Williams 2002). The baobabs are sensitive on frost but some baobabs in Namibia survived three nights with temperature -5 °C to -7 °C (Wickens & Lowe 2008).

Figure 3. Baobab trees on the Indian ocean coast in Kilifi, Kenya (Author archive)

Baobab have several abilities how to fight with fire and drought, early shedding of leaves, trunk contracts when the dry season begins, and circumference increase after heavy rainfall. Water can be also stored inside of the tree. Baobab have a thick bark with regenerative powers, which may protect the trees against the fire (Sidibe & Williams 2002). The thin translucent phellem in bark allows photosynthesis, which help survive dry season without leaves (Kotina et al. 2017).

Optimal soil is sandy topsoil over loams. Baobabs are commonly found on non-agricultural, rocky and lateritic soils. However, can even grow in acid and calcareous soils, poorly drained heavily-textured soils, sites receiving run-off, rocky hillsides or where water accumulates. Deep sands are not able to hold enough moisture and baobab on this soil can't survive (FAO 1993; Gebauer et al. 2002; Sidibe and Williams 2002).

According to the ´keystone mutualism´ concept, Gilbert (1980), baobabs can be defined as the tree which provides fundamental resources for animals such as food or shelter and in return, animals provide essential favours such as pollination or dispersal of fruits and seeds. Conservation is important from different views such as aesthetic, scientific or historic. Economic attractive or touristic interesting plants have a better chance for protection. With climatic change and poor management of landscape, calls for conservation are increasing (Venter and Witkowski 2013b). There are several factors which are threatening baobab populations such as cattle grazing, fires, drought land clearing for the establishment of mines, dams, agricultural expanding, unnatural concentration of elephants in game reserves, or trials of processing of the paper from wood in past. In small scale farms clearance of trees is not so common, because local people use baobab for commercial or subsistence purpose (Wickens & Lowe 2008). However, nowadays with climatic change farmers are cutting down baobabs to make space for agricultural crops such as maize and beans (Figure 4).

Figure 4. Fallen baobab with marks after axe (Author archive)

2.4. Morphology of *A. digitata*

A. digitata is a massive deciduous tree, up to 20-30 m tall with a diameter up to 2-10 m at adult age (Figure 5). The trunk is typically swollen and stout, tapering or cylindrical and abruptly bottle-shaped or short and squat. Due to human intervention or natural causes trees can have hollow trunks, this can be found in old and large individuals (Gebauer et al. 2002). The bark is smooth, reddish-brown to grey or purplish-grey, soft and possesses longitudinal fibers. The baobab has a large crown, primary branches either well distributed along the trunk or confined to the apex, stout but gradually tapering. Young branches are tomentose, rarely glaborous (Wickens 1982; Rahul et al. 2015). *A. digitata* produces an extensive lateral root system until 50 m from the trunk with high water holding capacity (Rahul et al. 2015). The roots are lateral with tubers on the end, the main roots of old trees are relatively shallow and rarely extend beyond 2 m depth, this adaptation is great for make profit from low annual precipitation, which falls in the form of infrequent heavy rain (Gebauer et al. 2002; Sidibe & Williams 2002; Rahul et al. 2015). Roots of baobab could be colonized by symbiotic fungi *Glomus* sp., but there was no increase in biomass and low dependency (Sidibe & Williams 2002).

Typical habit of *Adansonia* is pachycaul from the Greek: pachycaulos, meaning ´thick stem´. This term was invented by Theophrastus of Eresos (370 – c.285 BC) (Liddell

& Scott 1940). Pachycauls are characterized by swollen trunks which are developed due to water storing parenchyma cells, this we could be found in whole genus *Asansonia*. This strategy with a combination of proportion (short and stout) is important in drier areas. In living baobab can be stored 64,2 – 75.5% of water and can remain up to 18 months without leaves (Wickens & Lowe 2008). In terms of controlling of water loss, baobab is considered as most effective during dry season when loss is only up to 1500 litres of water and when they have leaves it is only 400 litres (Gebauer et al. 2002). However, baobab cannot be classified as succulent because they are invaders of arid areas, even that they have some xeromorphic characteristics. When the trees are felled and striped, cattle can chew the wood survive (Wickens & Lowe 2008).

According to the theory of Koechlin et al. (1974) which said that baobabs are generally tall with small and compact crown which is typical for competition for light and with slow adaptation on drought canopy is more open especially in case of *A. digitata* in Africa. Their trunk is also changing due to environmental change is shorter and stouter for better water storage. Crown spreading, and trunk shape have strong correlation because open crown and heavy branches need support of buttresses, so the diameter of the stem is not connected with age of baobab (Wickens & Lowe 2008).

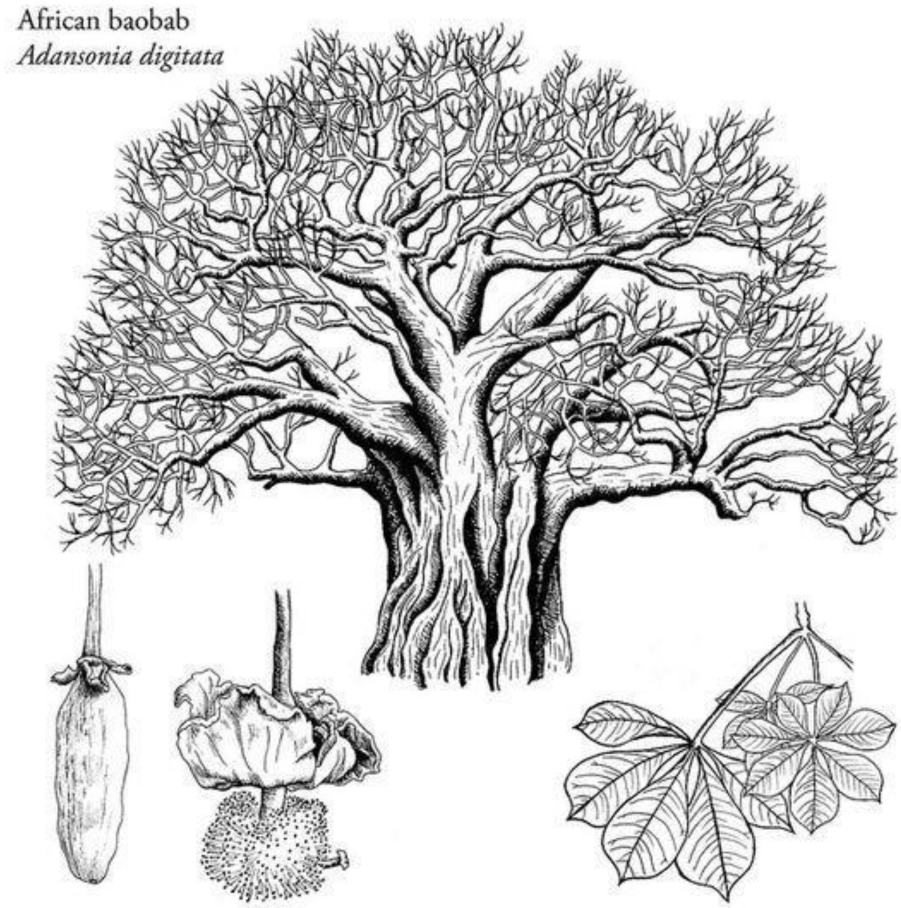

Figure 5. Habit, Fruit, Flower and leaf of *A. digitata* by Louise Jasper

Leaves are alternate, sometimes occur on short spurs on the trunk (it is uncertain if it's normal or a result of stripping the bark) (Wickens 1982). First leaves of young baobabs are simple (Wickens & Lowe 2008). Adult trees begin each season by producing simple 2-3-foliate leaves and they are early deciduous. Later will come out mature leaves with 20 cm diameter with about 5 to 9 foliate, the medial leaflet can be 5-15 ×2-7 cm and leaf petiole length is up to 16 cm long (Figure 6). Leaflets are sessile to shortly petiolulate, with elliptic to ovate-elliptic shape, with an acuminate apex and decurrent base. Margins are entire and leaves are stellate pubescent below till young starts be glabrous. Stipules falling off easily, shape is subulate or narrowly triangular, 2-5mm long and glabrous except for ciliate margins (Sidibe & Williams 2002; Kehlenbeck et al. 2015; Rahul et al. 2015).

Figure 6. Leaf of *A. digitata* with unknown diseases (Author archive)

The inflorescence of baobabs consists of a showy bisexual single flower, solitary or paired, situated in the axils of leaves near the tips of reproductive branches. Pedicels tomentose has varied wide range from 20 cm long in southern and eastern Africa, up to 90 cm long in West Africa, with two small early caducous bracteoles (Wickens 1982; Sidibe & Williams 2002). The Flower bud is globose with an apex apiculate to conical. Calyx is (3-)5 lobed. Lobes are 5-9 x 3-5cm long with triangular or oblong-triangular shape, Calyx 3-5-lobed, 5-9 x 3-7 cm, divided to 1/2 or 3/4. Corolla has 5 partite made by white overlapping, hairy inside, petals in obovate shape 5-9 x 4-8cm. The androecium is formed up of 720-1,600 stamens forming cylindrical or tapering, 3-5 cm long tube. Anthers are 2mm long and reniform. The ovary is conical to globose and it is made by 5-10 locular. The style exceeds the anthers about 15mm beyond. The white stigma with irregular lobes (Wickens 1982; Sidibe & Williams 2002; Rahul et al. 2015). The life span of the flowers is not more than 24 hours (Gebauer et al. 2002).

Fruits are highly variable in size and shape, but usually the shape is globose to ovoid, and size range from 7.5 to 54 cm long x 7.5-20 cm wide. Outside of fruit is covered by yellowish to greenish-brown velvety hairs. Pericarp is woody, 8-10 mm thick and inside contains a dry yellowish-white, floury mealy acidic pulp (Figure 7). Seeds are embedded in the pulp, dark brown to reddish black, 10-13 x 1-10 x 4-5 mm with smooth testa,large embryo, and folded cotylendons (Wickens 1982; Gebauer et al. 2002; Sidibe & Williams 2002; Wickens & Lowe 2008).

Figure 7. Cross section of baobab fruit with and without pulp (Author archive)

2.4.1. Age

Baobabs are long living trees. However, estimation of age is problematic because girth, diameter and wide of rings is changing with water content so trees with good access to water could be bigger but not older. Also, young trees are growing much faster than mature ones. Counting of annual rings is also complicated because it is also connected with the supply of water and without regular rainfalls will not produce them reliably. Measuring of them with boring tools have some difficulties, tools must design for trunk with 5 m or more in radius and when trunk is hollow or rotten measurement is not efficient (Wickens & Lowe 2008). The only reliable method of estimating the age is radiocarbon dating. Patrut et al. (2013) found out by radiocarbon investigation that the oldest African baobab and the oldest tree among angiosperms with reliable dating results, it is Glencoe baobab in South Africa with age 1835 ± 40, which suffered two splits in 2009. Before this discovery, investigation was done in northeastern Namibia on a baobab called Grootboom. The corresponding calibrated results showed an age of 1275 ± 50 years. However, in late 2004 Grootboom collapsed unanticipated (Patrut et al. 2007).

2.5. Phenology

A. digitata development is divided into four major phases of growth according to Von Breitenbach (1985) sapling phase (up to 10–15 years), cone phase (up to 60–70 years), bottle phase (up to 200–300 years) and an old age phase (up to 500–800 years). From beginning, trees grow rapidly, especially in the cone phase, but with increasing age the increments are smaller, after reaching 6 m height the baobab usually increase 10 cm diameter at breast height (DBH) per year. (Von Breitenbach 1985; Swanepoel 1993; Wickens & Lowe 2008). Saplings and seedlings do not have the characteristic swollen trunk and they can be distinguished from other vegetation by different characteristics such as the number of leaves and the size of the plant. Saplings have typically simple leaves with combination 2-foliolate and 3-foliolate leaves (Wickens 1982; Wickens & Lowe 2008). Trees can be divided by DBH, seedlings 0-1 cm, sub-adults (DBH: 1–150 cm) and adults (DBH >150 cm) (Schumann et al. 2010). Between 30 and 40 years of age branches are spread and droop, and the trunk thickens rapidly, attaining 4-5 m in diameter after 100 years (Wickens 1982).

Baobabs lose their leaves usually before peak dry season (October to April), in this phase green layer below surface of the bark is responsible for photosynthesis, water is stored in the trunk (Wickens 1982; Gebauer et al. 2002; Assogbadjo et al. 2005; Wickens & Lowe 2008). However, some studies reported ecotypes with leaf retention during dry-season (Assogbadjo et al. 2005; Maranz et al. 2008; Gebauer et al. 2016). Wickens (1982) describe that adult trees have before they have digitate leaves, simple ones appear then soon fall.

The flowering time for *A. digitata* usually starts at the beginning of rainy season, although flowers can be found whole year leading to off-season fruits (Assogbadjo et al. 2005; Rahul et al. 2015; Gebauer et al. 2016). Flowers do not occur at the peak of the dry season (January – March) (Wickens, 1982; Sidibe & Williams 2002; Assogbadjo et al.

2005; Gebauer et al. 2016). One tree usually produces 1 to 50 flowers per day. Flowers start opening in the late afternoon and continues through night (Sidibe & Williams 2002). When flower is opened the calyx and corolla lobes curl back to expose the stamens, following morning calyx and corolla straighten and re-cover the stamens, in the late afternoon calyx stay but corolla falls off. The lifespan of the flowers is suggested with pollination period 16-20 hours (Wickens 1982). However, anthesis sometime lasts for less than one hour (Baum 1995). First flowering of young baobabs was reported in South Africa when trees were 16-17 years old, and at the age of 22-23 in Zimbabwe (Wickens 1982). Different time and age of flowering may reflect differences in climatic regimes (Wickens 1982; Sidibe and Williams 2002).

Pollination is mainly done by bats, baobabs are adapted for them with the opening of flowers in the late afternoon and releasing strong carrion (sour) smell to attracted bats. The characteristic smell of the flowers is caused by a proportion of sulphur compounds, mainly dimethyl disulphide. According to Duxoux (1983) the pollinating bats are males because the smell of flower is similar to female pheromones. *Eidolon helvum*, *Epomorphorus gambianus gambiensis* and *Rousettus egyptiacus* are main bat pollinators of baobab seek for nectar but also was noticed bats eat some pollen (Wickens 1982; Wickens & Lowe 2008; Rahul et al. 2015). Suggestion that wind or ant pollination is possible are discounted by Baum (1995), because the pollen is light and have small stigmatic surface. However strong small of flowers attracts bush babies (*Otolemur crussicaudatus* and *Galego senegalensis*) which feed on the flowers and destroying them, but they have still minor pollinating role (Wickens 1982; Sidibe and Williams 2002; Wickens & Lowe 2008). Bluebottles (*Crysomyia marginalis*), nocturnal moths (*Heliothis armigera*, *Diparopsis castanea*, *Earias biplaga*) and certain flies are attracted by strong carrion-like smell but their role as pollinators is not clean (Wickens & Lowe 2008).

The fruit development usually takes 5-6 months (Wickens 1982). Fruiting is seasonal and there are substantial regional differences. In Sudan, the fruiting occurs between August to October (Gebauer et al. 2016), in Benin between July to August (Assogbadjo et al. 2005). Fruiting peaks are at the beginning of the dry season. However, differences can occur, and mature fruits could be found at different times of the year (Assogbadjo et al. 2005; Gebauer et al. 2016)

2.6. Pests and diseases

A. digitata is a host of many insects. From order Orthopera the long-horned grasshopper (*Anepisceptus horridus*), the elegant grasshopper (*Zonocereus variegarus*) and stick insect from order Phasmida which are feeding on leaves. Order Hemiptera have some members such as *Odontopus exsanguinis, O. Sexpunctatus, Oxycarenus albipennis, Neodysdercus intermedius* and cotton-stainers such as *Dysdercus fasciatus, D. nigrofasciatus* and *D. superstitiosus*. The most described specie is *Dysdercus faciatus*, his life cycle is associated with baobab and cotton (Figure 8). They are feeding on cotton bolls and on the oil from baobab seeds, in a dry period when cotton or seeds are not available, they feed on leaves of baobab. Nests are in hollows and cracks of baobab and could be detected by red colour on the bark. *D. faciatus* can fly several kilometres so control measures are difficult and best method is attack them during a dry season when they are hiding in trees by spraying with paraffin twice a year. However, *A. digitata* is associated with another species such as flea beetles (*Podagrica* spp.) which damage leaves of crops and baobab, the longhorn beetle (*Analeptes trifasciata*) which is able kill young one by girdling. Cotton bollworm (*Heliothis armigera*), red bollworm (*Diparopsis castanea*) and spring bollworm (*Earias biplaga*) are serios agricultural pests which are damaging crops especially cotton and feeding on leaves and twigs of baobab. The baobab is also minor or alternative host for the ear borer (*Mucuna pruriens*) which attacking fruits of baobab and agriculture crops, the cocoa capsids (*Distantiella theobroma*) which is pest of cocoa and also is vector of the fungus *Nectria rigiduscula*, the mango mealybug (*Rastococcus iceryoides*) or *Gonimbrasia berlina* which feeds on leaves of baobab (Sidibe & Williams 2002; Wickens & Lowe 2008; Kehlenbeck et al. 2015).

Figure 8. One of the baobab pests: cotton-stainer (*Dysdercus faciatus*) (Author archive)

Nematodes are also a pest of *A. digitata* such as rootknot nematode (*Meloidogyne* spp.) and the reniform nematode (*Rotylenchulus reniformis*). Baobabs have the role of the source of these nematodes which can be harmful for agriculture crops such as sweet potatoes (*Ipomoea batatas*). Against *Meloidogyne incognita* nematocidal activity was found in leaves of baobab (Sidibe & Williams 2002; Wickens & Lowe 2008).

Adansonia digitata is the host of few viruses. For virus of the Cacao swollen shoot badnavirus is the alternative host. This virus is devastating for cocoa plantation and vectors are mealybugs from Pseudococcoidae which are affecting the baobab. This disease can seriously infected seedlings. However, the conclusion from the investigation of this virus is that baobab is not a source of original outbreaks. *A. digitata* is also is susceptible host of the Cacao yellow mosaic tymovirus, the Okra mosaic tymovirus and the Cassava brown steak-associated cariavirus but on the other hand is not susceptible to Clitoria yellow vein virus and Hibiscus latent ringspot virus (Sidibe and Williams 2002; Wickens & Lowe 2008; Ameyaw 2015).

Baobabs have only few parasites. One of them is *Loranthus mechouvii*, mistletoe, which is not dangerous parasite. Parasitic figs which can let to die of whole tree are reported (Wickens 1982; Sidibe & Williams 2002).

Fungi also attack baobabs especially when wood is rooting or dead. King Alfred's cakes *Daldinia concertica*, the bracket fungi (*Coriolopsis strumosa*) and *Trametes* *socrotrana* are microfuges which attack dead wood. *Phyllosticta* spp. which causes a leaf spot and *Leveillula taurica* which causes powdery mildew are two proved fungi diseases which attacking healthy tree. Study done by Cruywagen et al. (2015) study fungi of black mould which could kill the trees, four fungi *Aureobasidium pullulans*, unknown *Cladosporium* sp., *Toxicocladosporium irritans* and a new species of *Rachicladosporium* described as *R. africanum* were found. However, with global climatic change could be found in Africa many cases of dieback, die of branches and sunken areas which is believed related to fungi *Lasiodiplodia theobrome*.

Diseases are unfortunately not so well investigated and one of the reasons is that economic value of baobab is not so important to attract funds for study these problems (Sidibe & Williams 2002; Wickens & Lowe 2008; Kehlenbeck et al. 2015).

2.7. Uses of baobab

Indigenous knowledge is increasing its importance in past few years. It is mainly due to conservation purposes or uses in pharmacology and food industries. Indigenous knowledge is usually passed orally from one generation to another. However, this valuable knowledge is losing due to transformation to modern life style. (Lisao et al. 2017).

A. digitata could be named as "tree of life" that's mean the tree is multipurpose, every part could be use by communities of the savannah as a food source, medicine or spiritual, cultural and traditional purpose (Kotina 2017; Lisao et al. 2017; Sidibe & Williams 2002). International trade with seed oil and fruit pulp for cosmetic and food industry is already well-developed in South Africa and Malawi (Buchmann et al. 2010). Demand for the baobab products are increasing, one of the reasons is that European commission and USA approved fruit pulp as a novel food ingredient (EC 2008; FDA 2009). This situation make pressure on natural resource which leads to an importance for promoting successful conservation of African baobab (Sidibe & Williams 2002; Lisao et al. 2017).

Baobab serve as a signpost for inhabitants or travellers (Figure 9). Baobabs were usually planted in the middle of the village and some serve as notice board. They were also providing shade which is important in arid areas. Arab traders use them for marking trade tracks. In town such as Malakal, Sudan or Messina in South Africa could be found avenues of baobabs (Wickens & Lowe 2008).

A. digitata is widely use as cistern of water for surviving long dry period (Figure 9). This use was developed independently in Madagascar, Australia and Africa. The opening is made in the spot where trunk is divided, then the trunk is hollowed artificially when thickness 30cm is undamaged or trunk is hollowed naturally, when is hollow fill-up with water during rainy season opening is closed with mad cap (Wickens & Lowe 2008).

Figure 9. Artificially hollowed *A. digitata* for storage of water (A) and as signpost (B) Kilifi, Kenya (Author Archive)

Hollow baobabs can be used as rain shelters or bus shelters, dwellings, stable, garage for a car, petrol store, carpenter´s store, bar, post office, flush toilets, prison, tombs, graves (Wickens & Lowe 2008). They can be used as “towers” for searching for lions and cattle. Bee hives made from baobab bark can be attached on them. Parts of baobab could be used for toiletries, dyeing or their ash could be used as fertilizer (Wickens & Lowe 2008)

2.7.1. Leaves

Baobab leaves are for many populations in the central region of Africa basic commodity. The fresh young baobab leaves are harvest during the rainy season when the leaves are delicate. However, leaves from different trees have different desirability in taste, crude fibre, indumentum and mineral content, so not every tree produce favourable leaves (Wickens & Lowe 2008). This type of leaves is cut in the pieces and cooked or can be used as a vegetable. At the end of the rainy season, plenty of leaves are harvested for drying them, as the whole leaf or grinded into a powder which is used for domestic use or for the marketing (Rahul et al. 2015). Drying should be done on indirect sun and the whole leaves have higher level of pro-vitamin A than powder (Sidibe & Williams 2002). In West Africa, the leaves are part of daily dishes and they are sold on rural and urban markets. The fresh ones are rich in vitamin C as well as containing uronic acids, rhamnose and other sugars, tannins, catechins (Wickens 1982) also providing protein and mineral source especially iron, calcium, magnesium, potassium and manganese (Maranz 2008; Buchmann et al. 2010). Leaves are used for tanning (Abbiw 1990). Smoke from burning leaves could be used as insect repellent (Lisao et al. 2017). Leaves are sometimes use for speeding up process of fermentation of wine (Storrs 1982). Fresh leaves are cooked in water spinach or mixed and cooked with coarser vegetables like cassava leaves or eaten raw or mixed with peanuts as a salad (Wickens & Lowe 2008). Powder is flavouring agent to sauces, soups over porridges, cereals, thick gruels of grains, or boiled (Wickens & Lowe 2008; Buchmann et al. 2010; Rahul et al. 2015; Gebauver 2016). Leaves are harvest as fodder for domestic animals such as cattle, goat, camels and donkeys (Wickens & Lowe 2008; Lisao et al. 2017). Livestock browsed fallen leaves and young shoots. Fodder value is great, with 1 feed unit kg^{-1} dry matter (or 6.9 MJ kg^{-1} dry matter) and 110 g kg^{-1} of digestible crude protein. Fresh green leaves can substitute vegetables in area where is lack of water by pruning (Gebauver 2016). Only scientific data of yield is from Mali more than 130 kg of fresh leaves per tree and year (Dhillion & Gustad 2004).

2.7.2. Fruits and flowers

Baobab pulp is mealy, dry and tastes acidic. It is rich in mucilage, free tartaric acids, calcium, vitamin B, pectins, tartarate, and it contains ten times higher concentration of vitamin C than oranges but low in protein and fat (Gustad et al. 2004; Buchmann et al. 2010). The pulp is eaten fresh or can be dissolved in water or milk (Lisao et al. 2017). The liquid is then used as refreshing drink, sauce, soups and couscous, alternate for cream of tartar in baking, fermenting agent in local brewing of beer, porridge with millet or sorgum (Wickens & Lowe 2008). Powder with sweated water frozen can by consumed as an "ice lollipop." It is important not to boil the pulp for maintaining the high vitamin C content. (Buchmann et al. 2010; Rahul et al. 2015). Fruit shell is used as fuel (Lisao et al. 2017). Pulp is used for making paper with low quality (Kamatou 2011). Long term storage of pulp is done by sun drying and then store in containers with sodium metabisulphite (Zahra'u 2014).

Seed oils is an important source of nutritional oils, for cosmetic and pharmaceutical use (Rahul et al. 2015; Lisao et al. 2017). Providing protein and mono- and polyunsaturated fatty acids (Buchmann et al. 2010). Seed have a nutritious value 1803 kJ/100g that is 50% higher than leaves, moisture 8.1%, protein 33.7%, fat 30.6%, carbohydrates 4.8%, fibre 16.9%, ash 5.9%, contain high levels of lysine, thiamine, Ca and Fe and also phosphorous, calcium and magnesium (Zahra'u 2014). Remaining shells from extraction of oil are used as feed for chickens or in mixture for goats and cattle (Lisao et al., 2017; Wickens, 2008). Seeds could be roasted and then eaten or use as coffee substitute (Wickens and Lowe 2008; Zahra'u 2014; Lisao et al. 2017). Neckless could be also crafted from the seeds of baobab (Buchmann et al. 2010). Flour can be obtained from seed and then used for cereal, porridge, gruels, soups or mixed with honey for drinks (Wickens & Lowe 2008; Buchmann et al. 2010).

Flowers are eaten by goats (Lisao et al. 2017). Pollen grain from flowers is used as glue (Kamatou 2011). Flowers are eaten raw for their sweet taste of nectar or use as flavour to drinks (Wickens & Lowe 2008).

2.7.3. Bark

The bark fibres of *A. digitata* have been (and continue to be) widely used by rural people for making ropes, cordage, harness straps, strings for musical instruments, baskets, bags, nets, snares, fishing lines and nets, making a paper, mats and cloth (Wickens & Lowe 2008; Kotina 2017). Ropes can be used in construction of traditional houses or traditional mats. Wild animals, mainly elephants obtained salt from the sap from chewing of wood (Wickens, 2008). Bark is used for feeding of cattle, donkeys and goats during drought or could be used as fermentation agent in the milk (Lisao et al. 2017). From bark can be obtained tragacanth-like gum and starchy deposit which are edible (Wickens and Lowe 2008). Trunks can be used as dugout canoes and bark is used for tanning.

2.7.4. Baobab uses as a medicine

Leaves are used as a prophylactic against fever, against excessive sweating, and as an astringent (Kamatou, 2011). The leaves are used to treat kidney and bladder diseases, asthma, otitis, general fatigue, diarrhoea, inflammations, insect bites, guinea worm and as a tonic because they have hyposensitive and antihistamine properties (Wickens 1982; Sidibe and Williams 2002). Painful swellings could be treated by crushed young leaves (Sidibe and Williams 2002). Dried leaves are used as insect repellent (Kamatou 2011).

Seeds are soaked in water and taken as a remedy for cough and stomach pains (Kamatou, 2011; Lisao et al. 2017). Swollen joints are cured by paste made from the baobab fruit (Wickens & Lowe 2008). Fruits are used for curing microbial diseases (Kamatou 2011). Soaked bark in water, mixture with leaves or solution is used for treatment of stomach pain, inflammation or swollen body parts. Medicinal use relates to birth, women belly is thread with belt for inner bark which is passed from one generation to other and new born babies are washed in solution or threads from bark are tie around hands, legs and waist (Lisao et al. 2017). Bark can be also used as substitute for quinine to relieve fever (Kamatou 2011). Dried baobab bark for treat the fever associated with malaria (Wickens & Lowe 2008). Stem bark can be used for wound healing and anaemia (Kamatou 2011). Roots could be used as a cough remedy after they are boiled in water (Kamatou 2011; Lisao et al. 2017). Diarrhoea and hiccough can be treated by oil from the seeds (Kamatou 2011).

2.7.5. Traditions associated with baobab

Throughout Africa the baobab is regarded with awe by most indigenous people; some even consider it bewitched (Wickens & Lowe, 2008). It is widely believed that God planted the trees upside down, there is many stories why baobab is was planted like that (Wickens 1982). Some people believe that trees possess souls or are inhabited by ancestral spirits such as Resa, the Lord of Rain and they are worshipped or worshiped as totem in Zimbabwe (Wickens 1982; Vick 2001). *A. digitata* is also related to evil spirits in some part of Africa and local people are protecting from them by belts or charms (Wickens & Lowe 2008). Baobabs serve as shrines for offerings and praying (Norris 1982). Is also believed that if tree will be removed it will bring misfortune or curse or if local baobabs die, their community will break up (Wickens 1982, Blench & Dendo 2004; Wickens & Lowe 2008). Baobab is in southern Nigeria worshipped as a fertility tree and in Burkina Faso special names for born kids under this tree are given (Wickens 1982). In Sudan is believed that mythical creatures Anag hollowed baobab by giant fingernail (Blunt 1923). In Senegal and Zimbabwe, it is believed that starts as creeper which coils itself around a tree, engulf and strangles it and turns into a baobab (Wickens 1982; Mullin 1991).

Balls and porridge made from baobab are related to end of Ramadan, end of Lent and Easter (Wickens & Lowe 2008).

2.8. Baobab cultivation and silvicultural practices

2.8.1. Natural regeration

Recent reports are warning about lack of natural regeneration. Critical stage is when trees are young, and they are sensitive on drought. They need ground water or annual precipitations from 350 -500 mm. Regeneration is usually very rare, for example in South Africa the regeneration occurs every 100-150 years (Wickens & Lowe 2008). Main factors which are influencing regeneration now are change of climate and change of land use other factors are deforestation, fires, increasing of population, cultivation and livestock also elephants in game reserves can damage regeneration (Dhillion & Gustad 2004; Wickens & Lowe 2008). Topple or breaking of branches is causes by strong wind due to loose of natural windbreaks and loose of turgor in branches due drought (Wickens

& Lowe 2008). Baobabs are successful in regrowth they can produce shoots from damaged rootstock or even when baobab is uprooted (Wickens & Lowe 2008). Destructive uses of seeds by human is factor which influencing low recruitment of baobab (Lisao et al. 2017). Baboons are another factor which influence recruitment, predation of immature fruit resulted in up to 85% fruit loss (Venter& Witkowski 2011).

2.8.2. Propagation from seeds

Collecting of the seeds could be done different methods. The easiest one and most common is way until the fruit will fall on the ground, this method has some disadvantages, if the fruit laying on the ground for long time it can be contaminated or lose viability, fallen fruits could be immature (Wickens & Lowe 2008). Another method is climbing up a tree by ladder. Throwing of stone, poles and sticks can be used for harvesting fruits from the canopy. After this, fruits must be store in cool dry place to protect them (Sidibe & Williams 2002).

On single tree could be found mature 250 fruits with 30 kg of pulp and more (Ibiyemi 1988; UNCTAD 2005). The connection between fruits and animals and humans is important for germination. Termites penetrate woody shell and by eating pulp releasing seeds which can germinate. Furthermore, seeds can be dispersal by human which eat the pulp and split seeds or by animals such elephants (*Loxodonta africana*), eland (*Trafelophus oryx*), baboons (*Papio* spp.) and chimpanzees (*Pan troglodytes*), another dispersal agent can be river or sea. Digestive system of animal help to germination of seed by eliminating of any inhibiting factors, soften the testa and make uptake of water easier (Watson 2007; Wickens & Lowe 2008).

However, survival of seedling is complicated. Drought or eating of them by animals and people are main factors which are main menaces to young baobabs (Sidibe & Williams 2002). Study done by Venter and Witkowski (2013) was testing if the lack of natural regeneration is caused by seed or establishment (microsite) limiting. Two study areas were established, one open and second one closed for livestock. The percentage of emerged seeds wasn´t high in closed plot 6.33% and in open 2% after approx. one year, after emergency almost all die due to the moisture stress and insect browsing in case of closed plot and all young ones die due to the goat browsing. Even when they try to plant seedlings, rainfall and livestock were main problems. From this study could be clear that planting and protection is key for maintenance this species.

However, seeds need due to their hard and non-permeable testa pretreatment. Natural germination is less than 20 percent (Danthu et al. 1995). Ensowo (1991) found the fruit pulp as an inhibitor of germination also if seed are treated with herbicides and fungicides the germination failed. Germination and chance of survival depend on the rainfall, because rainfall can washout pulp which is inhibitor (Sidibe & Williams 2002). According Razanameharizaka et al. (2006) seed of *A. digitata* are from two-thirds water impermeable and need scarification or different treatment to allow germination.

2.9. Seed pre-treatment

Before sowing the seed or any other action connected with propagation of seeds is good to make simple test. Put seeds in the water and if they are floating to remove them because embryo is missing (Wickens & Lowe 2008).

Due to low seed germination (Sidibé & Williams 2002), several methods were established for increasing of germination rate of *Adansonia digitata*. The easies one and most available in rural conditions is manual scarification, because do not required special tools and energy. Second one is soaking or boiling seeds in the water. This method required stopwatch, thermometer and water. Third one is soaking in the acids which are expensive for people in rural areas and they could be dangerous in hands of non-specialist for technician, also can be dangerous for the environment without proper management.

2.9.1. Manual testa scarification

Mechanical pre-treatment of seed including tapping with a hammer, nicking by knife or file, or scarifying with coarse glass paper (Esenowo 1991; Wickens & Lowe 2008). Manual scarification (chipping) is one of the methods that help germination. This method is common in rural areas where acid is not available or too expensive (Sidibe & Williams 2002). Maghembe et al. (1994) done scarification of seeds with result of 90% germination. Razanameharizaka et al. (2006) get after manual scarification 99% of germination and without it only 27%. Danthu et al. (1995) get 65 – 80% of germination by removal of a small fragment of a seed coat, but this method could lead to necrosis of 10% to25 %. Manual scarification and then soaking in the water for 6 hours led to only 2% of germination because rapid absorption of water kill embryo. Assogbadjo et al. (2010) were testing if a 5 – 10 mm^2 fragment of the seed coat will be removed with pruning shears will be necessary for germination and the result was 57% for non-treated seeds and 14% for scarified seeds on day 25, this demonstrate that baobab seed can germinate without scarification of its seed coat.

2.9.2. Boiling and soaking

Immersion is one of the methods which is used for treatment of seeds, Maghembe et al. (1994) immersed the seeds in boiling water, when seeds were immersed for 30 seconds and then sown, the germination was 23% and was just immersed for few second and then left to cool for 12 hours before sowing the germination was 35%. Razanameharizaka et al. (2006) boiled seed for 15 seconds with 90% and more germination. Falemara et al. (2013) was testing boiling of seeds for 5, 7 and 10 minutes and then sown in sandy soil with result 3%, 3% and 5% respectively. In 2014 Falemara et al. testing the same experiment and on sandy soil get 0%, 0%, 5%, respectively, but on sawdust get higher 5 %, 10 %, 10% respectively. Boiling of seeds in water for 15 minutes is also possible but there is risk of inhabitation of germination (Sidibe & Williams 2002). After 189 day Anonymous (1955) get 90% germination with treatment of hot water and 8% with cold water. Esenowo (1991) tried soaking seed in water with 50-60 °C for 30-50 min and result was 70-80% germination, in just few second in 70-80 °C water gave 20-30% germination then soaking in distilled water for three day gave 50% gemination and for five days gave none. Johansson (1999) try different methods of soaking and boiling. Soaking seed for three days with or without pulp this was not successful, and he recommended to increase temperature to 30 °C. Boiling with pulp for 5 minutes gave 10% of germination and boiling in hot water for 5 x 1 minute with cooling down in-between gave even less.

Maghembe et al. (1994) tried cut a piece of coat and then soaking in cold water for 72 hours this method gave 92% of germination and putting seed in container of hot water for 48 hours gave 96%. Falemara et al. (2013) were testing soaking of seed in soaking in cold water (25-28 °C) for 6, 12 and 24 hours, soaking in hot water (100 °C) for 5, 7 and 10 minutes and best result for cold water was 12 hours with result 22% and for hot water 10 minutes with only 5% germination. Falemara et al. (2014) repeated this test but result was in same substrate (sandy) 5% germination in hot water for 10 minutes and 30% in cold water for 12 hours. Usman and Asan (2017) cold water at 25 °C for 6 hours, hot water or 100 °C for 10 minutes and the result was 0% of germination.

2.9.3. Treatment of seeds with acids

Soaking in HCl (pH = 2.5) for 8 hours which simulated elephant digestion was not successful and seed even did not swell, maybe duration was too short (Johansson, 1999).

One of the methods is soak the seeds in sulphuric acid. According to Danthu et al. (1995) soaking of seeds 6-12h in concentrated sulphuric acid led to 90% and more germination. Esenowo (1991) was testing concentrated sulphuric acid and nitric acid for 15 minutes, which resulted in 98% germination when sulphuric acid was used, and in 86% gernmination rate in case of nitric acid. Razanameharizaka et al. (2006) used H_2SO_4 95 % and seeds germinated successfully (90% and more) if the period of application ranged from 3 to 12 hours of soaking. Mali Forest Research Institute used soaking 90 minutes in sulphuric acid then 24 hours water rinsing, and result was 92% of germination (Sidibe and Williams, 2002). In Burkina Faso, soaking the seeds in 95% concentrated H_2SO_4 for 45 minutes was tested and it gave 80% germination rate (Bationo 2003; Bationo et al. 2009).

Diouf et al. (2015) were studied different morphological traits and their effect on germination rates, the best rates were obtained for seeds that had been soaked for 6, 8, and 12 hours in concentrated sulfuric acid (96%), there was not any significant differences among these three soaking durations and germination rate was from 80 – 100%.

Falemara et al. (2013) were testing soaking of seed in acid (H_2SO_4) for 1, 6 and 12 hours at 10%, 50% and 98% concentration levels and best result was 70% germination after one hour in 98% sulphuric acid. Falemara et al. (2014) repeated this test and the result was similar, in sandy substrate 85% germination after one hour in 98% sulphuric acid was achieved. Usman and Asan (2017) were also testing soaking of seeds in H_2SO_4 for 1 hour with result 93,33% of germination.

2.9.4. Dry heat treatment of the seeds

Johansson (1999) tried simulation of exposure to fire for 5 minutes with temperature 250 °C. This killed all seeds. At temperature about 100 °C some seeds survived and swelled but did not germinate.

2.9.5. Germination *In vitro*

In vitro seed germination of baobab was tested in Kew´s Seed Bank at Wakehurst Place, where two different methods were used. Sterilization was done in 10% sodium hypochlorite. The seeds were either scarified and then soaked for one day in distilled water of temperature 27 °C, or just scarified. The first method gave 75% germination, the latter 80% germination (Wickens & Lowe 2008). In both cases, the *in vitro* cultures were maintained at 26 °C and 12/12 hrs (light/dark) regime.

2.10. Aftercare and seedling management

Ideal substrate in nursery is mixture of three parts: top soil, one part of sand and one part of compost (Sidibe & Williams 2002). Planting is done by two methods. First one is transplanting, seeds are in nursery 10 × 25 cm in nursery and then transplanted with 250 × 250 cm (Sidibé & Williams 2002; Kalinganire et al. 2007). Second method is direct sowing in density 15 x 15 cm (Bationo 2003; Bationo et al. 2009) or 50 x 20 cm (SCUC 2006; Assogbadjo et al. 2010). In nursery is important watering and protection from rodents and monkeys which love young seedlings (Figure 10). Kalinganire et al. (2007) suggest watering of seedling every morning and evening, Assogbadjo et al. (2010) reported watering once a day in the evening.

Fertilization of substrate is desirable. In Burkina Faso they tried 44 kg per 100 m^2 of compost or manure (Bationo 2003; Bationo et al. 2009), in Mali was used 625 kg manure per 100 m^2 (SCUC, 2006) and 100 kg per 100 m^2 of compost or manure (Kalinganire et al. 2007), Sidibé and Williams (2002) were using chemical fertilizers, bi- or tricalcium phosphate and urea with 46% N.

Figure 10. Damaged seedling by baboons (Author archive)

When seedling produces first sprout, the best is to put them in shady place for next 8 days and then 4 - 7 days to half shade. When seedling is 3 - 4 months old it is possible to transplant it to selected plot. Planting of 40 - 50 cm tall baobabs is done in the beginning of rainy season. Recommended spacing is 10 × 10 m in the hole 60 cm × 60 cm × 60 cm with organic fertilizer or matter (Sidibe & Williams 2002). In good condition baobab can reach 3 m height in 2 years and 12 m in 15 years (Wickens & Lowe 2008). Trees can be propagated for leaf production, first harvest is in 40 days after direct sowing followed monthly harvests, all leaves are harvested but terminal buds are left, yield is 400 kg per 100 m^2 per month for the first two months and then 200 kg per 100 m^2 per month (Bationo 2003; Bationo et al. 2009).

2.11. Vegetative propagation

Vegetative propagation by cutting of stem or by grafting, grafting extremely significantly shortens time of first flowering from 8-23 years (raised from seeds) to 3-4 years after grafting (Wickens 1982; Kalinganire et al. 2007; Jenya et al. 2018). Grafting is used for obtaining preferable fruit traits because phenotypic fruit traits are linked to genotypic characteristics (Ndungu et al. 1995). Results from Senegal and Mali showed 85% survival rate, Top- and side-grafting give the best results, but top-grafting is preferred because it is easier method (Kalinganire et al. 2007). Anjarwalla et al. (2017) were also testing Top- and side-grafting in Kenya with result 63% of survival rate, top-grafting showed slightly more survival success than side grafting (71% vs. 55%). Maranz et al. (2008) tested successfully cross-species grafting where *A.digitata* was used as rootstock for Madagascar species for better nutritional qualities and isolation of the exotic biomass from the soil and from foraging termites (Maranz et al. 2008). Chip budding of baobab seedling is also successful (Danthu and Soloviev 2000).

2.11.1. Micropropagation

Singh et al. (2010) were testing germination *in vitro* with 1, 30, 40 and 60 days old seeds after harvesting without pre-treatment and 75 days old seeds soaked in HNO_3 for 24 hours which were then soaked in tap water for 1-10 days then sterilized in 0.1% $HgCl_2$ for 1-10 min and rinsed with sterilized distilled. They were using Murashige and Skoog (MS) (Murashige & Skoog 1962) medium with 3% sucrose and 0.8% agar and half-strength Murashige and Skoog medium and then incubated the cultures in dark for one week at 25 ± 2 °C temperature. Only two groups germinated, 30 days old seeds without pre-treatment with germination rate 85% on full MS and 90% on half MS, and 40 days old seed without pre-treatment with germination rate 80% on full MS and 85% on half-strength MS. However, lower percentage for full MS was compensated with significantly better growth of seedling.

N’Doye et al. (2012) tested *in vitro* germination of *A. digitata*. They soaked seeds in 95% concentrated H_2SO_4 for 12 hours according to Danthu et al. (1995) and sterilizied them in NaOCl for 5 minutes. Seeds were sown in MS culture medium and put in dark incubator with temperature 27 ± 1 °C this lead to germination rate of 90%.

2.11.2. Micropropagation of baobab

Adventitious shoot production in baobab was tested using different types of seedling segments as primary explants (cotyledonary nodes, axillary nodes and terminal apex) and cytokinins 6-benzylaminopurine (BAP) and kinetin alone, or in combination with auxin 1-Naphthaleneacetic acid (NAA) or active charcoal (AC). Optimal results were obtained using MS + BAP 0.5 mg/l, especially for apex average number of shoots, for multiplication factor, for axillary nodes mean number of shoots, for mean number of nodes, and for cotyledonary nodes multiplication factor optimal concertation of plant growth regulator (PGR) was 2. 2 g/l AC and BAP at 5 mg/l. For rooting, half-strength MS medium was combined with the levels of the growth regulators, NAA or Indole-3-butyric acid (IBA) at concentrations of 1, 2.5 and 5 mg/l. Generally, the auxin NAA proved to be more effective than IBA for baobab in vitro rooting (N'Doye et al. 2012).

Fasola and Okerenkporo (2012) tested micropropagation on MS and Woody Plant Medium (WPM) (McCown & Lloyd 1981) in combination with cytokinins BAP, Kinetin (KIN), auxin NNA and additive supplement (coconut water). MS medium proved to be better than WPM since the plants cultivated on the former medium showed highest number of nodes, maximum length of shoots and roots, regardless of PGRs used. In embryo regeneration optimal result for promoting nodes were obtained using BAP 0.02 mg/l and KIN 0.03 mg/l, for the longest shoots, BAP 0.04 mg/L and KIN 0.03 mg/L gave the longest roots. All combinations for shoot regeneration were successful but BAP gave the longest shoots and KIN with 0.02 mg/L NNA gave the longest roots.

Rolli et al. (2016) studied in vitro propagation using two-node segments. Seed were soaked for 24 hours in H_2SO_4 98% then acid was washout by $NaHCO_3$ and then soaked in 37 °C deionized water for 24 hours after this procedure sown in substrate. Four-week-old seedling are cut in two-node segments and then sterilized in 70% ethanol and then soaked in 2% sodium hypochlorite and rinsed in distilled water. Testing media were combination of MS with 0.2, 2 or 20 m/l BAP, 2-isopentenyl adenine or Zeatin Riboside, alone or in combination with 0.2 or 20 m/l IBA. Combination of 0.35 or 3.5 m/l zeatin riboside and 20 m/l IBA had best result in forming of micro shoots. These shoot-tips were tested on 0.2 or 20 m/l IBA for rooting and 20 m/l IBA was significantly better, but both concentrations were 100% successful in acclimatization.

Despite numerous studies available on in vitro shoot multiplication of baobab, rather low number of new shoots and nodes were reported as a result of this propagation process. Indirect organogenesis or somatic embryogenesis might be more effective methods for mass production of baobab plants. However, this techniques in baobab has not been optimized yet.

2.12. Silviculture management

Baobabs are heavily pruned in Sudanian zone for leave production (Sidibé & Williams 2002). Pruning of *A. digitata* influenced reproductive performance. Pruning for fruit production is common in West Africa with combination of debarking, moderate intensity of pruning on medium and large trees increase production of fruits but young ones are vulnerable to pruning (Schumann et al. 2010). Pruning is more common in villages and croplands because walking distance is short where trees with good tasting leaves were more pruned to avoid development of branches and increase food quality of leaves (Dhillion & Gustad, 2004).

Fertilization can be done by organic or mineral fertilizers. Organic fertilizers such as manure, compost, green legume manure is recommended, especially for young trees. Mineral fertilizers are costly and not always available in rural areas. Irrigation of trees is not necessary, nevertheless if present, better growth and shorter dormant period were observed (SCUC, 2006).

Use of baobab in agroforestry system is also possible. Pearl millet, vegetables or cereals can by used with baobab in intercropping strategy. This strategy has good results against weeds, improve aeration of soil and brings different products compere to monoculture. However, disadvantage of this method is competition for nutrients between species. Baobabs could be used as windbreaks in agroforestry system (SCUC 2006).

2.12.1. Fruit harvest

Harvesting of baobab fruits have long history as a subsistence product. The stability of population showed not harmful impact of fruit harvesting, but now with change of environment, increasing of livestock, polulation and other factors the future of population is in danger (Wickens 1982; Dhillion & Gustad 2004; Venter & Witkowski

2013a; Venter & Witkowski 2013b). Ibiyemi et al. (1988) quoted an unsubstantiated figure of 250 fruit per mature tree. However, fruit production varies significantly between years and land-use types, majority of adult trees (59%) produced less than 25 fruit per tree per and only 5% produced ≥ 300 fruit per year, but average production was 77 fruits per tree per year (Venter and Witkowski 2011). Assogbadjo et al. (2005) also reported varied mean fruit production in Benin between 57.1 and 157.4 fruit per tree in different climatic zones. Fruit production is strongly determined by variations in flower numbers (Venter 2012). Fruit harvest levels of 33–90% sustainable under moderate to zero livestock numbers (Venter &Witkowski 2013b). In period between May and June the fruits are ready for harvest (Venter 2012). Methods for harvesting a tree is climbing up a tree by ladder or using poles and sticks (Sidibe & Williams 2002).

3. Objectives

The main objective of the thesis was to define suitable ways of *Adansonia digitata* L. propagation and silviculture management in Kenya.

The specific objectives were:

1. To assess the most effective, fastest, and cheapest method of baobab germination in greenhouse conditions.
2. To induce *in vitro* callogenesis and regeneration of baobabs by indirect morphogenesis.
3. To evaluate local knowledge of baobab tree management and utilization by surveys with Kenyan farmers.

The research questions were following:

i. What is the best method of seed pre-treatment for local people?
ii. Is it possible to perform *in vitro* callogenesis and regeneration of baobabs?
iii. What are the main challenges of baobab tree management?

4. Materials and methods

4.1. Design of seed pre-treatment and *ex vitro* germination experiment

This experiment was performed in the Botanical Garden of the Faculty of Tropical AgriSciences of the CULS Prague in 2017. Seeds were collected by Chládová (2016) from South-eastern Kenya in 2015. In this experiment we tested three seed pre-treatment methods to increase germination rate. The applied methods were following i) mechanical scarification by sandpaper, ii) boiling the seeds in water for 5 seconds, iii) soaking the seeds in 96% sulfuric acid and iv) the control treatment. For every pre-treatment method and control treatment, 144 seeds were used. Each method was replicated three times. In total, 1,726 seeds were used.

Before executing every method, a simple water seed viability test was done. This test is based on soaking seeds in a container with water. If the seeds float, they are likely to be poor germinators. However, if the seeds sink to the bottom of the container, it should still be viable and suitable for further use (Sacande 2006; Wickens & Lowe 2008).

i) Mechanical scarification by sandpaper. For this method we were using sandpaper attached to power drill to remove seed testa. After this treatment, seeds were immediately sown into the soil. This is a relatively easy method, however, care has to be taken not to remove part of the embryo with the testa, because otherwise the seed would not germinate.

ii) Boiling of seeds in water for 5 seconds. The water was brought to boiling for 15 minutes, then seeds were immersed in the boiling water for 5 seconds. After boiling, the seeds were removed and allowed to cool down and sown into the soil.

iii) Soaking of seeds in 96% sulfuric acid. The third treatment included soaking of the seeds in 96% sulfuric acid (H_2SO_4) for 6 hours. This intermediate time period was chosen based on literature review (Diouf et al. 2015). After the soaking, the seeds were removed, washed and rinsed in running tap water to remove any remaining acid, and then sown into the soil.

The experiment was designed for 34 days and the germination of seeds was measured every second day. Fro sowing mixture of soils was used (30% sand, white peat 25%, black peat 25%, compost 20%) Seeds were watered twice every day and temperature was 23 ± 2 °C in the greenhouse of Botanical garden.

4.1.1. Data collection and evaluation of germination *ex vitro*

Collection of data was done by counting new seedlings every second day, seedling was counted and write down when two first leaves fully developed. On the end of experiment germinated seeds were counted and they were weight for estimation of final biomass.

To assess the most effective, fastest, and cheapest method of baobab germination pre-treatment, following parameters were measured: final germination percentage measured by counting the germinated seedlings, mean germination time evaluated was evaluated from recording germinated seeds every second day, effects of pre-treatment on germination and biomass were figured out from development of young baobabs. One germination parameter was assessed:

1. Mean germination time (MGT) = $\Sigma Fx/\Sigma F$; where F is the number of seeds germinated on day x (Al-Mudaris, 1998).

The data were statistically analysed using SPSS (IBM, 2013). To determine the most suitable pre-treatment method, ANOVA (Analysis of variance), Duncan’s Multiple Range Test (DMRT) and Tukey's HSD (honestly significant difference) test was carried out for significantly different parameters.

4.2. Indirect *in vitro* morphogenesis

4.2.1. Plant material and callus initiation

Experiments were carried out in Plant Tissue Cultures Laboratory of the FTA, Czech University of Life Sciences Prague in 2017. Seeds of *A. digitata* were collected by Chládová (Chládová 2016) in South-eastern Kenya in 2015 and stored at the CULS Prague. Embryos from seeds were extracted by sandpaper attached to a power drill. Their surface was sterilized with 70% ethanol for one minute and then put in 10% NaClO for

10 minutes followed by additional washing with sterile distilled water three times to wash out all sterilizing agents. In flow box seed embryos were split along the embryonic axis, then put on callus initiation culture media. Four different media were assessed, for each treatment were used 25 explants (Figure 11).

Figure 11. Preparation of seeds for extraction of embryonic axes (explants).

The media for induction of callus contained MS salts, 30 g/l sucrose, 100 mg/l myo-inositol, 8 g/l agar and they were supplemented with different concentrations and combinations of BAP, KIN, Dichlorophenoxyacetic acid (2.4-D), and NAA (Table 1). The pH of the media was adjusted to 5.7 with KOH. The medium was poured into Erlenmeyer flasks (100 ml), each containing 25 ml. The culture medium was sterilized in autoclave at 120 °C and a pressure of 100 Pa for 20 min.

The calli after their initiation were regularly sub-cultured every 3-4 weeks and cultivated on the media mentioned above, in order to obtain sufficient calli for regeneration. Cultures were maintained at 25/23 °C under a 16/8 h light/dark regime with 36 µmol m^{-2} s^{-1} cool white fluorescent light.

Table 1. Composition of media for induction of callus

Medium for induction callus from seeds	Plant growth regulators added to culture medium
M0	MS
M1	MS + 2.4-D 1 mg/l
M2	MS + 2.4-D 2 mg/l
M3	MS + NAA 1 + KIN 0.3 mg/l
M4	MS + 2.4-D + BAP 0.1 mg/l

The second experiment was induction of callus from leaf segments. For this trial 2.4-D and different concentrations of BAP were used as follows: BAP (0.3; 0.7; 1; 6 mg/l) and 2.4-D 1 mg/l.

In calli texture, colour and growth intensity was evaluated.

4.2.2. Callus regeneration

Regeneration of plants from calli was tested several media which are listed in Table 2. Cultures were maintained at 25/23°C under a 16/8 h light/dark regime with 36 μmol m^{-2} s^{-1} cool white fluorescent light.

Table 2. Composition of regeration media of callus

Medium for regeneration of callus	Composition of plant growth substances
M5	MS + NAA 1 + BAP 0.1 mg/l
M6	MS + IBA 1 + BAP 0.1 mg/l
M7	MS + NAA 1 mg/l
M8	MS + IBA 1 mg/l
M9	½ MS
M10	¼ MS

4.3. The survey of tree management and utilization

4.3.1. Study site

The survey was done in the Republic of Kenya. Kenya extends over 580,370 km^2 and is divided into 8 provinces and 70 districts. The population consensus from 2017 was 49,699,862 (The World Bank Group 2019). The altitude varies from sea level to the highest point Mt. Kenya with 5,199 masl. Agro-Climatic zones ranging from humid to very arid ares (Mwangi and Mutua 2015). Main portion of land (80%) is arid and semiarid, 17% is land with high agriculture and 3% is covered by forest (Herrero 2010;

FAO 2015; Mwangi and Mutua 2015). Gross Domestic Product per capita is 1,507.81 USD and main economic sector is agriculture (FAO 2015, The World Bank Group 2019).

The climate of Kenya is tropical, but due to altitude and land formation, south-western part of the country is more moderate. On the coast the climate is humid and hot and with higher altitudes the temperature and precipitations are changing. Due to topography the highest elevation of Kenya has annual temperature average of 15° C and annual rainfalls can reach 1,800 mm, while low plateau receives only 320 mm and annual temperature averages 29 °C, however the average annual rainfall in Kenya is 630 mm (Herrero 2010; FAO 2015).

A. digitata could be found in various vegetation types such as deciduous bushland, woodland and wooden grassland (Wickens & Lowe 2008). Distribution of the baobabs in Kenya is in two belts, one is along the coastal region and the second in the inland from north-east around Kitui town towards the Tanzanian border east of Mt. Kilimanjaro (Figure 12) (Gebauer 2016).

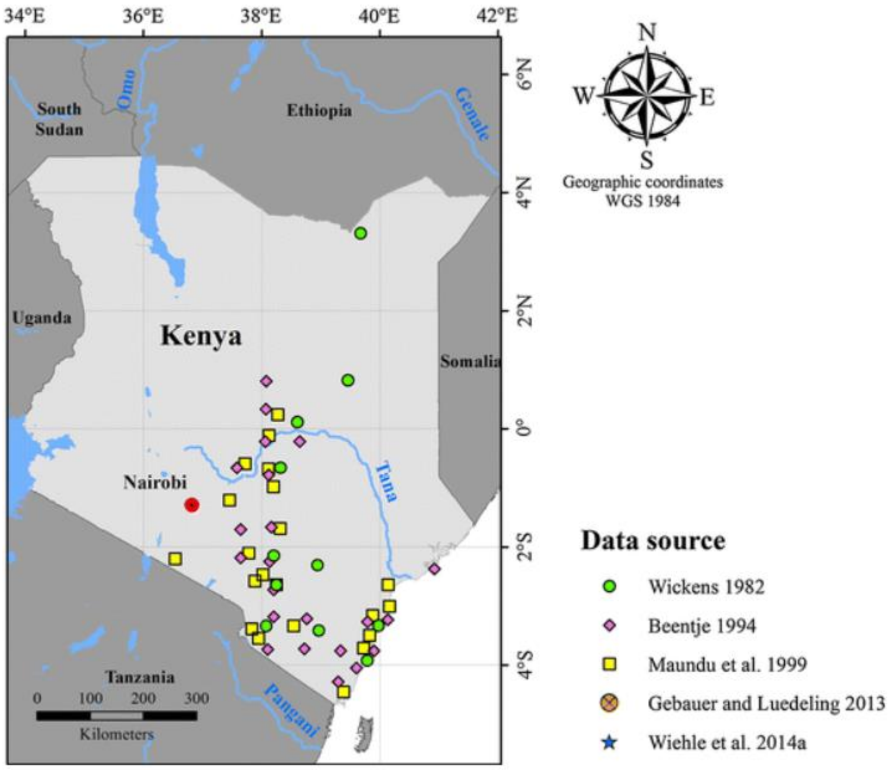

Figure 12. The distribution of baobab (*A. digitata*) in Kenya. Adopted from Gebauer et al. (2016)

4.3.2. Sampling locations

The data collection was carried out in two geographically and ecologically different regions; in Kilifi county, which is in the Coastal province and then in Makueni County in the Eastern inland province (Figure 13). In Kilifi county, surveys were performed in villages around Kilifi and Malindi town; in Makueni county, surveys were conducted around Kibwezi town. Locations of farmers in Kilifi country, were selected with help of assistant from Pwani University (Job Mbiti) and with help of inspectors from Kilifi Country Government, Department of Agriculture, Livestock and Fisheries. In Makueni County, locations of farmers were chosen with help of local assistants.

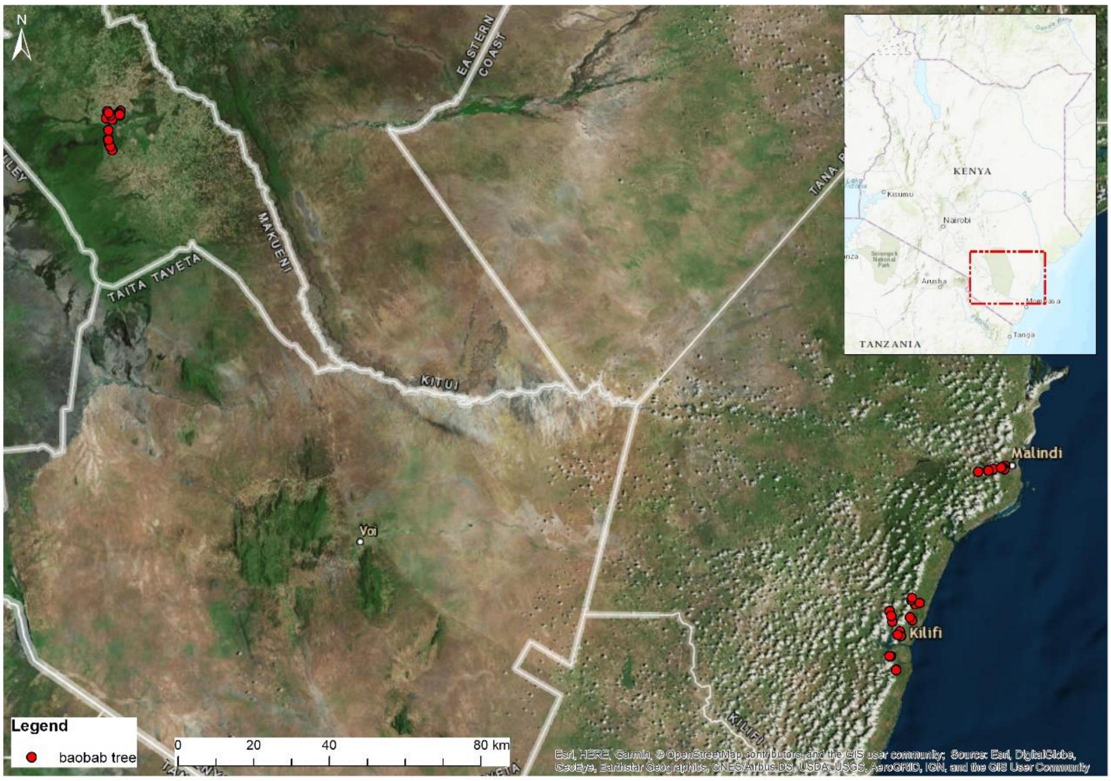

Figure 13. Map of Kenya (upper- right corner) with the study site marked in red and map of sampled trees (red circles) adapted from ArcGIS software (ESRI, 2011).

Malindi is in 12 masl and Kilifi in 8 masl, average annual rainfall is 1000-1100 mm and mean annual temperature reaches 26 °C (Figure 14). Kilifi has mostly Luvisols whereas in Malindi could be found various soils such as Arenosols, Ferralsols, Luvisols, Planosols, Vertisols. Both regions have climate of tropical savanna. According to Jaetzold et al. (2012a) Malindi and Kilifi belong to Cashewnut-Cassava Agro-ecological zone which means medium cropping season with intermediate rains. First rainy season is important for main crops while the second one is sometimes weak or missing completely. Main crops, which are dependent on the first rainy season, include maize, sorghum, sweet potatoes, kenaf, sunflower, soya beans, dolichos beans, kales, onions, okra, aubergines, sweet pepper, egg plants, chillies, Chinese cabbage, water and sweet melons, cucumbers, pumpkins or zucchini. The crops that need more than just first rainy season are cashew nuts, cassava, sisal, mangoes and castor.

Kibwezi is located in hot semi-arid zone with average annual rainfall less than 700 mm and mean annual temperature is 23 °C (Figure 14). There are two types of soil, Luvisols and Ferralsols. Jaetzold et al. (2012b) classified Kibwezi to Livestock-Millet Zone, i.e. cropping season is short and weak. Potential yield in this region depends on both rainy seasons. First rainy season is important for proso millet, hog millet, green gram and second for maize, millets, sorghum, cowpeas, chickpeas, dolichos beans, groundnuts, pumpkins. Other crops are castor, sisal, cassava, yeheb nuts.

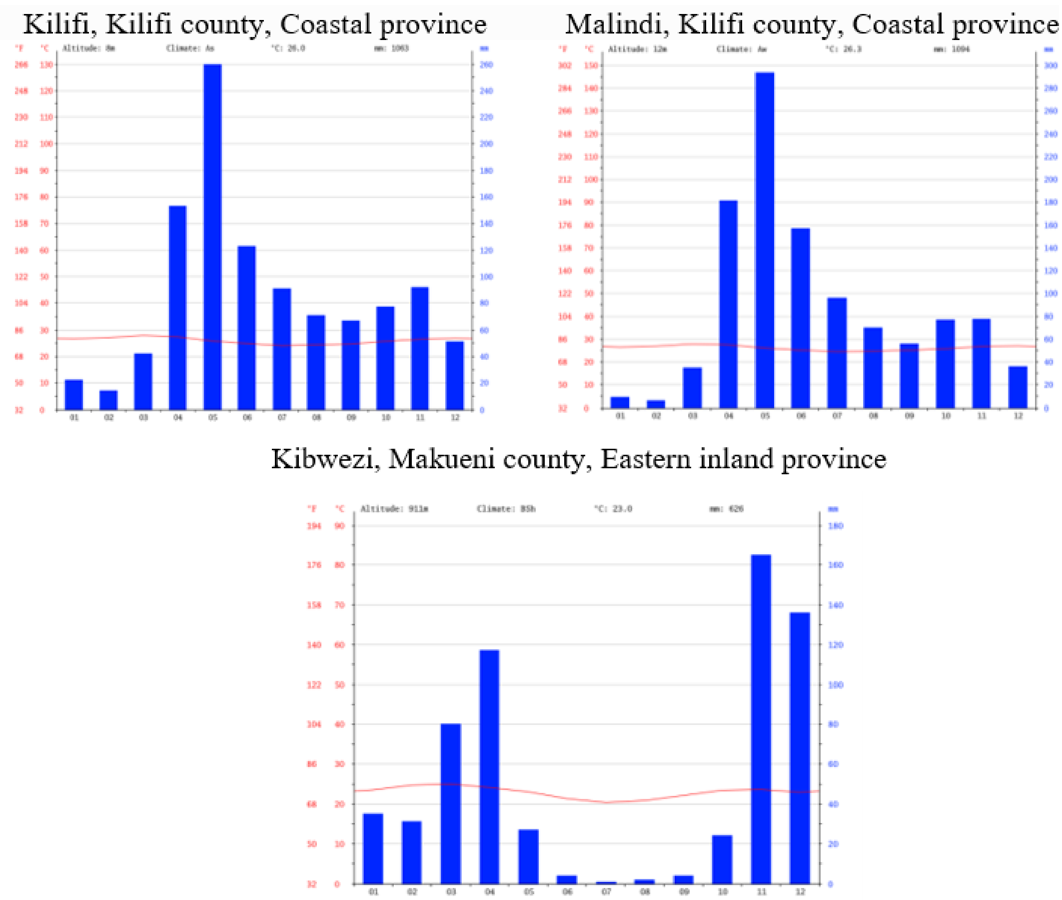

Figure 14. Climate diagrams of three study locations in Kenya: Kilifi, Malindi and Kibwezi. Source: http://en.climate-data.org/

4.3.3. Data collection in Kenya

The data collection was done in August 2018 in the three locations mentioned above, using semi-structured questionnaire (Appendix 1). This type of interview is based on the system where the interviewer asks open-ended questions in an effort to contrive information from the interviewee.

Data were collected from 55 farmers. In Kilifi country, 30 farmers were interviewed with help of local assistant and translator (Job Mbiti from Pwani University) and with help of Kilifi Country Government, Department of Agriculture, Livestock and Fisheries, which assigned inspectors for better communication with farmers. In Makueni County, 25 surveys were done with help of local assistant and translator Charles Gitahi Waruhiu with permission of Kenya Forestry Research Institute (KEFRI).

The materials used included: questionnaire form, camera, and mobile phone which was able to record GPS coordinates of the farms.

In our survey were 28 women and 27 men. In Kibwezi participated more women (60%) whereas in Kilifi more men (63%), while in Malindi the ratio of men and women was equal. Most of the farmers have secondary school (41.8%), the rest finished primary school (30%) or have no education (16.3%), but four farmers had degree from university. Every region has a different major ethnicity, in Kibwezi it was Kamba (96%), in Malindi Giriama (81.8%) but in Kilifi, there were found three main ethnicity Giriama (36.8%), Chonyi (15.7%) and Taila (10.5%). Socio-economic status was estimated for most of the farmers as average, but five farmers received the best – mostly those farmers with higher education level (university).

The questionnaire form was adopted from Meinhold et al. (2016), who previously used it in Sudan. Before initiation of the interview with the farmer, every question in the questionnaire was explained to the translator, because people from rural areas can only speak Swahili, therefore explanation of the questions to the translator was necessary for collecting precision data. The questionnaire could be divided into four parts. The first part involved socio-demographic data. In the second part, information was obtained about local use, ownership, knowledge and folklore about baobab tree. The third part deal with tree management including questions about planting and rising, pre-treatment methods, interaction with other cultivated crops, pruning or harvesting (Appendix 1).

4.3.4. Data evaluation of questionnaires

Data gathered from the respondents were analyzed via descriptive statistics, such as means, standard deviation and frequencies. Excel 365 (Microsoft, 2019) was used for data ender and coding, as well as for generating descriptive indicators.

5. Results

5.1. Germination evaluation

In total, 1,726 seeds were used for testing effectiveness of pre-treatment methods of germination of *A. digitata* seeds 34 days after plating (DAP). The most effective pre-treatment method was soaking them in 96% sulfuric acid for 6 hours (germination percentage 81.9%) (Figure 15). Other two pre-treatment methods, manual scarification (27.7%) and boiling in water for 5 seconds (33.5%), did not show any essential difference. From the control treatment, only one seed germinated (0.7%) (Figure 15). High error in scarification treatment was done due bad manipulation skills of operator.

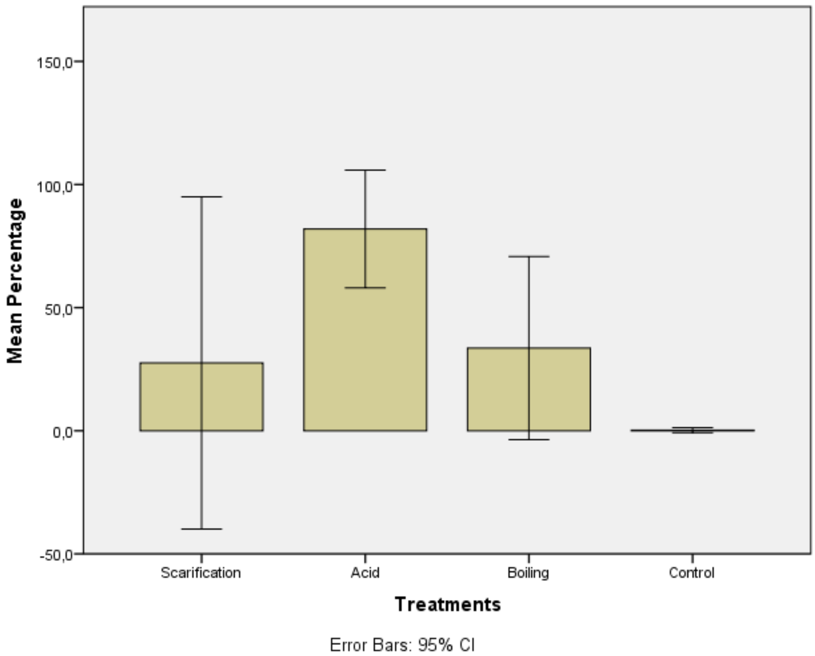

Figure 15. Mean germination percentage of *A. digitata* seeds (34 days after planting). Measured by ANOVA.

The same results could be found in the testing of mean germination time. In Figure 16 can be seen that seeds which were treated with 96% sulfuric acid for 6 hours had the fastest germination (11th day). Manual scarification and boiling in water had mean germination time in 17.9 days and 16.2 days, respectively. The only germinated seed from the control group germinated on the 12th day. In this experiment no significant value was found

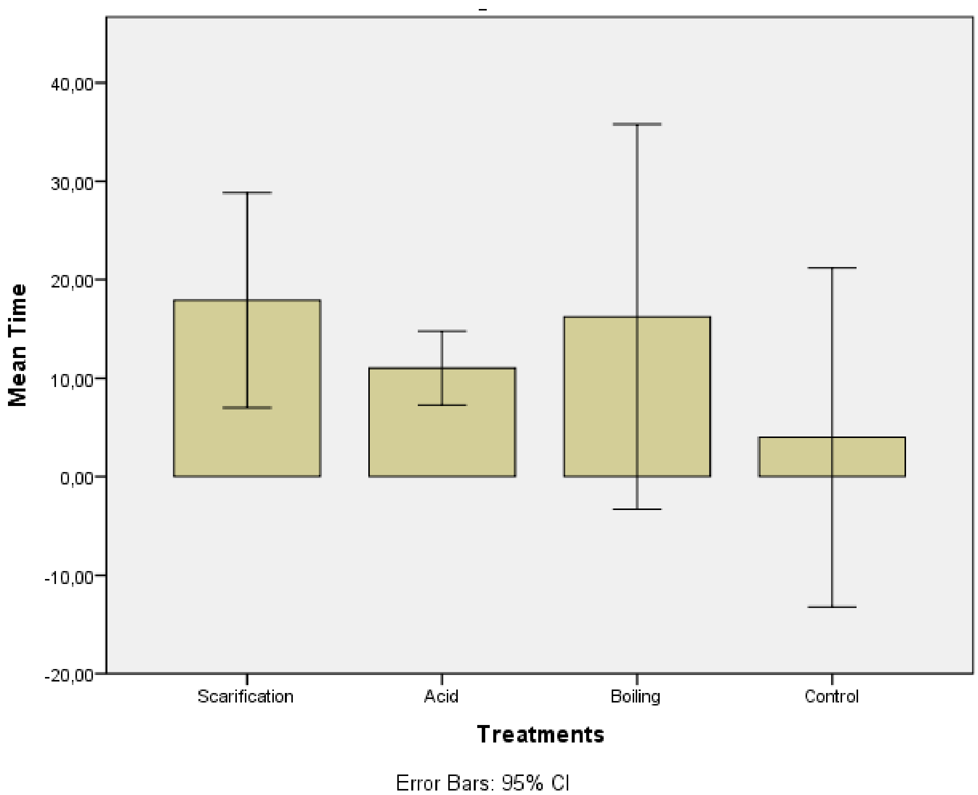

Figure 16. Mean germination time of *A. digitata* seeds (34 days after plating). Measured by ANOVA.

Figure 17. Germinated seeds with acid pre-treatment in greenhouse of Botanical garden FTZ (Author archive)

Quantitative data of germinated seeds were assessed to see if there is a difference among pre-treatment methods (Table 3) (Figure 18). The best result showed treatment with 96% sulfuric acid, which was significantly higher than the rest of the treatments. Scarification and boiling treatments showed no significant differences between them, in term of seeds germination and biomass of *A. digitata*. The result of control treatment has significant difference in germination of seeds and was unquestionably lower than other methods in biomass. High error in scarification treatment is also done due bad manipulation skills of operator.

Table 3. Effects of pre-treatments on germination and on biomass of seeds of *A. digitata* (34 DAP). Effects were measured by ANOVA. Numbers with the same letters within a row are not significantly different at p=0.05.

	Scarification	**Acid**	**Boiling**	**Control**
Average number of germinated seeds after 34 DAP	39.67^{b}	118.33^{a}	48.33^{b}	0.33^{c}
Average biomass per seed after 34 DAP[g]	0.999^{b}	4.220^{a}	1.032^{b}	0.006^{c}

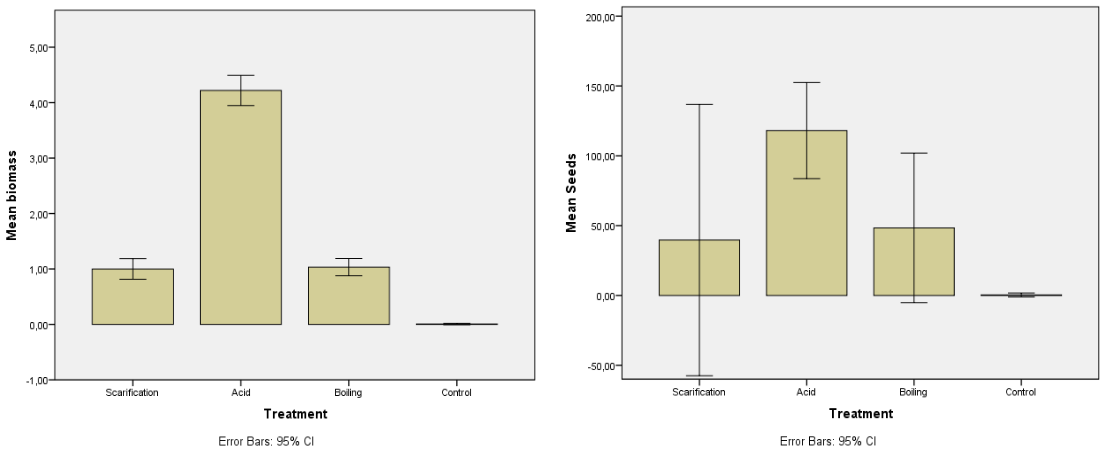

Figure 18. Graphs of pre-treatments effects on germination and on biomass of seeds of *A. digitata* (34 DAP). Effects were measured by ANOVA

5.2. Evaluation of indirect *in vitro* morphogenesis

Results from evaluation of indirect *in vitro* morphogenesis showed various types of callus such as compact, watery and friable (Figure 19). The different colours observed in the experiment were green, light green and white (Table 4).

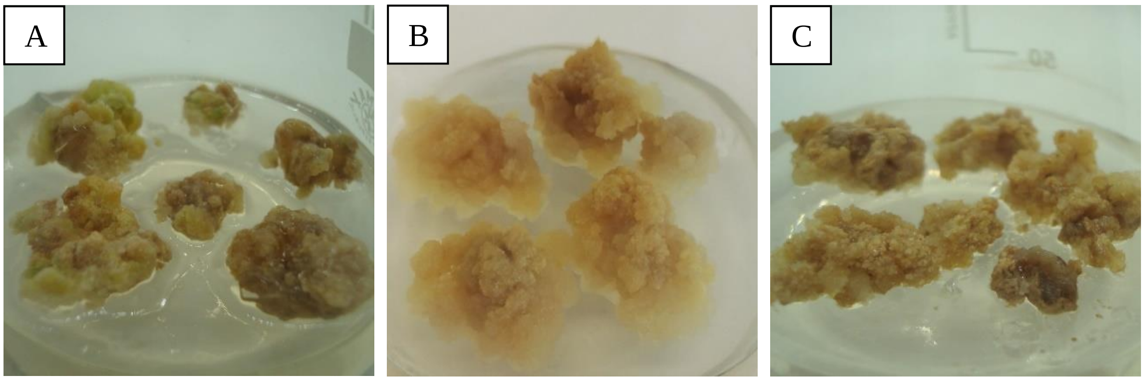

Figure 19. Compart callus on M3 medium (MS + NAA 1 + KIN 0.3 mg/l) (A), watery callus on M10 medium (¼ MS) (B) and friable callus on M7 (MS + NNA 1 mg/l) (C) (Author archive)

After two week of inoculation, all embryonic axes on all four callus induction media (M1, M2, M3, M4) began to inflate and began to produce a small amount of callus. The best growth regulator concentrations were chosen based on the growth intensity of callus (MS + 2.4-D + BAP 0.1 mg/l) (Figure 16) and (MS + 2.4 D 1 mg/l). Callus on M1 medium had friable texture, light green and green colour and fast growth intensity, callus on M4 media showed rapid growth, it had friable texture and, in the beginning, has white colour which with increasing time turned to light green (Table 4). These calli were identified as superior over calli from other treatments and were used for plant regeneration in further experiment. Induction of callus from leaf segments was not achieved on 2.4-D and different concentrations of BAP.

Table 4. Effect of BAP and NAA combinations on induction of various colours, textures, weight and callus percentage from leaf explants

Medium	Medium type	Concentration of PGR	Texture	Colour	Growth Intensity
M1	induction	MS + 2.4-D 1 mg/l	F	LG	+ +
M2	induction	MS + 2.4-D 2 mg/l	F	G	+
M3	induction	MS + NAA 1 + KIN 0.3 mg/l	F, C	G, W	+
M4	induction	MS + 2.4-D 1 + BAP 0.1 mg/l	F	LG, W	+ + +
M5	regeneration	MS + NAA 1 + BAP 0.1 mg/l	F, C	LG	+ +
M6	regeneration	MS + IBA 1 + BAP 0.1 mg/l	C	LG, G	+
M7	regeneration	MS + NNA 1 mg/l	F	G	+
M8	regeneration	MS + IBA 1 mg/l	F	LG	+
M9	regeneration	½ MS	F	G	-
M10	regeneration	¼ MS	W, LG	G	- -

Texture: C = compact, F =friable, W = watery. Colour: W = white, G = green, LG = yellow, R = red, BI black, P purple, G grey, L light, D dark. Growth intensity: + slow growing, + + fast growing, + + + rapid grow; or - slow dying, - - fast dying

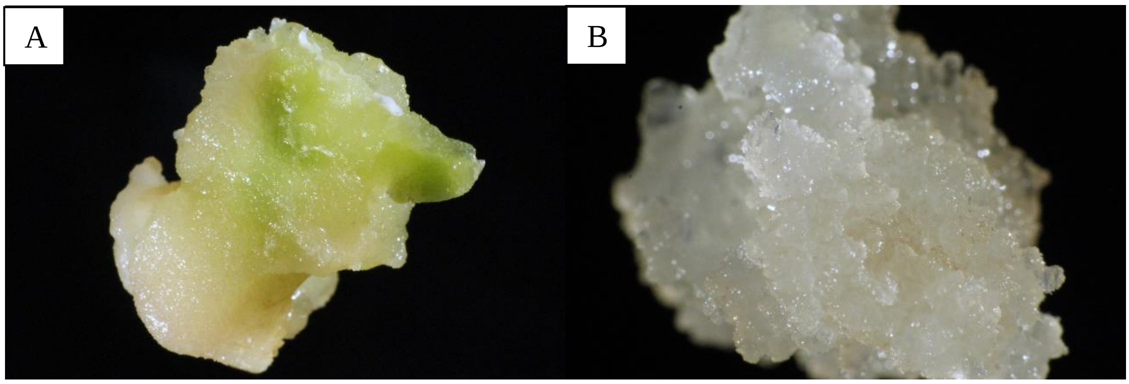

Figure 20. Callus on M1 medium (MS + 2.4 D 1 mg/l) (A) and M4 medium (MS + 2.4-D + BAP 0.1 mg/l) (B) (Author archive)

5.2.1. Results of indirect morphogenesis

After several multiplication of calli developed on induction media, they were transferred to regeneration media, mainly from two initiations media with best growth intensity, M1 (MS + 2.4-D 1 mg/l) and M4 (MS + 2.4-D 1 + BAP 0.1 mg/l). However, indirect *in vitro* morphogenesis was not achieved on regeneration media (M5, M6, M7, M8, M9, M10) (Table 4). In two years of experiment, despite regular subcultivation of calli on fresh media, no morphogenetic response occur, neither somatic embryogenesis, nor organogenesis.

5.3. Results of survey about tree management and utilization

In one part, information about local use, ownership, knowledge and folklore about baobab tree were collected. Every region has different local name for *A.digitata*; in Kibwezi it was *Muamba*, in Malindi *Muyu* and in Kilifi it was *Mbuyu* which is also a name for baobab in Swahili. In the survey only two local names for seed were found *Mbeu* and *Uyu*. All respondents mentioned that in the past there were more baobabs compared to nowadays.

The baobabs are connected with folklore which, differs with culture. In Kilifi and Malindi, the most frequent belief is that baobabs are associated with evil spirit, while some respondents even reported they saw it. The second most common answer was, that baobabs are used as shrine (Figure 21), they scoop out hole/cavities for this use. In Kilifi the locals worship the baobab as an idol and they also believed that cutting off baobab brought curse or death. In Kibwezi, we found a wider range of beliefs, the most usual one being that baobabs attract rain, that cutting of trees would bring curse or death or that, baobabs were planted by gods. Minority around Kibwezi believes, that baobabs are associated with evil spirits or djinns, baobab can predict rains or they are worshipped as an idol.

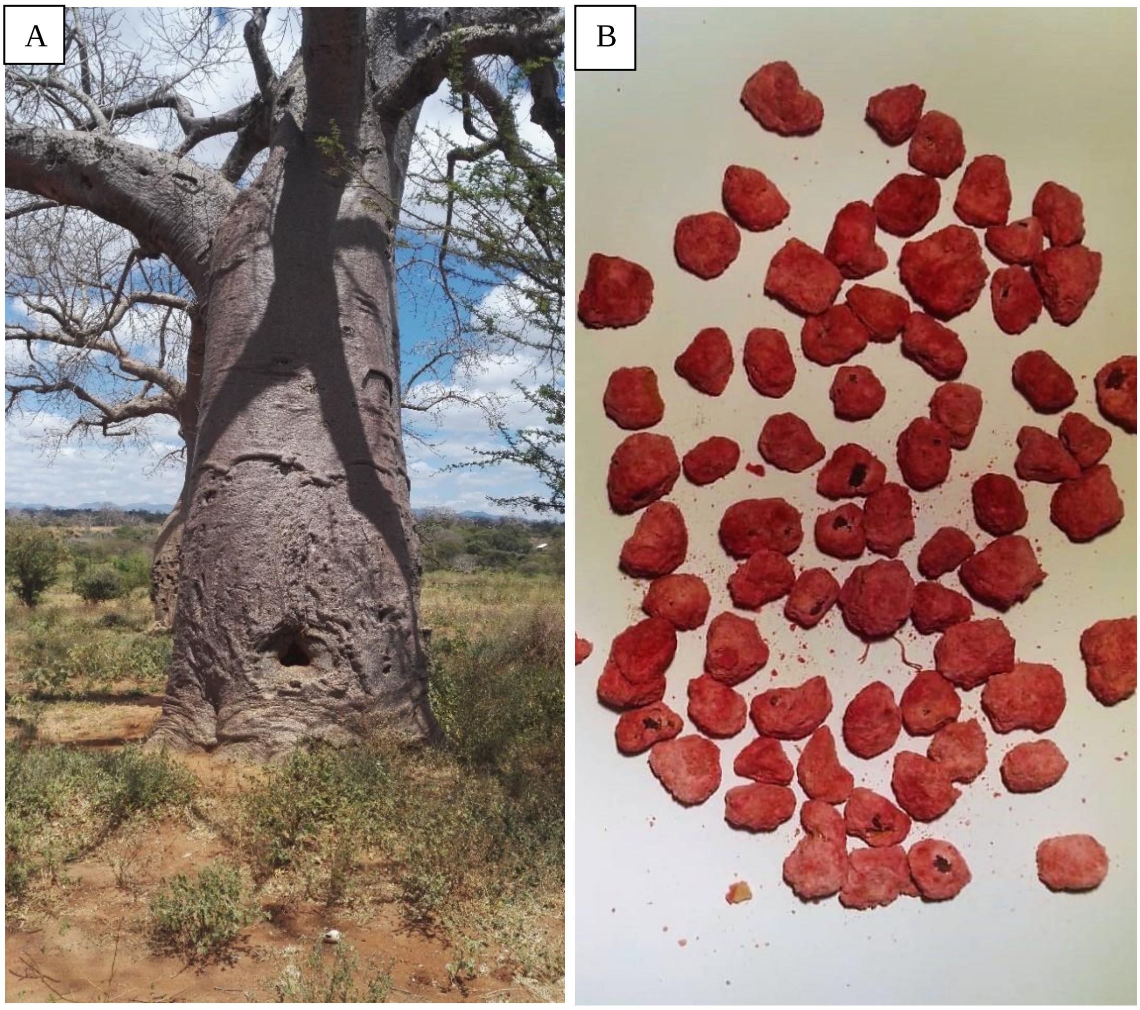

Figure 21. Different uses of baobabs in Kenya. A) Baobab with hollow trunk, used as a shrine B) sweets made from seeds with pulp (Author archive)

In the uses of baobab were found significant differences between coastal and inland areas. In Kilifi and Malindi, the most common use was making sweets from seeds with pulp (Figure 21), then using leaves as vegetable and pulp from fruits for making juice. Another similar but minority in these two areas was use of baobab tree for firewood in Kilifi and in Malindi. In Kilifi one or two farmers use baobab for medicinal purposes, pulp for porridge, leaves as fodder, bark for making ropers and baskets, empty fruits for making rat traps

Table 5. Results from survey with Percentage frequency, N = number of farmers

	Kibwezi		Kilifi		Malindi	
	N = 25	%	N = 19	%	N = 11	%
What is local name for baobab tree and seed?	Muamba	100	Mbuyu	89.4	Muyu	100
	Mbeu = seed	20	Muyu	21	Mbuyu	45.4
			Kilamba	5.2	Kamba	9
			Uyu = seed	5.2		
When do you harvest it?	June - September	88	August - December	57.8	August - December	100
	August - December	8	July - September	10.5		
	June - October	4	June - August	5.2		
Is available only in season or throughout the year?	In season	100	In season	73.6	In season	100
			Trought year	26.3		
Do you harvest both fruits and leaves of baobabs?	Only Fruits	76	Only Fruits	36.8	Only Fruits	45.4
	Both	24	Both	63.1	Both	54.5
Do you use/collect the fruits and leaves from the wild?	From farm	96	From wild	100	From wild	100
	From wild	4				

Table 5. Continued

	Kibwezi		Kilifi		Malindi	
	N = 25	%	N = 19	%	N = 11	%
Which trait is the most important for you and why?	Difference in size and taste	96	Difference in size and taste	21	Difference in size and taste	18.1
	No aware	4	No aware	78.9	No aware	81.1
	Pest-free	24				
What are the advantages of owning a baobab tree?	Just for domestic use	52	For better family income	89	For better family income	90
	For better family income	40				
Do you/would you plant baobab for commercial or subsistence purposes?	No interest	76	For both	47.3	For both	72.7
	Commercial	20	Commercial	26.3	Commercial	18.1
	Only subsistence	4	Only subsistence	26.3	Only subsistence	9
What is the source of planting material?	Nature	100	Nature	100	Nature	100

Table 5. Continued

	Kibwezi		Kilifi		Malindi	
	N = 25	%	N = 19	%	N = 11	%
Do you use any seed treatments to induce germination?	No	100	No	94.7	No	100
			Scarification	5.2		
Establishing problem?	Long time to mature	84.2	Long time to mature	81.8	Long time to mature	
Where do you grow this species?	In the compond	100	In the nature	94.7	In the nature	90.9
			In the compond	5.2	In the compond	9
What are the main threats (pests and diseases)?	Pests	84	Not observed	63.1	Not observed	45.4
	Both	16	Both	21	Both	27.2
			Pests	15.7	Pests	27.2
Do you somehow managed the trees cutting, pruning?	No pruning	80	No pruning	78.9	No pruning	100
	When tree overbearing	16	For firewood	21		
	For firewood	4				

Table 5. Continued

	Kibwezi		Kilifi		Malindi	
	N = 25	%	N = 19	%	N = 11	%
Plants interaction with other cultivated crops?	Negative	64	No interaction	100	No interaction	100
	Positive	44				
	No interaction	8				
What are the uses of this plant?	Eating raw	88	Making sweets	89.4	Making sweets	100
	Making sweets	36	Used as Vegetable	63.1	Used as Vegetable	72.7
	Bark for making ropes and baskets	36	Making juice	12	Making juice	54.5
	Fodder	24	Firewood	10.5	Firewood	27.7
	Making juice	12	Medicinal use	10.5	Canoes	9
	Extraction of oil	4	Extraction of oil	10.5		
			Rat traps from fruit	5.2		
			Porridge from pulp	5.2		
			Fodder	5.2		
			Bark for making ropes and baskets	5.2		
			Repellent	5.2		

Table 5 Continued

	Kibwezi		Kilifi		Malindi	
	N = 25	%	N = 19	%	N = 11	%
Is there any mention about any folklore?	Attracts rain	56	Association with evil spirit	84.2	Association with evil spirit	90.9
	Cutting them brought curse or dead	28	Used as a shrine	31.5	Used as a shrine	18.1
	Planted by gods	12	Worship as idol	5.2		
	Association with Djinns	8	Cutting them brought curse or dead	5.2		
	Predict rain	4				
	Worship as idol	4				
	Association with evil spirit	4				

and burning of seeds as insect repellent. Only two farmers used baobab seeds for extraction of oil. In Malindi baobab was used for making canoes and fruits for making porridge and rat traps, each of these uses were reported by one farmer.

In Kibwezi the most common uses were eating of raw pulp or making porridge from pulp. Other common uses were using seeds for making sweets, making ropes and baskets from bark, using leaves as fodder and powder from pulp is used to make juice. Only one farmer mentioned used of baobab pulp powder and seed oil for commercial purposes.

In inland area, all farmers are only using baobabs in their compound, but in coastal area, they usually use trees located in the nature. These results corresponding with question if they are collecting fruits and leaves from wild.

Another part was about tree management. Harvesting of fruits takes place in the harvesting season (91%), only five farmers in Kilifi report that they are harvesting fruits the whole year. Most of farmers in Kibwezi reported the main fruit harvest season from June to September. In Malindi and Kilifi, farmers reported harvesting season from August to December. Almost half (47.2%) of the interviewed farmers, mainly those from coastal areas, are also harvesting leaves.

The main source of planting material, seeds or seedlings is collected from nature. In general, farmers are not planting baobabs because it takes long time to produce a fruit (93.4%). The most of farmers are not using any seed pre-treatment method because they did not know about the benefits of it. Only one farmer knew about manual scarification of seeds as pre-treatment method. Most of the farmers do not prune their trees (86.3%). However, some cut branches of overbearing trees or for firewood. Farmers were also asked if they observed any pest or diseases. In Kibwezi nearly all farmers responded that main problem are pests and also diseases (Figure 22). In Kilifi farmers did not observe any pest and diseases, but some farmers noticed pests and diseases. In Malindi, the results were similar, where farmers did not see any pest or diseases.

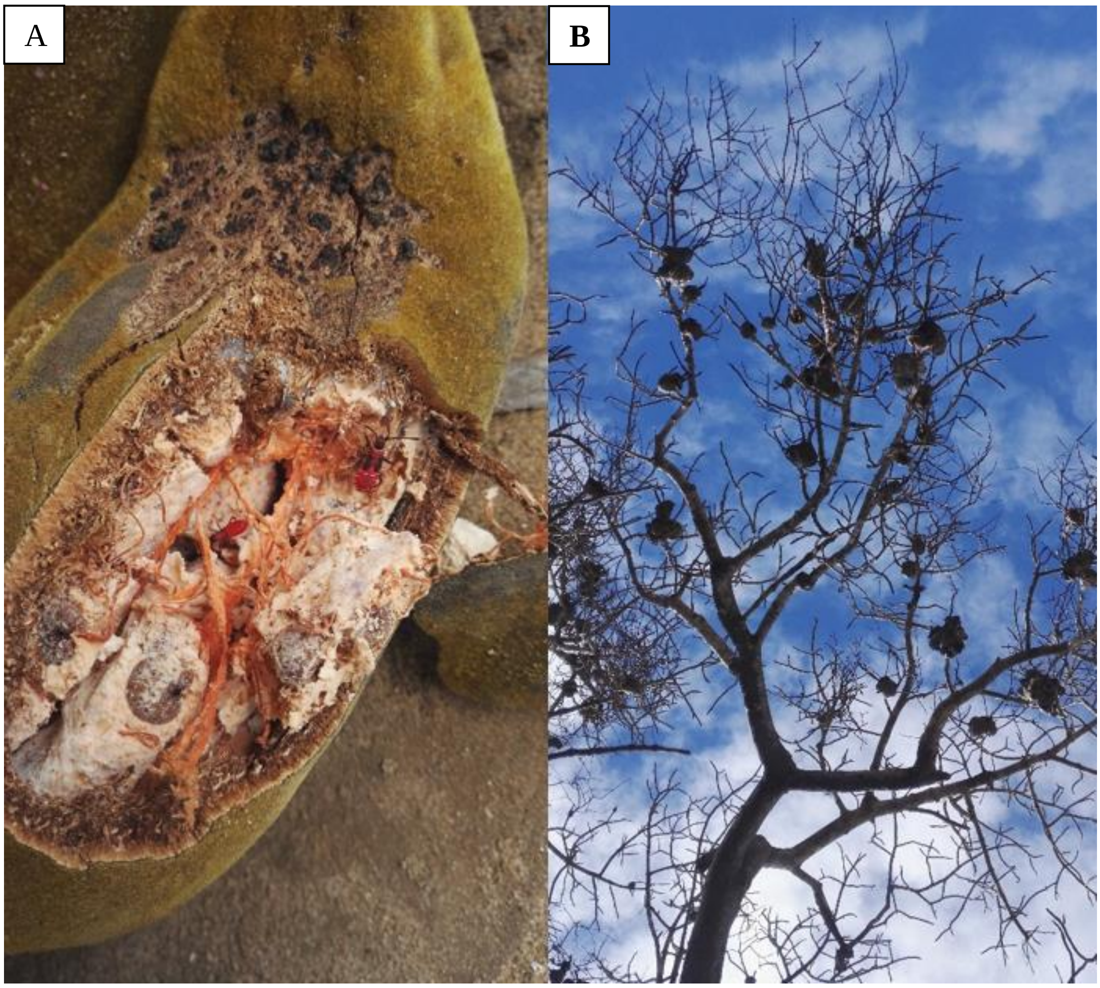

Figure 22. Pest of *Dysdercus* spp. In baobab fruit (A) and unknown diseases which attacking branches of baobab (B).

When farmers were asked if they would plant baobab for commercial or subsistence purposes, the most of them in Kibwezi said they do not have interest, mainly for reason they do not seen commercial value. However, five farmers answered they would like to plant baobab trees for commercial purposes, because they already sell fruits for making powder and oil to one company. In Malindi and Kilifi the farmers would like to plant baobabs for commercial and subsistence purpose.

The most important fruit trait for farmer in Kibwezi was size and taste, they prefer big fruits with sweet pulp and pest-free.

6. Discussion

6.1. Germination experiment

In this study we tested three treatments methods of seeds to find out the best one for people of rural areas of Africa. Most effective method was treatment with acid, but it is not suitable for people from these areas. The most suitable for these conditions was chosen boiling in the water, because it is easy to handle and does not require any special items.

Mechanical scarification by sandpaper. Manual scarification in some cases has good results of 90% and more (Maghembe et al. 1994; Razanameharizaka et al. 2006). However, our result showed only 27.7% germination rate. Such low germination rate was also observed by Assogbadjo et al. (2010), who obtained only 14%. This method can lead to inhibition of the seeds and necrosis of 10% to 25% due to rapid absorption of water which could kill the embryo, or if the scarified seeds are followed by soaking in water it could lead to only 2% of germination because of rapid absorption of water which kills the embryo (Danthu et al., 1995). Manual scarification depends on manual skill of operator and is not adaptable to a big scale production.

Boiling of seeds in water for 5 seconds. Highest germination rate with boiling seeds report Razanameharizaka et al. (2006), when more than ninety per cent of seeds germinated after boiling for 15 seconds, however they tested this method on small numbers of seeds (15 - 25). In our experiment, we boiled seeds for 5 seconds, because this time was suggested as few seconds which obtained the best results from literature (Maghembe et al. 1994), however we obtained only 33.5% of germination rate. The similar value was observed by Maghembe et al. (1994) which were testing immersion for few seconds with result 35%. Johansson (1999) tried boiling seeds with pulp for 5 minutes and get 10% of germination and boiling in hot water for 5 times per for 1 minute with cooling down in-between gave him even less germination. Falemara et al. (2013) were testing boiling of seeds for 5, 7 and 10 minutes and then sowning in sandy soil with result 3%, 3% and 5% respectively. Falemara et al. (2014) tested the same experiment and on sandy soil get 0 %, 0%, 5%, respectively, but on sawdust get higher 5%, 10%, 10%

respectively. Sidibe and Williams (2002) report that boiling of seeds in water for 15 minutes is also possible but there is high risk of killing the embryos.

Soaking of seeds in 96% sulphuric acid. For pre-treatment with acid is mainly used sulphuric acid but could be found other acid such HCl, which was reported to fail, or concentrated nitric acid with 86% germination rate (Johansson 1999; Esenowo 1991). Soaking seeds in concentrated sulphuric acid for one hour get result 70-93.33% (Falemara et al. 2013; Falemara et al. 2014; Usman & Asan 2017). Shorter time, 15 minutes resulted in 98% germination (Esenowo 1991), 45 minutes get 80% germination rate (Bationo 2003; Bationo et al. 2009) and longer 90 minutes get 92% of germination (Sidibe and Williams, 2002). Danthu et al. (1995) soaked seeds from 6 to 12h in concentrated sulphuric acid with result 90% germination and more. Diouf et al. (2015) also soaked seeds for 6, 8, and 12 hours in concentrated sulphuric acid (96%) without any significant differences among these three soaking durations and germination rate was from 80 – 100%. Our result was 81.9% after soaking seeds in 96% sulphuric acid for 6 hours. We think that similar concentrations of acid and different time could result in same germination percentage. Reason why, could be found in work of Diouf et al. (2015), who was testing acid treatment on seeds from seven provenances of Senegal and reported that optimal time for this treatment could also depend on testa thickness and seed size which might be influenced by environmental factors.

From these experiments is clear that most effective and fastest method was treatment with acid. However, this method is expensive and require usage of dangerous chemical to human health, therefore it is not advisable for farmers. Manual scarification requires some tool for operation and skill for achieve high percentage of germination, but this method is slow and is good only for small scale. Cheap and easy method which does not require any special tool or skill is boing, which is the best method for local people of Kenya and can be used for large scale programs.

6.2. Callogenesis

In this study, callus from seed axes was successfully induced, however plant regeneration was not achieved. Indirect morphogenesis in baobab has not been reported yet, however other studies in Malvaceae, focused on regeneration of plants from callus are available.

Sie et al. (2010) in *Hibiscus sabdariffa* L. reported that optimal medium for initiation of callus is MS medium containing 0.1mg/l 2.4-D + 0.5 mg/l KIN and MS with 0.1 mg/l 2.4-D + 0.1 mg/l KIN. Similarly, to this study, in baobab, callus was initiated on medium supplemented with 2.4-D, or with combination of 2.4-D and cytokinin. Likewise, Seth and Panigrahi (2019) in *Abutilon indicum* L. reported initiation of callus on MS medium supplemented with 1 mg/l 2.4-D +2 mg/l BAP and Seth et al. (2017) obtain callus on MS + 1 mg/l 2.4-D. Irshad et al. (2017) in *Abelmoschus esculentus* L. reported optimal medium with composition of MS + 0.5 mg/l 2.4-D + 1.5 mg/l BAP supplemented with 200 mg/l AC. Our results are congruent with these results of initiation of callus. Application of 2.4-D or combination 2.4-D with KIN or BAP can be recommended to obtain callus from primary explant.

For regeneration of plants from callus, Seth and Panigrahi (2019) used MS + 0.5 mg/l NAA + 2 mg/ BAP + 200 mg/l adenine sulphate and Seth et al. (2017) used MS + 3 mg/l BAP + 0.5 mg/l NAA + 200 mg/l AC + 2 mg/l ascorbic acid. Irshad et al. (2017) was using MS + 0.5 mg/l 2.4-D +1.5 mg/l BAP and MS + 1.5 mg/l NAA +0.5 mg/l BAP for regeneration. However, in our study, regeneration medium M5 containing also a combination of BAP and NAA (and without 2,4-D), did not proved to be efficient for indirect somatic embryognesis, nor organogenesis. Application of AC, adenine suplhate or ascorbic acid, as reported in previously mentioned studies may lead to successfull morhogenesis.

We can conclude that with MS medium it is possible to obtain sufficient results in whole process of callogenesis. Even if we did not get regeneration of callus, the initiation of callus is still successful result. Moreover, our study was one of the first who tested this propagation method of baobab.

6.3. Farmer survey

For survey, we used semi-structured questionnaire, which are known to have the chance to discover knowledge about important information (Yengoh & Brogaard 2014) if we compared them to only structured questionnaires.

Results from survey showed that every ethnicity have own name for baobab ethnicity Kamba in Kibwezi using name *Muamba*, ethnicity Giriama in Malindy using

Muyu. In Kilifi is commonly used Swahili name *Mbuyu*. Similar names for baoabab were reported in Zimbabwe and South Africa (Kehlenbeck et al. 2015).

A lot of people believed that baobabs are associated with evil spirits, not only in Kenya but throughout the Africa (Wickens & Lowe 2008). Using baobab as a shrine could be found also in Niger (Norris 1982). Bringing misfortune, curse or dead by cutting down a baobab is also common believe in Africa (Wickens 1982, Blench & Dendo 2004; Wickens & Lowe 2008). In Kibwezi, citizens believe that baobabs can predict rains, and attract rain, I suggest that this believe is based on climatic situation, because average annual rainfall is very low in this region, less than 700 mm.

Differences between inland and coastal area could be observed in uses of baobab, it is probably caused by different climatic conditions in both regions. In coastal area, which is more humid, people eat leaves as vegetable and fruits are used for commercial purposes e.g. selling sweets from seeds with pulp or making juice (Wickens & Lowe 2008; Lisao et al. 2017). On the other hand, people from inland area are using baobab differently. They usually eat fruit pulp raw or use it as porridge, for making juice and sometimes make sweets for family income. (Wickens & Lowe 2008; Lisao et al. 2017). Similar observations were captured in our questionnaires. More people from inland area around Kibwezi town are aware of fruit variations in size and taste than people from coastal area. Nevertheless, in both regions locals use leaves as fodder, bark for making ropes and baskets (Wickens & Lowe 2008; Kotina 2017; Lisao et al. 2017). Only few farmers from both areas are using seeds for oil production, those farmers had knowledge about the market with this product and good level of education. The better education enhances their knowledge for selling their products and sometimes even in international trade (Buchmann et al. 2010).

Willingness of planting and management of baobabs is generally very low; it is due to the fact that farmers are not aware of benefits which baobab can bring to their farm (increase family income, diversifying diet, etc.), and only few farmers were effectively selling their baobab products on the market. The majority of farmers did not see a problem with germination of baobab from seed, but they reported that the main problem is drought, which young baobabs cannot withstand (Sidibe & Williams 2002; Wickens & Lowe 2008). In Africa, pruning of trees is usually not common, even though this technique could provide higher yield of leaves and fruits (Sidibé & Williams 2002; Dhillion &

Gustad, 2004; Schumann et al. 2010; Gebauver 2016). In our survey, none of the farmers prune their baobab trees.

Harvesting is in both regions seasonal. In inland area around Kibwezi town, harvesting season was reported from June to September. In Malindi and Kilifi, farmers reported harvesting season from August to December. The differences in harvesting season are probably caused by different climatic condition, which trees adapted to. Similar observations that harvesting season is different from one region to other or even between year was also reported by Assogbadjo et al. (2005) in Benin and Gebauer et al. (2016) in Kenya and Sudan.

7. Conclusions

The main objective of this study was to determine suitable ways of *Adansonia digitata* L. propagation and silviculture management in Kenya.

This study revealed that the most effective method of baobab seed germination was using pre-treatment with concentrated sulphuric acid. However, usage of such dangerous products even if possible, in laboratory, are not advisable for farmers. Therefore, we recommend immersing seeds in boiling water could serve as alternative solution for people from rural areas because it did not require any special skills or tools.

We also tested indirect somatic embryogenesis; this method of propagation was not fully successful and reached only half a way (initiation of callus) thus needs more time for development of optimal methodology. However, this method can be used only in laboratory, never the less in the future could be useful for conservation of this remarkable specie. Future research should take knowledge attained during this research.

From our survey in Kenya we conclude that the main problem of *A. digitata* in Kenya is regeneration and conservation due to the changing climate, and low knowledge of baobab tree management and ways how to add value to the products from this tree. We recommend, promote products from baobab in local and international markets, because economic attractivity could be one way to conserve this valuable and important resource.

8. References

Abbiw DK. 1990. Useful plants of Ghana. West African use of wild and cultivated plants. International Technology Publishers, London.

Ahmed MB, Salahin M, Karim MA, Razvy MM, Sultana M, Hossain M, Islam R. 2007. An efficient method for *in vitro* clonal propagation of a newly introduced sweetener plant (*Stevia rebaudiana* Bertoni) in Bangladesh. American-Eurasian Journal of Scientific Research **2(2)**:121-125.

Al-Mudaris M. 1998. Notes on various parameters recording the speed of seed germination. Der Tropenlandwirt **99**:147-54.

Ameyaw GA, Dzahini-Obiatey HK, Domfeh O, Oppong FK, Abaka-Ewusie K. 2015. History and data analyses of 'cutting out'method for Cocoa Swollen Shoot Virus Disease (CSSVD) control in Ghana. Journal of Plant Diseases and Protection **122(5-6)**:200-206.

Anjarwalla P, Ofori D, Owino A, Matuku D, Adika W, Njogu K, & Kehlenbeck K. 2017. Testing different grafting methods for vegetative propagation of baobab (Adansonia digitata L.) in Kenya to assist its domestication and promote cultivation. Forests, Trees and Livelihoods **26(2)**:85-95.

Anonymous. 1955. Investigations on seeds. For Res India **1950-1951(1)**:18-19.

Arbelaez PE. 1956. Plantas utiles de Colombia. Bogota: Libreria Colombiana. 141p. (Italian).

Assogbadjo AE, Glèlè Kakaï R, Edon S, Kyndt T, Sinsin B. 2010. Natural variation in fruit characteristics, seed germination and seedling growth of *Adansonia digitata* L. in Benin. New Forests **41(1)**:113-125.

Assogbadjo AE, Sinsin B, Van Damme P. 2005. Caractères morphologiques et production des capsules de baobab (*Adansonia digitata* L.) au Bénin. Fruits **60(5)**:327-340.

Bationo BA, Nieyidouba L, Demers N, Kandji S. 2009. Culture du baobab *Adansonia digitata* L (Bombacaceae) en planche maraîchère: une méthode pour simplifier sa récolte et favoriser sa propagation au sahel. Bois Forêts des Tropiques **299**:79-86.

Bationo BA. 2003. On peut cultiver le baobab comme la salade. Journal Évasion **372**:5.

Baum D. 1995. A Systematic Revision of Adansonia (Bombacaceae). Annals of the Missouri Botanical Garden **82**:440-471.

Bell KL, Rangan H, Kull CA, Murphy DJ. 2015. The history of introduction of the African baobab (*Adansonia digitata*, Malvaceae: Bombacoideae) in the Indian subcontinent. Royal Society open science **2(9)**:150-370.

Blench R, Dendo M. 2004. Cultural and biological interactions in the savanna woodlands of Northern Ghana: sacred forests and management of trees. Page 29. Conference Trees, Rain and Politics in Africa, Oxford University.

Blunt HS. 1923 Tebeldis. Sudan Notes Rec **6**:114-117.

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. Ecology of Food and Nutrition **49(3)**:145-172.

Capital Bussiness. 2009. Kenya to ban raw cashew nuts exports. Available from: https://www.capitalfm.co.ke/business/2009/04/kenya-to-ban-raw-cashew-nuts-exports/ (accessed April 2019).

Chládová A. 2016. Genetic diversity of baobab (*Adansonia digitata* L.) along an elevation transect in Kenya [MSc. Thesis] Czech Univerzity of Life Sciences Prague, Prague.

Christenhusz MJ, Byng JW. 2016. The number of known plants species in the world and its annual increase. Phytotaxa **261(3)**:201-217.

Cron GV, Karimi N, Glennon KL, Udeh CA, Witkowski ETF, Venter SM, Assogbadjo A, Baum DA. 2016. — One African baobab species or two? Synonymy of Adansonia kilima and *A. digitata*. Taxon **65**:1037-1049.

Cruywagen EM, Crous PW, Roux J, Slippers B, Wingfield MJ. 2015. Fungi associated with black mould on baobab trees in southern Africa. Antonie van Leeuwenhoek **108(1)**:85-95.

Danthu P, Roussel J, Gaye A, Mazzoudi EHEl. 1995. Baobab (*Adansonia digitata* L.) seed pretreatment for germination improvement. Seed Science & Technology **23**:469-475.

Dhillion SS, 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.

Diouf M, Samba SAN, Ndoye O, Van Damme P. 2015. Difference in germination rate of Baobab (*Adansonia digitata* L.) provenances contrasting in their seed morphometrics when pretreated with concentrated sulfuric acid. African Journal of Agricultural Research **10(12)**:1412-1420.

Dourie C, Whitaker J, Grundy I. 2015. — Verifying the presence of the newly discovered African baobab, Adansonia kilima, in Zimbabwe through morphological analysis. South African Journal of Botany **100**:164-168.

Duvall CS. 2007. Human settlement and baobab distribution in south-western Mali. Journal of Biogeography **34(11)**:1947-1961.

Duxoux E. 1983 La pollinisation des fleurs de baobab est-elle seulement le fait des males de la roussette paillée Eidolon helvum? Rev Ecol (Terre et Vie) **38**:229-231.

EC. 2008. Commission decision: authorizing the placing on the market of baobab dried fruit pulp as a novel food ingredient under regulation (EC) No 258/97 of the European Parliament and of the Council. Off J Eur Union L **183(38)**:1–2.

Esenowo GJ. 1991. Studies on germination of *Adansonia digitata* seeds. The Journal of Agricultural Science **117(1)**:81-84.

ESRI. Released 2011. ArcGIS Desktop, Version 10.5.1. Redlands, CA: Environmental Systems Research Institute.

Falemara BC, Chomini MS, Thlama DM, Udenkwere M. 2014. Pre-Germination and Dormancy Response of *Adansonia digitata* L. Seeds to Pre-treatment techniques and growth media. European Journal of Agriculture and Forestry Research **2(1)**:31-41.

Falemara BC, Nwadike C, Obashola EO. 2013. Germination response of baobab seeds (*Adansonia Digitata* L) as influenced by three pre-treatment techniques. Pages 44-45 in Popoola L, Idumah FO, Ogunsanwo OY,Azeez IO, Editors. 35th Conference of the Forestry Association of Nigeria, Forest Industry in a Dynamic Global Environment, Sokoto.

FAO. 1993. Indigenous multipurpose trees of Tanzania: uses and economic benefits for people. Rome: FAO.

Fasola TR, Okerenkporo MT. 2012. Micropropagation of baobab (*Adansonia digitata* Linn.), an economic plant. Journal of South Pacific Agriculture **16**:24-29.

FDA. 2009. Agency Response Letter GRAS Notice No. GRN 000273, 25/July/2009. US Food and Drug Administration. Available from http://www.fda.gov/food/ingredientspackaginglabeling/ gras/noticeinventory/ucm174945.htm (accessed April 2019).

Gebauer J, Adam YO, Sanchez AC, Darr D, Eltahir ME, Fadl KE, Hunsche M. 2016. Africa's wooden elephant: the baobab tree (*Adansonia digitata* L.) in Sudan and Kenya: a review. Genetic resources and crop evolution **63(3)**:377-399.

Gustad G, Dhillion SS, Sidibé D. 2004. Local use and cultural and economic value of products from trees in the parklands of the municipality of Cinzana, Mali. Economic Botany **58(4)**:578.

Herrero M, Ringler C, van de Steeg J, Thornton P, Zhu T, Bryan E, Omolo A, Koo J, Notenbaert A. 2010. Climate Variability and Climate Change and Their Impacts on Kenya's Agriculture Sector. International Livestock Research Institute, Nairobi, Kenya.

Ibiyemi SA, Abiodun A, Akanji SA. 1988. *Andasonia digitata* Bombax and Parkia filicoideae Welw: fruit pulp for the soft drink industry. Food chemistry **28(2)**:111-116.

IBM Corp. Released 2013. IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp.

Irshad M, He B, Liu S, Mitra S, Debnath B, Li M, Qiu D. 2017. *In vitro* regeneration of Abelmoschus esculentus L. cv. Wufu: Influence of anti-browning additives on phenolic secretion and callus formation frequency in explants. Horticulture, Environment, and Biotechnology **58(5)**:503-513.

Jaetzold R, Schmidt H, Hornetz B, Shisanya C. 2012a. Farm management handbook of Kenya: Natural Conditions and Farm Management Information. Vol II. 2nd Edition. Part C: East Kenya. Subpart C2: Coast Province. Nairobi. Ministry of Agriculture and German Agency for International Cooperation, 85-390.

Jaetzold R, Schmidt H, Hornetz B, Shisanya C. 2012b. Farm management handbook of Kenya: Natural Conditions and Farm Management Information. Vol II. 2nd Edition. Part C: East Kenya. Subpart C1: Eastern Province. Nairobi. Ministry of Agriculture and German Agency for International Cooperation, 355-468.

Jenya H, Munthali CR, Mhango J. 2018. Amenability of African baobab (*Adansonia digitata* L.) to vegetative propagation techniques. Journal of Sustainable Forestry **37(6)**:632-644.

Johansson M. 1999. The baobab tree in Kondoa Irangi Hills, Tanzania. Swedish University of Agricultural Sciences, Minor Field Studies **74**:1-43.

Kalinganire A, Weber JC, Uwamariya A, Kone B. 2007. Improving rural livelihoods through domestication of indigenous fruit trees in the parklands of the Sahel. Fruit Trees **10**:186-203.

Kamatou GPP, Vermaak I, Viljoen AM. 2011. An updated review of *Adansonia digitata*: A commercially important African tree. South African Journal of Botany **77(4)**: 908-919.

Kehlenbeck K, Padulosi S, Alercia A. 2015. Descriptors for Baobab (*Adansonia digitata* L.). Biodiversity International, Rome, Italy and World Agroforestry Centre, Nairobi, Kenya.

Koechlin J, Guillaumet JL, Morat P. 1974. Flore et végétation de Madagascar. Cramer, Vaduz.

Kotina EL, Oskolski AA, Tilney PM, Wyk BEV. 2017. Bark anatomy of *Adansonia digitata* L. (Malvaceae). Adansonia **39(1)**:31-40.

Liddell HSR, Scott R. 1940. Jones HS. A Greek-English Lexicon. 9th edition, 2 vols. Cleradon Press, Oxford.

Lisao K, Geldenhuys CJ, Chirwa PW. 2017. Traditional uses and local perspectives on baobab (*Adansonia digitata*) population structure by selected ethnic groups in northern Namibia. South African Journal of Botany **113**:449-456.

Maghembe JA, Kwesiga F, Ngulube M, Prins H, Malaya FM. 1994. Domestication potential of indigenous fruit trees of the miombo woodlands of southern Africa. Pages 220-229 in Leakey RRB, Newton AC, editors. Tropical trees: the potential for domestication and the rebuilding of forest resources. HMSO, London.

McCown BH, Lloyd G. 1981. Woody Plant Medium (WPM)—A Mineral Nutrient Formulation for Microculture of Woody Plant Species. HortScience **16**:453-453.

Maranz S, Niang A, Kalinganire A, Konate D, Kaya B. 2008. Potential to harness superior nutritional qualities of exotic baobabs if local adaptation can be conferred through grafting. Agroforest Syst **72**:231–239.

Meinhold K, Adam OY, Chimuleke M. 2016. The Baofood Project: Enhancing Local Food Security and Nutrition in Eastern Africa with the Baobab Tree. Available from www.baofood.de (accessed April 2019).

Microsoft Corp. Released 2019. Microsoft Excel 365 for Windows, Version 16.0.11328.20230. Redmond, Washington: Microsoft Corp.

Mullin LT. 1991 The baobab – giant of Zimbabwe´s lowveld. Excelsa **15**:63-67.

Murashige T, Skoog F. 1962. A revised medium for rapid growth and bio-assays with tobacco tissue cultures. Physiologia Plantarum **15(3)**: 473-497.

Mwangi KK, Mutua F. 2015. Modelling Kenya's vulnerability to climate change: a multifactor approach. International Journal of Science and Research **6**:12-19.

N'doye AL, Sambe MAN, Sy MO. 2012. Propagation of African baobab (*Adansonia Digitata* L., Bombacoideae, Malvaceae) germplasm through *in vitro* cloning. Advances in Environmental Biology **6(10)**:2749-2758.

Norris HT. 1982. The Berbers in Arabic Literature. Longman, London.

Pettigrew FRS, Jack D, Bell KL, Bhagwandin A, Grinan E, Jillani N, Vickers CE. 2012. Morphology, ploidy and molecular phylogenetics reveal a new diploid species from Africa in the baobab genus Adansonia (Malvaceae: Bombacoideae). Taxon **61(6)**:1240-1250.

Rahul J, Jain MK, Singh SP, Kamal RK, Naz A, Gupta AK, Mrityunjay SK. 2015. *Adansonia digitata* L.(baobab): a review of traditional information and taxonomic description. Asian Pacific Journal of Tropical Biomedicine **5(1)**:79-84.

Razanameharizaka J, Grouzis M, Ravelomanana D, Danthu P. 2006. Seed storage behaviour and seed germination in African and Malagasy baobabs (Adansonia species). Seed Science Research **16(1)**:83-88.

Rolli E, Brunoni F, Bruni R. 2016. An optimized method for *in vitro* propagation of African baobab (*Adansonia digitata* L.) using two-node segments. Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology **150(4)**:750-756.

Sacande M, Rønne C, Sanon M. 2006. Seed Leaflet-*Adansonia digitata* L. Millennium Seed Bank Project, UK and Forest & Landscape Denmark, 109.

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. Forest Ecology and Management **260(11)**:2035-2044.

SCUC. 2006. Baobab Manual, Field Manual for Extension Workers and Farmers, University of Southampton, Southampton, UK.

Seth S, Panigrahi J. 2019. *In vitro* organogenesis of Abutilon indicum (L.) Sweet from leaf derived callus and assessment of genetic fidelity using ISSR markers. The Journal of Horticultural Science and Biotechnology **94(1)**:70-79.

Seth S, Rath SC, Rout GR, Panigrahi J. 2017. Somatic embryogenesis in Abutilon indicum (L.) Sweet and assessment of genetic homogeneity using SCoT markers. Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology **151(4)**:704-714.

Sidibe M, Williams JT. 2002. Baobab, *Adansonia digitata* L. International Centre for Underutilised Crops. Southampton, UK.

Sie RS, Charles G, Sakhanokho HF, Toueix Y, Djè Y, Sangaré A, Branchard M. 2010. Protocols for callus and somatic embryo initiation for Hibiscus sabdariffa L. (Malvaceae): influence of explant type, sugar, and plant growth regulators. Australian journal of crop science **4(2)**:98-106.

Singh S, Rai S, Khan S. 2010. *In vitro* seed germination of *Adansonia digitata* L.: an endangered medicinal tree. Nanobiotechnica Universale **1(2)**:107-112.

Stevens PF. 2012. Angiosperm Phylogeny Website. Available at http://www.mobot.org/MOBOT/research/APweb/ (accessed April 2019).

Storrs AEG. 1982. More about Trees (A sequel to Know your trees). Forest Department, Ndola.

Swanepoel CM. 1993. Notes and Records Baobab phenology and growth in the Zambezi Valley, Zimbabwe. African Journal of Ecology **31(1)**:84-86.

The World Bank Group. 2019. Population, total | Data. (n.d.). Available from http://www.fao.org/nr/water/aquastat/countries_regions/ken/index.stm (accessed April 2019).

UNCTAD. 2005. Market brief in the European union for selected natural ingredients derived from native species. *Adansonia digitata* L. Baobab. Available from http://www.biotrade.org/ResourcesPublications/biotradebrief-baobab.pdf (accessed April 2019).

Usman IA, Asan TV. 2017. Influence of different pretreatments on seed germination and growth rate of *Adansonia digitata* (Aaertn) seedlings. Journal of Research in Forestry, Wildlife and Environment **9(2)**:8-14.

Van den Bilcke N, De Smedt S, Simbo DJ, Samson R. 2013. Sap flow and water use in African baobab (*Adansonia digitata* L.) seedlings in response to drought stress. South African Journal of Botany **88**:438-446.

Venter SM, Witkowski ET. 2011. Baobab (*Adansonia digitata* L.) fruit production in communal and conservation land-use types in Southern Africa. Forest Ecology and Management **261(3)**:630-639.

Venter SM, Witkowski ETF. 2013a. Where are the young baobabs? Factors affecting regeneration of *Adansonia digitata* L. in a communally managed region of southern Africa. Journal of arid environments **92**:1-13.

Venter SM, Witkowski ET. (2013b). Using a deterministic population model to evaluate population stability and the effects of fruit harvesting and livestock on baobab (*Adansonia digitata* L.) populations in five land-use types. Forest ecology and management **303**:113-120.

Venter SM. 2012. The ecology of baobabs (*Adansonia digitata* L.) in relation to sustainable utilization in Northern Venda, South Africa [PhD. Thesis] University of the Witwatersrand, Johannesburg.

Vick K. 2001. Trunk line to the spirit world. Washington Post.

Von Breitenbach F. 1985. Aantekeninge oor die groeitempo van aangeplante kremetartbome (*Adansonia digitata*) en opmerkinge ten opsigte van lewenstyd, groeifases en genetiese variasie van die spesie. J. Dendrol **5**:1-21.

Watson R. 2007. The African baobab. Cape Town, South Africa: Struik Publisher.

Wickens GE, Lowe P. 2008. The baobabs: pachycauls of Africa, Madagascar and Australia. Springer Science & Business Media.

Wickens GE. (1982). The baobab: Africa's upside-down tree. Kew bulletin **37**:173-209.

Yengoh GT, Brogaard S. 2014. Explaining low yields and low food production in Cameroon: a farmers' perspective. GeoJournal **79**:279-295.

Zahra'u B, Mohammed AS, Ghazali HM, Karim R. 2014. Baobab tree (*Adansonia digitata* L) parts: nutrition, applications in food and uses in ethno-medicine a review. Ann Nutr Disord & Ther **1(3)**:1011.

Appendices

Appendix 1: semi-structured questionnaire

BAOBAB QUESTIONNAIRE

Village (district): Name:

Date: Gender:

GPS and altitude: Age:

Nationality/Ethnicity: Education:

Socio-economic status: self-evaluation 1=best 2=average 3=worst

What is local name for baobab tree and seed?	
When do you harvest it?	
Is available only in season or throughout the year?	

What are the uses of this plant? *(fruit pulp, seeds and leaves and also about non-food products and services from the tree, e.g. ropes, medicine, stored water, shade, fodder)*	
Do you harvest both fruits and leaves of baobabs?	
Do you use/collect the fruits and leaves of this species from the wild?	
Do you/would you plant baobab for commercial or subsistence purposes?	
Where and how do you grow this species?	
What is the source of planting material?	
What are the worst problems in establishing this species?	
Do you use any seed treatments to induce germination?	

Which trait is the most important for you and why? (Yield, resistance, fruit size, taste, etc…)	
What are the advantages of owning a baobab tree?	
What are the main threats to the baobab? (pests and diseases)	
Was in history more or less trees?	
Is there any mention about any folklore? (taboos, stories and/or superstitons) *(In Kenya, some people believe that djinns are living in baobab trees, which can harm people, thus, baobabs should be cut down close to houses or schools.)*	
Do you somehow managed the trees cutting, pruning?	
Plants interaction with other cultivated crops?(positive/negative)	