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Soil properties under baobab trees (*Adansonia digitata* L.) and their influence on fruit nutrient content

MSc. Thesis

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DECLARATION

This is to certify that this thesis entitled "Soil properties under baobab (*Adansonia digitata* L.) and their influence on fruit nutrient content", submitted in partial fulfilment for the award of the MSc. Degree in Tropical Crop Management and Ecology under Department of Crop Science and Agroforestry, Czech University of Life Sciences Prague written by me, the undersigned AWUOL MAKUEI JOSEPH MAGAI is my own work done with technical and scientific support from my supervisor doc. Ing. Bohdan Lojka, Ph.D. and co-supervisors; Prof. Katja Kehlenbeck Ph.D. and Ing. Jakub Houska, Ph.D. I also have to admit that the plant data used here to correlate with soil analyses results were obtained from ICRAF Nairobi Kenya under agreement and were previously used by ICRAF for a socioeconomic study. I also have to admit that all the information used here have been cited and that this work has never been published anywhere before.

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AWUOL MAKUEI JOSEPH MAGAI

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ABSTRACT

Baobab (*Adansonia digitata* L.) is a multipurpose tree whose leaves and fruit pulps are consumed by rural population in Africa to benefit from higher levels of vitamin C than in orange and calcium than in cow milk. Several studies however reported high variation in concentration of chemical elements of the pulp, but the cause is not well attributed. The aim of this study was to determine the influence of soil properties on fruit nutrient content in two geographical regions of Kenya: Inland highland (IH) and Coastal lowland (CL) zones. Data of baobab pulp nutrient contents were obtained from previous study of ICRAF, where fruit pulp of baobab trees from coastal and inland region of Kenya were sampled to assess major nutrients. In this study, soil samples under those 63 baobabs were collected and analysed for pH and selected macro- and micronutrients. Simple t-test was used to determine variability of soil chemical and pulp nutrients composition and distribution between the two geographical zones of Kenya. Principal Component Analysis and simple correlation methods were used to assess the relationship among major pulp nutrients and soil chemical elements at different soil layers. The results from t-test indicated that there was variation in soil chemical properties between the two zones; the soils in coastal sites had higher pH, Ca, S total P and plant available P contents, whereas inland sites had high K and Mg contents. Results also showed that there were significant differences of pulp nutrient contents between the two zones. The fruit pulp of IH baobabs had higher content of vitamin C, Fe and Mg whereas CL baobabs had higher total acidity, K and ash content. Furthermore, there was medium high correlation of pulp nutrients with some soil elements at a coefficient ranging between 0.42 to 0.72 and -0.44 to -0.64 for positive and negative correlation, respectively. Soil K, Cu and Co positively correlated with vit. C and Fe contents in pulp. On the other hand, soil pH, S, total P and plant available P positively correlated with pulp ash, acidity and K contents. The correlation revealed an influence of soil chemical composition on pulp nutrient content. Considering that IH soils were higher in K and possibly Cu and Co, IH baobab pulps were correspondingly higher in vit. C and Fe. The CL fruit pulps, where the soils were higher in S, Ca and P, were correspondingly higher in ash, K and more acidic. Pulp Ca content was, however, uniform between the two zones. We conclude that baobab pulp nutrients are influenced by underlying soil chemical elements, hence, we recommend the use of P, K, Ca, S, Si and micro nutrient such as Cu and Co to improve baobab fruit pulp quality.

Keywords: *Adansonia digitata*, baobab, nutrient contents, pulp composition, soil properties

ABSTRAKT

Baobab (*Adansonia digitata* L.) je víceúčelový strom, jehož listy a plody jsou konzumovány venkovskou populací v Africe kvůli obsahu vitamínu C, který je vyšší než u pomeranče, a vápníku, jehož obsah je vyšší než u kravského mléka. Několik studií zjistilo vysokou variabilitu v koncentracích živin v dužině baobabu, jejíž příčiny však nejsou dobře zdokumentovány. Cílem této studie bylo určit vliv půdních vlastností na obsah živin v plodech baobabu ve dvou zeměpisných oblastech Keni: vnitrozemská vysočina (IH) a pobřežní nížina (CL). Údaje o obsahu živin plodů baobabu byly získány z předchozí studie organizace ICRAF, kde byla odebrána dužina z plodů baobabů z pobřežních a vnitrozemských oblastí Keni, a stanoveny obsahy hlavních prvků. V této studii byly odebrány půdní vzorky pod těmito 63 stromy a stanoveno pH a obsahy vybraných makro- a stopových prvků. Jednoduchý t-test byl použit pro stanovení variability chemického složení půdy a dužiny plodů podle rozdělení mezi dvěma zeměpisnými oblastmi Keni. Analýza hlavních komponent a jednoduché korelační metody byly použity pro posouzení vztahů mezi obsahy prvků v plodech a v půdě podle různých půdních vrstev. Výsledky z t-testu ukázaly rozdíly v chemických vlastnostech půd mezi oběma zónami. Půdy v pobřežních lokalitách měly vyšší pH, i obsahy Ca, celkového i dostupného P, zatímco ve vnitrozemí měly vysoký obsah K a Mg. Výsledky také ukázaly, že existují významné rozdíly v obsahu prvků v plodech mezi oběma zónami. Dužina IH baobabů měla vyšší obsah vitaminu C, Fe a Mg, zatímco CL baobaby měly vyšší kyselost, obsah popelovin a K. Kromě toho byly zjištěny korelace mezi obsahy prvků v plodech a v půdě, s koeficientem v rozmezí mezi 0,42 až 0,72 pro pozitivní a -0,44 až -0,64 pro negativní korelace. Půdní obsah K, Cu a Co pozitivně korelovaly s obsahem vit. C a Fe v plodech. Na druhé straně, pH půdy, S, P, celkový a přístupný P pozitivně korelovaly s obsahem popelovin, kyselostí a obsahu K. Korelace odhalila vliv chemického složení půdy na obsah živin v plodech. Vzhledem k tomu, že IH půda měla vyšší obsah K a případně i Cu a Co, plody z oblasti IH měly vyšší obsah vit. C a Fe. Na druhou stranu CL půdy, které měly vyšší obsah S, Ca a P, ovlivnily u plodů vyšší obsah popelovin, K a kyselost. Obsah Ca v plodech neukázal rozdíly mezi dvěma zónami. Došli jsme k závěru, že obsahy živin v plodech baobabu jsou ovlivněny chemickým složením půdy a proto doporučujeme použití hnojiv s obsahem P, K, Ca, S, Si ale i stopových prvků jako Cu či Co pro zlepšení kvality plodů.

Klíčová slova: *Adansonia digitata*, baobab, obsah živin, půdní vlastnosti, složení dužiny

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1 INTRODUCTION

Baobab tree (*Adansonia digitata* L.) is a multipurpose tree, whose leaves, seeds and fruit pulp are traditionally consumed by rural population in Africa. The leaves are commonly eaten fresh as vegetable or in the form of dried powder for seasoning in the Savannah areas of West Africa, Kenya, Tanzania, Malawi and Zimbabwe. The dried pulp is commonly used to prepare fruit juice or mixed with porridge or gruel in part of East Africa, to benefit from generally higher level of vitamin C than in oranges and calcium than in cow milk (Assogbadjo et al., 2012). Numerous studies on nutritional concentration of baobab parts reviewing various chemical analyses reveal that different baobab parts (pulp, leaves and seeds) are rich in other nutrients such as Fe, Vitamin A, K, Mg, Zn etc. (Faichney and White, 1983; Chadare et al., 2008; Gebauer, et al., 2016). The plant edible parts have become an important nutritional source for the rural population in Africa and hence, there is need to bring the tree under domestication and better management (Mbora et al., 2008; Buchmann et al., 2010; Gebauer et al., 2016). However, several studies reported huge variation in the nutrient contents among trees and regions (Yazzie et al., 1994; Nour et al., 1980). Moreover, the exact cause of this variation in different baobab parts is still not exactly known. Several studies have attributed the cause of chemical variation in baobab parts to ecological isolation and genetic differentiation, while others suggest the cause may encompass many parameters including soil chemical composition. Assogbadjo et al. (2012) reported that the variation of chemical composition in baobab parts is attributed to intraspecific genetic variation. Chadare et al. (2009) on the other hand provided an explanation on the variation, saying it could be due to several parameters, including soil composition and climatic conditions. Thus, it could be hypothesized that the variation in the pulp nutrient contents may be influenced by soil chemical composition.

This study attempts to determine the soil properties under selected baobab trees in two different zones of Kenya (inland highland and coastal lowland), and to assess the impact of those soil properties on nutrient composition of baobab fruit pulp. The results from this study could be used to identify suitable soils for the growth of baobab and recommending guidelines for soil fertility management.

2 LITERATURE REVIEW

2.1 Baobab (*Adansonia digitata* L.)

Baobab is one of the most remarkable tree species in the world and an important indigenous fruit tree (IFT) throughout the drier areas of Africa as well as a representative of the wooden 'big five'. It is usually referred to as wooden or vegetative elephant (Gebauer et al., 2016). Due to its massive and bulky appearance in many African savannah and eye catching profile of this unique tree which usually attracts many travellers and tourists, it is widely used as a motif on postcards, calendars and postage (Gebauer et al., 2016). This tree has evolved formidable resilience in order to survive in major dry and rocky areas of the old continent (Watson, 2007).

2.1.1 Botanical description

The baobab is the largest and massive tree found in Africa that normally attends a height of up to 25 m (Gebauer et al., 2002; Osman, 2004). It has a massive cylindrical trunk, 10–14 m in girth, and a spreading crown of up to 30 m in diameter that resembles the root system of an inverted tree (Figure 1). Many African folk tales suggest that God might have planted the baobab upside down (Gebauer et al., 2002; Osman, 2004). The trunk is covered with smooth greyish bark with thickness ranging from 50 to 100 mm (Obizoba and Amaechi, 1993; Gebauer et al., 2002). The compound leaves are palmately lobed, similar to size of the hand and with 5 to 7 (mainly for adult) leaflets that are clustered at the base (Figure 1) (Gebauer et al., 2002; Orwa et al., 2009). The flowers are white, large and pendulous, with 5 petals and 5 cup shaped sepals; they reach up to 200 mm in diameter (Gebauer et al., 2002). The fruit is a large indehiscent, egg shaped, often greater than 1,200 mm in length, with yellowish brown haired hard woody outer shell filled with creamy pulp and numerous dark brown kidney shaped seeds (Figure 1) (Gebauer et al., 2002; Kehlenbeck et al., 2015). The pollination is usually performed by the fruit bat (***Rousettus aegyptiacus* E.).** The large white flowers emerge in the late afternoon from the large green and round buds during October to December. They emit sweet carrion scent that attracts the pollinating bats (Gebauer et al., 2002; Kehlenbeck et al., 2015). The rooting system is an extensive lateral system and much more spreading than the crown, and producing tubers at the end (Gebauer et al., 2002). Although not much work on rooting system has been carried out, it is

considered to have a shallow rooting system, ranging from the surface to 1.8 m (Gebauer et al., 2016).

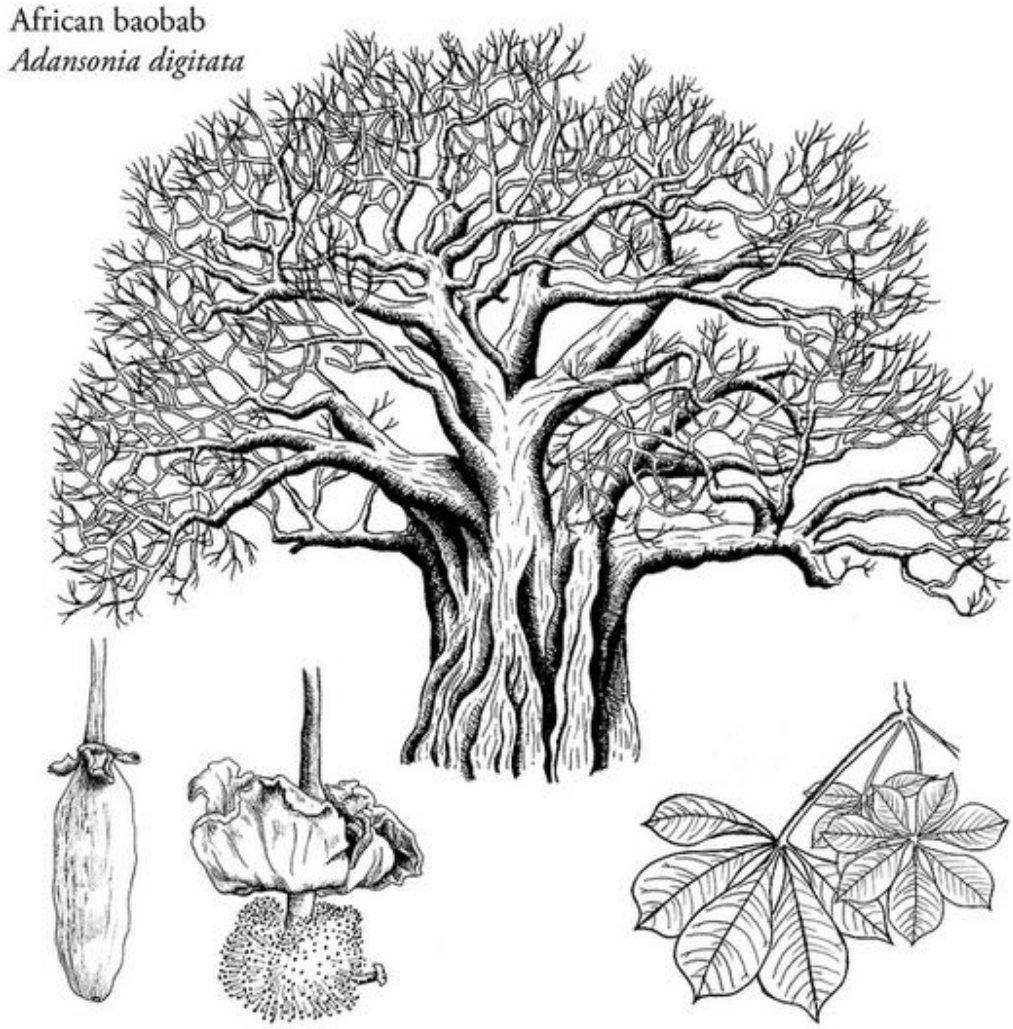

Figure 1. Baobab – tree habit, leaves, flower and fruit

2.1.2 Taxonomy, origin and distribution

The name baobab is probably derived from the Arabic word ‘buhibab’ which means “fruit with many seeds”, its scientific names, ‘Adansonia’ was given by Carl von Linnaeus in honour of French scientist, Michel Adanson who was the first European botanist to see and describe the baobab tree in its native habitat, while the term ‘digitata’ refers to the shape of the tree leaf

(Gebauer et al., 2016). Many refer to it as dead rat tree, monkey bread tree, upside down tree etc. (Gebauer et al., 2002). In Sudan, it is commonly called 'tabaldi' in Arabic and its fruit is separately called gungolez, while in Kenya, it is commonly call Mbuyu in Khiswahili; the fact that there exist different names for the fruit indicates its specific importance to the local people (Gebauer et al., 2016).

Adansonia digitata L. belongs to Malvaceae family according to AFG taxonomic classification (Table 1) (Obizoba and Maechi, 1993; Gebauer et al., 2002; Bosch et al., 2004).

Table 1. *Adansonia digitata* taxonomic classification

Class	**Equisetopsida C.**
Subclass	Magnolidae
Order	Malvale Juss.
Family	Malvaceae Juss.
Genus	*Adansonia L.*
Species	*Adansonia digitata L.*

Source: Missouri botanical garden (2015)

The genus *Adansonia* comprises eight species: six of these species are endemic to Madagascar and one (***A. girigorii*** L.) is endemic to Australia, while *A. digitata* L. is the only species known to Africa mainland (Gebauer et al., 2002; Kehlenbeck et al., 2015).

Baobab (***A. digitata***) is known to have originated in West Africa, probably around present day Senegal and its vicinity, and migrated to subsequently cover most tropical countries majorly in Africa, but also to Asia (Figure 2) (Gebauer et al., 2002).

2.1.3 Ecological requirements

Baobab is a deciduous plant that stays leafless for most of the year and occurs naturally in drier areas of Africa, mainly in the Sahelian, Sudano-Sahelian and Sudano zones. The distribution extends through woodland, savannah and grassland of Sub-Saharan Africa to about 25°S (Chadare et al., 2008). The plant occurs in almost all soil types; from stony, sandy, silt through clay type and even in acidic soils. The optimal soil is free drained soil with pH 6.5 (Nour et al., 1980). The optimum rainfall ranges from 250 to 1,500 mm per annum and the altitude ranges from sea level to about 1,500 m above sea level. The optimum temperature usually ranges from 25 °C to about 27 °C with minimum winter temperature between 10 °C and 13 °C. The

plant cannot tolerate even a mild frost (Osman, 2004). Baobab usually lives as solitary but in some instants it grows in association with other plant species. In Sudan, it is usually associated with tamarind (*Tamarindus indica* L.), and in humid areas, it may live in association with lianas.

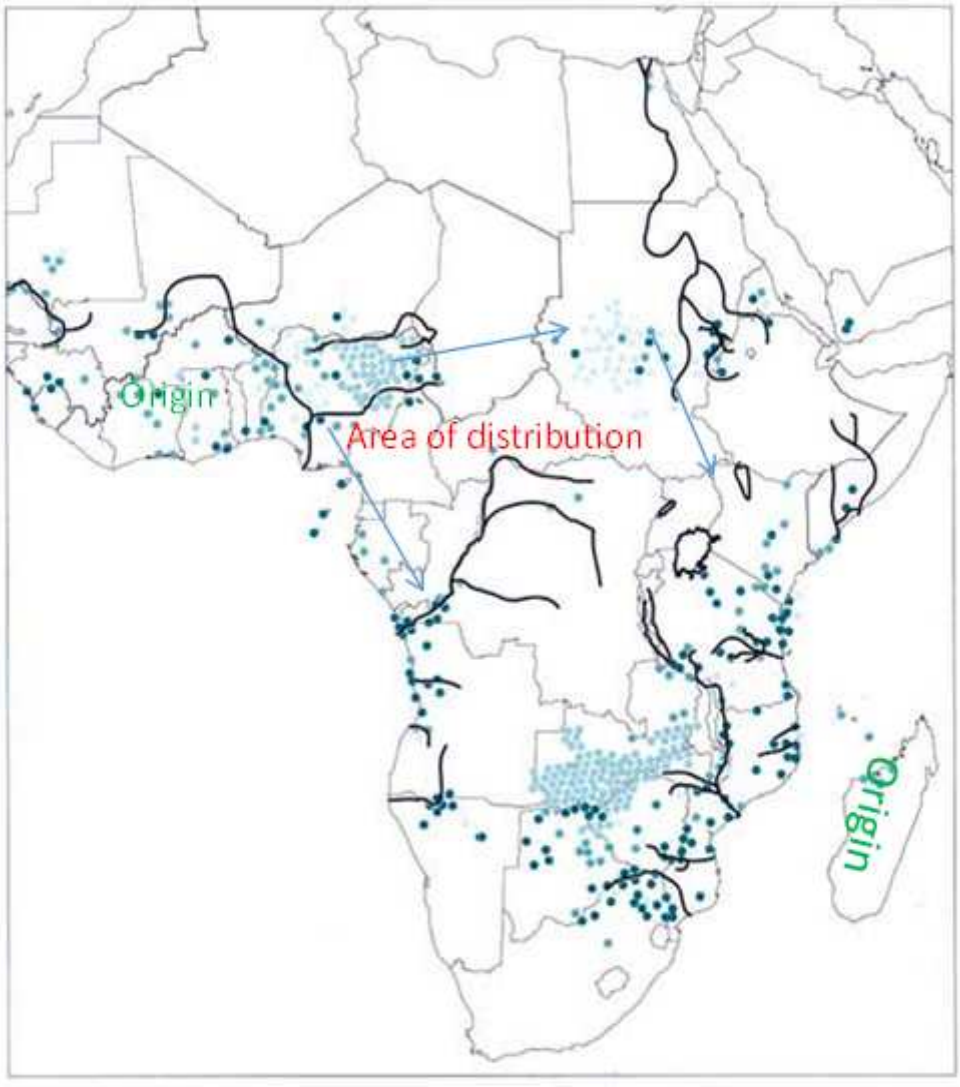

Figure 2. Map of the origin and distribution of baobab (Gebauer et al., 2002).
The green dots in the map refer to origin, the blue dots refer to distribution.

2.1.3 Phenology

Baobab is one of the long-life tree species among the angiosperm which make them living monuments (Watson, 2007). The radiocarbon dating investigation conducted in Namibia using grootboom shows an age of about 1,275 years (Patrut et al., 2007).

Baobab trees can live normally for about 800 years that are categorised into four principle phases, which are referred to as: sapling phase (10–15 years), cone phase (60–70 years) usually with faster growth, bottle phase (200–300 years) and old phase (500–800 years); the two last phases are characterized by slow growth (Gebauer et al., 2002). The plant grows rapidly attaining a diameter of 4-5 m in the first 100 years (Wickens, 1982). The sapling phase is characterized by simple leaf. Baobab retains leaves for only four months of the year; however, flowering may proceed regardless of leaf absence which justified the fact that baobab use grey bark for photosynthesis (Gebauer et al., 2002). Flowering can take place in the first 16 to 17 years of the lifecycle which falls in the sapling phase, as has been reported in South Africa by Wickens (1982). The reproduction cycle is variable from region to region. In Sudan, baobab usually flowers from May to July and bears fruit from August to October (Gebauer et al., 2002). Propagation is usually done by seeds. Baobab experiences pronounced seed dormancy with only 20% germination, thus dormancy has to be broken, commonly by acidic scarification for 6 to 12 hours (Chadare et al., 2009).

2.1.3 The uses

In many rural communities of the developing world, livelihood revolves around exploration of the natural resources for income, food and other products, in time of hardship especially when there is shortfall in agriculture crop production, wild edible fruits constitute security option (Gebauer et al., 2016). Across sub-Sahara Africa, wild indigenous fruit trees (IFT) are used for wide range of purposes, fulfilling subsistence as well as commercial objectives (Gebauer et al., 2016).

In Africa, baobab is one of the IFT and the most important multipurpose tree whose fruit pulp, seed, bark, flower, leaves and root are used for food, medicine and fibre (Chadare et al., 2008) (Figure 3).

The pulp, a powdery substance inside a woody shell (creamy in colour), and leaves are rich in ascorbic acid (vitamin C), potassium, sugar and calcium, and both are consumed mostly by rural population in Africa (Chadare et al., 2008; Assogbadjo et al., 2012). The nutrient-rich parts of baobab plant have recently attracted the interest of consumer product industry which seeks to use its material (Buchmann et al., 2010; Gebauer et al., 2016). The dried pulp is commonly used to prepare fruit juice or mixed with porridge or gruel in part of East Africa to benefit from a high

level of vitamin C which is reported to be around 500 mg/100 g of dry pulp, compared to 40 mg/100 g in orange. The pulp also contains as much as 700 mg of Ca/100 g as compared to 300 mg/100 g in cow milk (Osman, 2004). Drink from dry pulp is also believed to treat fever and other illnesses.

The leaves are commonly eaten fresh as vegetable or in the form of dried powder for seasoning in the savannah areas of West Africa, Kenya, Tanzania, Malawi and Zimbabwe. Fresh leaves are a good source of fodder for domestic animals (Assogbadjo et al., 2012).

The seeds are usually roasted and used as substitute for coffee. The bark is commonly used as a source of fibre for mate, rope, fishing line and net, sack and clothing (Assogbadjo et al., 2012).

In the recent years, international interest in the species has intensified following the acceptance of baobab fruit pulp as food ingredient by the European Union (EU) and the US food and drug administration (FDA) which was initiated by Phyto Trade Africa (Gebauer et al., 2016). A recent study by Gebauer et al. (2014) revealed more than 300 products with baobab parts as an ingredient which are already available in European market (Gebauer et al., 2016). The products ranged from foodstuff such as soft drinks, sandwich spread, cereal bar, sweets and chocolate to cosmetics, including after-shave, shampoo and foot spray (Gebauer et al., 2016).

Most of the baobab products such as dried and fresh leaves, whole fruit and processed pulp and extracted bark fibre are available in market of most African countries with varying prices depending of seasonality, for instance, fresh leaves are sold from 0.06-0.18 USD per kg during rainy season while the price of dried leaves varies between 0.09-0.18 USD per kg during dry season. Fruits are sold at the local markets for prices between 0.18-0.46 USD per kg while at international market it is sold for 6.4 USD per kg and pulp powder costs 0.73-0.91 USD per kg (SCUC, 2006).

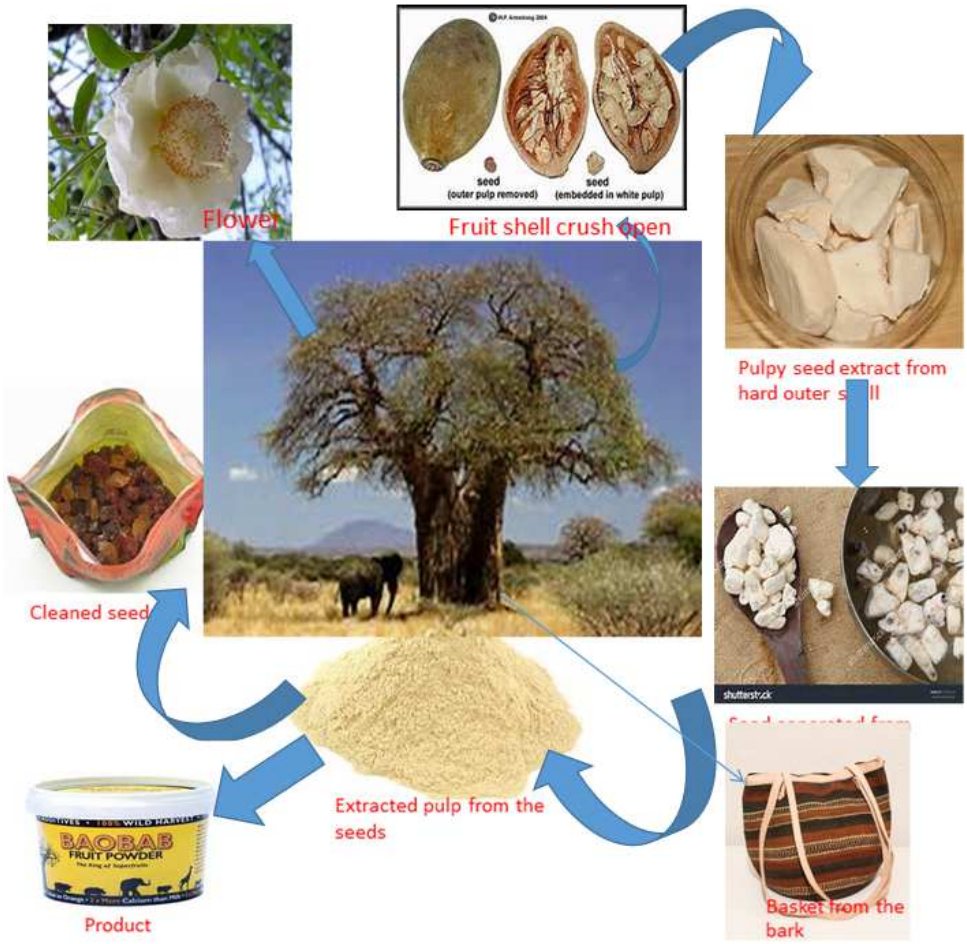

Figure 3. Uses of baobab modified from Chadare et al. (2008)

2.1.4 Chemical composition of various baobab parts

Numerous studies on nutritional concentration of baobab parts revealed that its pulp, leaves and seeds are rich in various nutrients (Yazzie et al., 1994, Nordeide et al., 1996; Sidibe and William, 2002; Chadare et al., 2008; Chadare et al., 2009). However, there is a huge variation in reported values for given chemical elements in the species. Several data from various authors indicate great variability in baobab nutritional quantity in leaves (Table 2) and fruit pulp (Table 3).

Studies conducted in Benin suggested that the variation in chemical composition of various parts of baobab depends strongly on genetic differentiation as a result of ecological isolation, as well as intraspecific variation (Yazzie et al., 1994; Chadare et al., 2009; Assogbadjo et al., 2012). Gebauer et al. (2002) attributed variation in baobab parts' chemical composition to intra specific

genetic variation. The study on genetic diversity of natural baobab populations in Benin by Assogbadjo et al. (2012) revealed that genetic differentiation between populations originating from different climatic zones was due to physical isolation across three climatic zones, presuming different genetic structuring.

On the other hand, Chadare et al. (2009) suggested that the variation could be a result of several parameters including composition of the soil, influence of the climate and the provenance of the sample. However, there is no study that has specified the probable cause of variation.

Assogbadjo et al. (2012) also concur with the suggestion that physicochemical characteristics of soil seem to influence the nutritive value of baobab parts. Moreover, according to the preceding authors, highly basic soil rich in carbon, clay, fine silt and organic matter were positively correlated to concentration of iron (Fe), potassium (K), vitamin C, carbon (C), zinc (Zn), proteins and lipids in the fruit pulp. On the other hand, negative correlation was found for the relationship between the soil chemical composition and baobab fruit pulp concentration of magnesium (Mg), calcium (Ca), vitamin A and fibre (Assogbadjo et al., 2012).

Furthermore, Assogbadjo et al. (2012) evaluated baobab trees in different climatic zones of Benin and did not find any significant differences of all basic nutrients such as protein, lipid, carbohydrate, fibre, macronutrients and micronutrients such as Ca, Mg, K, and vit. A across climate zones. However, differences were revealed for nutrients such as Fe, Zn and vit. Particularly, the difference was notable for the concentration of Fe in the leaf, Zn in the pulp and vit. C in all baobab parts. Moreover, Assogbadjo et al. (2012) reported a positive correlation between biochemical composition of the baobab parts, and the physicochemical properties of the soil with exception of vit. A, vit. C and dry matter. The biochemical parameters were significantly correlated on two different axes of Principal Component Analysis; on the first axis, Fe, Ca, K, carbohydrate and fibre showed positive correlation, whereas, Mg, Zn, protein and lipids on the second axis showed negative correlation.

Table 2. Chemical composition of baobab leaves according to various authors.

Element	Unit	Content	Source
Water	g/100g	6.4-8.2	Nordeide et al. (1996); Lockett et al. (2000)
Energy	kJ/100 g	1,180 -1,581	Becker (1983); Nordeide et al. (1996)
Carbohydrate	g/100 g	40-69	Nordeide et al. (1996); Lockett et al. (2000)
Proteins	g/100 g	10-14	Yazzie et al. (1994); Nordeide et al. (1996); Lockett et al. (2000)
Fats	g/100 g	4.0-6.3	Becker (1983); Lockett et al. (2000)
Ash	g/100 g	11.5-15.9	Nordeide et al. (1996); Lockett et al. (2000)
Calcium high values	mg/100g	1,470-2,640	Yazzie et al. (1994); Sena et al. (1998)
Calcium low values	mg/100g	307- 2,240	Yazzie et al. (1994); Boukari et al. (2001)
Magnesium	mg/100g	94-549	Smith et al. (1996); Glew et al. (1997)
Potassium	mg/100g	140-1,080	Yazzie et al. (1994); Lockett et al. (2000)
Phosphorus	mg/100g	115-876	Lockett et al. (2000); Barminas et al. (1998)
Sodium	mg/100g	3.8 -163	Sena et al. (1998); Glew et al. (1997)
Manganese	mg/100g	1.9-9.8	Yazzie et al. (1994); Barminas et al. (1998)
Zinc low value	mg/100g	0.7-4.0	Yazzie et al. (1994); Smith et al. (1996)
Zinc high value	mg/100g	22.4	Barminas et al. (1998)
Iron	mg/100g	1.2 -100	Yazzie et al. (1994); Smith et al. (1996)

Table 3. Chemical composition of baobab pulp, according to various authors

Element	Unit	Content	Source
Water	g/100g	2-27	Nour et al. (1980); Becker (1983); Lockett et al. (2000); Soloviev et al. (2004)
Carbohydrates	g/100g	47-88	Wehmeyer (1966); Murray et al. (2001)
Energy	KJ/100g	849 -1,495	Murray et al. (2001); Osman (2004)
Crude proteins low values	g/100g	2.5-3.6	Lockett et al. (2000); Osman (2004)
Crude proteins high value	g/100g	15.3	Obizoba and Amaechi (1993)
Fibre low value	g/100g	6.0-12.5	Lockett et al. (2000); Osman (2004)
Fibre high value	g/100g	45.1	Murray et al. (2001)
Ash	g/100g	4.1-6.4	Busson (1965); Lockett et al. (2000)
pH		3.3	Nour et al. (1980)
Vitamin C	mg/100g	150-500	Scheuring et al. (1999)
Calcium high values	mg/100g	390 -700	Nour et al. (1980); Prentice et al. (1993)
Calcium low values	mg/100g	3.0	Obizoba and Amaechi (1993)
Magnesium	mg/100g	100-300	Sena et al. (1998); Osman (2004)
Potassium	mg/100g	726 -3,272	Saka and Msonthi (1994)
Phosphorus	mg/100g	4-425	Obizoba and Amaechi (1993); Sena et al. (1998)
Sodium	mg/100g	0.8-31.2	Sena et al. (1998); Osman (2004)
Copper	mg/100g	BDL-1.8	Glew et al. (1997); Osman (2004)
Manganese	mg/100g	BDL-1.0	Glew et al. (1997); Sena et al. (1998)
Zinc	mg/100g	0.5-3.2	Sena et al. (1998); Lockett et al. (2000)
Iron	mg/100g	1.1-10.4	Amold et al. (1995); Osman (2004)

BDL: below detection limit

2.1.6 Baobab domestication and cultivation

Africa has the highest number of wild edible fruit species, about 1,200 species most of which are still not domesticated. Domestication could become the basis for integrating new commercial high value species and cultivars into existing farming systems (Gebauer et al., 2016). Several studies in different African countries such as Benin, Malawi, Mali, Nigeria, Tanzania and South Africa have highlighted baobab taxon as a priority species for further domestication and enhanced utilization.

Though there have been attempts to domesticate the baobab tree especially in the aforementioned West African countries, baobab is still not widely adopted for cultivation due to the fact that it takes quite long period of time to reach productive stage (Wickens, 1982). The other important reasons include difficulties in germination and establishment and all in all, there is very little knowledge about fertility requirement considering its high variability in parts nutrient content (Chadare et al., 2009). Germination is hindered by the hard seed coat; according to a report from Mali research institution which carried out germination trial, the rate was recorded at 92% after soaking the seeds in sulphuric acid (H_2SO_4) for 90 minutes followed by rinsing with water for 24 hours (Sidibe and William, 2002). The seeds are then planted in nursery bed or in polyethylene bags after which they can be transplanted after three to four month of age (Sidibe and William, 2002). Vegetative propagation has also been reported to accomplish promising results especially by stem cutting and grafting (Sidibe and William, 2002). SCUC (2006) reported an advantage of vegetative established baobab as it produces as early as three to four years compared to trees grown from seeds that bear first fruit in 10 to 23 years.

Fertility management is of great attention especially for young trees, application of organic fertilizer such as compost or green manure has been recommended (SCUC, 2006). Soliman and Mahmoud (2013) investigated the response of baobab on the application of compost, zeolite and mixture of zeolite and compost in Egypt; they discovered that baobab growth characteristics significantly improved with application of zeolite. Many reports however revealed that baobab at old stage require less fertility management (Sidibe and William, 2002). The agroforestry practice for baobab management is usually a parkland

system where it is grown in mixture with cereals such as sorghum and pearl millet to help in soil aeration and income diversification and provides services such as shade for livestock and farm workers (SCUC, 2006).

According to Arum (1989) baobab productivity is reported at around 200 kg fruit per tree per season, but the yield varies with age and environmental factors, old aged baobab produced eight times more fruits as young baobab of the same genotype (Venter and Witkowsky, 2011).

2.2 Major soil types in Kenya

Soil consists of solid particles, water and air and it serves as a natural medium for plant growth. The solid particles are made up of mineral components such as sand, silt and clay and organic components consisting of decomposed plant and animal's materials. Clay and organic matter play the crucial role of releasing plant nutrients through cations adsorption. Microorganism too play a crucial role of decomposing plant and animal matter as well as helping certain group of plants fix atmospheric nitrogen (Gachene and Kimaru, 2003). The essential plant nutrients include basic nutrients (C, H and O), macronutrients (N, P, K, S, Ca and Mg) and micronutrients (B, Fe, Mn, Zn, Cu and Mo) and those which are tolerable at some percentage, this include Si, Cl, Na and Al. An element is considered essential when its deficiency does not allow the plant to complete its lifecycle, its symptom is specific to it and it is directly involved in the nutrition of an individual plant (Gachene and Kimaru, 2003). There are three major plant nutrients based on their quantity of uptake by the plant, this includes nitrogen, phosphorus and potassium, each of which have its own function in the plant (Gachene and Kimaru, 2003). Nitrogen is an essential component of amino acids and protein and is needed for cell division and reproduction, plants that are deficient in N are stunted in growth and yellow. Phosphorus is needed for cell division and reproduction as well and it is deficiency causes slow growth, it promotes root establishment and formation as well as flowering and photosynthesis and leave size increase, deficiency leads to flowering and fruiting limitations, fruit often drop premature and roots are slow to form. Potassium increases plant vigour and resistance to diseases, promotes production of sugar,

starch and oil and increases the grain and fruit size and improves overall quality, potassium deficiency results in small sized fruit (Gachene and Kimaru, 2003).

Kenya has a wide range of soils, which is a result of various factors including geological factor, the relief and climate (Gachene and Kimaru, 2003). There is great variability in the types of Kenyan soils range from sandy to clayey, shallow to deep, low fertile to high fertile; most of them however have serious limiting factors such as salinity/sodocity, acidity, nutrient leaching problem etc. (Gachene and Kimaru, 2003).

The major soils used in agriculture include ferralsols, vertisols, acrisols, lixisols, luvisols, andosols and nitosol (Gachene and Kimaru, 2003). More specifically, the inland semi-arid highland regions comprise shallow lixisols and ferralsols with poorly developed profile. Soil formation process is too slow here due to erosion coupled with leaching. The profile depth is not exceeding 1 m and the soil formation process is 0.001 cm per year which is actually less than erosion rate that varies from 0.3 to 1.2 cm per year. These soils are characterised by crusted hard pan and red to yellowish colour. They are poor in organic matter content, nitrogen (N) and phosphorus (P) and rich in potassium (K), iron (Fe) and aluminium (Al) (Gachimbi et al., 2002; Gachene and Kimaru, 2003). The pH ranges from 5.6 to 6.9. The top soil is of low CEC (13 cmol/kg) and low base saturation (46%) (FAO/IIASA/ISRIC/ISSCAS/JRC, 2012).

The coastal lowland soils are categorized in to two distinctive types based on the land formations, the soil of the inland coastal plains and the soil of the inter-tidal plains (Boxem et al., 1987). The soils of the tidal plain extend 5 to 15 km from the coastline with <2% gradient and up to 20 m altitude, these soils developed over recent marine alluvium and comprise unripen clays, whereas the soil of the inland coastal plain extend up to 35 km from the inter-tidal plain and are separated by the raise of coral reef and rise up to 100 m altitudes, the soil formation is mainly fluvial and coral limestone admixture (Boxem et al., 1987). Erosion may exceed the deposition or compensate each other. The soils are well drained unlike in the case of tidal plain, these soils are sandier ferralic arenosols. The dominant soil type here ranges from eutric vertisols from marine alluvium deposit to well drained sandy ferralic aerosols which developed from fluvisols deposit and limestone admixture. The texture may vary from sandy to heavy clay soil, they are mainly of neutral

pH which allows most plant nutrient release, especially plant available phosphorus, and of high calcium and reduced FeS_2 content (Boxem et al., 1987; FAO/IIASA/ISRIC/ISSCAS/JRC, 2012).

In their study of soil chemical variation across and along three topographic positions in Nigeria, Ogeh and Ukodu (2012) reported that pH increases with soil depth along the soil profile. They also found that total and plant available P contents were high in the upper slope and decreased with depth. However, the major cations were variable in the upper and bottom slope with high concentration in the mid slope (Ogeh and Ukodu, 2012). Butros et al. (2010) in a separate study in Levant of Mediterranean region confirmed that there was a significant variability in soil chemical composition along the slope transects and depth profile. Soil pH increased with depth or with slope along the transect, exchangeable Ca decreased with soil depth and along transect line high Ca concentration at the soil surface was due to accumulation of calcareous silt and the decrease especially with slope was due to leaching. Extractable Mg increased down profile due to leaching, extractable Na increased with depth to certain depth and then decreased again, while K concentration was variable due to its great mobility and slightly increased toward the surface due to the presence of elite minerals in this arid region (Butros et al., 2010). The distribution of Fe oxide and type of clay mineral indicates more weathering in decent direction and with soil depth which is attributed to higher availability of moisture along the same direction.

2.3 Influences of soil on plant growth and nutrient composition

Soil fertility is the capacity of soil to supply plant with essential nutrients, and the availability of nutrients is closely connected to soil fertility (John et al., 2007). There is ample evidence that provides suggestions that plant species distribution is determined by soil and habitat factor at landscape and regional scale (John et al., 2007).

Soil properties can strongly influence the leaf and pulp nutrient contents of fruit trees and vice-versa. The chemical characteristics of mandarin fruit (*Citrus reticulata* L.) are influenced by the location, soil properties, as well as tree nutrient status, and the orchard with optimum soil and leaf nutrient level produced fruit with better quality (Khan et al.,

2011). Rocha-Perez et al. (2004) reported that there is statistically significant negative correlation between soil pH and willow leaves foxglove (*Digitalis obscura*, L.*)* leaf content of Mn (r=-0.702), Zn (r=-0.705) and Fe (r=-0.66). Sibylle et al. (2015) who investigated the influence of tamarind (*Tamarinds indica* L.) on under lying soil in Western Madagascar reported that the litter accumulation from tamarind leaves as well as exudates from the roots improve soil chemical properties underneath the tamarind, especially the level of soil organic matter and total nitrogen while pH as compared to uncovered soil. Tamarind, a tropical fruit tree that usually lives in closed association with baobab in many sub-Sahara Africa especially in Sudan is reported to require fertility management for quality fruit production, application of NPK can improve fruit quality (Sibylle et al., 2015).

The only known study evaluating the influence of soil properties on baobab pulp nutrient contents was done by Assogbadjo et al. (2012). According to their study conducted across three climatic and geographic zones of Benin to determine the variation of baobab chemical composition, as well as to investigate the influence of soil on baobab chemical composition within the zone, the authors did not find any statistical significant difference for baobab micronutrient concentration such as Ca, Mg, K and vit. A across the three zones. However, there was a statistically significant difference for Fe, Zn and vit. C concentrations. Furthermore, an 81.5% coefficient of correlation explained the relationship between the soil chemical composition and nutrient composition of baobab. It was suggested that physicochemical characteristics of the soil seemed to influences the nutritive value of baobab parts. Specifically, highly basic soil rich in carbon, clay, fine silt and organic matter positively correlated with concentration of Fe, K, vit. C, Zn, carbohydrate, protein and lipids and a negatively correlated with Mg, Ca, vit. A and fibre in fruit pulp.

Soliman and Mahmoud (2013) who investigated the response of baobab on the application of compost, zeolite and mixture of zeolite and compost in Egypt discovered that baobab growth characteristics significantly improved with application of zeolite, a commercial absorbent comprising of cations such as Na, K, Ca, Mg, Al and Si. A significant increase was also reported on such element as vitamin C, N, P, K, Zn, Mn and Fe in the baobab leaves. In another study, Larwanou et al. (2014) investigated the effect of fertilization and watering regime on early growth and leaf biomass production for moringa

(*Moringa oleifera* Lam.*)* and baobab and recommended the application of NPK fertilizer, especially for earlier growth of baobab.

3 OBJECTIVES

The main aim of this study was to assess the influence of soil properties on chemical composition of baobab (*A. digitata* L.) fruit pulp in Inland Highland (IH) and Coastal Lowland (CL) zones of Kenya.

Specific objectives of this study included:

a) To analyse soil chemical composition for each sampled baobab in IH and CL zones.
b) To analyse the nutrient composition and concentration in the baobab fruit pulp.
c) To assess the relationship between soil chemical properties and nutrient composition of baobab fruit pulp.

The following research questions were formulated to address the study objectives:

1. Is there any variation in soil chemical composition between inland and coastal geographic regions of Kenya?
2. Is there any variation in nutrient composition of baobab fruit pulp from inland and coastal regions of Kenya?
3. Is there any correlation between soil properties and nutrient composition of baobab fruit pulp?

4 MATERIALS AND METHOD

4.1 Study area description

The study was conducted around Eastern and Coast province of Kenya, along Mombasa highway and the coast of the Indian Ocean. The study area covered six main locations for 63 baobabs, namely: Kibwezi, Mtito Andei, Voi, Diani, Kilifi and Malindi (Figure 4). The locations were categorised into two main geographic zones according to climate and altitude: Inland Highlands (IH) and Coastal Lowlands (CL). The inland zone comprises of Kibwezi, Mtito Andei and Voi and falls within agro ecological zone V while the coastal zone comprises of Diani, Kilifi and Malindi and falls within agro ecological zone III (Figure 4).

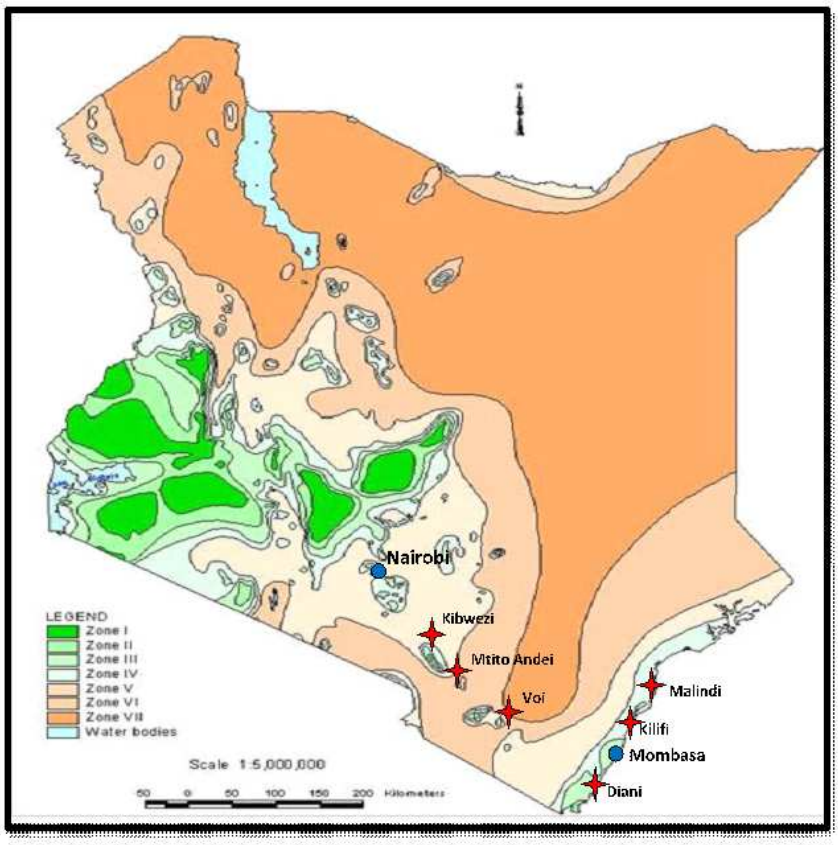

Figure 4. Agro-climatic zones of Kenya and main sampling locations (Sombroek et al., 1982**).** Red star: sampling location, light pale shaded region in the map (containing Kibwezi, Mtito Andei and Voi): AEZ V, Light green shaded region in the map far South (containing Diani, Kilifi and Malindi): AEZ III

4.1.1 Inland sampling sites

The inland highland (IH) zone covered three sampling locations (Kibwezi, Mtito Andei and Voi) with 10 sampling sites that lie in the altitudes between 652 and 994 m a.s.l. (Table 4). The sampling sites are characterized by bimodal rainfall with shorter rainy season between November and January, and a longer one between March and April, with rainfall that range between 150–680 mm of precipitation per annum. The temperatures are relatively stable throughout the year and range between 22 and 25 °C depending on the elevation (Figure 5) but lower compared to coastal regions.

The agro ecological subzones of this region are LM5 (livestock millet subzone) and IL5 (inner lowland livestock millet subzone). LM5 is characterized by a weak and very short to short cropping season with yield potential for proso millet (*Panicum miliacium*) and green gram (*Vigna radiata*) in the first rainy season; and for maize (*Zea mays*), sorghum (*Sorghum bicolor*), cowpeas (*Vigna ugnuiculata*), chickpeas (*Cicer arietinum*), dolichos beans (*Lablab purpureus*), groundnuts (*Arachis hypogaea*), pumpkins (*Cucurbita pepo*) in the second rainy season, meanwhile castor (*Ricinus communis*), sisal (*Agave sisalana*), cassava (*Manihot esculenta*) and yeheb nuts (*Cordeauxia edulis)* give yield during the whole year. IL5 is quite similar to LM5 with the typical cropping season being very uncertain, very short to short and the most common crops that include foxtail (*Setaria italica*), proso millet, cowpeas, green grams, bambara groundnuts during the first rainy season; pearl millet *(Pennisetum glaucum*), sorghum, proso millet, foxtail millet, black and green grams, moth beans *(Vigna aconitifolia*), cowpeas, chick peas, rapeseed (*Brassica napus*), mung beans, French beans (*Phaseulus vulgare*), bambara groundnuts in the second rainy season and sisal, castor, yeheb nuts, opuntia (*Opuntia sabulata*), cassava and Neem tree (*Azadirachta indica*) providing yield throughout the year (Jaetzold et al., 2012). The vegetation cover of this area varies with the decreasing elevation from open grassland with some scattered Soap berry tree (*Balanites aegyptiaca L.)*, over woodland with acacia (*Acacia* spp.), mixture of deciduous and shrub land comprising mainly of baobab (*Adansonia digitata* L.), acacia (*Acacia albida* Rojas*)*, leucaena (*Leucaena diversifolia Benz)*, Combritum (*Combritum apiculatum* Sond)., Atriplex (*Atriplex nummularia* Lindl.),

Euphorbia (*Euphorbia milifera* Seub) to a mixture of deciduous trees and wood land (Jaetzold et al., 2012).

The dominant soil types found in the area comprise of lixisols, these are sandy clay loam soil with pH ranged from 5.6 to 6.9. The top soil is of low CEC (13 cmol/kg) and low base saturation (46%) vulnerable to leaching and relatively high Fe content (FAO/IIASA/ISRIC/ISSCAS/JRC, 2012).

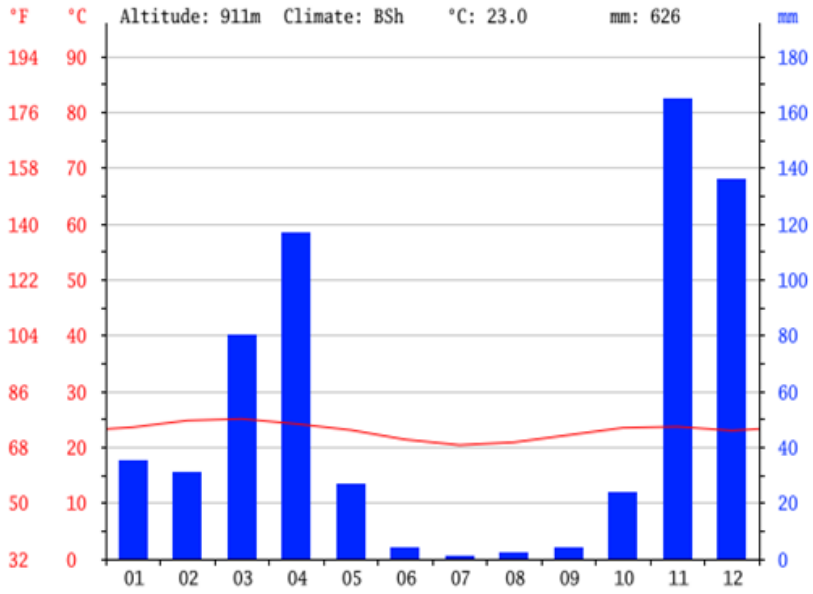

Figure 5. Rainfall and temperature records of Kibwezi for 2015 (climate-data.org)

4.1.2 Coastal sampling sites

The coastal lowland (CL) zone covered three sampling sites and locations (Diani, Kilifi and Malindi) that are located close to the sea between 19 and 457 m a.s.l. (Table 4). The climate is hot and humid and experiences coastal bimodal rainfall with the longest rainy season starting toward the end of March, peaking in April and May and decreasing until October, with total annual precipitation amounting to 1,000– 1,300 mm. The average annual temperature varies between 24 and 27 °C (Figure 6).

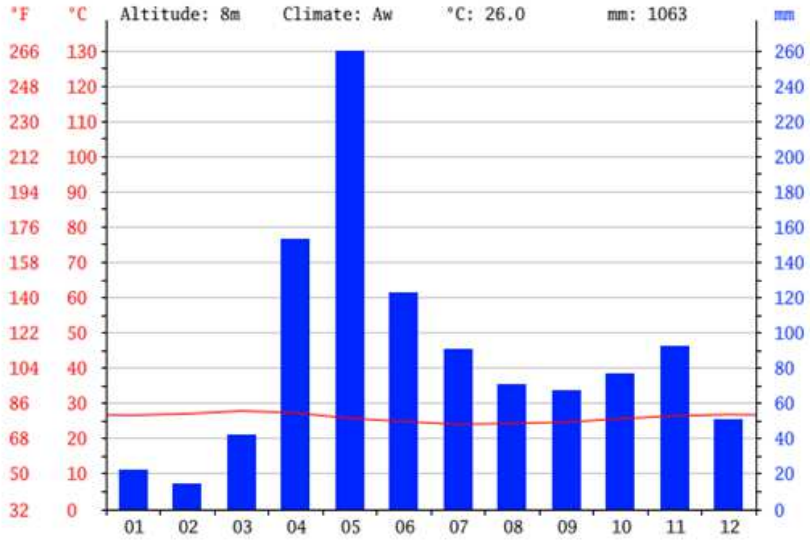

Figure 6. Rainfall and temperature records of Kilifi for 2015 (climate-data.org)

The agro ecological zones of this area are CL3 (coconut cassava zone) and CL4 (cashew nut cassava zone). CL3 is characterized by medium to long and uncertain cropping season; yield potential for the first rainy season is favourable for maize, white sorghum, sweet potatoes (*Ipomoea balata*), cowpeas, dolichos beans, winged beans (*Psophocarpus tetragonolobus*), roselle (*Hibiscus sabdariffa*); nearly all vegetables, esp. chillies (*Capsicum annum*), brinjals (*Solanum melongena*), tomatoes (*Solanum lycopersicum*), onions (*Allium cepa*), kales cabbages (*Brassica oleracae*), while in the whole year, the following crops are favoured: coconuts (*Cocus nucifera*), cassava, bixa (*Bixa orellana)*, mangoes (*Mangifera indica*), bananas (*Musa* spp.), pawpaws (*Carica papaya*), avocadoes (*Persea americana*), sisal, pineapples (*Ananas comosus*), guavas *(Psidium guajava*), castor, citrus (*Citrus* spp.). The typical cropping season for CL4 is medium, followed by intermediate rains, and towards inland with a very uncertain second rainy season; during the first rainy season, there is yield potential for maize, sorghum, sweet potatoes, kenaf *(Hibiscus canabinus*), sunflower (*Helianthus anuus*), soya beans (*Glycin max*), dolichos beans, kales, onions, okra (*Abelmuscus esculenta*), sweet pepper, egg plants, chillies, Chinese cabbage, water and sweet melons *(Benincasa hispida*), cucumbers, pumpkins and

during the whole year cashew nuts (*Anacadium ocidentale*), cassava, sisal, mangoes and castor give yield (Jaetzold et al., 2012).

The vegetation cover of this region is mostly moist evergreen woodland forest. The common tree species include baobab, coconut (*Cocus nucifera*), *Casuarina spp*., *Prosopis juliflora*, *Mimosa pudica*, *Cassia siamea*, and *Tamarindus indica* (Jaetzold et al., 2012).

The dominant soil types in this area comprises of vertisols and ferralsols which are clay and clay loam respectively (FAO/IIASA/ISRIC/ISSCAS/JRC, 2009). Characterized by moderate drainage, relatively high pH that range from 5.2 to 8.5 with an average of 7.2 and high CEC of 30 cmol/kg and 12 cmol/kg for vertisols and ferralsols respectively and base saturation of 100% and 80% for vertisols and ferralsols respectively (FAO/IIASA/ISRIC/ISSCAS/JRC, 2012).

Table 4. Characterization of the study locations and number of tree and soil samples (FAO, 1996; Gachene and Kimaru, 2003; Jaetzold et al., 2012).

Sampling locations	Zone	Sampling sites	Trees sampled	Soil samples	AEZ	T (°C)	Rainfall (mm/year)	Altitude (m.a.s.l.)	Soils
Kibwezi	IH	6	28	84	LM5	22-25	150-650	844-944	Haplic lixisols
Mtito Andei	IH	2	10	30	LM5	22-25	150-650	712-810	Rhodic ferralsols
Voi	IH	2	10	30	IL5	27	550-680	652-758	Rhodic ferralsols
Diani	CL	1	5	9	CL3	26-27	1200-1400	21-31	Albic Arenosols
Kilifi	CL	1	5	15	CL3	24-27	1200-1300	40-55	Eutric vertisols
Malindi	CL	1	5	15	CL3	24-27	1200-1300	17-55	Haplic ferralsols
Total		13	63	183					

T: average annual temperature, AEZ: agro ecological zone, CL2: lowland sugar cane marginal zone, CL4: lowland cashew nut cassava zone, IL5: inner lowland livestock millet subzone, LM5: livestock millet Subzone

4.2 Fruit and soil sampling

This study used the transect line sampling design previously employed by ICRAF in 2012 to interview government stakeholders, and to locate baobab farmers in Eastern and Costal regions of Kenya. The method was a government oriented investigation in which a team from Kenyan forest research institution (KFRI), Kenya forest services (KFS) and ministry of agriculture (MoA) instructed ICRAF to sample baobab farmers along Mombasa highway and coastal regions. The aim of this previous study was to collect basic demographic and socioeconomic data of baobab farmers, as well as to gather information on occurrence, fruit production and marketing of baobab in Eastern and Coastal Kenya. In addition, fruit samples of the 64 baobab trees of the selected farmers were sampled for morphological characterisation and analyses of nutritional composition of fruit pulp (Kehlenbeck and Waruhiu, 2014).

The present study used 63 of the 64 originals baobabs, which were located in the six locations (Table 4), belonging to two geographical zones, IH and CL, to collect soil samples under each tree in July - August 2015. Under the crown of each of the 63 baobab trees, at least three soil samples were taken at different depths using an auger for excavating the soil samples. Per tree, two pits were located in a standardized opposite arrangement, with consideration of sun direction under the tree crown and at half distance between the base of the trunk and the limit of the crown cover (Figure 7). Each pit provided three sub-samples from three different depths labelled as topsoil sample (0-20 cm), medium-soil sample (21-40 cm) and sub-soil sample (41-60 cm). Two sub-samples under a tree from the same depth were combined together to make one sample which consequently resulted in three soil samples per tree. However, it is important to note that due to auger restriction by the coral reef at subsoil layer, six samples were not collected from Diani location and as such, only a total of 183 samples were collected as opposed to initial plan of 189 samples (Table 4).

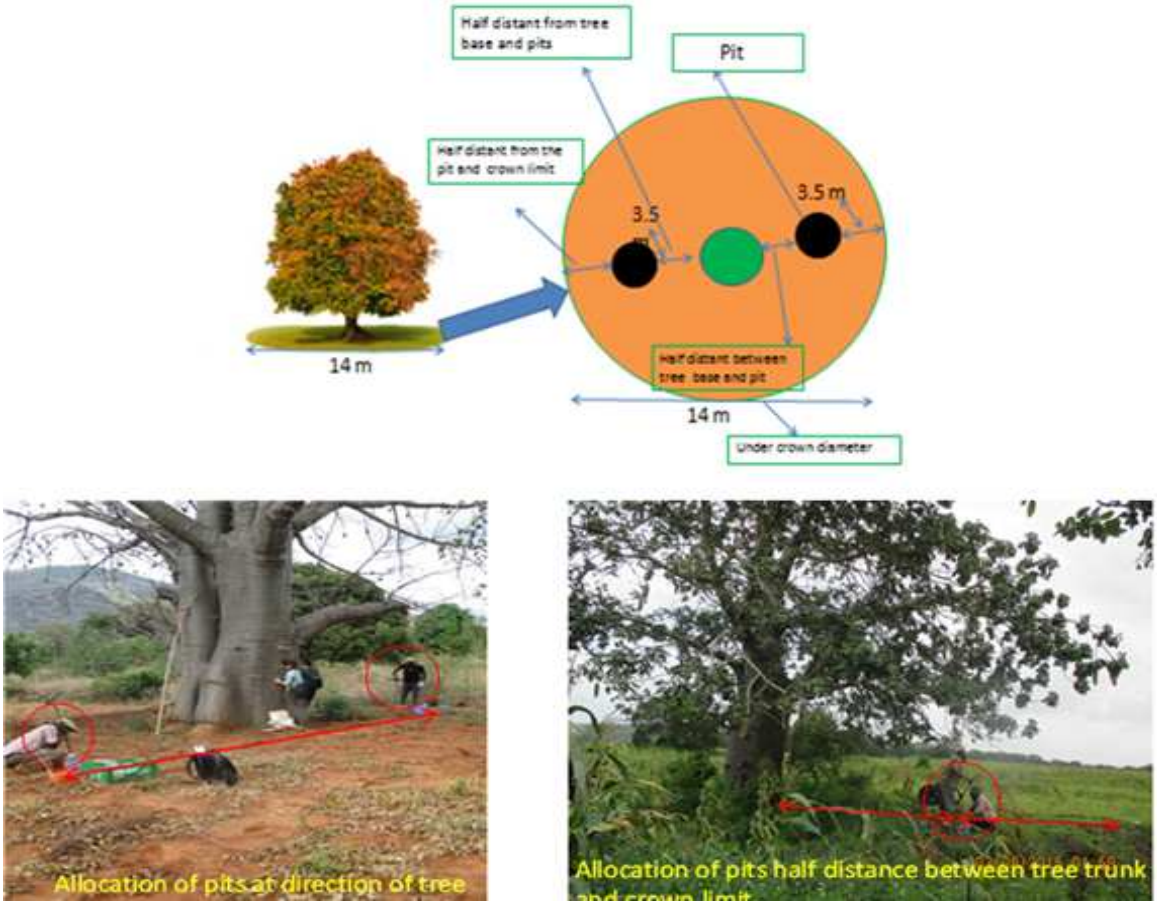

Figure 7. Soil sampling - allocation of the pits at opposite directions of tree trunk and at half distance between the trunk and crown limit.

The collected soil samples were mixed well in a bucket using hands, large stones were removed and large aggregates crushed before the soil was packed in 500 g polyethylene bags and labelled both inside and outside with their respective ID.

Subsequently, the soil samples from the field were transported to ICRAF laboratory in Nairobi, and transferred to drying chamber, where they were dried up at constant temperature of about 65 $^{\circ}$C for six days. After drying, they were ground into fine tilth and sieved while removing foreign materials and gravel on 2 mm sieve (see ANNEX 2). From the pure sieved soil, 100 g of every sample were separated and transported to the Czech University of Life Sciences Prague for laboratory analyses.

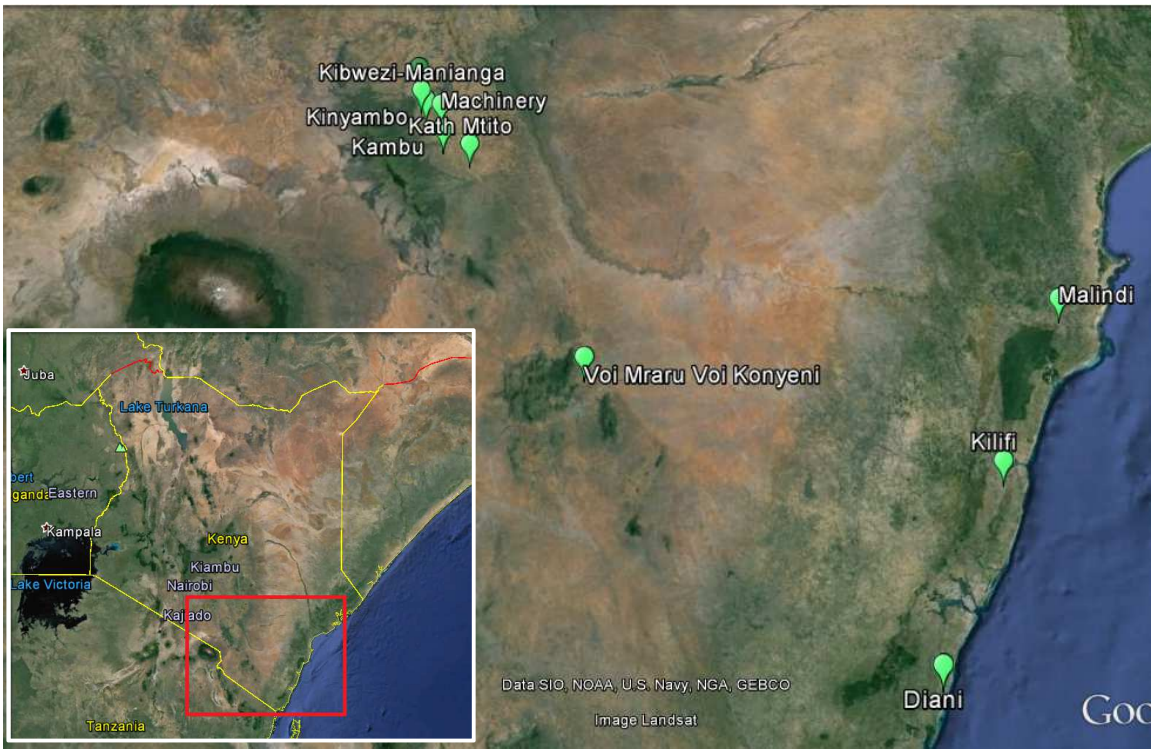

Figure 8. Map of the sampling sites. Light green conical shapes from the map indicate sampling sites overlapping.

4.3 Fruit pulp analysis

Data on nutrient composition of baobab fruit pulp were obtained from ICRAF baobab pulp nutrient analysis report (John et al., 2013). The fruit pulp analysis was conducted in ICRAF seed and plant domestication laboratory for water, vit. C, total acidity, ash and pulp minerals as described below.

4.3.1 Pulp water content

The method of the Association of official agriculture and chemist (AOAC) after USDA (1984), which is official method of dry matter analysis, was used. An empty container was weighted and the measurement recorded as W1, 3 g pulp sample were then weighted into pre-weighted container and measurement were recorded as W2, the sample were then oven

dried and allowed to cool and weighted to form W3. Moisture content was calculated as follows:

$$\text{Water (Moisture) (g/100 g)} = \frac{(W2 - W3)}{(W2 - W1)} \times 100$$

Dry matter (%) = 100- Water (w w/)

Where:

W1	= weight of empty container (g)
W2	= weight of container + sample before drying (g)
W2- W1	= weight of sample (g)
W3	= weight of container + sample after drying (g)
W2- W3	= loss of weight (g)

4.3.2 Determination of Vitamin C

Vitamin C (Vit C) was analysed using AOAC dye titration method adopted after Nielsen (2010), which is based on the reduction of 2, 6 dichloroindophenol to a colourless solution by ascorbic acid. 15g of HPO_3 (Meta phosphoric acid) was dissolved in 40 ml of CH_3COOH (acetic acid) and 200 ml of 0.15 M H_2SO_4 (sulphuric acid) solution was then diluted in 500 ml of water and filtered. 50 mg USP ASCL reference standard was prepared and mixed in 50 ml HPO_3-CH_3COOH solution. 50 mg of 2,6 dichloroindophenol was dissolved in 50 ml of distilled water and 42 mg of $NaHCO_3$, the solution water then filtered and diluted to 200 ml with distilled water, 5 ml of sample solution was then titrated into triplicate with 2,6-dichloroindophenol solution to determine the reducing capacity of extracted Vit. C, the end solution was detected by rose pink colour, Vit. C was then then calculated using following formula:

Vit. C = $(X - B) \times \frac{F}{E} \times \frac{V}{Y}$

X = average mL for test solution titration,

B = average mL for test blank titration,

F = mg ascorbic acid equivalent to 1.0 mL indophenol standard solution,

E = number of grams

V = volume initial test solution (50 or100 ml),

Y = volume test solution titrated (5ml).

4.3.3 Determination of total acidity

Total acidity analysis was carried out by mixing 2.5 g pulp powder in 50 ml distilled water and homogenized in 50 ml conical flask, 5 ml of the sample solution was placed in a beaker and titrated against 0.1 N NaOH with phenolphthalein as an indicator, total acidity was then calculated as:

$$\text{Titratable acidity } (\%) = \frac{Titre\ volume \times 0.006404 \times 1000}{Sample\ weight}$$

:

And expressed as 0.006404=Equivalent weight of citric acid

4.3.4 Determination of ash

Crucible were heated in furnace for 1 hour at 500 ^{0}C and cooled in desiccator for 30 minutes. 4 g pulp sample were then weighted into the crucible and charred over a heated plate until smoking ceased. The crucible with sample was then placed in a furnace for 6 hours at 500 ^{0}C after which they were cooled at a desiccator and weighted. The ash was then calculated as follows:

$$\text{Ash } (\%) = \frac{\text{Weight of ash x 100}}{\text{Weight of sample}}$$

4.3.5 Determination of individual minerals from ash

Fe and Zn: 10 ml ash sample was diluted in 100 ml of 1N HCl to make 100 ppm. 10 ml of 100 ppm solution was again diluted to make 10 ppm and more solutions 0.1 ppm, 0.2 ppm, 0.4 ppm, 0.8 ppm, 1.6 ppm and 3.2 ppm then Fe and Zn were determined by atomic absorption spectroscopic (AAS).

Ca and Mg: Due to their high amount, further dilution was done to ensure they are in the range detectable by AAS, 200 µl ash solutions was diluted in 100 ml of 1N HCl ratio of (1:200), 5 ml of 1% lithium chloride (LiCl) was added to 5 ml of sample ratio of (1:1) then Ca and Mg were then determined by AAS.

K and Na: Analyses of K and Na was carried out using flame photometry, for K, 2 ppm, 4 ppm, 8 ppm and 10 ppm standard sample were prepared prior to analysis then each sample were diluted 50 times as 200 µl in 10 ml of 1 N HCl then the standards were run to obtain standard curve after which the samples were analyzed, measurements were done in duplicates whereas Na standard was prepared for 10 ppm, 20 ppm, 30 ppm, 40 ppm and 50 ppm, 5 ml of each samples were then diluted to 50 ml with distilled water then measurement was done in duplicates.

4.4 Soil analyses

The analysis for soil chemical properties was carried out in the Laboratory of Soil Science of the Czech University of Life Science Prague. The soil parameters which were analysed from each of the collected soil samples included soil pH and content of major macro- and micronutrients.

4.4.1 Determination of pH

The pH measurement was carried out using classical pH meter with combined electrodes; the reference electrode and the glass electrode that used water solution. This was the preferred pH meter used in the Laboratory of Soil Science since it measures both conductivity and pH.

The preparation of the sample involved the measurement of 10 g soil samples on a standard scale in to a 250 ml glass beaker and labelled with respective ID. Then 20 ml deionized water was added and the mixture was placed on mechanical shaker for 5 minutes, operating at a speed of 150 m/sec then the solution was placed on pH meter and the pH reading was recorded.

4.4.2 Determination of cations

Cations determination was carried out using ICP (Inductive Coupled Plasma) extract from $BaCl_2$ solution after Gillman (1979). This method was preferred due to its multi-element analysis capability. The cations measured were Al, As, B, Ba, Ca, Cd, Cr, Mg, Na, Mn K, Co, Cu, Ni, P, Pb, Sb, S, V, Fe and Zn. The 2.5 g of a finely milled soil sample were weighted into a 50 ml topped plastic conical tube. And then, 30 ml of $BaCl_2$ solution was added and the mixture was placed on to mechanical shaker for 1 hour and then after shaking, the solution was centrifuged for 10 minutes to separate the liquid and solid phases. After centrifugation, the soil residue was filtered out. Then the finally, the filtrate was transferred in to volumetric flask for cations extraction in ICP.

4.4.3 Determination of plant available phosphorus

Plant available phosphorus (plant available P) analysis was carried out in an alkaline sodium bicarbonate extract at pH 8.5 after Olsen (1954). The Olsen method was preferred because of its suitability for analyses of calcareous soil. The 2.5 g of finely milled soil sample was weighted and mixed in to a 50 ml of 0.5 M sodium bicarbonate and the solution was placed on to reciprocal shaker for 30 minutes. After shaking, the mixture was then filtered. Ortho phosphorus in the filtrate extract was then determined calorimetrically at 630 nm in a Technicom autoanalyzer by reacting it with ammonium molybdate using ascorbic acid as a reducing agent. The obtained values were then represented as ppm.

4.5 Data evaluation - statistical analysis

After the required parameters were determined using laboratory analysis, all data were uploaded into an excel sheet as a combination of the raw data files and then the data were edited for quality control. After data cleaning, data analysis was carried out as follows.

4.5.1 Statistical differences between two zones

A simple t-test was conducted using SPSS version 19 to determine if there were statistical differences in soil chemical properties, as well as the fruit pulp nutrient composition between the two agro-ecological zones, namely the IH and CL zones. The composite means from the average soil samples from all three layers were compared between two zones as well as based on individual layers. In the same way, the differences in fruit pulp nutrient composition between two zones were also compared using t-test as well.

4.5.2 Variation across sampling sites and soil depths

In addition, variation of pulp nutrient composition across sampling sites and soil profile was also carried out using principle component analyses (PCA) in STATISTICA software. This was done to justify whether there was any relationship between variation of pulp nutrient contents from different geographical locations and soil nutrient contents across soil profile. The PCA allowed us to correlate, the pulp nutrient contents with soil nutrients, soil layers and sampling locations.

4.9.3 Correlation between soil and fruit parameters

The relationship between each soil chemical elements and each pulp nutrients were calculated using STATISTIKA software, expressed by correlation coefficient (r), which according to Svatosova and Kaba (2008) determines the degree to which two variables are associated and obtained by dividing the covariant of the two variables by the product of their standard deviation.

$$\rho_{xy} = \frac{Cov(r_x, r_y)}{\sigma_x \sigma_y}$$

The values range from -1 to +1. If the value of r is -1, which means perfect converse relationship, as one variable increases the other decreases and if the value of r is + 1, it indicates direct proportional relationship to mean as one variable increases the other vairable increases as well. Svatosova and Kaba (2008) assigned scale for r as such if r ranges from 0 to 0.3 the dependency is weak, if r ranges from 0.3-0.8 the dependency is medium and if r ranges from 0.8 to 1 the dependency is strong.

5 RESULTS

5.1 Variation in soil chemical properties between two geographical zones

Differences of soil chemical properties between IH and CL zones were examined at two separate levels, namely across the whole soil profile (averaging the layers), and also at the individual soil layers (separating the soil layers).

5.1.1 Variation of soil chemical composition in the whole soil profile

There were statistically significant differences for all macro-elements between the two main geographic locations of IH and CL; however, there was no difference in soil pH between inland and coastal zones (Table 5). Significantly higher values of Ca, S, total P and plant available P were found in coastal locations; while, the mean values for K and Mg were higher in inland locations. Although there was a significant difference for plant avail. P in the two zones, in both locations, the mean values were very low, which suggests that it was likely a limiting soil factor.

Table 5. The combined means (±SE) of pH and soil macro-nutrient contents of soil samples from inland highland (IH) and coastal lowland (CL) zones.

Zones	pH	Ca mg/100g	K mg/100g	Mg mg/100g	S mg/100g	Total P mg/100g	Avail. P ppm
IH	6.92±0.043	8.43±0.326	3.21±0.115	1.67±0.054	0.064±0.0049	0.007±0.0006	11.46±1.527
CL	7.02±0.100	11.85±1.975	1.71±0.141	1.20±0.103	0.119±0.0319	0.012±0.0016	18.70±2.538
SD	NS	**	**	**	**	**	**

SD – Statistical difference, NS – mean (±SE) are not significant at $p \leq 0.05$, ** - mean (±SE) are significant at $p \leq 0.05$, SE – standard error

Looking at micronutrients (Table 6), there were statistically significant differences for Mn, Na and Al. Both Mn and Na had the higher mean values in inland zone, while the higher mean value for Al was found in coastal zone. The mean values of the rest of the micronutrients were not significantly different between the two zones.

Table 6. The combined means (±SE) of soil micro-nutrient contents of soil samples from inland highland (IH) and coastal lowland (CL) zones.

Zones	Fe mg/100g	B mg/100g $\times10^{-3}$	Cu mg/100g $\times10^{-2}$	Mn mg/100g $\times10^{-2}$	Na mg/100g	Zn mg/100g $\times10^{-3}$	Co mg/100g $\times10^{-3}$	Al mg/100g $\times10^{-2}$	Si mg/100g
IH	0.24±0.016	5.0±0.09	1.75±0.078	9.98±0.928	0.33±0.013	5.9±0.21	2.1±0.14	5.83±0.356	0.16±0.007
CL	0.26±0.027	4.6±0.21	1.56±0.124	3.39±0.676	0.24±0.014	6.3±0.53	2.1±0.19	7.80±0.017	0.16±0.016
SD	NS	NS	NS	**	**	NS	NS	**	NS

SD – Statistical difference, NS – mean (±SE) are not significant at p≤0.05, ** - mean (±SE) are significant at p≤0.05, SE – standard error

5.1.2 Variation of soil chemical composition across soil profile

The concentration of macronutrients across the soil profile (comparing each soil layer) showed variable trends (Table 7). In the topsoil layer, there were only significant mean differences for Ca, K, S and total P, as well as soil pH, while, the mean values for Mg and plant available P were not significantly different between the two zones. In the medium soil layer, only Ca, K, Mg and S showed significant mean difference between the two locations. In this layer, soil pH was not different between the two locations. For sub-soil layer, the mean values for only soil pH, K, Mg and S were significantly different between the inland and coastal zones. Notably, the mean values for plant available P was consistently not significantly different between the sampling locations, in all the three soil layers.

Table 7. The means of pH and soil macronutrients (±SE) from each soil layer of soil samples from inland highland (IH) and coastal lowland (CL) zones.

Zones	pH	Ca mg/100g	K mg/100g	Mg mg/100g	S mg/100g	Total P mg/100g	Avail. P ppm
1-IL	6.98±0.065	9.40±0.591	3.84±0.219	1.66±0.103	0.074±0.009	0.008±0.001	13.54±2.480
1-CL	6.63±0.117	14.19±4.307	1.97±0.277	1.24±0.211	0.153±0.070	0.014±0.003	21.55±4.770
SD	**	**	**	NS	**	**	NS
2-IL	6.66±0.070	8.32±0.531	3.13±0.186	1.65±0.089	0.062±0.008	0.007±0.001	9.59±2.239
2-CL	6.85±0.077	13.39±3.911	1.71±0.206	1.22±0.191	0.144±0.064	0.012±0.003	16.91±4.001
SD	NS	**	**	**	**	NS	NS
3-IL	7.12±0.073	7.57±0.550	2.67±0.151	1.72±0.089	0.055±0.008	0.006±0.001	11.24±3.158
3-CL	7.57±0.165	7.97±1.141	1.45±0.242	1.13±0.138	0.060±0.015	0.011±0.003	17.64±4.673
SD	**	NS	**	**	NS	**	NS

1, 2 & 3 corresponds to soil layer 0-20cm, 21-40cm & 41-60cm respectively; SD - statistical differences; NS - not significant at p≤0.05, ** - Significant at p≤0.05

Looking at micronutrients (Table 9), apart from Mn in the medium soil layer and Na in the sub-soil layer, there were no significant differences between the inland and coastal zones across soil profile.

Table 8. The means of soil micronutrients (±SE) from each soil layer of soil samples from inland highland (IH) and coastal lowland (CL) zones of Kenya.

Zones	Fe mg/100g	B mg/100g $\times 10^{-3}$	Cu mg/100g $\times 10^{-2}$	Mn mg/100g $\times 10^{-2}$	Na mg/100g	Zn mg/100g $\times 10^{-3}$	Co mg/100g $\times 10^{-3}$	Al mg/100g $\times 10^{-2}$	Si mg/100g
1-IH	0.25±0.026	5.1±0.18	1.82±0.123	8.94±1.765	0.34±0.029	5.8±0.29	2.2±0.30	6.50±0.685	0.18±0.012
1-CL	0.27±0.047	4.4±0.33	1.51±0.190	2.80±1.230	0.23±0.019	6.7±0.94	02.1±0.28	8.74±1.901	0.16±0.028
SD	NS	NS	NS	NS	NS	NS	NS	NS	NS
2-IH	0.22±0.028	5.0±0.14	1.87±0.164	10.60±1.420	0.33±0.020	6.1±0.43	1.9±0.16	5.81±0.625	0.16±0.014
2-CL	0.28±0.051	5.0±0.39	1.72±0.286	3.69±1.325	0.26±0.029	5.6±0.68	2.1±0.38	08.23±0.813	0.16±0.020
SD	NS	NS	NS	**	NS	NS	NS	NS	NS
3-IH	0.25±0.029	4.9±0.14	1.57±0.111	10.41±1.643	0.33±0.017	5.9±0.035	2.1±0.23	5.17±0.524	0.16±0.012
3-CL	0.24±0.045	4.6±0.38	1.45±0.159	3.69±1.030	0.24±0.023	6.5±1.14	2.2±0.34	6.45±1.652	0.15±0.037
SD	NS	NS	NS	NS	**	NS	NS	NS	NS

1, 2 & 3 corresponds to soil layer 0-20cm, 21-40cm & 41-60cm respectively; SD - statistical differences; NS - not significant at $p \leq 0.05$, ** - Significant at $p \leq 0.05$

5.2 Variability of pulp nutrient contents and chemical properties across geographical zones

We found significant differences for the concentration of most fruit pulp nutrient contents and other chemical properties, apart from water and Ca content, between inland and coastal zones (Table 10). Fruit pulp from coastal zone had lower pH, higher total acidity, ash and K contents while, fruit pulp from inland trees were less acidic and had higher content of vit. C, Zn, Fe and Mg.

Table 9. The means of baobab fruit pulp chemical properties and nutrient contents from IH and CL zones.

Zone	pH	Water g/ 100 g EP	Vit. C mg/ 100 g EP	Tot acidity g eq citric acid/100 g	Ash g/ 100 g EP	Zn mg/ 100 g EP	Fe mg/ 100 g EP	Ca (mg)/ 100 g EP	Mg mg/ 100 g EP	K mg/ 100 g EP
IH	3.13±0.007	10.3±0.065	184.7±5.40	10.2±0.129	5.04±0.065	1.21±0.049	1.31±0.051	389.9±10.92	202.1±5.1	896±17.5
CL	3.01±0.012	10.3±0.160	145.1±9.45	14.6±0.191	6.10±0.153	0.96±0.081	0.71±0.039	379.1±11.81	168.2±6.8	1,324±61.6
SD	**	NS	**	**	**	**	**	NS	**	**

SD – Statistical difference, NS – mean (±SE) are not significant at $p \leq 0.05$, ** - mean (±SE) are significant at $p \leq 0.05$, SE – standard error

Combined evaluation of fruit pulp nutrient content based on locations, soil profile and soil chemical analysis using Principle component analysis (PCA) (Figure 9) revealed that Malindi (CL location) fruit pulps were high in ash, total acidy and Fe while Kibwezi-Kale (IH location) fruit pulps were high in K, correlated mainly by soil chemicals influence at the top layer. The fruit pulps from Kath-Mtito, Kambu, Machinery and Mtito were high in Zn and Mg while that of Kilifi were high in Ca, correlated mainly by soil chemicals influence at the medium soil layer. Lastly, the fruit pulps from Kibwezi and Kibwezi-Manyanga were higher in water and vit. C content, correlated by soil chemicals influence at the sub-soil layer.

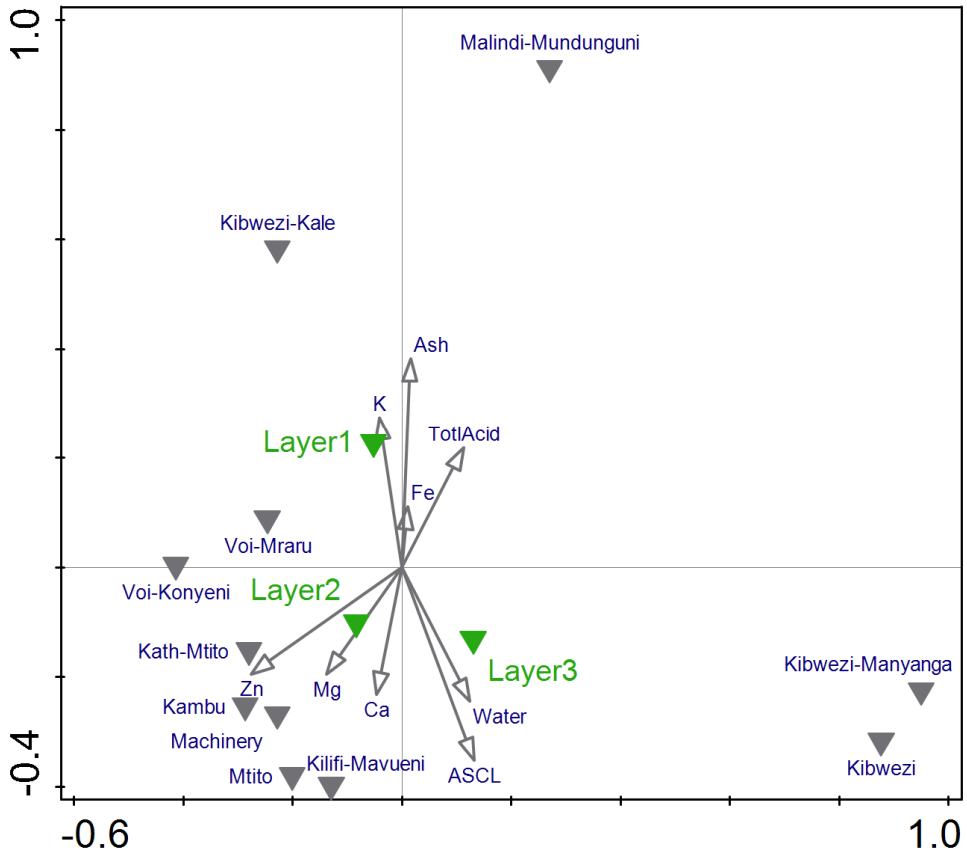

Figure 9. Combined evaluation of fruit pulp nutrient content based on locations, soil profile and soil chemical analysis using Principle component analysis (PCA). Grey arrows - projections of fruit pulp nutrients, green triangles - soil layers, grey triangles - projections of sampling sites. Sampling sites that belong to IH zone includes; Kibwezi, Kibwezi-Kale, Kibwezi–Manyanga, Kath-Mtito, Kambu, and Mtito Andei. Sampling site that belong to CL zone includes; Malindi and Kilifi.

5.3 Correlations between soil chemical properties and pulp nutrients content

The correlation between each soil chemical property and nutrient contents and pulp nutrient content and chemical properties was examined separately at each layer and expressed by correspondent correlation coefficient (Table 10). In some cases, we found medium strong correlation (positive or negative) among major nutrients in fruit pulp and soil (numbers in red).

Vit. C was positively correlated with soil K and micronutrients such as Cu and Co mainly in top-soil layer and negatively correlated with S, total and plant available P and Si. This negative correlation was increasing with soil depth.

Ca was positively correlated with Si mainly at the medium and sub layers while negatively correlated with soil pH and plant available P mainly at the top layer.

K was positively correlated with soil pH, Ca, S, total and plant available P, Zn and Si. The correlation was mainly high at top and medium layer while negatively correlated with K and Mn

Fe was positively correlated with K plant available P, Fe and Cu. The correlation was high mainly with K, while negatively correlated with total p and Zn. The negative correlation was increasing with depth.

Mg was negatively correlated with soil pH and Fe mainly at the top and medium layers while positively correlated with Fe at the sub layer.

Ash was positively correlated with soil pH, Ca, S total and plant available P and Si while negatively correlated with Mn and Co. Both correlations were proved mainly at the top and medium layers.

Zn was positively correlated with Ca, K, Mg, S and Si mainly at the top and medium layers while negatively correlated with total and plant available P only at the sub layer.

Pulp water content was positively correlated with soil pH and micronutrients such as Cu, Zn and Co while negatively correlated with total and plant available P, K and Fe. Those correlations were higher in the medium and in the sub-soil layers.

Total acidity was positively correlated with soil pH, Ca, total and plant avail. P. The correlation was higher mainly at the medium and sub layers while negatively correlated to cations such as K, Fe, Mn and Si. This negative correlation was high with K and Mn.

It was notable that Ca was weakly correlated to soil properties ($r \leq 0.3$) and that pulp content of total acidity, ash, Fe and K had relatively higher correlation ($r=0.52–0.72$) with soil pH, total P, K, S, and plant available P in comparison to other nutrients while in contrast, pulp content of vit. C was much more negatively influenced by total P, S, Si and plant available P while only positively affected by micronutrients such as Co and Cu.

Table 10. Correlation coefficients of baobab fruit pulp properties with soil chemical properties for each soil layer. Numbers in red show medium-strong correlation (r =0.3-0.8).

Soil prop.	Soil layer	Fruit pulp properties and nutrient content								
		Vit. C	Ca	K	Fe	Mg	Ash	Zn	Water	Total Acidity
pH	0-20	0.005	-0.392	0.587	0.251	-0.483	0.643	-0.116	-0.11	0.342
	21-40	-0.216	-0.133	0.726	-0.053	-0.37	0.547	-0.131	0.305	0.692
	41-60	-0.213	-0.169	0.567	-0.115	-0.242	0.48	-0.162	0.335	0.674
Ca	0-20	-0.195	-0.076	0.475	0.228	0.01	0.482	0.251	-0.088	0.219
	21-40	-0.27	0.058	0.413	0.096	0.026	0.432	0.419	0.026	0.308
	41-60	-0.429	0.003	0.25	-0.119	-0.034	0.176	0.188	0.104	0.332
K	0-20	0.375	-0.189	-0.243	0.679	0.035	-0.13	0.311	-0.345	-0.583
	21-40	0.396	-0.13	-0.344	0.62	0.094	-0.219	0.235	-0.179	-0.566
	41-60	0.2	-0.186	-0.413	0.727	0.096	-0.297	0.112	-0.122	-0.648
Mg	0-20	-0.022	-0.081	0.114	0.187	0.052	-0.082	0.275	-0.184	-0.228
	21-40	-0.077	-0.043	-0.016	0.141	0.215	-0.138	0.377	-0.17	-0.267
	41-60	0.063	-0.118	-0.041	0.271	0.183	-0.145	0.364	-0.11	-0.297
S	0-20	-0.259	-0.05	0.523	0.249	0.057	0.521	0.306	-0.164	0.179
	21-40	-0.324	0.148	0.406	0.13	0.147	0.47	0.528	-0.057	0.217
	41-60	-0.473	0.102	0.231	-0.057	0.094	0.242	0.284	0.105	0.284
Tot. P	0-20	-0.444	-0.223	0.483	0.037	-0.157	0.629	-0.149	-0.215	0.41
	21-40	-0.475	0.047	0.297	-0.325	-0.25	0.54	-0.203	-0.354	0.523
	41-60	-0.544	0.007	0.27	-0.351	-0.23	0.433	-0.306	-0.234	0.547
Avail.P	0-20	-0.246	-0.371	0.27	0.468	-0.189	0.381	-0.224	-0.228	0.032
	21-40	-0.408	-0.166	0.338	-0.003	-0.295	0.544	-0.22	-0.314	0.383
	41-60	-0.459	-0.15	0.235	-0.324	-0.232	0.312	-0.354	-0.188	0.467
Fe	0-20	-0.081	0.027	0.134	0.148	0.037	-0.05	0.179	-0.141	-0.243
	21-40	-0.006	-0.157	0.073	-0.036	-0.308	0.053	-0.172	-0.575	0.114
	41-60	0.179	-0.026	-0.051	0.461	0.325	-0.129	0.197	-0.267	-0.488
Cu	0-20	0.462	-0.049	-0.059	0.376	0.036	-0.083	0.219	0.126	-0.19
	21-40	0.158	0.142	-0.098	0.142	0.151	-0.18	-0.016	0.473	-0.063
	41-60	0.062	0.228	0.128	0.107	-0.251	0.134	0.287	0.218	-0.082
Mn	0-20	0.169	0.218	-0.444	-0.115	0.123	-0.334	0.223	-0.099	-0.325
	21-40	0.015	0.199	-0.518	-0.02	0.101	-0.342	0.198	-0.271	-0.506
	41-60	0.199	0.074	-0.247	0.216	-0.184	-0.271	-0.1	0.002	-0.388
	0-20	0.172	0.029	0.244	0.238	0.054	0.024	-0.108	0.128	0.031
Zn	21-40	0.288	0.102	-0.144	0.076	0.049	-0.038	0.201	0.098	-0.106
	41-60	0.128	0.094	0.396	-0.368	0.063	0.03	-0.229	0.453	0.24
	0-20	0.451	-0.113	-0.197	0.145	-0.017	-0.105	-0.205	0.337	-0.049
Co	21-40	0.266	-0.186	-0.215	-0.105	-0.094	-0.3	-0.154	0.338	-0.106
	41-60	0.354	-0.032	-0.168	0.236	-0.243	-0.214	-0.177	0.17	-0.258
Si	0-20	-0.387	0.344	-0.088	0.223	0.275	0.13	0.435	-0.244	-0.339
	21-40	-0.073	0.319	0.346	-0.146	-0.185	0.426	0.389	-0.216	0.229
	41-60	-0.596	0.344	0.061	-0.117	0.188	0.301	0.238	-0.203	0.101

6 DISCUSSION

The aim of this study was to assess the influence of soil properties on chemical composition of baobab (*Adansonia digitata* L.). This was done by comparing both soil chemical elements and fruit pulp nutrient content of baobab trees found in inland (IH) and coastal (CL) zone of Kenya, and by correlating pulp nutrients with soil chemical elements under baobab trees across sampling sites.

6.1 Soil chemical composition and variability across locations and soil layers

Our work showed significant variation in soil chemical composition between two zones, the IH and CL, both as a whole and across individual soil layer profile. There was slightly higher pH in the CL as compared to IH, although it was not significant on the whole soil profile; these results corresponded with the study area soil data published by FAO/IIASA/ISRIC/ISSCAS/JRC (2012), which indicated that inland regions soils have relatively lower pH as compared to coastal regions soils. The report showed that the soil type commonly dominating in the IH was rhodic ferralsols and haplic lixisols with relatively low pH, base saturation and CEC as compared to soil at CL, which was reported as being dominated by eutric vertisols and ferralic arenosols with relatively high pH, CEC and base saturation. Moreover, on individual profiles there was significant variation in pH values between top and sub-soil layers, the results were showing pH increased with soil depth in both zones. This finding corresponds to the work of Butros et al. (2010) which indicated that pH increases with decreases in altitudes and soil depth. Their study in Mediterranean region showed significant variability in soil chemical composition along transect of slope topography and soil profile depth. It also matched with the findings from the study of Ogeh and Ukodu (2012) who reported from Nigeria that soil physical and chemical composition varies greatly with soil profile. The authors reported that soil pH increased with depth or with slope along transect.

The contents of Ca, S, total and plant available P were found significantly higher at coastal zone on the whole soil profile, which coincides with the research done by Boxem et al. (1987) whose findings from the study of soil of Kilifi area indicated that coastal soils

consist of eutric vertisols developed largely from marine deposits, ferralic arenosols which are the admixture of coral limestone and fluvisols. All of these are neutral soils with optimum pH that allow release of major plant nutrient. The finding also added that soils are specifically rich in Ca. On the other hand, the soils of the IH zone were significantly higher in K and Mg and low in both total and plant available P as well as S. This corresponded with the work of Gachimbi et al. (2002) whose findings from the study on semi-arid soils of Eastern Kenya indicated that the soils were poor in organic matter content, N and P but high in K and Fe.

Moreover, on the individual soil profiles level, there was significant variation in exchangeable Ca in top- and medium-soil layer with trend showing a general decrease with soil depth with high concentration still observed in coastal soil samples. This result is in agreement with the work of Butros et al. (2010), whose study in the Mediterranean region of Lavant along transect of slop topography indicated that Ca concentration was decreasing with soil depth and along the transect line. The study added that Ca concentration was high at the surface due to addition of calcareous silt and decreased with slope due to leaching. In our case the higher Ca concentration at the top and medium layer and generally in CL was due to the fact that the coastal soils developed from depositions of corral limestone and alluvial admixture and marine depositions at the shore of the Indian Ocean. It was mentioned earlier from the study of Boxem et al. (1987) that coastal soils are high in Ca.

The K content in the individual soil layers showed significant differences between IH and CL samples, the higher concentration observed from the IH in all layers and the trend showed general decreasing in concentration with soil depth. This corresponded with the work of Butros et al. (2010) who stated that K concentration increased toward the soil surface and with altitude along the transect. He added that K concentration was variable due to the element's great mobility, and slightly increasing toward the soil surface due to presence of elite minerals in the arid region. The IH zone in our study was arid region with higher altitude as compared to CL. It was also observed from this work that K concentration was higher at the top layer, which might be due to accumulation of elite minerals.

The Mg contents in individual soil layers showed significant differences between IH and CL samples only for the medium and sub-soil layers, with higher concentration in all layers in IH zone and slightly increasing with soil depth especially in the IH zone. This again matched the work of Butros et al. (2010) where extractable Mg increased trough the soil profile as a result of leaching.

On the level of individual soil layers, S showed significant differences in the top and medium soil layers with overall decreasing trend while total P showed significant differences on the top and sub-soil layers with over all decreasing amount with increasing depth. In all cases, higher concentration of S and total P was still observed in the CL, this corresponded with the study of Ogeh and Ukodu (2012) whose report from Nigeria indicated general decreasing tendency with increasing soil profile depth for total and plant available P. However, unlike the aforementioned case, the content of plant available P for each soil layer did not show significant differences between CL and IH sites, although the differences can be observed on the means across all profile between the two zones, the IH and CL, with overall higher concentration in the CL sites and with general decreasing trends from top to sub-soil layers. The results corresponded with finding from Ogeh and Ukodu (2012) who indicated that both total and plant available P decreases with depth.

The results further indicated that there were not any significant differences for most micronutrients between IH and CL zones, except for Mn, Na and Al, where Mn and Na contents were found higher in IH zone. This may be due to the fact that IH soils are subjected to erosion and leaching during sporadic but heavy rains, which results in the loss of major cations and increase in Fe content as mentioned by Gachimbi et al. (2012), although our work did not show any differences for Fe concentration from IH zone and as well as Mn concentration was not indicated from the study. The leaching condition from IH soils that result in high Fe concentration would also definitely involve the increase of Mn and Al. Moreover, the vertisols soil that developed from unripen clay of marine sediment, part of the CL soil is expected to have high Al concentration although this was not found from the work of Boxem et al. (1987), who states that vertisols are of low pH and high Al and Fe in general. Mn and Na showed significant differences at individual layers especially at the lower layers with slight increase with depth at CL. This corresponded with work of

Butros et al. (2010) who indicated that Na concentration increased with depth. Most other micronutrients however did not show any significant differences between zones, both in the whole profile and in the individual layers. This may mean that the concentration of most micronutrient remain constant throughout the two main zones.

6.2 Variability of pulp nutrients across geographical locations

Our study reported significant differences in fruit pulp nutrient contents between the two study zones, the IH and CL, except for the amount of water and Ca content. Fruit pulp from coastal zone had lower pH, higher total acidity, ash and K contents, while fruit pulp from inland trees was less acidic and had higher content of vit. C, Zn, Fe and Mg. Our findings contrast with Chadare et al. (2009) and Assogbadjo et al. (2012) who reported differences in fruit pulp content only for Fe, Zn and vit. C. The combined evaluation of fruit pulp nutrients content based on locations, soil profiles and soil chemical properties was carried out using PCA to investigate whether these variations in fruit pulp nutrient between IH and CL zones depend on individual locations and whether it was defined by soil chemical distribution across soil layers. Our results clearly showed that the differences in pulp nutrient contents were based on locations and soil profiles, and thus influenced by soil properties. This showed that fruits from CL zone trees were high in ash, total acidity and K, specifically in Malindi site, caused by the high influence of soil chemical elements at topsoil. For example, higher ash contents were influenced by higher pH, Ca, S and total P contents at topsoil layer at Kilifi site and was also caused by high influence of soil chemical elements at the medium soil layer which was due to influence of Si in this layer. Whereas fruits from IH zone were high in Fe specifically at Kibwezi Kale, which was probably caused by high influence of soil chemical elements at the top soil layer specifically the K, Zn and Mg; at Kath-Mtito, Kambu and Machinery caused by high influence soil chemical elements at the medium layer specifically by soil Ca and S; and Vit. C at Kibwezi site caused by influence of soil chemical elements at the sub layer, more specifically by soil Co. This corresponded with Chadare et al. (2009), who attributed the variation in chemical composition of baobab fruit mainly to soil factors and geographic isolation.

Comparing our results of fruit pulp nutrient contents with other studies, most of our results fall within the range reported in those studies while some fall below (Table 11).

Table 11. Comparison of pulp chemical elements from our results with sources from previous studies.

Elements	Unit	Quantity range this study	Quantity range found in literature	Sources
pH		3.01-3.13	3.3	Nour et al. (1980)
Water	g/100g	10.28-10.33	2-27	Nour et al. (1980); Becker (1983); Lockett et al. (2000); Soloviev et al. (2004)
Vit. C	mg/100g	145-185	150-500	Scheuring et al. (1999)
Ash	mg/100g	5.04-6.10	4.1-6.4	Busson (1965); Lockett et al. (2000)
Zn	mg/100g	0.96-1.21	0.5-3.2	Sena et al. (1998); Lockett et al. (2000)
Fe	mg/100g	0.71-1.31	1.10-10.4	Amold et al. (1995); Osman (2004)
Ca	mg/100g	370-389	390 -700	Nour et al. (1980); Prentice et al. (1993)
Mg	mg/100g	168-202	100-300	Sena et al. (1998); Osman (2004)
K	mg/100g	896-1,324	726 -3,272	Saka and Msonthi (1994)

In both locations, the pH was slightly lower than the value reported by Nour et al. (1980); water content falls within the range reported by Nour et al. (1980), Becker (1983), Lockett et al. (2000) and Soloviev et al. (2004); Vitamin C was within the range reported by Scheuring et al. (1999); ash was within the range but slightly higher than the values reported by Buson (1965) and Lockett et al. (2000); Zn was within the range reported by Sena et al. (1998) and Lockett et al. (2000); Fe was at the lower limits within the range reported by Amold et al. (1995) and Osman (2004); Ca was slightly at the lower limit within the range reported for higher Ca value by Nour et al. (1980) and Prentice et al. (1993). Mg was within the range reported by Sena et al. (1998) and Osman (2000), K as well was within the range reported by Saka and Msonthi (1994).

In general, our results have narrow ranges, both the lower and upper limits fall within the range of previous authors with exception of ash which means that our baobab pulps nutrients varied less as compared to that of other areas.

6.3 Correlation of pulp nutrient with soil chemical elements

There was relatively high correlation of most pulp nutrients with soil chemical elements with correlation coefficient ranging from 0.43 to 0.72 for positive and -0.44 to -0.64 for negative correlation. Referring to the correlation range defined by Svatosova and Kaba (2008) the results from this study fall in the range for medium correlation.

It was observed that total acidity, ash, Fe, K and Zn contents of fruit pulp had relatively higher and significant positive correlation (0.41–0.72) with soil pH, total and plant available P, K, S and Ca. In contrast, pulp content of vit. C was negatively influenced by total and plant available P, S and Si; while only positively correlated to soil K and interestingly micronutrients such as Co and Cu. Probably the reason that IH zone baobabs are high in vit. C is due to the fact that the IH soils are low in both total and available P as well as S and high in K. So there is an urging question, if the use of P or K fertilization could have any significant effects on the fruit pulp vit. C content. Gachene and Kimaru (2003) mentioned that both P and K play some common roles in plant production they said that P promotes flowering and that deficiency cause flowering and fruiting limit, fruit often drop premature while K increases grain and fruit size and improves overall quality, its deficiency resulting in small sized fruit, they did not however mention the effect of either nutrient on vit. C fruit content.

We did not detect any strong correlation of pulp Ca concentration to any soil nutrients; however, it was weakly correlated to Si at the lower layers, moreover, both the IH and CL soils showed no significant variation in the level of soil Si, giving the fact that Si contents seem to be pre condition for fruit pulp Ca content.

Assogbadjo et al. (2012) mentioned that physicochemical characteristics of soil influence the nutritive value of baobab parts. Based on principle component analysis to correlate baobab nutrients with soil chemical composition, their report indicated that highly basic soil rich in carbon, clay, fine silt and organic matter positively influenced the concentration of Fe, K, vit. C and Zn, however, it negatively influenced the concentration of Ca and Mg, in our case this soil type corresponds with CL soil which according to Gachene and Kimaru (2003) mean those soils rich in major plant nutrients including N, P,

K, Ca, S and Mg. Our result goes well with Assogbadjo et al. (2012) and in accordance with definition of basic soil by Gachene and Kimaru (2003). In general, the positive correlation of pulp Fe and vit. C content with soil K and pulp K, Zn and ash contents with soil pH, total and plant available P, Ca and S displayed by our study corresponded to that of Assogbadjo et al. (2012) and more specifically concurs with the negative correlation he reported for fruit pulp content of Ca and Mg.

Correlation of pulp nutrients to soil chemical elements explained how the level of soil chemical elements determines the pulp content of nutrients. One may suppose that the correlation follows the distribution of soil chemical elements between zones or among locations as well as across profiles in some instance; for example, vit. C was high in IH pulp samples due to the fact that it correlated with K which is higher from the IH soil, the correlation also follows K distribution in soil profile as seen variable with depth since the distribution of K is not constant and sometimes increases toward the surface. On the other hand, fruit pulp content of K was high in CL samples since it correlated with pH, Ca, S, total and plant available P which are found higher in the CL. One may not rule out that the correlation followed these elements distribution across profile. Correlation with pH seem increasing with deeper soil profiles, while the correlation decreases across soil profile with Ca, S and total P, just as the distribution of these elements decreases with soil depth.

Pulp Fe contents were high in IH sites due to the fact that it correlated with soil K which is high in IH soils and correlation follows K irregular distribution, however decreased with total and plant available P distribution. Pulp ash was high in CL samples due to the fact that it is correlated with pH, Ca, S, total and plant available P which are actually found higher in CL soil. Correlation also follows Ca, S, and total P distribution with decreasing trend as the elements distribution decreased with soil depth. The pulp total acidity was high in CL sites samples due to the fact that it correlated with soil pH, Ca, S, total and plant available P which are found high in the CL. However, total acidity correlation increased with soil depth regardless of soil chemical distribution with exception of pH.

6.4. Genetic diversity among baobab populations

It is now obvious that the two geographical zones of Kenya have quite distinctive baobab populations as determined by differences is pulp nutrient contents, which are based on variation in the soil between the zones. However, the fruit pulp nutrient differences could possibly be also caused by intraspecific genetic diversity among baobab populations, in our case among baobab highland and lowland populations. Our observation witnessed morphological differences between IH and CL baobab populations. IH baobabs had rather small sized fruits and leaves as compared to those of CL. We could still believe soil chemical elements play such functions in plant as in the case of phosphorus reported by Gachene and Kimaru (2003) that it increases leaf size and size and number of fruits. CL baobab trees were all green with big leaves and large fruits, which were not ripen by then as compared to IH baobabs which had small and scared leaves and abundance of small sized fruits. Still we cannot rule out the contribution of other factors in the distinction between these two groups of baobab populations. As reported earlier by Assogbadjo et al. (2012) that the variation of baobab chemical composition and concentration may be caused by ecological isolation and intragenic differentiation and Chadare et al. (2009) who also reported that it may be due to soil and climatic condition. The two zones were located at different elevations and climates as well. The IH is a highland arid zone with long dry period. This may lead to small sized fruit and leaves as well as long period of leaf absence in addition to lack of phosphorus in the soil of this zone that obviously results in smaller fruits. In the case of CL zone, high rainfall could result in large fruits and broad leaves that are available all year round. Still genetic isolation could have also played role in this variation as reported by Chládová (2016). She found that based on morphological and genetic markers, there was high genetic variation of baobab populations between IH and CL, though that variation between two groups was low as compared to the one within each group. However, the genetic distances between IH and CL baobab trees even suggested the existence of two separate species. However, these findings have yet to be confirmed by following investigation.

7. CONCLUSION

Baobab is one of the valuable nutritive plant species from Africa that has recently drawn attention for improvement of nutrition of local population and thus there is urgent need of its domestication and silvicultural management. There are major challenges, however, such as lack of knowledge of the cause of variability in nutrient content and how to address this to encompass fertility management. This study investigated the influence of soil properties on chemical composition of baobab in two main zones of Kenya (inland and coastal provinces).

The study revealed high variability of soil chemical composition between two zones, inland highland and coastal lowland, where baobabs are found and used in Kenya. We found significant deficiencies of major nutrients in highland soils with exception of K and Mg, whereas coastal soils were richer in major nutrient such as Ca, S and P. The highland soils were also more acidic than the coastal ones. This could also reflect that there was high variability in pulp nutrient contents between the two zones, where highland baobabs were richer in vit. C, Fe, Mg and Zn, whereas coastal baobabs were more acidic and richer in ash and K contents. The study also revealed that there was medium strong correlation between several soil chemical elements and pulp nutrient contents. The correlation was showing the dependency of baobab pulp nutrients on soil chemical distribution both between zones and across soil layers. However, the major nutrient deficiency highland soils, which were only richer in K, determined higher content of vit. C and Fe in the pulp, whereas the nutrients richer coastal soils, which were higher in Ca, S, total and plant available P produced fruits that were poorer in vit. C and Fe, but richer in ash and K contents. The exception was fruit Ca contents whose concentrations were determined by soil Si, varying across sites in both zones. Given the fact that the quality of baobab pulp is considered higher with increasing contents of vit. C, Ca and Fe, one can therefore conclude that highland baobab pulps are more nutritious as compare to that of coastal ones because of higher soil K, but probably also microelements such as Cu and Co and lower S, total and plant available P. Both locations had equal pulp content of Ca because of the Si soil contents varied across both zones.

Based on our results we could recommend some soil fertility management. If production target should be the fruits with higher contents of vit. C and Fe, application of fertilizers with higher contents of K, Si, and micro-elements such as Cu and Co should be highly recommended.

REFERENCES

Amold TH, Well MJ, Wehmeyer AS. 1995. Koisan food plants: Taxa with potential for economic exploitation plants for arid land. Wickens GE, Field DV, Goodin JR. editors. Plants for Arid Lands. London: Allen and Unwin. pp 69–86.

Arum G. 1989. Baobab, *Adansonia digitata L.* Indigenous tree training series. Norwegian Agency for International Development (NORAD). KENGO. 24 pp.

Assogbadjo AE, Chadare FJ, Kakai RG, Fandohan B, Forson BJJ. 2012. Variation in biochemical composition of baobab (*Adansonia digitata* L.) pulp, leaves and seeds in relation to soil types and tree provenances. Agricultural Ecosystems and Environment 157: 94–99.

Barminas JT, Charles M, Emmanuel D. 1998. Mineral composition of non-conventional leafy vegetable. Plant food for human nutrition 53: 29–36.

Becker B. 1983. The contribution of wild plants to human nutrition in Ferlo (Northen Senegal). Agroforestry systems 1: 257–267.

Bosch C, Sie K, Asafa B. 2004. Adansonia digitata L. PROTA (plant resource of tropical Africa). Available at http://www.prota4u.org/: accessed 2015-4-25.

Boukari I, Shier NWFernandez RXE, Frisch J, Watkins BA Pawloski L, Fly AD. 2001. Calcium Analysis of Selected Western African Foods. Journal of Food Composition and Analysis 14: 37-42.

Boxem HW, Meester de T, Smaling EMA. 1987. Soil of the Kilifi area, Kenya. Madison: Pudoc, Centre for Agricultural Pub. and Documentation, 249 pp.

Butros IH, Taimeh YA, Ziadat MF. 2010. Variation in soil chemical properties along toposequence in arid region of Levant. CATENA 83 (1): 34-45.

Buchman 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.

Busson F. 1965. Plantes alimentaires de I' Ouest Africaine, Etude botanique, biologique et chimique. Marseille, France: Leconte. 568 pp.

Chadare FJ, Linnemann AR, Hounhouigan JD, Nout MJR, Van Boekel MAJS. 2008. Baobab Food Products: A Review on their Composition and Nutritional Value. Critical Reviews in Food Science and Nutrition 49 (3): 254-274.

Chládová A. 2016. Genetic diversity of baobab (Adansonia digitata L) along an elevation transect in Kenya [MSc.]. Prague: Czech University of Life Sciences Prague. 77 pp.

Climate data. 2015. Available at www.climate-data.org: accessed 2015-1-26.

Faichney GJ, White GA. 1983. Methods for the analysis of feeds eaten by ruminants. Melbourne, Australia: Commonwealth Scientific and Industrial Research Organization. 36 pp.

FAO. 1996. Agro-ecological Zoning Guidelines. FAO Soils Bulletin 73. Available at www.fao.org: accessed 2015-4-25.

FAO/IIASA/ISRIC/ISSCAS/JRC. 2012. *Harmonized World Soil Database (version 1.2)*. Available at http://www.iiasa.ac.at/: accessed 2015-4-25.

Gachene CKK, Kimaru G. 2003. Soil Fertility and Land Productivity: A guide for extension workers in the Eastern Africa region, Regional Land Management Unit (RELMA)/ Swedish International Development Cooperation Agency (SIDA) ICRAF house Girgiri. ISBN: 9966-896-66-X.

Gachimbi LN, Jager de A, Keulen Van H, Thuramira EG, Nandwa SM. 2002. Participatory diagnosis of soil nutrient depletion in semi-arid areas of Kenya: managing Africa's soil. London: IEED. 22 pp.

Gebauer J, Adam YO, Cuní Sanchez A, Darr D, Eltahir MES, Fadl KEM, Fernsebner G, Frei M, Habte T-Y, Hammer K, Hunsche M, Johnson H, Kordofani M, Krawinkel M, Kugler F, Luedeling E, Mahmoud TE, Maina A, Mithöfer D, Munthali CRY, Noga F, North R, Owino WO, Prinz K, Rimberia FK, Saied A, Schüring M, Sennhenn A, Späth MA, Taha MEN, Triebel A, Wichern F, Wiehle M, Wrage-Mönnig N, Kehlenbeck K. 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.

Gebauer J, El-Siddig K, Ebert G. 2002. Baobab (*Adansonia digitata* L.): a Review on a Multipurpose Tree with Promising Future in the Sudan. Gartenbauwissenschaft 67 (4): 155–160.

Gillman GP. 1979. A proposed method for the measurement of exchange properties of highly weathered soils. Australian Journal of Soil Research 17: 129–139.

Glew RH, Van der Jagt DJ, Lockett C, Grivetti LE, Smith GC, Pastuszyn A, Millson M. 1997. Amino acid, fatty acid and mineral composition of 24 indigenous plants of Burkina Faso. Journal of Food Composition and Analysis 10: 205–217.

Jaetzold R, Schmidt H, Hornetz B, Schisanya C. 2012. Farm management handbook of Kenya; Natural conditions and farm management information.Vol 11. 2nd edition. Part C: East Kenya. Subpart c1: Eastern province. Nairobi. Ministry of agriculture and Germany agency for international cooperation (GTZ), pp 355-468.

John R, Dalling J, Harms K, Yavit J, Stallard R, Mirabello M, Hubell S, Valencia R, Navarrete H, Vallejo M, Foster R. 2007. Soil nutrient influence spatial distribution of tropical trees. Proceedings of the National Academy of Sciences 104 (3): 864–869.

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

Kehlenbeck K, Waruhiu CG. 2014. Report on occurrence, fruit production and marketing of baobab (*Adansonia digitata*) in eastern and coastal Kenya. Report from ICRAF.

Khan A, Nascer M, Malik A, Basra S, Khalid K, Amin B, Rajwana S, Din M. 2011. Location, soil and tree nutrient status influence the quality of kinnow mandarin. International Journal of Agriculture and Biology 13 (4): 498–504.

Larwanou M, Adamou M, Abasse T. 2014. Effect of fertilizer and watering regime on early growth and leaf biomass production for two food tree species in the Sahel: *Moringa oleifera* Lam. and *Adansonia digitata* L. Journal of Agricultural Science and Applications 3 (4): 82–88.

Lockett CT, Calvert CC, Grivetti LE. 2000. Energy and micronutrient composition of dietary and medicinal wild plant consumed during drought. Study of rural Fulani.

North-eastern Nigeria. International Journal of Food Sciences and Nutrition. 51(3): 195-208.

Mbora A, Jamnadass R, Lilles J-PB. 2008. Growing high priority fruits and nuts in Kenya: Uses and management. Nairobi: The World Agroforestry Centre. 61 pp.

Mbuvi JP. 2000. Makueni District Profile: Soil Fertility Management. Drylands Research Working Paper 6. Crewkerne: Drylands Research. 19 pp.

Murray SS, Schoeninger MJ, Bunn HT, Pickering TR, Marlett JA. 2001. Nutritional composition of some wild plants foods and honey used by Hadza Foragers of Tanzania. Journal of Food Composition and Analysis 13: 1–11.

Nielsen SS. 2010. Vitamin C Determination by Indophenol Method. Nielsen SS, editor. Food Analysis Laboratory Manual. New York: Springer Science and Bussiness Media. pp 55-60.

Nordeide MB, Hatloy A, Folling M, Lied E, Oshaug A. 1996. Nutrient composition and nutritional importance of green leaves and wild food resources in an agricultural district, Koutiala, In Southern Mali. International Journal of Food Science and Nutrition 47: 455–468.

Nour AA, Magboul BL, Kheiri NH. 1980. Chemical composition of baobab fruit (*Adansonia digitata* L.). Tropical Science 22: 383–388.

Obizoba IC, Amaechi NA. 1993. The effect of processing method on the chemical composition of baobab (*Adansonia digitata* L.) pulp and seed. Ecology of Food and Nutrition 29: 199–205.

Ogeh JS, Ukodo E. 2012. Profile distribution of physical and chemical properties in soil of toposequence in Benin. Nigerian Journal of Basic and Applied Science 20 (1): 68–72.

Olsen S, Cole C, Watanabe F, Dean L. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular Nr 939, US Gov. Print. Office, Washington, D.C.

Orwa C, Mutua A, Kindt R, Jamnadass R, Anthony S. 2009. Agroforestry tree Database: a tree reference and selection guide version 4.0. World Agroforestry Centre, Kenya.

Osman MA. 2004. Chemical and nutrient analysis of baobab (*Adansonia digitata* L.) fruit and seed protein solubility. Plant Foods for Human Nutrition. 59 (1): 29–33.

Patrut A, Von Reden K, Lowy D, Albert A, Pohlman J, Wittmann R, Gerlach D, Xu L, Mitchell C. 2007. Radio carbon dating of a very large African baobab. Tree Physiology 27: 1569-1574.

Prentice A, Laskey MA, Shaw J, Hudson GJ, Day KC, Jarjou LMA, Dibba B, Paul AA. 1993. The calcium and phosphorus intakes of rural Gambian women during pregnancy and lactation. British Journal of Nutrition. 69 (3): 885–896.

Roca-Perez L, Boluda R, Bermudez P. 2004. Soil-plant relation, micronutrient content and cardenolide production in natural population of *Digitalis obscura* L. Journal of Plant Nutrition and Soil Science 167 (1): 79–84.

Saka JDK, Msonthi JD. 1994. Nutritional value of edible fruit of indigenous wild trees in Malawi. Forest Ecology and Management 64: 245–248.

Scheuring JF, Sidibe M, Frigg M. 1999. Malian agronomic research identifies local baobab trees as source of vitamin A and vitamin C. Sight and Life Newsletter 1: 21–24.

Sena LP, Van der Jagt DJ, Rivera C, Tsin ATC, Muhamadu L, Muhamadu O, Millson M, Pastuszyn A, Glew RH. 1998. Analysis of nutritional components of eight famine foods of the Republic of Niger. Plant Foods for Human Nutrition 52 (1): 17–30.

Sidibe M, William JT. 2002. Baobab *Adansonia digitata* L. Southampton, UK: International Centre for Underutilised Crops. 105 pp.

Sibylle F, Susan H, Andreas B, Rainer J. 2015. Soil properties under manured *Tamarindus indica L*. in the littoral plain of South-western Madagascar. Arid Land Research and Management 29 (2): 167-179.

Smith GC, Clegg MS, Keen CL, Grivetti LE. 1996. Mineral value of selected plant foods common to Southern Burkina Faso and to Niamey, Niger, West Africa. International Journal of Food Science and Nutrition 47 (1): 41–53.

Soliman, SH, Mahmoud M. 2013.Response of *Adansonia digitata* to compost and zeolite in replacement of chemical fertilizer, American-Eurasian Journal of Agricultural and Environmental Sciences 13 (2): 198–206.

Soloviev P, Niang T D, Gaye A, Totte A. 2004. Variabilité des caractères physico-chimiques des fruits de trois espèces ligneuses de cueillette récoltés au Sénégal: Adansonia digitata, Balanites aegyptiaca et Tamarindus indica. Fruits 59 (25): 109–119.

Sombroek, WG, Braun HMH, Pouw BJA Van D. 1982. Explanatory soil map and agro-climatic zone map of Kenya. scale 1:1000 000, pp 56.

SCUC. 2006. Baobab manual. Field manual for extension workers and farmers. Southampton, UK: University of Southampton. 41 pp.

Svatosova L, Kaba B. 2001. Statistika. Prague: Czech University of Life Sciences Prague. 141 pp.

Touber L. 1983. Soils and Vegetation of the Amboseli Kibwezi area, Nairobi: Reconnaissance Soil Survey Report No. R6. KSS.

USDA. 1984. AOAC: Official Methods of Analysis (Volume 1). Arlington: AOAC. 1230 pp.

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

Wanangwe J, Stadlmayr B, Kehlenbeck K. 2013. Report on nutrition analyses of the baobab (*Adansonia digitata* L.). Nairobi Kenya. Report from ICRAF.

Watson R. 2007. The African baobab. Cape town, South Africa: Struik publisher. 203 pp.

Wehmeyer AS. 1966. The nutrient composition of some edible wild fruits found in the Transvaal. South African Medical Journal 40: 1102-1104.

Wickens GE. 1982. The baobab: Africa's upside down tree. Kew Bulletin 37 (2): 173-209.

Yazzie D, Van der Jagt DJ, Pastuszyn A, Okolo A, Glew RH. 1994. The amino acid and mineral content of baobab (*Adansonia digitata* L.) leaves. Journal of Food Composition and Analysis 7: 189–193.

ANNEX 1: Soil data

Sampling locations	Targeted samples					Achieved soil samples			
	Sub. Locations	Top soil (0-20 cm)	Med. Soil (21-40 cm)	Sub. Soil (41-60 cm)	Total	Top soil (0-20 cm)	Med. Soil (21-40 cm)	Sub. Soil (41-60)	Total
Kibwezi	KBW001	1	1	1	3	1	1	1	3
	kBW002	1	1	1	3	1	1	1	3
	KBW003	1	1	1	3	1	1	1	3
	KBW004	1	1	1	3	1	1	1	3
	KBW005	1	1	1	3	1	1	1	3
Kibwezi total		5	5	5	15	5	5	5	15
Kibwezi-Manyanga	KBWMNYGA001	1	1	1	3	1	1	1	3
	KBWMNYGA002	1	1	1	3	1	1	1	3
	KBWMNYGA003	1	1	1	3	1	1	1	3
	KBWMNYGA004	1	1	1	3	1	1	1	3
	KBWMNYGA005	1	1	1	3	1	1	1	3
Kibwezi-manyanga total		5	5	5	15	5	5	5	15
Kibwezi-Kale	KBWKA001	1	1	1	3	1	1	1	3
	KBWKA002	1	1	1	3	1	1	1	3
	KBWKA003	1	1	1	3	1	1	1	3
	KBWKA004	1	1	1	3	1	1	1	3
	KBWKA005	1	1	1	3	1	1	1	3
Kibwezi-kale total		5	5	5	15	5	5	5	15
Machinery	MACH001	1	1	1	3	1	1	1	3
	MACH002	1	1	1	3	1	1	1	3
	MACH003	1	1	1	3	1	1	1	3
	MACH004	1	1	1	3	1	1	1	3

	MACH005	1	1	1	3	1	1	1	3
Machinery total		5	5	5	15	5	5	5	15
Kinyambo	KINY001	1	1	1	3	1	1	1	3
	KINY002	1	1	1	3	1	1	1	3
	KINY003	1	1	1	3	1	1	1	3
	KINY004	1	1	1	3	1	1	1	3
	KINY005	1	1	1	3	1	1	1	3
Kinyambu total		5	5	5	15	5	5	5	15
Kambu	KAMB001	1	1	1	3	1	1	1	3
	KAMB002	1	1	1	3	1	1	1	3
	KAMB003	1	1	1	3	1	1	1	3
Kambu total		3	3	3	9	3	3	3	9
Mtito	MTO001	1	1	1	3	1	1	1	3
	MTO002	1	1	1	3	1	1	1	3
	MTO003	1	1	1	3	1	1	1	3
	MTO004	1	1	1	3	1	1	1	3
	MTO005	1	1	1	3	1	1	1	3
Mtito total		5	5	5	15	5	5	5	15
Kath-Mtito	KTHMTO001	1	1	1	3	1	1	1	3
	KTHMTO002	1	1	1	3	1	1	1	3
	KTHMTO003	1	1	1	3	1	1	1	3
	KTHMTO004	1	1	1	3	1	1	1	3
	KTHMTO005	1	1	1	3	1	1	1	3
Kath- Mtito total		5	5	5	15	5	5	5	15
Voi-Mraru	VMRU001	1	1	1	3	1	1	1	3
	VMRU002	1	1	1	3	1	1	1	3
	VMRU003	1	1	1	3	1	1	1	3
	VMRU004	1	1	1	3	1	1	1	3
	VMRU005	1	1	1	3	1	1	1	3

Voi-Mraru total		5	5	5	15	5	5	5	15
Voi-Konyeni	VKONY001	1	1	1	3	1	1	1	3
	VKONY002	1	1	1	3	1	1	1	3
	VKONY003	1	1	1	3	1	1	1	3
	VKONY004	1	1	1	3	1	1	1	3
	VKONY005	1	1	1	3	1	1	1	3
voi-Konyeni total		5	5	5	15	5	5	5	15
Diani	DN001	1	1	1	3	1	1	1	3
	DN002	1	1	1	3	1	0	0	1
	DN003	1	1	1	3	1	0	0	1
	DN004	1	1	1	3	1	1	0	2
	DN005	1	1	1	3	1	1	0	2
Diani total		5	5	5	15	5	3	1	9
Kilifi-Mavueni	KLFMAV001	1	1	1	3	1	1	1	3
	KLFMAV002	1	1	1	3	1	1	1	3
	KLFMAV003	1	1	1	3	1	1	1	3
	KFMAV004	1	1	1	3	1	1	1	3
	KLFMAV005	1	1	1	3	1	1	1	3
Kilifi-Mavueni total		5	5	5	15	5	5	5	15
Malindi-Mandunguni	MLDMAN001	1	1	1	3	1	1	1	3
	MLDMAN002	1	1	1	3	1	1	1	3
	MLDMAN003	1	1	1	3	1	1	1	3
	MLDMAN004	1	1	1	3	1	1	1	3
	MLDMAN005	1	1	1	3	1	1	1	3
Malindi-Mandunguni total		5	5	5	15	5	5	5	15
Sub. Total		**63**	**63**	**63**	**189**	**63**	**61**	**59**	**183**

ANNEX 2: Soil sampling and processing

Soil samples in the drying chamber at ICRAF soil laboratory

Soil at milling and sieving process