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Assessment of the status of African Baobab populations and fatty acids composition of its crude oil in semi arid areas of Tanzania

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ASSESSMENT OF THE STATUS OF AFRICAN BAOBAB POPULATIONS AND FATTY ACIDS COMPOSITION OF ITS CRUDE OIL IN SEMI ARID AREAS OF TANZANIA

Upendo Msalilwa

A Thesis submitted in fulfillment of the requirements for the Degree of Doctor of Philosophy in Life Sciences of the Nelson Mandela African Institution of Science and Technology

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ABSTRACT

Baobab (*Adansonia digitata* L.) is a deciduous non-timber tree species that is facing severe threats from both anthropogenic and climatic pressures across its range states. Additionally, baobab seed oil has been used for many years by local populations as medicine to treat different diseases, beauty, and food purposes. However, consumption of baobab seed oil has been reported to cause health effects emanating from the presence of carcinogenic ingredients known as Cyclopropenoid Fatty Acids (CFPAs). Ecological survey and laboratory analysis were carried out to asses the status of Baobab populations and characterize their fatty acid of seeds clued oil respectively. In ecological survey, stratified random sampling design composed of the three land-use types: strictly protected areas, non-strictly protected areas, and unprotected areas were used to select the grids for the study. Baobabs were sampled in belt transect of 1 km long and a 50 m wide, which were carried out in 337 grids located in three different land-uses types. In the laboratory analysis, the physico-chemical properties were determined according to Official Methods of Analysis of the Association of Official Analytical Chemists. The quantification of fatty acid before and after heating was done by the analysis of derivative fatty acid methyl-esters by using Gas-Liquid Chromatography. Baobab density was found to be highest in strictly protected areas (2.45 ± 1.29) and the lowest in unprotected areas (1.52 ± 1.00). The density of adult, sub-adult and juvenile populations were 1.53 ± 0.105, 0.82 ± 0.149 and 0.33 ± 0.253 plants/ha respectively. Furthermore, the results show bell shaped and inverse *J*-shaped distributions in the unprotected areas and strictly protected areas, respectively. The number of baobabs damaged was higher than undamaged in all land-use types. There were no significant differences in terms of physico-chemical properties in three different regions. It was found that the baobab crude oil contains mainly twelve essential fatty acids and two different CFPAs. The most abundant fatty acids were Palmitic acid, Oleic acid and Linoleic acid in all the three regions. The major breakdown of CPFAs started at 200 °C that would be the best temperature in the refining process of the baobab oil. The findings from this study are important in understanding the status of baobab populations and CPFAs of their crude oil in different land uses and serve to inform decision-akers towards sustainable management of this species. Furthermore, the information from this study is vital in understanding the role of biophysical conditions and land uses in shaping the population persistence of the species in its range areas in Tanzania.

DECLARATION

I, Upendo Msalilwa, do hereby declare to the Senate of the Nelson Mandela African Institution of Science and Technology that this thesis is my own work and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance for the thesis entitled "Assessment of the status of African baobab populations and fatty acids composition of its crude oil in semi-arid areas of Tanzania" in fulfillment of the Award of Doctor of Philosophy in Life Sciences at the Nelson Mandela-African Institution of Science and Technology.

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DEDICATION

This dissertation is dedicated to my late father, Mr. Lufingo Philipo Msalilwa, my mother, Mrs. Anamary Msalilwa, who laid down the foundation of my education and to my lovely husband, Dr. Geofrey Soka, for his tireless support, prayers and encouragement.

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LIST OF ACRONYMS, ABBREVIATIONS AND SYMBOLS

^0C	Degrees Centigrade
ANCOVA	Analysis of Covariance
ANOVA	Analysis of Variance
AOAC	Official Methods of Analysis of the Association of Official Analytical Chemists
CFPA	Cylopropenoid Fatty Acids
CM	Centimeter
FAME	Fatty Acid Methyl-Esters
FAO	Food and Agriculture Organization
FDA	Food Drug Administration
GLC	Gas-Liquid Chromatography
GLM	General Linear Model
GPS	Global Positioning System
ICUC	International Centre for Underutilized Crops
IFAD	International Fund for Agricultural Development
IPCC	Intergovernmental Panel on Climate Change
IUCN	The International Union for Conservation of Nature
LSD	Least Significant Difference
MEA	Millennium Ecosystem Assessment
NRI	Natural Resources Institute
NTFPs	Non-Timber Forest Products
SPSS	Statistical package for Social Science
TAFORI	Tanzania Forestry Research Institute
TAWIRI	Tanzania Wildlife Resarch Instutute
TFDA	Tanzania Food and Drugs Authority
TMA	Tanzania Meteorological Agency
WHO	World Health Organization

CHAPTER ONE

INTRODUCTION

1.1 Background of the problem

The African baobab (*Adansonia digitata* L.) are one among significant species producing non-timber forest products (NTFPs) used widely by human beings for different purposes (Sidibe & Williams, 2002; De-Caluwe *et al.,* 2009; Kamatou *et al.,* 2011). The baobab plant (genus *Adansonia*, family Malvaceae) comprises of eight species that are distributed worldwide of which seven are present in Madagascar (Razanamaro *et al*., 2015). The baobab offers shelter, a source of nutrition, clothing as well as raw material for many useful items. For example, baobab oil extracted from the seed is used in the cosmetics industry and is also sold internationally (Gruenwald & Galiza, 2005). Furthermore, baobab fruit pulp has been approved for sale in the European Union countries and the United States of America (De Smedt *et al.,* 2010). Lisao *et al.* (2018) reported that the bark is an essential part of the baobab and humans have harvested it for fodder and medicinal purposes. Also, elephants (*Loxodonta africana*) have been observed to utilize baobabs, especially in times of resource inadequacy (O'Connor *et al.,* 2007; Biru & Bekele, 2012; Msalilwa *et al.,* 2019).

One of the characteristics of the malvaceae family has the seed oils that contain essential fatty acids including Pamitic, Oleic and Linolenic and cyclic fatty acids (cyclopanic and cyclopenic) (Razafimamonjison *et al.,* 2017). It has been reported that cyclopropene fatty acids are often accompanied by a smaller proportion of cyclopropanic fatty acids, such as dihydrosterculic and dihydromalvalic acids, which are the dihydro analogues of cyclopropene fatty acids (Ralaimanarivo *et al.,* 1982). Studies reveled that cylopropenoic fatty acids (CFPAs) occur in lipids of the plant species of order Malvaceae, Tiliaceae, Bombacaceae and Sterculiaceae families, including the seeds of baobab (Carter & Frampton, 1964; Smith, 1970; Christie, 1970). The CPFAs that have been reported to be found in seed oil are Sterculic acid [8-(2-octyl-1-cyclopropenyl) octanoic acid] this is frequently the dominant CPFA and malvalic acid [7-(2-octyl-1-cyclopropenyl) heptanoic acid] (Wilson *et al*., 1961; Ahmad *et al*., 1981; Bohannon and Kleiman, 1978; Husain *et al*., 1980; Babu *et al*., 1980;Berry, 1980; Mustafa *et al*., 1986; Schmid & Patterson, 1988; Daulatabad *et al.,* 1998)

The African baobabs (*A. digitata*) are a keystone species with ecological significance as they provide important ecosystem goods and services (Jeltsch *et al*., 1996; Whyte, 2001;). The baobab trees add organic matter and nutrients through leaf-fall (Jeltsch *et al.*, (1996). It is regarded with awe by most indigenous people; some even consider it bewitched (Wickens & Lowe, 2008). Almost all parts of the tree are used in traditional medicine in Africa although this varies from one country to another (Nguta *et al.*, 2010). The baobab tree has multi-purpose uses and every part of the plant is reported to be useful (Sidibe and Williams, 2002; Gebauer *et al.,* 2002; De Caluwé *et al.,* 2010). The leaves, for instance, are used in the preparation of soup and seeds are used as a thickening agent in soups, but they can be fermented and used as a flavouring agent, or roasted and eaten as snacks (Addy, 2009). The pulp is either sucked or made into a drink while the bark is used in making ropes (Igboeli *et al.,* 1997). The baobab is widespread throughout the hot and drier regions of tropical Africa (FAO, 2001). It is extremely important to humans and animals in the dry areas of Africa because it offers shelter, source of nutrition, clothing as well as raw material for many useful items. The use practices differ across ethnic groups and the age of the baobab from which these parts are collected in Tanzania are not clearly understood.

While the baobab generates various products that are bartered and sold in urban and informal markets across Africa (Venter & Witkowski, 2010), these food products form an important source of income, especially in the dry season or at times of drought and are increasingly being commercialized and exported around the world, with pressures on its use growing. To manage the species and its associated products sustainably, a thorough understanding of the spatial distribution of the species, along with an understanding of the effects of land-use and environment factors on baobab density in these areas, is required especially during this era of increased land degradation and climate change. Land degradation is a major threat to sustainable management of biodiversity, and unsustainable land conversions and changes in climate and human populations have been predicted to increase pressure on baobab populations in their range areas (Schumann *et al.,* 2013). Furthermore, international interest in non-timber forest products (NTFP) has resulted in an increase on the utilization pressures in the species, which can potentially affect its abundance and distribution in the areas where it occurs.

Land-use intensification has been predicted to increase pressure on baobab populations in the future (Wilson, 1998; Schumann *et al.*, 2010; Schumann *et al.*, 2012; Van den Bilcke *et al.,* 2013). There is a need to conduct studies on baobab population structure in different land uses. Furthermore, human activities affect land and natural resources due to population growth and food requirement. The rise in human population growth has further increased pressure on exploited plant resources for subsistence use and may result in a reduction of baobabs in Tanzania. Many studies have shown that land-use and human activities influence the population structure of baobab due to economic and socio-cultural uses of the tree (Wilson, 2002; Schumann *et al.,* 2011). Baobab trees appear to thrive well in human settlements and crop fields while in other areas it is only in well-protected areas, supposedly with little human disturbance (Assogbadjo *et al.,* 2005; Duvall, 2007; Venter & Witkowski 2013). A study by Schumann *et al*. (2010) found that land-use type had a significant impact on the populations of baobabs between the protected area and unprotected communal area. In West Africa, there is a high population of baobabs in human-dominated landscapes, especially near homesteads (Duvall, 2007; Schumann *et al.,* 2011). In the Schumann *et al*. (2010) study, they observed an inverse '*J*-shape' for the park stands while the curve of the unprotected area stands was bell-shaped. A bell-shaped curve suggests episodic recruitment, with such periods of good recruitment to be widely spaced in time. This can happen over large areas related to good rainfall periods corresponding with periods of good fruit/seed production (Venter & Witkowski, 2010). Venter & Witkowski (2010) reported poor recruitment in natural areas (fruit/seed damage by wild animals) and good recruitment in communal areas near homesteads and cultivated areas. However, in some areas humans remove juvenile plants (Lisao *et al.,* 2018). Baobabs need to be protected against animals, especially during the juvenile stage (International Centre for Underutilized Crops [ICUC], 2002). Thus, there is an urgent need to conduct studies across different land-uses to determine the current status of *A. digitata* especially in Tanzania.

Population structure determines population stability (Shen *et al.,* 2013). A population with an inverse J-shaped size class distribution curve, with large numbers of juveniles relative to adults (higher recruitment), shows a healthy and potentially growing, stable population. Lack of juveniles indicates a declining population (Condit *et al.,* 1998; Miller, 2008). However, this may not hold for larger and longer-lived species such as baobab where trees can withstand population levels with low or episodic recruitment. Baobab population structure has been observed to display a bell-shaped distribution suggesting a higher proportion of trees in the middle size classes (Venter & Witkowski, 2010). The bell-shaped distribution could be due to episodic recruitment and considered normal for baobab (Venter & Witkowski, 2010).

1.2 Statement of the problem

The past three decades have witnessed the increased attention of the world community on issues relating to biodiversity conservation and the wise use of natural resources (CBD, 2020). In addition to local policies and institutions at national level, series of international conventions have been formulated to set up the frameworks for concerted actions to do away with negative utilization practices which undermine conservation and management of biodiversity. In almost all such high profile conventions (e.g. IPBES, CBD), trees such as African baobab and other biodiversity of the semi-arid and savanna environments have been discussed invariably in the context of vegetation cover categories such as "grasslands" or 'woodlands' with little emphasis on individual threats and values of particular species, which in principle have unique and specific ecological, socio-cultural and economic roles as much as forest resources collectively (Food and Agriculture Organization [FAO], 2001; Diaz *et al*., 2015).

Baobab is currently a tree species of high economic value internationally (Gruenwald & Galiza, 2005; De Smedt *et al.,* 2010). In the past decade, it has attracted the interest of several pharmaceutical companies and researchers due to its various traditional uses (medicinal, nutritional and cosmetic). Recently, the European Commission authorized the importation of baobab fruit pulp as a novel food (Buchmann *et al.*, 2010) and it was approved in 2009 by the Food and Drug Administration as a food ingredient in the United States of America (Addy, 2009; De Smedt *et al.,* 2010). There is a high demand for commercial baobab products in EU and United States, this tree with its edible fruits needs to be conserved and treasured (De Smedt *et al.,* 2010; Sanchez *et al.,* 2010). Despite its importance, there is inadequate specific information on the population characteristics of baobabs (Jensen *et al.*, 2011) and the sustainable use of the baobab products particularly for East Africa, including Tanzania. Due to land-use pressure, utilization demand and changes in climate, there is a need to carry out a study to provide better recommendations for the conservation and sustainable use of the tree.

Although it has attracted international interest, information on its status and distribution is not being widely collected and included in the national inventories and database despite of its important contribution towards national development (Lamien-Meda *et al.,* 2008; Aluko *et al*., 2016). In Tanzania, information on the baobab such as its role in the conservation of biodiversity as well as its ethno-botanical importance is not clearly known and thus this calls for rigorous studies about the numerous issues associated with the status and the values of

African baobab in the country. The baobab population has been reported to decline in its range areas due to low recruitment and loss of trees (Gruenwald & Galizia, 2005; Assogbadjo *et al.*, 2011; Munyebvu *et al.*, 2018). However, no studies have been conducted across the land to compare stands of baobab populations in protected areas with those of surrounding communal areas to determine the effects of land-use types on the population structure of the baobab in Tanzania. Therefore, this study aims to gather information on the status, distribution and ethno-botanical importance of the African baobab among others to formulate effective policies that will contribute to effective and sustainable management both within and outside protected areas in the areas of its geographical localities in Tanzania.

Baobab products (e.g. seed oil, fruit pulp) are increasingly being commercialized and exported around the world leading to increased pressure on this resource (Sidibe & Williams, 2002). Several ethno-pharmacological studies have reported that baobab seed oil have antioxidant, prebiotic activity, anti-inflammatory, analgesic, antipyretic activity, anti-diarrhea, ant-dysentery activity and excipient (Ibrahim *et al*., 2014; Refaat *et al.*, 2014) and other conditions including hypertension, diabetes, obesity and abdominal ailment (Mazed *et al*., 2009). These properties have made baobab products to be widely used in both traditional and modern medicines. Despite the fact that use of baobab oil is increasing and gaining popularity due to its medicinal values Tanzania Food and Drug Authority (TFDA) issued a contradicting statement condemning consumption of baobab oil for health reasons. According to Sillo (2013) and Food and Drug Authority of Tanzania (TFDA, 2013) the health effect of baobab emanate from presence of carcinogenic ingredient known as Cyclopropenoid Fatty Acids (CPFA). The CPFA in baobab oil ranges between 10 and 12.8%, which is far above the recommended level of 0.4% for human consumption (TFDA, 2013). Furthermore, according to the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) baobab oil is not included as edible oil and is not in the group of vegetable oils.

Although it is a potential fruit for improving local diets and livelihoods, this fruit (of the African baobab) is underutilized and its potential not yet fully acknowledged (Aluko *et al.*, 2016). Although, the government of Tanzania has banned consumption of baobab oil, there is evidence that most people are still using it for treatment of various diseases. Therefore, a need to characterize and quantify the levels of CPFA in baobab seed oil and detect an efficient method to remove/reduce their concentrations without impacting the quality of the other fatty acids and other beneficial properties of the oil.

1.3 Rationale of the study

In many areas where baobab grows, the baobab trees have been valued eminently and are utilized in many ways including making a wide variety of products such as food, fibre and medicine and in this way provide an invaluable resource to local and international communities. It is thus essential that the resource is managed sustainably to ensure its long-term persistence and productivity (Venter & Wiskowski, 2013). Baobab products have attracted interest by different societies both locally and internationally, raising the pressure over its use and lack of monitoring data is likely to lead its to its extinction. Some baobab species are threatened with extinction due to potential drivers such as climate change and land uses. In Tanzania, some communities have raised the demand of the use of this as a source of income, food and medicine values. This study was intended to investigate on the extent to which what is happening in different land uses, the information from which will advance the understanding of different land uses and biophysical factors influence baobab populations and generate strategies for sustainable use and conservation of the species.

1.4 Research objectives

1.4.1 General objective

The main objective of this study was to conduct a comparative assessment on the status of African baobab populations and characterization of fatty acids in baobab seeds crude oil in the semi-arid areas in Tanzania.

1.4.2 Specific objectives

The specific objectives of this study were:

(i) To determine the distribution and abundance of baobab populations in different of land-uses in semi-arid areas in Tanzania.

(ii) To assess the main drivers of abundance and distribution of baobabs in semi-arid areas in Tanzania.

(iii) To assess the structure of baobab populations in different land uses in semi-arid areas in Tanzania.

(iv) To assess the variations in physio-chemical properties of baobab seeds crude oil from the semi-arid areas of Tanzania.

(v) To determine the effects of heating on the reduction of the Cyclopropenoid Fatty Acids (CFPAs) concentrations in baobab seeds crude oil from semi-arid areas in Tanzania.

1.5 Research questions

The research questions addressed in this study were:

(i) What is the distribution and abundance of baobab populations in different land-uses of the semi-arid areas in Tanzania?

(ii) What is the effect of land-uses and environmental factors on the abundance and distribution of baobab populations in the semi-arid areas of Tanzania?

(iii) What is the structure of baobab populations in different land uses in semi-arid areas of Tanzania?

(iv) What are the variations in physio-chemical properties and compositions of baobab seeds crude oil from different regions in Tanzania?

(v) What is the effective way for removing the CFPAs from baobab crude oil from semi-arid regions of Tanzania?

1.6 Significance of the study

This study aimed at investigating African baobab populations' status and detects an efficient method to reduce the Cyclopropenoid Fatty Acids (CFPAs) concentrations in baobab oil. The highest baobab density were found in strickty protected area and the lowest in unprotected area. Also the study found that the major break down of the CFPAs were at 200 ^{0}C. Knowing the status of *A. digitata* populations will contribute to the sustainable use and conservation of the species. Also, detecting the methods of reducing CFPAs in Baobab oil will decrease the health effect emanate from the presence of carcinogenic ingredient known as Cyclopropenoid Fatty Acids (CFPAs). Baobab is one of the most important non-timber forest products providing ecological and socioeconomic significance to rural communities in Tanzania. Due to the socio-economic and cultural importance of this species, different communities in

Tanzania tend to over-utilize the plant species without taking into account the regeneration potential of the species and the health effect of the baobab oil. Therefore, a better understanding of the population structure and local uses of *A. digitata* before its full potential and sustainable harvesting is crucial. This study focused on understanding the population structure of the baobab in terms of abundance and demography in order to influence management practices for more sustainable use and conservation of the species.

1.7 Delineation of the study

The study was cross-sectional, where data were collected once. This type of design is relevant to the study because the information collected during this period represents the long term observations that would have been depicted from the same area as baobab has a longer life span whose life history characteristics collected during study are indicative of the long term observations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Baobab taxonomy and mode of production

The baobab tree belongs to Kingdom: Plantae; Phylum: Tracheophyta; Class: Magnoliopsida; Order: Malvales; Family: Malvaceae; Genus: *Adansonia*; Species: *digitata*; Botanical name: *A. digitata*; English name: Baobab (Rahul *et al.,* 2015; Bosch *et al.,* 2004). The genus *Adansonia* comprises nine species distributed across their range states and most of these are endemic to Madagascar (Razanamaro *et al*., 2015).

Adansonia digitata is widely spread over the African savanna through natural reproduction (seeds). The distribution of this at present is limited to wild or semi-domesticated individuals in mixed land uses in Africa. Its distribution is threatened by seedling clearance for other land use and potentially by overharvesting induced by growing commercial use of baobab fruit. The large white flowers of this tree are pollinated by fruit bats that feed on the nectar at night and other small mammals (Maloof, 2001; Sidibe & Williams, 2002; Watson, 2007). The protection of these pollinators is important for the production of fruits (Whyte, 2001). According to Sidibe and Williams (2002), the flowers emit a scent that attracts bats. The sour scent of the flowers also attracts certain flies and nocturnal moths as well as several species of bollworms that might result in some pollination (Sidibe & Williams, 2002).

Animals eat the fruit contents once the outer shell has withered and broken, and may at the same occasion assist in seed dispersal (Wickens & Lowe, 2008). Dormancy is broken when the seeds pass through the digestive tract of animals consuming the fruit. The hollow trunks provide shelter to many small animals and birds and offer ideal breeding sites (Whyte, 2001). Many animals including Monkey (*Macaca fascicularis*), African Elephant (*Loxodonta africana*) and birds as well as humans are agents of baobab seed dispersal (Wickens & Lowe, 2008). The baobab tree is an important tree that improves biodiversity by its attraction of various pollinating species. Any decline in baobab population would have an effect on such species (Whyte, 2001).

2.2 Baobab as Non-timber forest products (NTFPs)

Non-timber forest products (NTFPs) encompass “all biological materials other than timber, which are extracted from forests, other wooded lands and trees outside forests for human use (Gubbi & MacMillan, 2008). The NTFPs are important forest products especially in remote areas where they form alternative sources of livelihoods. Non-timber forest products (NTFPs) are increasingly becoming important in terms of rural and urban livelihoods, as there is an established cause-and-effect relationship between poverty and forest degradation in the cause of deriving subsistence households’ needs (Shackleton & Shackleton, 2004). Non-timber forest products provide livelihood benefits by assisting households to cope with sudden changes in the economic, social or bio-physical environments in which households exist and function (Shackleton, 2001). Collection and use of NTFPs to meet daily needs for energy, shelter, food and medicine allows scarce cash resources to be used to secure other household needs (Shackleton & Shackleton, 2004).

The fruit pulp, seeds, leaves, flowers, roots, and bark of baobab are edible and they have been studied by scientists for their useful properties. The fruit pulp have very high vitamin C, calcium, phosphorus, carbohydrates, fibers, potassium, proteins and lipids content, which can be used in seasoning as an appetizer and also make juices. Seeds contain appreciable quantities of phosphorus, magnesium, zinc, sodium, iron, manganese, whereas they have high levels of lysine, thiamine, calcium and iron. Baobab has numerous biological properties including antimicrobial, anti-malarial, diarrhoea, anaemia, asthma, antiviral, anti-oxidant and anti-inflammatory activities amongst others. Phytochemical investigation revealed the presence of flavonoids, phytosterols, amino acids, fatty acids, vitamins and minerals (Rahul *et al.*, 2015). Understanding the traditional knowledge and customs of local people concerning this and other plants and their medical, religious and other uses is crucial.

2.3 Potential zones where baobab has been naturally occurring

Adansonia digitata is the most widespread of the *Adansonia* species and is native to the African continent. It is widespread throughout the hot and drier regions of tropical Africa (FAO, 2001). The baobab is an important indigenous fruit tree throughout the drylands of Africa, Malaysia, China, Jamaica and Australia (Aluko *et al.*, 2016). However, little is known about how different parts of the baobab tree are used among ethnic groups in semi-arid zones. They often occur as widely spaced individuals or small groups of individuals scattered over large areas. In Tanzana, higher populations are found in Dodoma, Singida, Manyara, Kilimanjaro, Iringa, Tabora and Shinyanga regions. Baobabs occur at low altitudes in hot dry woodland (Coates-Palgrave, 1983). Literature coincides that a minimum of 550-600 mm annual precipitation is necessary for *Adansonia digitata* to grow. *Adansoia digitata* grows on marginal soils as they exist throughout the semi-arid regions. The sandy soils with low nutrition of the semi-arid zones of Tanzania have been reported to be suitable for *A. digitata* (Wickens, 1982). The species has been reported to prefer deep well-drained soils at elevations between 450 and 600 m.a.s.l (Wickens, 1982).

2.4 Baobab biodiversity conservation in Tanzania

Biological diversity means the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems (CBD, 2005). Loss of biodiversity is a growing trend in virtually all earth ecosystems. The Millennium Ecosystem Assessment document shows that losses of biodiversity and the related changes in the environment have been more rapid in the past 50 years than ever before in human history (MEA 2005). Tropical biodiversity is foreseen to be critically threatened not only by climate change but also by land-use changes (Sodhi *et al.,* 2009). Many animal and plant populations have declined in numbers, geographical distribution, or both. A few studies have addressed the potential consequences of future climate changes on biodiversity in Africa. Several previous studies have already addressed the potential consequences of future climate changes on biodiversity in Africa: predicting that more African plant species will experience losses of the climatically suitable area by 2085 (McClean *et al.,* 2005); while up to 25 - 40% of African mammals will potentially be critically endangered by 2080 due to loss of climatically suitable area (Thuiller *et al.,* 2006). Furthermore, a study by Wickens and Lowe (2008) reported that the baobab tree is threatened by climate change and indicated that better conservation strategies are urgently needed. Therefore, understanding how biodiversity is changing over time and space, why it is changing, and what the consequences of the changes are for ecosystems, their services, and human well-being is crucial especially in semi-arid regions in Tanzania.

2.5 Emerging issues and challenges associated with baobab conservation

Baobab has been reported to associate with human habitation for centuries in many regions of Africa and establishes an enormous economic and nutritional importance to rural communities (Assogbadjo *et al.,* 2008; De Smedt *et al.,* 2010; Aluko *et al.,* 2016). Many households in semi-arid areas are financially-poor and strongly depend on natural resources such as NTFPs for livelihood (Schumann *et al.,* 2012). Increasing threats on NTFPs providing tree species, due to land-use intensification require ecological studies as well as additional information about species' uses and management practiced by local people (Schumanna *et al.,* 2012). Due to the socio-economic and cultural importance of this species, different communities in Tanzania tend to over utilize the plant species without taking into account the regeneration potential of the species. Baobab is one of the important NTFPs providing ecological and socio-economic significance to rural communities in Tanzania. There is a need to have a better understanding of the population structure and local uses of *A. digitata* before its full potential and sustainable harvesting is realized. Knowledge of the population structure of tree species across their geographic ranges is essential for sustainable use and management of any tree resources (Zhang *et al.,* 2015).

Furthermore, in sub-Saharan Africa, baobab seed oil has been used for many years by local populations for medicine, beauty, and food purposes (Kamatou *et al.,* 2011). In Tanzania, local people use baobab seed oil for medicinal purpose. Several ethno-pharmacological studies have reported that baobab seed oil has antioxidant, prebiotic activity, anti-inflammatory, analgesic, antipyretic activity, anti-diarrhoea, ant-dysentery activity and excipient (Ibrahim *et al.,* 2014; Refaat *et al.,* 2014) and other conditions including hypertension, diabetes, obesity and abdominal ailment (Mazed *et al.,* 2009). These properties have made baobab products to be widely used in both traditional and modern medicines. Even though the use of baobab oil is increasing and gaining popularity due to its medicinal values, the Tanzania Food and Drug Authority issued a contradictory statement condemning the consumption of baobab oil for health reasons. According to Sillo (2013) and TFDA (2013), the health effect of baobab emanates from the presence of carcinogenic ingredients known as CFPAs. The CFPAs in baobab oil ranged between 10 and 12.8%, which is far above the recommended level of 0.4% for human consumption (TFDA, 2013). Experiments on rats have shown retarded growth rate, increased liver size, delayed sexual development in female altered fatty acid metabolism (Phelps *et al.,* 1965), and increased liver cancer incidences when fed in conjunction with aflatoxin *B1* or *M1* in rainbow trout (Fan *et al.,* 1982). According to the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) baobab oil is not recommend as edible oil and is not in the group of vegetable oils. Although the government of Tanzania has banned the consumption of baobab oil, there is evidence that most people are still using it for the treatment of various diseases. In Tanzania, baobab oil is used for human consumption for the treatment of various diseases and it is known to have the CFPAs. Due to its uses baobab oil requires post-extraction treatments such as heat treatments to reduce or remove these cyclopropenoid fatty acids from the baobab seed oils to render them fit for consumption. A need to characterize and quantify the levels of CFPAs in baobab seed oil and detect an efficient method to remove/reduce their concentrations without impacting the quality of the other fatty acids has arisen.

Deforestation especially clearance of woodlands is a growing trend in virtually all savannah ecosystems. It has been reported that losses of natural vegetation and the related changes in the environment have been more alarming in the past 50 years than ever before in human history and many plant populations have declined in numbers, geographical distribution, or both (Ruddiman, 2003). Millennium Ecosystem Assessment (MEA, 2005), reveals further that the recent decline in biodiversity is the outcomes of human actions and activities that have increased the extinction rate more than the natural rate. Reduced seedling survival resulting mainly from browsing by herbivores, felling by humans and climate changes have been reported to hinder baobab recruitment (Munyebvu *et al.,* 2018). *Adansonia digitata* like other tree species is vulnerable to overexploitation of baobab fruits resulting from man-made, animal and environmental emerging challenges as discussed in following sections.

2.5.1 Emerging challenges related to the environment

(i) The influence of climate change and variability on baobab populations

Climate change and variability have been reported to be a major threat to the forestry resources including Non-timber Forest Products (Msalilwa *et al.,* 2013). Variations of annual rainfall and temperature affect the growth and development of forestry resources, which lead to a change in its abundance and distribution (Amissah *et al.,* 2015). It has been predicted that Africa is likely to experience marked climatic changes and variability with the drying and warming in the sub-tropical regions and small increases in precipitation in the tropics (Hulme *et al.,* 2001; Boko *et al.,* 2007). Climate change-related events such as drought have affected ecosystems and people (Boko *et al.,* 2007; Msalilwa *et al.,* 2013). In recent years, the African continent has been reported to be highly exposed to the predicted climate changes due to weak adaptive ability and interactions of additional confounding challenges to climate change such as temperature and rainfall. Temperature influences the growth, abundance and distribution of a number of several plant species. Plant growth may be affected indirectly by changes in temperature due to its effects in increasing the occurrence of plant diseases, other pests and the influence on photosynthetic processes. Table 1 shows the projected impact of climate change on plant species. Pollination is one of the most sensitive phenological stages to temperature extremes across all species and during this developmental stage, temperature extremes greatly affect production. Every plant species has a specific temperature range represented by a minimum, maximum, and optimum for its growth and development. For example, the optimal growth day temperature for baobabs ranges between 19 °C and 35 °C (Orwa *et al.*, 2009).

It is predicted by the Intergovernmental Panel of Climate Change (IPCC, 2007) that the expected changes in temperature for the next 30 - 50 years will be in the range of 2 – 3 °C. A study by Doughty and Goulden (2008) found that the in short-term, leaf-level measurements of carbon assimilation in many tropical forest regions showed that net carbon assimilation declined with an increase in daytime temperatures. In many countries where seasonal variability in temperature is large compared with daily variation, an increase in temperature may affect the distribution of a limited number of species (Lewis & King, 2014; Vasseur *et al.,* 2014). However, in areas with more considerable temperature variation, temperature increases are likely to shift the distribution of plant species (Toledo *et al.,* 2012; Amissah *et al.,* 2015). Therefore, there is a need to conduct studies on the effect of temperature on baobabs to develop appropriate recommendations for the conservation of this important tree species.

Table 1: Projected impact of climate change and variability on plant species

Projected impacts	Model	Source
About 50 000 African plant species impacted: substantial reductions in areas of suitable climate for 81 - 97% of the 5,197 African plants examined, 25 - 42% lose all area by 2085	Africa Hadley Centre Third Generation Coupled GCM (HadCM3) for years 2025, 2055, 2085, plus other models - shifts in climate suitability examined	1PCC (2014)
Future distribution in 2050 of 975 endemic plant species in Southern Africa distributed among seven life forms endemic flora of Southern Africa on average decreases with 41% in species richness among habitats and with 39% on species distribution range for the most optimistic scenario	SDMs were fitted to climatic data using the BIOMOD package in SPLUS	Gandiwa (2011)
Fynbos and succulent Karoo biomes: losses of between 51 and 61%	Africa for years 2025, 2055, 2085, plus other models - shifts in climate suitability examined	Tafangenyasha (1997)
Projected losses by 2050, critically endangered taxa (e.g. Proteaceae) in South Africa: losses increase, and up to 2% of the 227 taxa become extinct increase, and up to 2% of the 227 taxa become extinct	(HadCM2 IS92aGGa)	IPCC (2014)

Adopted from IPCC, 2014

The amount and regularity of rainfall affect the occurrence of the particular plant species as well as their growth and development. Rainfall in the form of water is one of the components of the photosynthesis and it affects plant growth of several plant species. The less the amount of water the less the photosynthetic process, hence low plant growth. The suitable average annual rainfall that baobab can grow better is between 300 and 500 mm (Orwa *et al.,* 2009) although the African baobab may still survive between the average annual rainfall condition ranging from 90-1500 mm (Orwa *et al.,* 2009; Bosch *et al.,* 2004).

A study by Msalilwa *et al.* (2019) revealed that baobab populations are more strongly influenced by rainfall than by temperature. Furthermore, regardless of the land use, the annual rain is the main factor that determines baobab distribution in semi-arid areas of Tanzania (Msalilwa *et al.,* 2019). However, research evidence suggests that due to climate change and variability, unpredicted higher rainfall associated with floods has been reported in various parts including the semi-arid areas (Kupika *et al.,* 2014; Thornton *et al.,* 2014) where baobab is grown. Generally, baobab cannot withstand seasonal flooding or severe waterlogging as such events may kill even the mature trees (Bosch *et al.,* 2004; Heuzé *et al.,* 2016) and result in the decline in baobab population.

Climate change could have negative effect on baobab productivity hence negative effect to people's livelihoods (Cuni Sanchez *et al.,* 2010). A study by Cuni *et al. (*2010) predicted that there would be no areas in Namibia suitable for baobab growth in future due to effects of climate change caused by a change in land use and global warming. It has been further reported that the baobab populations are threatened by climate change and indicated that better conservation strategies are needed (Wickens & Lowe, 2008). A study by Bomhard *et al.* (2005) addressed the potential consequences of future climate changes on plant biodiversity and suggested the mitigation of appropriate management strategies. Among the most vulnerable species to reductions in suitable habitat are those with delayed maturation and reduced ability to recover from population reductions, difficult to inhabit new suitable areas and/or those that are already under human pressure (Araujo *et al.,* 2006). The baobab tree meets all the suggested criteria including its long life-span (Patrut *et al.,* 2007), it is naturally dispersed by animals and it is under considerable threat from human use. In view of current global trends related to climate change, there is a need for assessing the climatic factors that control the population dynamics and its uses in order to recommend sustainable management practices for the future conservation of the species.

(ii) Land-use change and the decline in baobab populations

In Africa, baobab is found in all land uses including protected and unprotected areas. It has been reported that the survival and presence of baobab populations depends on the land uses in a specific area. Anthropogenic activities for example deforestation, agricultural activities, harvesting of some Non-timber Forest Products have an effect on land cover changes as well as land use. Land-use intensification has been predicted to cause more pressure on baobabs (Wilson, 1998, Schumanna *et al.,* 2010; Schumanna *et al.,* 2012). A study by Schumanna *et* *al.* (2010) found that land-use type had a significant impact on the populations of the baobabs between the protected area and the unprotected communal area. Human activities affect land and natural resources due to population growth and food requirement. Transformation of wildlands into agriculture lands, settlements and other uses due to the human population growth results into competition for land. These activities result in pressure on other land resources including baobab populations. It has been shown that not only land-use type impact the population structure of baobabs but also human activities through socio-cultural and economic uses of the tree impacts the population (Wilson, 1998, Schumann *et al.*, 2012). The semi-arid areas of Africa face intractable challenges related to practical pathways to social and environmental sustainability in rangelands. The rangelands makeup ~90% of habitat for the species and the rangeland area is currently undergoing a seismic change in scientific understanding of their dynamics, and shifts from communal to private tenure, coupled with the effects of climate change. Therefore, studying the population composition and dynamics of the baobabs across different land-use types is necessary to understanding the factors that shape the population structure on which the tree conservation strategies can be modelled.

Raising the status of land use to a more strictly protected area (i.e., National Park and forest reserve) may save the baobab populations from unsustainable utilization and hence stable population. A stable population is the one showing an inverse 'J-shape' diameter distribution. This indicates good recruitment or increases in population i.e. higher numbers of seedlings and juveniles compared to the adults while its opposite is true for the J-shape' diameter distribution. Though, for the long-lived species, like the baobab, may show a bell-shaped distribution, *i.e.* a large number of trees in the middle size classes (Venter & Witkowski, 2010). The bell-shaped distribution is considered to be normal for baobab (Venter & Witkowski, 2010). In the Schumanna *et al.* (2010) study, they observed an inverse 'J-shape' for the park stands while the curve of the unprotected area stands was bell-shaped, suggesting a lack of recruitment. Baobabs need to be protected against animals, especially during the juvenile stage (ICUC, 2006). Thus, there is an urgent need to conduct studies across land use to compare stands of baobab populations in the protected areas against those in the surrounding communal areas to determine its effects on the populations of the baobab.

2.5.2 Emerging challenges related to herbivory: Baobab - elephant interactions

Elephants have been known to destroy baobab trees leading to the death and reduction in densities (Edkins *et al.,* 2008; Mpofu *et al.,* 2012). *Adansonia digitata* is broadly prone to elephant destruction (Owen-Smith, 1988). It has been observed that elephants frequently kill baobab trees through debarking the stem and then make deep holes into the trunk (Weyerhaeuser, 1985; Swanepoel, 1993). Lisao *et al.* (2018) observed that elephant destruction accounted for about 41% of the damaged baobab stems. Furthermore, Barnes (1980) reported that baobab abundances decline as the elephant densities increase and the species recover when elephant densities decline due to illegal killing. Moreover, a study by Edkins *et al.* (2008) concludes that the impact of the increase of elephants on baobabs is confounded by other interventions such as drought, impacts of other herbivores and fire (Plate 1C). Extensive destruction to baobabs (Plate 1A) may indicate that elephant population, regardless of its absolute density, has reached a level at which it has already initiated major vegetation changes (Swanepoel & Swanepoel, 1986). The incomparable lifespan of the baobab means any short-term alteration in mortality resulting from an elephant attack may have long-term consequences (Weyerhaeuser, 1985). While recent studies Gandiwa *et al.* (2011) and Kupika *et al.* (2014) have reported elephant impacts on a baobab, no studies have assessed the impact of elephant activities on baobab population structure, recruitment and associated elephant damage in semi-arid regions of Tanzania.

Plate 1: Severely damaged baobab trunk by elephant in Ruaha National Park, Tanzania (A), harvested baobab fruits in Central Tanzania (B) and felling of baobab trees and use of fire to create farmland (C)

Several studies: Bond and Keeley (2005); Mapaure and Campbell (2002); Sankaran *et al.* (2008) and Gandiwa *et al.* (2011) have confirmed that elephants play an important role in vegetation changes in African savannahs and elsewhere. For example, elephants cause a direct impact on natural vegetation by feeding on trees, pushing stems over, snapping and debarking (Barnes, 1980; Swanepoel & Swanepoel, 1986; O'Connor *et al.,* 2007; Shannon *et al.,* 2008; Boundja *et al.,* 2010). The pattern of elephant effects on baobabs has been reported to be unpredictable especially on small trees (Swanepoel, 1993; Weyerhaeuser, 1985; Barnes *et al.,* 1994). Scholars: Swanepoel (1993); Barnes *et al.* (1994) and Wilson (1998) have documented the distribution and population structure of *A. digitata* which is determined by the elephant population. As Swanepoel (1993) notes, the impact of elephant activities on large trees such as baobabs is of concern since the trees are conspicuous and are aesthetically appealing. Baobab densities have declined in numbers within the protected areas, while some mature individual trees preferred by elephants have remained intact in human-dominated areas (Guy, 1982; Mpofu *et al.,* 2012). In protected areas, elephants utilize baobab, especially in times of resource inadequacy (Owen-Smith, 1988; O'Connor *et al.,* 2007; Hayward & Zawadzka, 2010; Biru & Bekele, 2012). A study by Barnes *et al.* (1994) found that baobab densities declined due to elephant browsing in Ruaha National Park. Baobab trees were also slightly affected for the same reasons in Lake Manyara in 1969 and 1981 (Owen-Smith, 1988). During this period, only 13% of the trees remained undamaged, but the annual tree mortality stood at 1% per annum (Owen-Smith, 1988). There is a need to conduct a study on the impact of elephants on baobab population structure in protected areas.

2.5.3 Emerging challenges related to human activities

(i) Impact of fire on baobab populations

In ecological terms, fire acts as a huge herbivore consuming biomass and affecting the world's biome distribution. Forest fires are considered to be a potential hazard with physical, biological, ecological and environmental consequences (Jaiswal *et al.,* 2002). The impact of fire on the environment and biota depends on the timing, behaviour, intensity and frequency of occurrence. Regarding the timing, if wildfire is set during the dry seasons, its intensity and behaviour will be higher which may have more negative effects on plant species including baobabs. A study by Mpofu (2012) reveals that wildfire is among the other factors that potentially destroy the juvenile and seedlings before recruiting to the large trees. Fire recurrence shapes the composition and distribution of ecosystems in the world (Bond *et al.,* 2005) and this may have a severe impact on baobab population.

Fires enter forests through human activities. These may be purposeful or accidental fires (Carment *et al.,* 2011). For instance, the indigenous communities may set fire to aid in the collection of honey (Narendran *et al.,* 2001; Saha, 2002) and, hence, causing negative impact to the baobab and other plant populations. This is due to the fact that baobab trees support the production of the honey in trunk holes (Rashford, 2015; Ribeiro *et al.,* 2019) and baobab branches are also useful in supporting the beehives (Ribeiro *et al.,* 2019). Given the above, it is crucial to manage fire incidences in protected and unprotected areas in semi-arid areas where baobab is grown.

(ii) The emergence of new markets for baobab products

Adansonia digitata grows naturally throughout the semi-arid regions of (Africa International Fund for Agricultural Development [IFAD], 2011) and forms a significant source of livelihoods during drought (Duvall, 2007; Adam *et al.,* 2012). Its nutrient-rich fruit has the likelihood of playing a significant role in household diet and food safety in relegated marginalized communities (Jamnadass *et al.*, 2011). It has been established that the fruit pulp contains high quantities of essential minerals and vitamin C (Stadlmayr *et al.*, 2013) and antioxidant functions (Gebauer *et al.,* 2002). Also, local communities have been making sweets, juice and snacks from baobab fruit pulps (Gebauer *et al.*, 2013). However, the key questions here are how do different ethnic groups perceive baobab and put its products to use, and how does this influence the uptake and promotion of the plant as a food crop to unleash the potential of mitigating food and nutritional insecurity in these communities? Baobab also has various other uses including the production of traditional medicine and raw materials for making ropes, baskets, tools and handicrafts (Wickens & Lowe, 2008, North *et al.*, 2014).

Recently, the pulp from baobab fruit has been recognized as an exceptional food component in Europe and in the US markets (Food Drug Administration [FDA], 2009; North *et al.*, 2014). This is likely to lead to a significant growth of the demand and the establishment of a necessary condition for market availability thus increasing the possibility of its market. The realization that baobab has an extraordinary potential economic value may induce local populations to manage, plant and conserve the baobabs and hence sustain their livelihood.

Nevertheless, constraints against the full utilization of the economic potential of baobab products have been identified; and these include lack of knowledge on sustainable resource management techniques, inadequate fruit processing technologies, limited availability of planting material and lack of well-organized market chains (Wickens & Lowe, 2008). The current role of products from baobabs to food safety, local diets and income generation need to be examined further in Tanzania. The marketing pathways and market value chains for baobab products are poorly developed and research, extension agents and institutions largely abandon the species. Information on baobab products and markets and utilization has not been comprehensively disseminated. Therefore, research on baobab marketing is essential at a local and international scale.

(iii) Traditional medicinal use of *Adansonia digitata*

Adansonia digitata is a vital tree which is accredited in Africa for its medicinal value (Table 2). Several authors Gruenwald and Galiza (2005) and De-Smedt *et al.* (2010) have reported on the traditional medicinal use of the baobab plant parts. The products extracted from baobabs are used to treat various diseases such as diarrhoea, malaria and microbial contaminations (Gruenwald & Galiza 2005; Kamatou *et al.*, 2011). Moreover, bioactivity investigations on baobab have shown different beneficial effects, such as anti-oxidant and anti-inflammatory properties, prebiotic, analgesic, antipyretic, anti-diarrhoea, and ant-dysentery properties and excipient (Milza, 2002). Despite all the reports regarding the extensive uses of baobabs in traditional medicine since ancient times (De-Caluwé *et al.,* 2010), the population structure of baobab tree in different land uses in semi-arid zones of Tanzania are still limited. For the past decade, the baobab tree has attracted the curiosity of a number of scientists and pharmaceutical corporations due to its numerous medicinal uses (Adesanya *et al.,* 1988, Sidibe & Williams, 2002; Wickens & Lowe, 2008; Kaboré *et al.,* 2011). These properties have made the products of the baobab tree to have wide application in both traditional and modern medicines. Interestingly, the tree is valued among many indigenous communities; and some even consider it delightful (Wickens & Lowe, 2008). There is potential for promotion as a cash crop and hence expand its distribution in the semi-arid areas. Further studies are necessary to investigate the medicinal values of different baobab products.

Table 2: Traditional medicinal uses of *A. digitata* in different types of aliments

Aliments	Parts	Preparation	References
Diarrhoea, fever, inflammation, kidney and bladder diseases, blood clearing, asthma	Leaves	Decoction, infusion	Brendler *et al.* (2003)
Malaria, fever	Leaves	Mixed with water	Watt and Breyer-Brandwijk (1962)
Toothache, gingivitis	Leaves	Decoction	Tapsoba and Deschamps (2006)
Diaphoretic, fever remedy	Leaves	Decoction	Abbiw (1990)
Diaphoretic, kidney and bladder diseases, asthma, insect bites	Leaves	Decoction	Wickens (1982)
Fever, diarrhoea	Seeds	Mixed with water	Watt and Breyer-Brandwijk (1962)
Anaemia	Bark	Aqueous extract	Adesanya *et al.* (1988)
Coughs	Powdered seeds	Decoction	Watt and Breyer-Brandwijk (1962)
Wound healing	Stem bark	Decoction	Baillon (1876)

(iv) Challenges associated with destructive harvesting methods of baobab

Baobab tree parts (roots bark and leave) have been harvested for different uses. Root harvesting for the medicinal uses is detrimental to the baobab tree as may result in the killing of the tree hence reducing their population. Baobab barks are harvested for many uses including making brooms, ropes, threads and baskets. Intensive bark harvesting is detrimental to baobab health and survival. Leaves are harvested for food and medicinal purposes. Intensive leave harvesting may result in plant damage which affects the growth and survival of the baobab tree. Destructive harvesting methods are detrimental to the tree hence reducing the baobab population. Currently, local communities use traditional harvesting techniques of baobab fruit including shaking the branches and knocking the fruits using sticks, which frequently result in substantial losses. An increase of baobab ingredients in the food and pharmaceutical industries has caused the local community to harvest all fruits leaving nothing in the field (Plate 2a, 2b and 1b). This may result in unstable populations in the future. Moreover, cultural practices including debarking and root harvesting for various uses may have an impact on tree growth and survival. There is a need to conduct a thorough investigation on the impact of cultural practices on the sustainability of baobab in the semi-arid regions of Tanzania.

Plate 2: Processed baobab products in Central Tanzania: (A) Baobab powder extracted from fruit pulp, (B) Baobab oil extracted from the seed

2.6 Conservation strategies and sustainable utilization of baobab

The higher demand for baobab tree-based products will probably lead to overharvesting of baobab products in all land uses. Gruenwald and Galizia (2005) projected global growth in the demand for baobab products. Appropriate management of the resources is therefore vital to avoid over-exploitation resulting from the global increase in the demand for baobab products. Therefore, conservation action of the baobab is urgently needed since only a limited part of the current range of the baobab tree would retain suitable habitable conditions for viable populations of baobab in the future. Different conservation strategies could be implemented to preserve the baobab tree and maintain not only the diet, pharmaceutical and income resources of many local people but also the ecosystem where the baobab tree thrives. There is a need to implement diverse conservation programs including *in situ* conservation in protected areas, *ex-situ* conservation in the seed banks and conservation through sustainable use. For example, the establishment of protected areas has been suggested to be an important strategy that is often considered in conservation (Sanchez *et al.*, 2011). Moreover, current levels of protection within a protected area might not seem to be enough for the baobab tree. Elephants have been reported to kill both adults and seedlings in the protected areas (Barnes & Kapela, 1994; Edkins *et al.*, 2008). The protection of baobab trees from elephant destruction is very uncertain (Barnes, 1994). Baobab seedlings could be protected from other herbivores through fencing and/or through planting. Baobab fruit and bark harvesting in different protected areas is another problem that has remained remarkably high (Schumann *et al.*, 2010). In areas where the baobab tree is extensively used by local people living around the protected area, the baobab utilization could be limited to fruit harvesting.

Alternative possible conservation schemes, especially in areas with a high threat of habitat loss, might be *ex-situ* conservation in germplasm collections (Duarte *et al.*, 2018). Hampe and Petit (2005) cite the importance of managing the populations at the edge of shrinking ranges. Considering that baobab seeds are reported to remain viable for several years (Sacande *et al.*, 2006), seeds from wild populations could be collected and preserved in seed banks. Training of local communities in sustainable harvesting of baobab products could be organized as suggested by Buchmann *et al.* (2010). Similar training has successfully guided local harvesters in Namibia towards sustainable management of the Devil's Claw, *Harpagophytum procumbens* (Strohbach, 1999; Hammond, 2000). Giving value to the baobab tree and promoting its conservation could also help preserve the ecosystem where the baobab tree thrives and the plant and animals that feed, shelter or live in it.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area description

Baobab population structure was assessed in the semi-arid areas in Tanzania (Latitude: 2°39' 5.225"S, Longitude: 34° 8' 29.364" E) and (Latitude: 8° 2'53.048' S, Longitude: 35° 3' 18.731"E). The semi-arid areas in this study were operationally defined as the areas that have an annual rainfall of less than 800 mm and temperature ranges from 26 °C to 30 °C. The land uses in this area included National Parks, Forest Reserves, Game Controlled Areas, Game Reserves, Open Areas, Wildlife Management Areas, croplands, pastures and settlements (Fig 1).

The altitude of the area ranges from 490 m to 1400 m above mean sea level. The annual rainfall of the study area was less than 800 mm. The mean monthly minimum and maximum temperatures were 26ºC and 30ºC, respectively. Semi-arid areas are characterized by a low amount of rainfall, high evapotranspiration rates and uneven temporal and spatial distribution of rainfall (Nieuwolt, 1973). Consequently, the semi-arid areas have inherently low and unreliable crop and livestock production (Hatibu *et al.,* 1999). The human population density of the semi-arid areas is approximately 62 persons per square kilometre (World Bank, 1994). The main human activities practised in the farmlands in semi-arid areas are mainly livestock keeping and smallholder, rain-fed farming practices cultivating seasonal crops that include maize, millet, groundnuts and sorghum which are sometimes grown together with baobab trees.

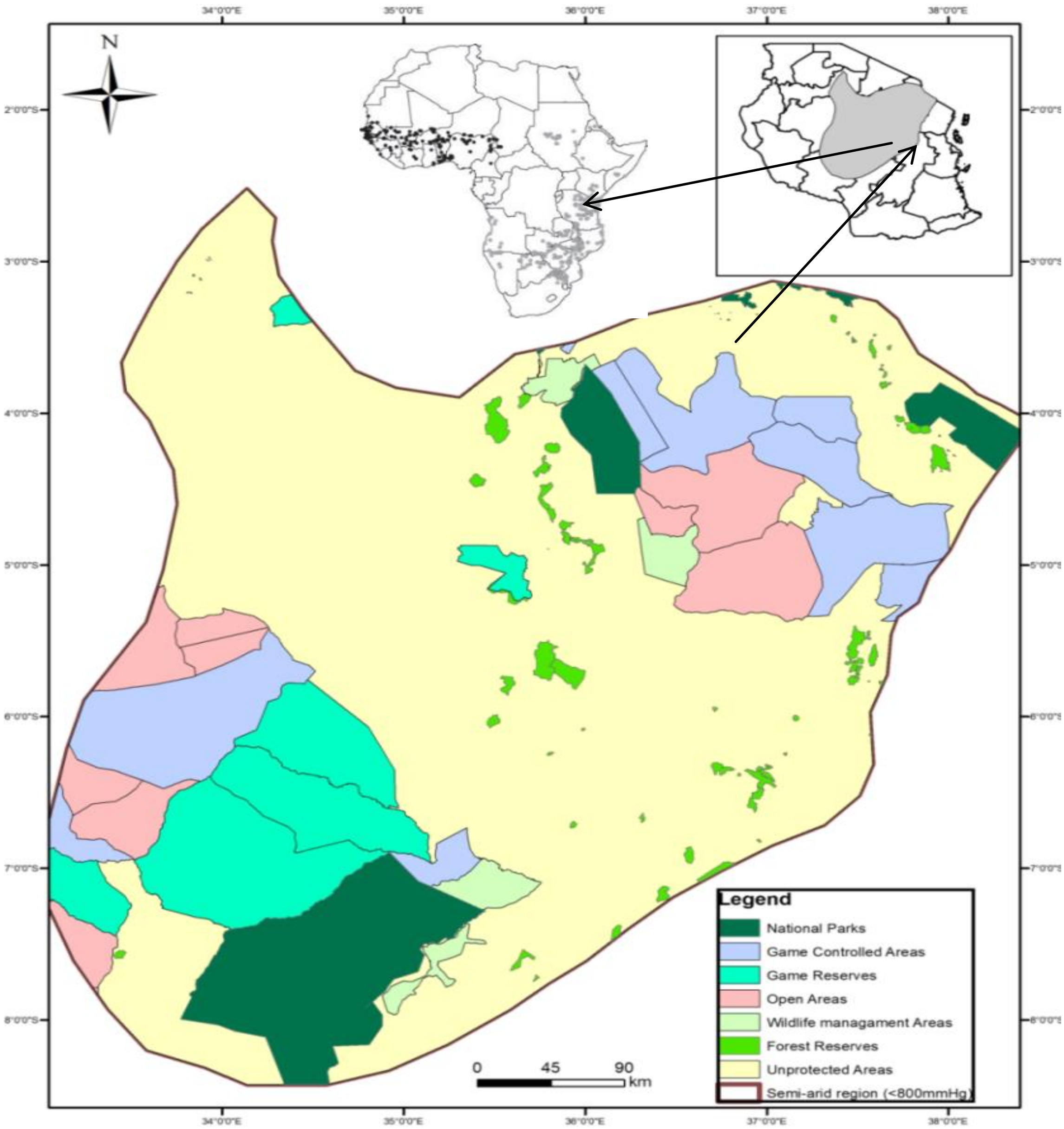

Figure 1: Map showing the location of the study, semi-arid area in Tanzania

3.2 Deskwork at Nelson Mandela African Institution of Science and Technology (NM-AIST)

This activity was done before a reconnaissance survey and actual field data collection. It involved the following activities:

3.2.1 Literature review

Existing literature from peer reviewed journal articles, books, theses and technical reports to establish the research gaps on the baobab issues were reviewed. These included the contributions of baobab tree as beneficial and valued tree crop, its distribution and the challenges associated with baobab conservation in Tanzania. The major output from this subactivity was a review article on the “emerging issues associated with conservation of African baobab (*Adansonia digitata* L.) in the semi-arid area of Tanzania”.

3.2.2 Acquisition of topographic maps, shapefiles and delineation of the semi arid map

The Tanzania topographical maps were obtained from Google Earth maps and the land use shapefiles were obtained from Tanzania Wildlife Research Institute (TAWIRI). The semi-arid area wasdelineated from the topographical map of Tanzania using climatic and biophysical variables. The semi-arid area in this study was defined as the area within Tanzania thatreceivesannual rainfall less than 800 mm. The mean monthly temperatures ranged from 26ºC to 30ºC. Thereafter,shape files of different land uses were overlaid on the semi-arid area map to delineatedifferent land uses within the semi-arid area.

3.2.3 Grids establishment and identification of global positioning system points for the selected grids

Grid squares of 20 km x 20 km were established on the semi-arid topographic map. The grids were marked from each land uses for identification.

3.2.4 Sample and plot size determination

Given the size of baobab tree and with reference to other studies on baobab, the sample size and plot size were determined. The sample size and the plot size were confirmed during a reconnaissance survey.

3.3 Research design and sampling strategy

A stratified systematic random sampling design was conducted using a topographic map of the study area. This topographic map was marked with equal grid squares of 20 km x 20 km size (Fig. 2) on a geographic information system (GIS) platform. Initially, a reconnaissance survey was done to determine the location and size of each grid and ensure the proportionate distribution of the sample points in different land-use types. Stratification was done using the existing land-use systems and baobab distribution and this reconciled the reality with information obtained from a topographic map. Ground-truthing was done during data collection to verify the exact land use. The focus of this study was on baobab distribution in certain land-use types other than the government's gazetted towns, urban, formal settlements and cities. Therefore, land-use was restricted to forms of human management of vegetation that turns out to affect baobab species. Following a study design, the land-use strater in this study were categorized into: (a) strictly protected areas (National Parks, Nature Reserves and Forest Reserves); (b) non-strictly protected areas (Game Controlled Areas, Game Reserves, Open Areas and Wildlife Management Areas) and (c) unprotected areas (croplands, pastures and settlements). The protected area categories here followed the standard designated categories of protected areas classified by the International Union for Conservation of Nature and Natural Resources (IUCN) (Dudley & Stolon, 2008).

The research design was cross-sectional, where data collection was done once. A total of 337 (40%) from 842 grid squares were randomly selected, using the topographic semi-arid map of a study area. The number of the selected grid squares in each land-use depended on the relative size of each land use. In each selected grid square, a belt transect of 1 km length and 50 m wide (5 ha) was established in the North-West corner of the grid square. At each land-use type, the selected grid square was navigated, following the GPS reading until the GPS direction became perpendicular to the direction that could be used to reach the desired grid square. Coordinates of all selected grid squares were loaded into a GPS and generated and plotted on the map of the study area. A total of 115 (34.12%) of the 337 selected grid squares were found to have baobabs (Fig. 2).

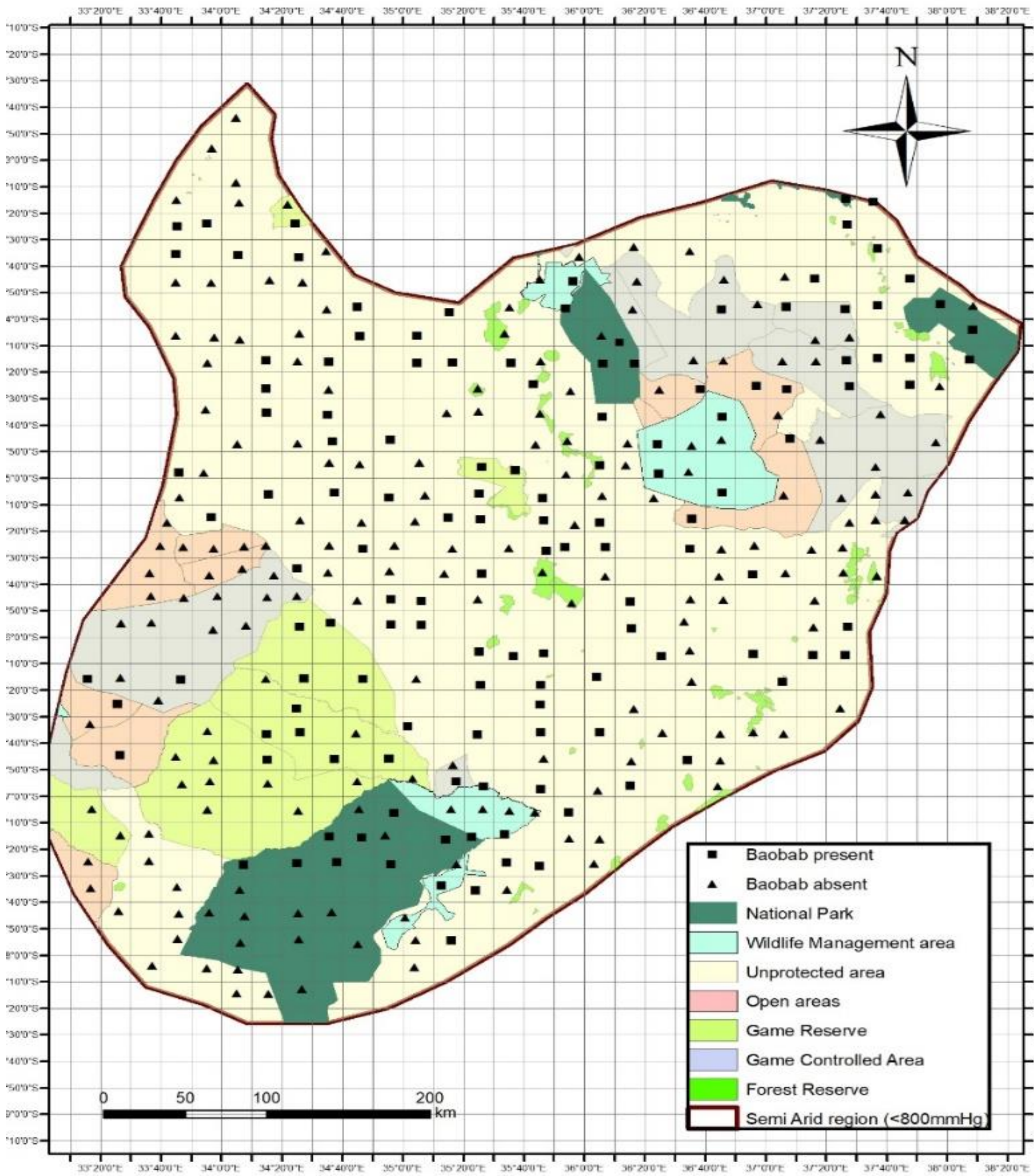

Figure 2: Map showing a presence and absence of the baobab stands in the surveyed grids in the semi-arid areas of Tanzania

3.4 Data collection

This study used a combination of approaches to collect data required to respond to each specific objective. Ecological surveys and laboratory analysis were conducted to collect the required data. The main data collection was done after conducting the reconnaissance survey in the baobab growing zones in Tanzania. The main aim was to get the basic information about the terrain characteristics, land-use systems and baobab distribution as well as to reconcile the reality with the information obtained from the topographic map. After the reconnaissance survey, the information generated was used to design and establish sampling points and sample size as described in the section below.

Using the map for the study area, the coordinates of all sampled points were plotted on maps and imputed in a Global Positioning System (GPS). The nearest land-use to a sample point was firstly located by using the combination of digitized land-use map of the study area, sampled points map and the topographic map. At each land-use type, the sampled point was navigated, following the GPS reading until the GPS direction became perpendicular to the direction that could be used to reach the desired point. The size of each grid was calculated during the reconnaissance survey to ensure the proportionate distribution of the sample points, which is a requirement of stratified random sampling (De-Greeter & Knotters, 2006). Data collection was done based on each objective as follows:

3.4.1 Determining distribution and abundance of baobab populations in different land-uses in the semi-arid areas of Tanzania

For a given belt transect, information on the number of baobab stems and land-uses was recorded. All baobab plants in each transect were counted (Appendix I). Based on the background hypothesis for this study, it was assumed that each survey grid was uniform in terms of baobab density and each land-use type was a representative of baobab occurrence in each area. Using the grid count located within the study area, the respective areas surveyed in a strictly protected area, non-strict protected area and unprotected area were 23 200 km^2, 46 400 km^2 and 65 200 km^2, respectively. The strictly protected area had 21 selected grids squares; non-strictly protected areas 26 selected grids squares and unprotected areas had 68 selected grids squares surveyed during the study period, covering approximately 40% of the entire semi-arid areas. The GPS coordinates obtained during the main field survey were used to generate the map of the selected grid square where the actual baobab stem data were collected (Fig. 2).

3.4.2 Assessing the main drivers of abundance and distribution of baobabs in the semi-arid areas of Tanzania

All the GPS coordinates from the main survey were plotted on the existing topographic map in order to establish the bio-physical drivers of the abundance and distribution of baobab in the semi-arid area of Tanzania. Official Development Assistance (ODA)/ Nomura Research

Institute (NRI) delineated the semi-arid lands concerning Tanzania's administrative regions (LRDC, 1987; NRI, 1991; NRI, 1996). This classification has been used widely by the World Bank amongst others (World Bank 1994: 14). The land use on each belt transect was located by using the combination of digitized land use map of the study area, sampled points map and the topographic map. The climate map was constructed from more than 30 years of rainfall and temperature data to reflect the distinctive patterns/gradients of this across the study area. The GPS coordinates obtained during the field survey were used to locate and estimate the actual points of the surveyed transects that were overlaid on the long-term precipitation rainfall and temperature maps spanning 30 years (Tanzania Meteorological Agency [TMA], 2014) to reconstruct rainfall and temperature data.

3.4.3 Determining the structure of baobab populations in different land uses in the semi-arid areas of Tanzania

In each belt transect, all baobab trees found were marked, enumerated, identified and recorded by trees' height, basal circumference (= girth), level of damage and status (dead or alive), presence of fruits/flowers/leaves, and land-use type. Tree height was measured with a clinometer. The basal girth of each stem was measured at breast height (1.3 m) to the nearest centimetre, using a flexible 50 m tape measure, expressed as stem girth at breast height (D/GBH). Where plant height was less than 1.3 m, basal stem girth was measured just above the buttress swelling (Mpofu *et al.,* 2012). For multi-stemmed plants, if the division was above the GBH, it was considered as one tree and if it was below, they were considered as two or more trees. Evidence of plant disturbances such as debarking, uprooting, leaf harvesting, tree stump and fire damages was also recorded. The level of damages (by animals or humans), were assessed to scale from 0 to 4, as follows: (0)-no damage, (1)-slight elephant damage-few scars, (2)-moderate damage-scars more numerous, (3)-severe damage-scarred deeply, and (4)-tree completely damaged-dead (Swanepoel & Swanepoel, 1986; Edkins *et al.,* 2008; Gandiwa *et al.*, 2011). The proportion of baobab stem damaged by fire was assessed to three levels: (0)-no damage, (1) -intermediate damage, and (2)-severe damage-scars more numerous.

Plate 3: Measurement of basal girth of baobab stem at breast height (A) and assess baobab stem damage by elephants in Tarangire National Park, Tanzania (B)

3.4.4 Characterization of baobab crude oil from the semi-arid areas of Tanzania

(i) Baobab fruits collection

The baobab fruits were collected during the main survey in Dodoma, Iringa, and Kilimanjaro regions. The selection criteria for the regions were the presence, accessibility, and the use of baobabs trees and their products. Nine *A. digitata* trees (three baobab trees in each region) were randomly selected to collect mature fruits. About 20 baobab mature and intact fruits were harvested from each tree. These fruits were collected during the dry season (August 2018 - February 2019). The geographical and environmental data were recorded in each sampled tree (Table 3).

Table 3: Geographical location and environmental conditions of regions where baobab fruits were collected

Region	Soil type (FAO/UNESCO classification)	Tree number	Latitude	Longitude	Altitude (m)	Temperature (°C)	Mean Annual Rainfall (mm)
Dodoma	Luvic Xerosol	1	-7.08992	35.95070	708	28	600
		2	-7.0898	35.952475	710	28	600
		3	-5.62227	35.837038	1265	29	900
Iringa	Eutirc Cambisol	1	-7.27386	35.738532	793	29	600
		2	-7.53059	36.662002	512	29	900
		3	-7.41308	36.963816	583	29	900
Kilimanjaro	Luvic Xerosol	1	-4.17142	37.477394	640	29	600
		2	-3.94645	35.803171	985	26	800
		3	-3.56617	36.111544	1091	27	800

(ii) Crude oil extraction and heat treatment

Hard woody shells were removed manually from baobab fruits from each area and these were carefully crushed to separate the seeds from the pulp using a pulp seed separator machine. The obtained seeds were further subjected to cold pressing for oil extraction while ensuring that the initial crude oil for analysis was prevented from contamination. The extracted crude baobab seed oil was kept in an amber-light bottle covered with its glass cover and immediately taken to the laboratory for analysis.

(iii) Analysis of baobab crude oil

Determination of the physico-chemical properties

The physico-chemical properties of baobab crude oil were determined following (Association of Official Analytical Chemists [AOAC], 2000). The baobab crude oil was obtained from 20 baobabs mature and intact fruits were the phisico-chemical properties parameters were analysed in three replicates per each region. These parameters include free fatty acid (meq/100 g oil), specific gravity (25 ^{o}C/25 ^{o}C), refractive index (27 ^{o}C), unsaponification value, saponification matter, peroxide value and iodine value. A total of twenty one (21) samples were analysed for the physico-chemical properties of baobab crude oil, which included three replicated per region.

- **Free fatty acids (FFA)**

Five (5) grams of homogenized crude oil samples were weighed in a 250 mL conical flask. About 50 - 100 mL of freshly neutralized hot ethyl alcohol was added to the oil sample followed by the addition of about 1 mL of phenolphthalein indicator. The mixture was boiled for about five mins and titrated while hot, against standard 0.1 N Potassium hydroxide solution while shaking vigorously until the mixture formed a pink colour, which persists for about 15 mins. Free fatty acid was obtained using the following formula:

Free fatty acid as oleic = (56.1xVxN)/W

Where;

V = Volume in mL of standard potassium hydroxide

N = Normality of the potassium hydroxide solution;

W = Weight in g of the sample

- **Specific gravity (SG)**

Five (5) g of baobab crude oil sample was warmed to 45 ^oC to melt oil molecules. Then the samples were left to cool until they reached a temperature of about 30 ^oC. The dry pycnometer was filled with the prepared sample in such a manner that prevented entrapment of air bubbles after removing the cap of the sidearm. The stopper was inserted, immersed in a water bath at 30 ^0C, and held for 30 mins. The bottle was removed from the water bath, cleaned, dried thoroughly, and weighed ensuring that the temperature did not fall below 30 °C. Specific gravity was calculated using the following formula:

Specific Gravity at 30^oC / 30^oC = (C – B)/ (A – B)

Where;

A = weight in g of specific gravity bottle with oil at 30 °C

B = weight in g of specific gravity bottle at 30 °C

C = weight in g of specific gravity bottle with water at 30 °C

- **Refractive index (RI)**

The refractive index was measured at 25 °C by Pen Refractometer (Atago, Japan) with resolution and accuracy values of 0.1 and ± 0.2 percent at 10-60 °C. The refractometer was set at 583.9 nm and left warm for 30 mins. The oil was poured on the double prism with the help of a screw head. The prisms were closed by tightening the screw heads. Then the refractometer values were taken and translated using a conversion table.

- **Saponification Value (SV)**

About 2.0 g of crude oil sample was added into a 250 mL Erlenmeyer flask, and then 25 mL of the alcoholic potassium hydroxide solution was added. A blank sample was then prepared by placing 2.0 g of distilled water. The sample and the blank flasks were boiled in the boiling water bath for 1 h under a reflux condenser. After boiling, the flask and the condenser were cooled with about 10 mL of hot ethyl alcohol neutral to phenolphthalein. The excessive potassium hydroxide was titrated with 0.5 N hydrochloric acid using about 1.0 mL phenolphthalein indicator. The saponified matter was obtained as follows:

Saponification Value = (56.1 (B-S) N)/ W

Where;

B = Volume in ml of standard hydrochloric acid required for the blank.

S = Volume in ml of standard hydrochloric acid required for the sample

N = Normality of the standard hydrochloric acid

W = Weight in gm of the oil/fat taken for the test.

- **Unsaponified matter**

Five (5) grams of well-mixed baobab crude oil sample were weighed into a 250 mL conical flask, then 50 mL of alcoholic potassium hydroxide solution was added and the content were gently boiled under a reflux air condenser for one h. After boiling, the condenser was washed with 10 mL of ethyl alcohol; the mixture was cooled and transferred to the separating funnel. About 50 mL of petroleum ether were added to the mixture in the separating funnel, shaken vigorously and the layers were allowed to separate. The lower soap layer was transferred into another separating funnel. The combined ether extract was washed three times with 25 mL portions of aqueous alcohol, and then washed with 25 mL portions of distilled water to ensure that the ether extract is free of alkali (washing is no longer alkaline to phenolphthalein). The ether solution was transferred into a 250 mL beaker, evaporated to about 5 mL and transferred quantitatively using several portions of ether into a 50 mL Erlenmeyer flask previously dried and weighed. The residues were dissolved in 50 mL of warm ethanol which was neutralized to a phenolphthalein endpoint and titrated with 0.02 N NaOH. The unsaponified matter was obtained as follows:

Unsaponifiable matter = (100 (A-B))/W

Where;

A = Weight in g of the residue

B = Weight in g of the free fatty acids in the extract

W = Weight in g of the sample

- **Peroxide value**

Five (5) grams of baobab crude oil sample were weighed into a 250 mL stoppered conical flask. Then 30 mL of acetic acid - chloroform solvent mixture were added and swirled to dissolve. About 0.5 mL saturated potassium iodide solution was added and left to stand for 1 min in the dark with occasional shaking, and then about 30 mL of water were added. The obtained mixture was slowly titrated against the liberated iodine of 0.1 N sodium thiosulphate solution, and vigorously shaken until the yellow colour was almost gone. About 0.5 mL starch solution was added as an indicator and continued titration while shaking vigorously to release all I_2 from the $CHCl_3$ layer until the blue colour disappeared. If less than 0.5 mL of 0.1 N $Na_2S_2O_3$ was used the process was repeated using 0.01 N $Na_2S_2O_3$. Peroxide value expressed as milli equivalent of peroxide oxygen per kg sample (meq/kg) was obtained by using the following equation:

Peroxide value expressed as milli equivalent of peroxide oxygen per kg sample (meq/kg): Peroxide value = ((A-B) * N * 100)/Weight of the sample

Where;

A= mL of Sodium Thiosulphate used for Blank

B = mL of Sodium Thiosulphate used for sample

N = Normality of Sodium Thiosulphate solution.

- **Iodine value (IV)**

About 5 g of baobab crude oil sample was weighed into a 250 mL conical flask with a glass stopper, and thereafter 25 mL of carbon tetrachloride were added to it. The contents were thoroughly mixed followed by the addition of 25 mL of Wij's solution and a glass stopper was placed on it. The mixture was left to stand for 30 mins with occasional stiring. Simultaneously, a blank was prepared by adding 5 g of distilled water instead of a sample. After standing for 30 mins, 15 mL of saturated potassium iodide solution were added, and then 100 mL of recently boiled and cooled water were added, rinsing in the stopper. The liberated iodine was titrated with 0.1 N Sodium Thiosulphate solution using starch as an indicator until the formed blue colour disappeared after thorough shaking with the stopper on. Iodine value was calculated by using the following formula:

Iodine value = 12.69 (B - S) Xn/W

Where;

B = volume in ml of standard Sodium Thiosulphate solution required for the blank.

S = volume in ml of standard Sodium Thiosulphate solution required for the sample.

N = normality of the standard Sodium Thiosulphate solution.

W = weight in g of the sample.

Quantification and characterization of fatty acids and CPFA in Baobab seeds crude oil

Triplicates of baobab crude oil samples from each region were subjected to quantification and characterization of fatty acids and CFPAs (Appendix III). Nine (9) baobab crude oil samples were analysed from the three regions. The fatty acid quantification was done using Gas Chromatography of methyl esters (Bianchini *et al.*, 1981).

- **Preparation of baobab seeds crude oil sample for FA profiling analysis**

The fatty acid (FA) profiles of the crude oils were determined as fatty acids methyl-esters (FAME) by Gas Chromatography through a method whereby alkaline hydrolysis is combined with Boron Triflouride (BF_3) catalyzed desterification (Metcalfe *et al.*, 1966). The baobab crude oil was methylated by putting 2 mg of the sample in a flask and refluxing with 5 mL of 95% of methanol-HCL for one hour. The methyl esters were extracted with three portions of hexane (5 mL) and then washed with distilled water (5 mL). The hexane layer was dried in a vacuum rotary evaporator and the residue was re-dissolved in 1 mL of hexane. Then 1 µL was injected into the GC under split mode of 60 °C (Shimadzu GC-2010 equipped with auto sampler) with a capillary column, Supelco Carbowax size 30m x 0.53 mm; injection temperature of 240 $^{\circ}$C, and detection temperature of 260 $^{\circ}$C under a flame ionization detector. Fatty acid methyl esters were identified by comparing the retention with standards times and expressed as percentages of the total methyl-esters**.**

- **Preparation of the Methyl Esters for Cyclopropenoid**

Methyl-esters were prepared from oils by refluxing approximately 100 mg of the crude oils with 5 mL of a solution of 1 % sodium methoxide (0.5 N) in methanol. After 20 mins, the solution was cooled, flooded with 15 mL of distilled water, and the methyl-esters extracted twice with 10 mL of petroleum ether (BP 30-60 °C). The esters were dried over anhydrous Sodium Sulfate and evaporated in a gentle stream of nitrogen just to dryness.

Derivative Formation: The methyl-esters were reacted with 15 mL of anhydrous methanol saturated with silver nitrate. The reaction was carried out for 20 h at room temperature. The normal methyl-esters and the reaction products from cyclopropenes were recovered from the reaction mixture by adding 30 mL of distilled water and by extracting twice with 10 mL of petroleum ether. The combined ether fractions were dried over anhydrous sodium sulfate and evaporated to a small volume in a stream of nitrogen. For the oils that contained a large amount of cyclopropenoid fatty acids (>5.0%) for example the petroleum ether solution of methyl-esters, the reaction products were directly injected into the gas-liquid chromatography. In this experiment, baobab crude oil was considered to have a low level of CPFAs. Then 1µL was injected into the GC under split mode of 60 °C (Shimadzu GC-2010 equipped with auto sampler) with a capillary column, Supelco Carbowax size 30 m x 0.53 mm; injection temperature of 240 °C, and detection temperature of 260 °C under a flame ionization detector. The fatty acid methyl esters were identified by comparing retention with standards times and expressed as percentages of the total methyl-esters.

3.4.5 Assessment of the effect of heating on the reduction of the concentrations of Cyclopropenoid Fatty Acids (CFPA) in baobab seeds crude oil from the semi-arid areas of Tanzania

The baobab crude oil from the three regions was subjected to three different high temperatures (150 °C, 200 °C and 250 °C) and boiling duration of 5, 10, 15, and 20 mins in a microwave oven (800 watts). The unheated crude oil sample was used as control (corresponding to 0 min). In these 3 x 3 factorial experiments, temperature and time were the treatments. After the heating experiment, the quantification of fatty acid and CPFA composition were carried out as shown in section titled ‘Quantification and characterization of fatty acids and CPFA in Baobab crude oil’. A total of 36 treatments were performed.

3.5 Data analysis

3.5.1 Distribution and abundance of baobab populations in different land-uses in the semi-arid areas of Tanzania

Baobab population variations and occurrences in three different land-use types (generated from the recent map of Tanzania and validated in the field) were compared across semi-arid regions of Tanzania. Using the coordinates and the baobab counts in each of the sampled Belt transects, the distribution (i.e. occurrence of baobab in the study area), abundance (variation in extent of occurrence of baobabs classified into high, medium and low) and density (number of baobabs per unit area) in the major land-use types were constructed. The distribution, abundance and density of baobabs trees were compared among the three land-use types in the study area.

3.5.2 Main drivers affecting the abundance and distribution of baobabs in the semi-arid areas of Tanzania

Mapping and descriptive statistics of each aspect were firstly done to compare the hotspots, distribution, and mean densities within and between land-use types and the rainfall and altitudinal gradients. Baobab numbers were converted into densities (baobab stems/ha) as follows: Baobab stem density = Number of individual trees/Area of the belt transect. A one-way analysis of variance (ANOVA) followed by Fisher's Least Significant Difference (LSD, $p < .05$) test was used to compare baobab population densities between the three land-use types. A general linear model (GLM), in SPSS version 17.0 (IBM Corp), was used to determine the effects of environmental variables on baobab density whereby land-use type was used as fixed/random factor with rainfall, temperature and elevation as covariates. Relationships between environmental variables (rainfall, temperature and elevation) and baobab density were analysed using Pearson's correlation analysis.

3.5.3 Population structure of baobab in different land uses in the semi-arid areas of Tanzania

Data were summarized by descriptive statistics (means and standard errors) per each belt transect before further analyses. A test for normality of the data was carried out on DBH classes between land-use types using the Kolmogorov-Smirnov test, before ANOVA procedures. Population structure of baobab in different land-use types in the semi-arid areas of Tanzania was based on baobab stem density in different age categories (juvenile, sub-adult and adult) and size classes, reproductive status (juvenile/mature ratio) and health status.

(i) Population density per land-use types

Baobab density was calculated from the following formula: density = numbers of baobab in a belt transect and then converted to ha^{-1}. Tree numbers were converted into densities (plants/ha), and girth to a diameter at breast height (DBH) in centimeters (cm). The SPSS 17.0 (IBM Corp. Chicago IL) was used for univariate analyses. Analysis of Variance (ANOVA) followed by Fisher’s Least Significant Difference (LSD, $p < 0.05$) test was used to compare different baobab age category densities within and between land-use types.

(ii) Size-class distributions

The basal stem girth was converted to stem diameter (DBH) before the analysis. Baobab size class distribution, adopted from Swanepoel and Swanepoel (1986), was based on 50 cm (D)GBH intervals, i.e. 0-50 cm; 51-100 cm; 101-150 cm; 151-200 cm; 201-250 cm; 251-300 cm; 301-350 cm, 351- 400 cm, 401-450 cm, 451-500 cm, 501-550 cm, 551-600 cm, 601-650 cm and 651-700 cm. Population structure was described as stem diameter distributions, based on the stem density in the different size-classes as per above increment intervals listed earlier in DBH. Demographics of sampled baobabs were presented as a number of individuals per size-class. In this study, the Juvenile baobabs considered to have stems <5 m height, the sub-adult baobabs were stems ≥5 m height and ≤1 m DBH, while adult baobabs were trees with DBH >1 m (after Venter and Witkowski 2013). Trees were also categorised in terms of fruit production. Seedlings were <1cm DBH, juvenile (not yet producing fruit) were <1 m DBH and mature (producing fruit) were trees ≥1 m DBH class (after Venter & Witkowski, 2010).

To obtain the status of baobab over four time periods, baobab population size-class distribution of similar even-aged cohorts was generated following Swanepoel and Swanepoel (1986) and Geldenhuys (2010) with minor modifications, whereby baobab stems were compared in four size categories across the three land-use types: classes 1 to 3 up to 150 cm (category I); classes 4 to 6 up to 300 cm (category II); classes 7 to 9 up to 450 cm (category III); and all classes above 450 cm (category IV). To allow for visual comparisons, size-class distributions (SCDs) were constructed and displayed graphically. Kolmogorov-Smirnov tests were used to compare size-class distributions and to test the prediction that all size-classes occurred in similar proportions among land-use types. Chi-square was done, using an equal number of baobabs sampled on each land-use type. ANOVA was used to compare DBH between land-use types following Edkins *et al.* (2007).

(iii) Population occurrence and distribution

Trees were divided into juveniles (generally not yet producing fruit), sub-adults and adults (producing fruit), based on fruit production per tree size class (Msalilwa, U. L. unpublished data). Kernel density in ArcGIS was used to generate baobab age-class distribution maps for different land-use types. Densities of juvenile, sub-adult and adult plants were reported for each land-use type. ANOVA followed by Fisher's least significant difference (LSD) was used to compare the density of juvenile, sub-adult and adult populations within and across land-use types. A general linear model (GLM) ANCOVA in SPSS17.0 (IBM Corp. Chicago IL) using land-use type and age category as fixed factors was run. The ANOVA test was used to find if the means of baobab age categories were different within and between land-use types. Where a significant difference was observed, a *post hoc* test by Fisher's Protected Least Significant Difference (LSD) at the $p < 0.05$ level of probability was used to determine significant differences among age category and land-use types.

3.5.4 Data analysis on baobab seed crude oil

Descriptive statistics were performed to quantify the amount of fatty acids (saturated and unsaturated fatty acids) and cyclic fatty acids (CPFAs) in baobab seed crude oil. The samples were analysed in triplicates and the data were presented as mean ± standard deviation (SD). One-way analysis of variance (ANOVA) was performed to test for significant differences between the composition of fatty acids and CPFAs in three different regions and treatments. ANOVA with Turkey's least significant difference (LSD) test was used in SPSS version 17.0 (SPSS, Chicago, IL, USA) to evaluate the differences between and within fatty acids and CPFAs. The differences were considered statistically significant at $p<0.05$.

3.5.5 Statistical analysis on the effect of heating on the reduction of the concentrations of Cyclopropenoid Fatty Acids (CFPA) in baobab crude oil from the semi-arid areas of Tanzania

A General Linear Model (GLM), Analysis of Covariance (ANCOVA) in Statisical Package for Social Science (SPSS) version 17.0 (IBM Corp. Chicago IL) was run using time as a fixed/random factor and temperature as a covariate to determine the effects of heat and boiling duration on the concentrations of fatty acids and CPFAs composition.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Distribution and abundance of baobab populations in different land-uses in the semi-arid areas of Tanzania

(i) Baobab abundance and distribution in Tanzania

The survey results revealed distinct and wide spatial variations of baobabs across different land-use types (Fig. 3). The most evident from the results were the varied distribution and hotspots of baobab across the study area and in land-use categories. Most of the baobab populations concentrated in the central regions (Dodoma and Singida) running from the southern central parts to the northern central parts of the country (Fig. 3). The result also indicated that baobab population and distribution are increasingly being isolated and fragmented mainly within strictly protected areas of varying size, habitat and environmental diversity. Furthermore, it was detected that strictly protected areas are baobab hotspots. In addition, it was noted that the hotspots reflected a gradient of elevation, rainfall and land use types.

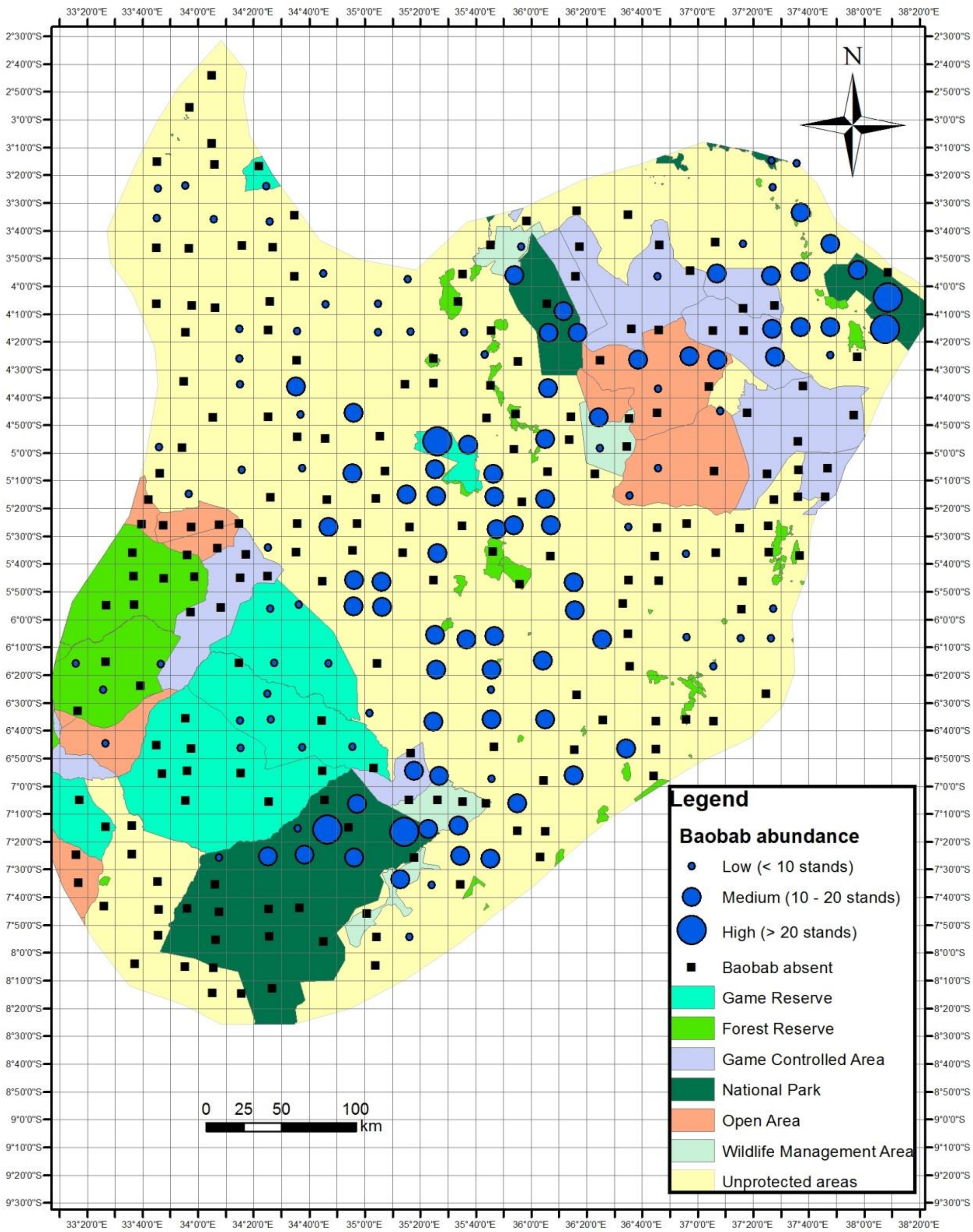

Figure 3: Map showing an abundance of baobabs in the surveyed grids in the semi-arid region

(ii) Variations of baobab density among land-use types

A total of 115 grids (34.12%) of the 337 surveyed grids had baobabs and the mean density was (1.86 ± 1.1) per ha across all land-use types in the study area. However, baobab density varied substantially and significantly ($F_{2, 115} = 5.436$, p = 0.006) across land-use types after controlling for rainfall, temperature, and elevation. Baobab densities did not vary significantly within land-use types in the semi-arid areas. There was no significant difference in baobab density within strictly protected areas and non-strictly protected areas ($F_{1,\ 21}$ = 0.117, p = 0.736, ($F_{1,\ 26}$ = 1.744, $p \leq 0.187$ respectively).

As summarized in Table 4, the highest baobab density (2.45±1.29 stems per ha) was observed in strictly protected areas. Non-strictly protected areas had an average density of 1.62±1.04 stems per ha. The lowest density (1.52±1.00 stems per ha) was recorded in unprotected areas (Table 4). Based on *post hoc* LSD multiple comparisons, baobab densities varied significantly across land-use types in the semi-arid region. Baobab density was greater for strictly protected areas than in the non-strictly and unprotected areas and this density differed significantly between strictly protected areas and unprotected areas ($p \leq 0.004$). Furthermore, there was a significant ($p \leq 0.003$) difference in baobab density between strictly and non-strictly protected areas. However, no significant ($p \leq 0.687$) difference in baobab density was observed between non-strictly protected and unprotected areas (Table 4).

Table 4: Baobab density in different land-use types in the semi-arid regions of Tanzania

Land-use type	Sample size (N)	Average abundance	Average stems per ha	Standard Error
Strictly protected areas	21	12.24a	2.45a	0.28
Non-strictly protected areas	26	8.12b	1.62b	0.20
Unprotected areas	68	7.16b	1.52b	0.13

4.1.2 Main drivers of abundance and distribution of baobabs in semi-arid areas of Tanzania

(i) Variations of baobabs with environmental factors and altitude

Baobab distribution showed different responses to the environmental variables studied. There was a significant ($F_{1,\ 115}$ = 22.289, $p \leq 0.001$) main effect of rainfall on baobab density across semi-arid regions. There was a significant negative correlation (r = -0.16, $p \leq 0.04$) between baobab density and rainfall, suggesting that baobab density declines with increasing rainfall (> 800 mm). As shown in Fig. 4, regardless of land use, rainfall ranges of between 500 and 650 mm per annum are key to the distribution of baobabs in the semi-arid regions of Tanzania. Also, there was no significant ($F_{1,\ 115}$ = 1.515, $p \leq 0.221$) main effect of temperature on baobab density (Fig. 5) though it was observed that baobab density was highest in areas with a mean temperature between 28^{o}C and 30^{o}C (Fig. 5). However, there was no significant (r = -0.06, p $\leq$ 0.24) correlation between baobab density and temperature. There was a significant ($F_{1, 115}$ = 8.201, $p \leq 0.005$) main effect of elevation on baobab density across the semi-arid region. Also, there was a significant (r = -0.37, $p \leq 0.001$) negative correlation between baobab density and elevation suggesting that baobab density declines with increasing elevation.

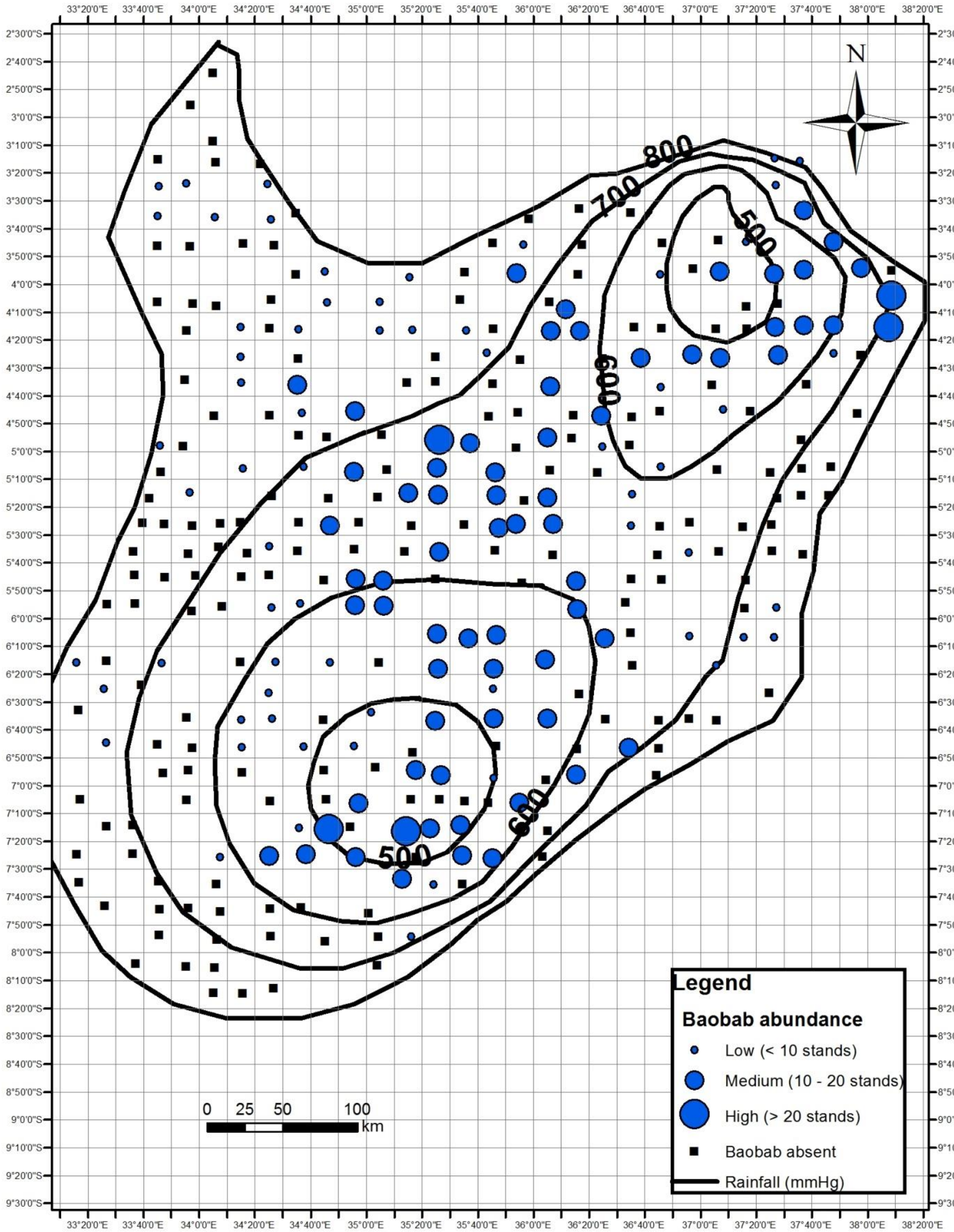

Figure 4: Map showing the effects of rainfall on baobabs distribution in the surveyed grids in the semi-arid region

The results shows different results when interacting factors on baobab density (Table 5). There was a significant interaction between land use x rainfall on baobab density ($F_{2,\ 115}$ =

3.763, p $\leq$ 0.027). In addition, there was a significant interaction between land use and elevation on baobab density ($F_{2,\,115}$ = 4.513, $p \leq 0.013$). A significant ($F_{2,\,115}$ = 7.845, p = 0.001) interaction between land use x temperature on baobab density was also found. There was a significant ($F_{1,\,115}$ = 20.759, $p \leq 0.001$) rainfall x elevation interaction on baobab density. Furthermore, there was a significant ($F_{1,\,115}$ = 26.277, $p \leq 0.001$) rainfall x temperature interaction on baobab density. Also, a significant ($F_{1,\,115}$ = 4.616, p = 0.034) elevation x temperature interaction on baobab density was observed. However, no significant ($F_{1,\,115}$ = 1.455, $p \leq 0.231$) rainfall x temperature x elevation interaction on baobab density was observed. There was a significant interaction between land use x rainfall x temperature x elevation on baobab density ($F_{2,\,115}$ = 3.680, $p \leq 0.029$).

Table 5: Interaction of factors affecting on baobab density

Interacting factors	***F statistics***	***P-values***
Land use x elevation	$F_{2,\,115}$ = 4.513	$p \leq 0.013$
Land use x temperature	$F_{2,\,115}$ = 7.845	$p \leq 0.001$
Land use x Rainfall	$F_{2,\,115}$ = 3.763	$p \leq 0.027$
Rainfall x elevation	$F_{1,\,115}$ = 26.277	$p \leq 0.001$
Elevation x temperature	$F_{1,\,115}$ = 4.616	$p \leq 0.034$
Rainfall x temperature x elevation	$F_{1,\,115}$ = 1.455	$p \leq 0.231$
Land use x rainfall x temperature x elevation	$F_{2,\,115}$ = 3.680	$p \leq 0.029$

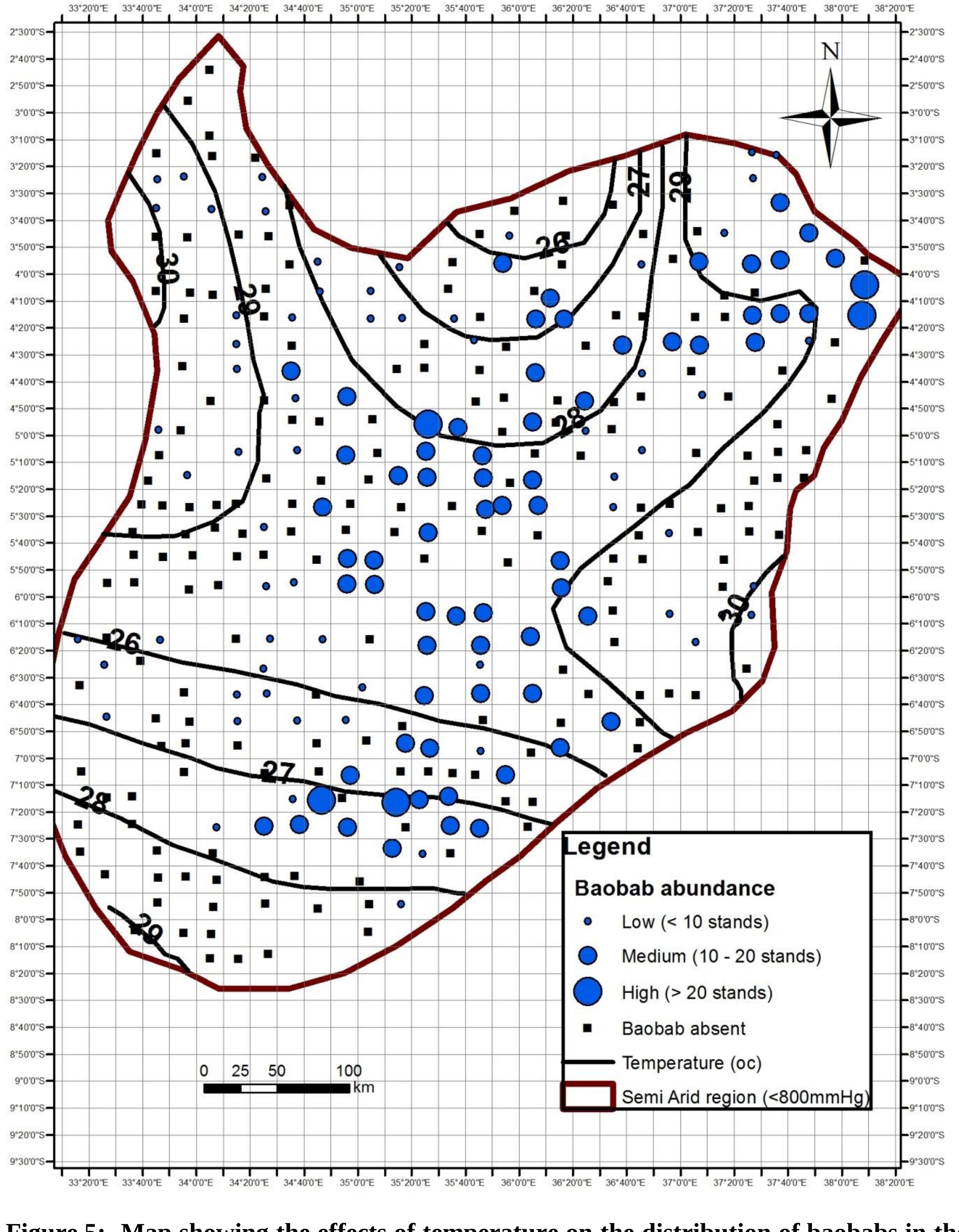

Figure 5: Map showing the effects of temperature on the distribution of baobabs in the surveyed grids in the semi-arid regions

4.1.3 Demography of baobab populations in different land uses in semi-arid areas of Tanzania

(i) Size class distribution of baobab in different land uses

In this study, the class distribution showed inverse *J*-shaped distributions in strictly protected areas versus bell-shaped distributions in non-strictly protected and unprotected areas, respectively (Fig. 6). The more or less similar pattern was observed when the size classes of baobab stems were grouped into four even cohort categories and compared by different land uses (Fig. 7). Strictly protected areas had the lowest diameter size-classes and fewest trees in the large size-classes. The highest numbers of trees were found in the 1-50 cm and 50-100 cm size classes in strictly protected areas. In non-strictly protected areas, the trees showed bell-shaped diameter distributions with the highest number of trees in the middle size classes i.e., 151-200 cm, 201-250 cm and 251-300 cm and the lowest in small diameter classes and large in higher diameter classes. The bell pattern of size-class distribution was observed with the majority of baobabs in diameter class ranges from 50 - 400 cm in unprotected areas. Chi-square independence test for comparing baobab DBH size class distribution showed no significant difference (χ^2 = 168.0, df = 156, p = 0.242) in strictly protected areas. Furthermore, there was no significant difference (χ^2 = 140.0, df = 130, p = 0.259) in DBH size-class distribution in non-strictly protected areas. Also, there was no significant difference (χ^2= 154.0, df = 143, p = 0.25) in DBH size class distribution of baobabs in unprotected areas.

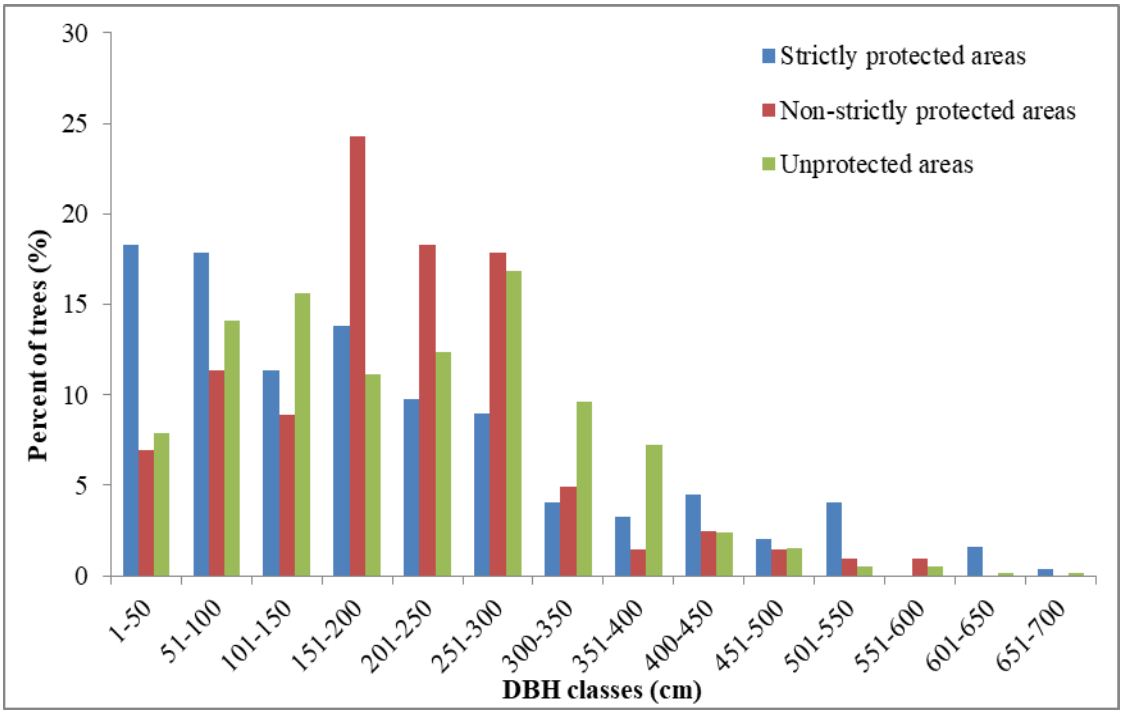

Figure 6: Size class distribution of baobabs in land-use types in the semi-arid areas in Tanzania

Baobab stems in time period I, suggest that the highest number of stems for the strictly protected areas compared to the other land-use types (Fig. 7). For time period II, the highest number of baobab stems was recorded in the non-strictly protected areas, while for time period III, the number of stems was more or less the same across the three land-use types. Within time period IV, the number of stems was slightly higher for the strictly protected areas compared to the other land-use types.

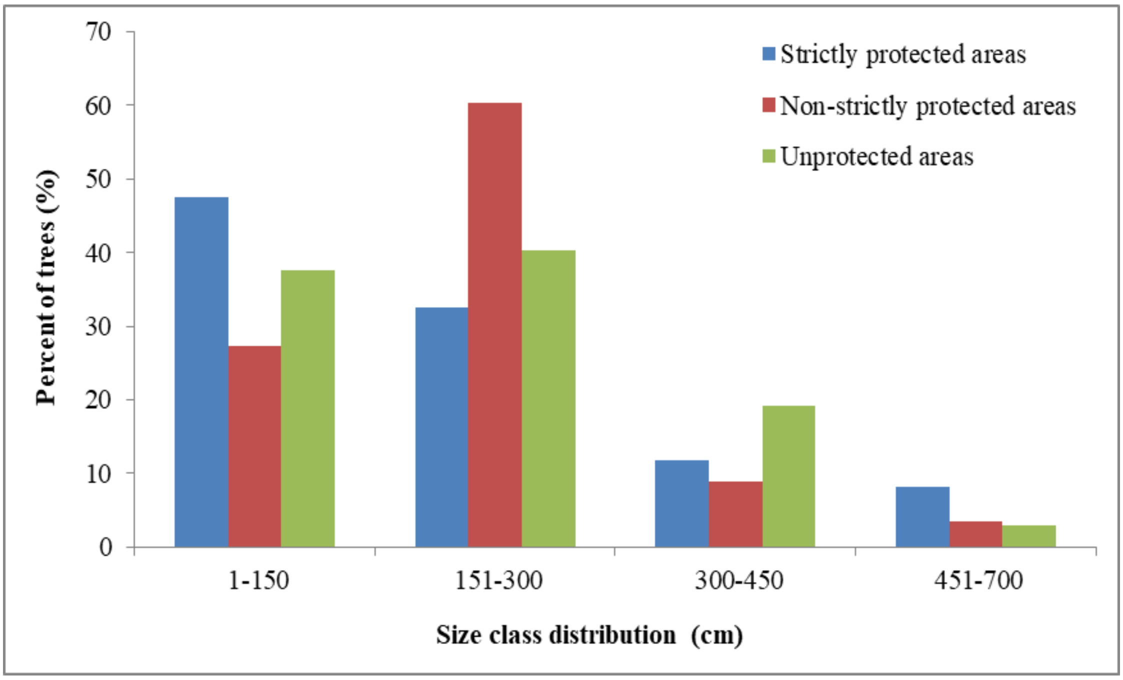

Figure 7: Size class categories of baobab over four time periods in land-use types in the semi-arid areas in Tanzania

There was a significant difference ($F_{(2,\ 1027)}$ = 24.776, p < 0.001) in baobab stem height between land-use types. The average baobab tree heights were 15.26±6.03 m, 14.32±4.6 m and 12.46±5.38 m for strictly protected areas, non-protected areas and unprotected areas respectively (Fig. 8). The average height for baobab trees across the semi-arid areas of Tanzania was 13.45±5.46 m.

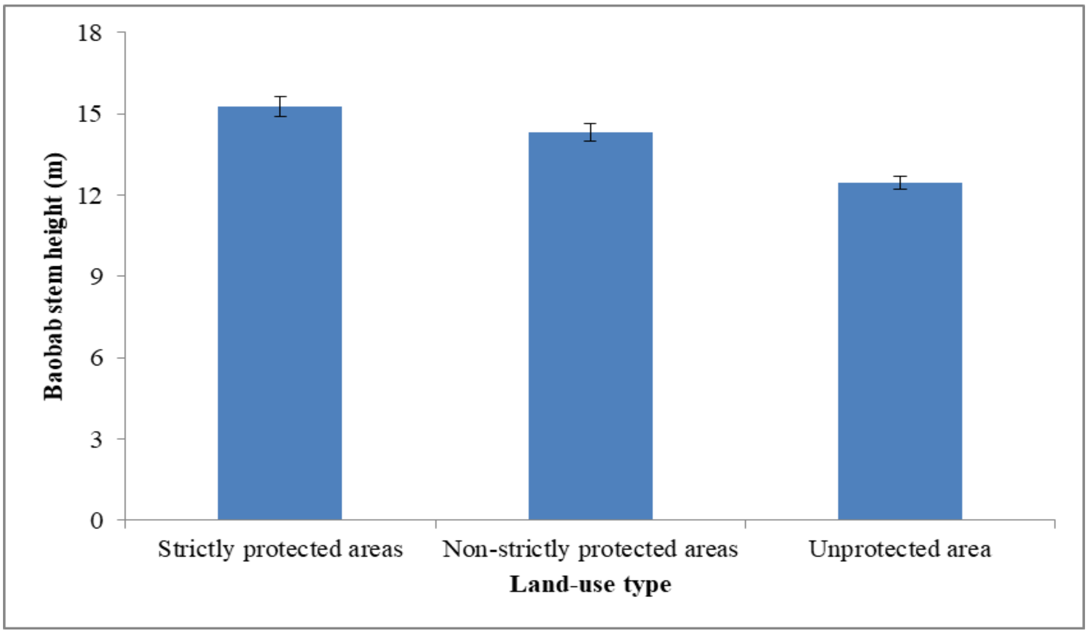

Figure 8: Baobab stems height (mean ± SE) in different land-use types in the semi-arid areas in Tanzania

(ii) Baobab spatial distribution and population density by age category

In total, 115 (34.12%) belt transects had baobabs, covering approximately 40% of the entire semi-arid areas. A total of 1033 baobab stems were recorded (246 stems in strictly protected areas, 201 stems in non-strictly protected areas and 586 stems in unprotected areas). Baobab population density across different land-use types ranged from 0.3 to 2.23 plants/ha. Land-use type ($F_{2, 165}$ = 8.201, p = 0.001) and age category ($F_{2, 153}$ = 5.194, p = 0.018) and the land-use type x age category interaction ($F_{5, 153}$ = 2.288, p = 0.049) significantly affected baobab density across the semi-arid areas. The distribution of the recorded stems over age class categories was 73% adults, 24% sub-adults and 3% juveniles. Very few juvenile baobabs were recorded across all land-uses in the semi-arid areas, with less than four (4) stems per belt transect. Only 16 (4.7%) of the 337 grid squares surveyed contained juveniles. Based on *post hoc* LSD multiple comparisons, the density of the baobab population varied substantially and significantly ($F_{2, 165}$ = 15.472, p < 0.001) as follows: 1.53±0.105 adults/ha, 0.82±0.149 sub-adults/ha and 0.33±0.253 juveniles/ha. The difference between juvenile and adult population densities was significant (p < 0.001), but the difference between juvenile and sub-adult population densities was not significant (p = 0.096).

Most juveniles were recorded in the strictly protected areas, especially towards the boundary of the national parks where most of the sub-adult baobabs were found, in the mainly unprotected central part of the semi-arid region. Adult baobabs were uniformly distributed across all land uses, with higher than average numbers in some of the National Parks (Ruaha and Mkomazi) (Fig. 9). The sub-adults age group was in the second position in the semi-arid region.

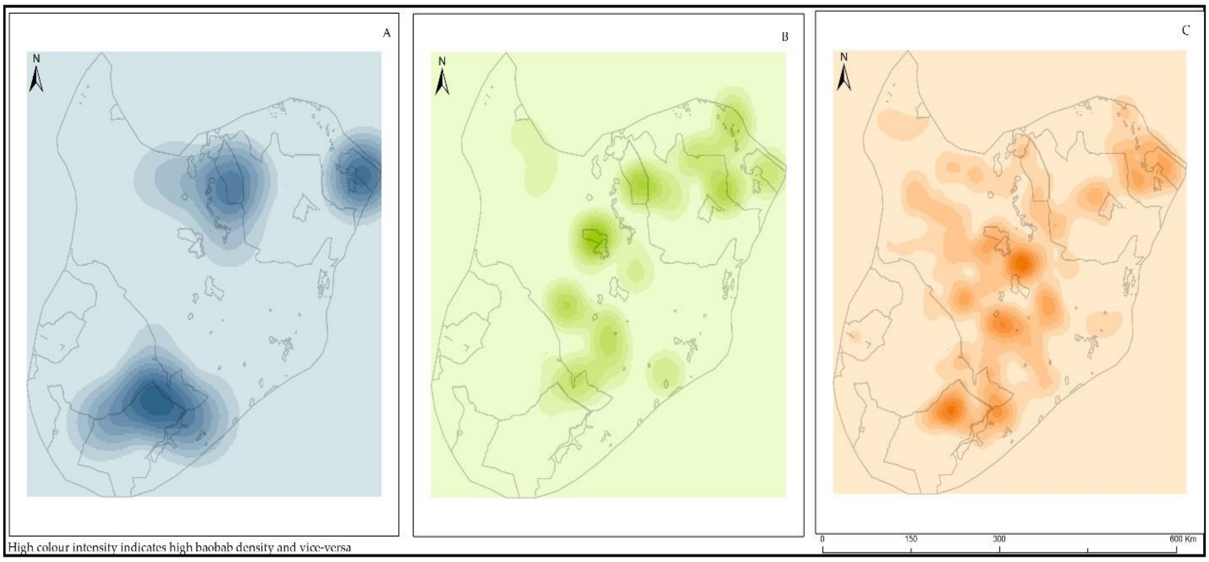

Figure 4: Baobab age-class: juvenile (A), sub-adults (B) and adults (C) distribution in the semi-arid areas in Tanzania

In strictly protected areas, baobab population density did not vary significantly across age categories ($F_{2,\ 24}$ = 4.404, p = 0.085), but the difference between adult and juvenile populations was marginally significant (p = 0.057). The population density was 2.23±0.29 plant/ha for adults, 1.25±0.62 plants/ha for sub-adults and 0.3±0.89 plants/ha for juveniles (Fig. 10). Higher percentage (53%) of adult baobabs was found in National Parks.

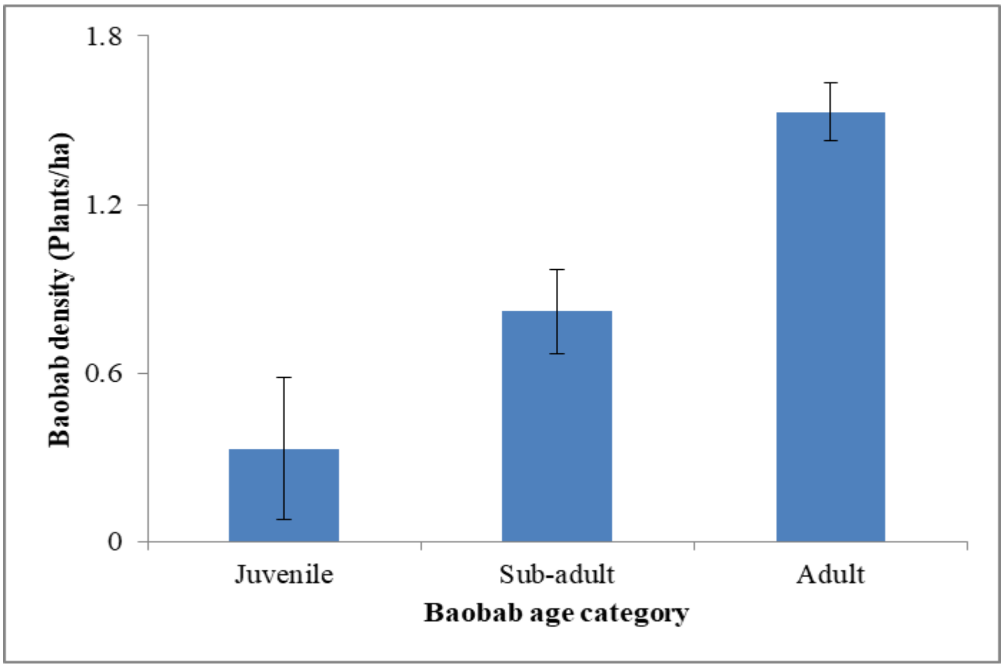

Figure 5: Density (mean ± SE) of juvenile, sub-adult and adult baobab populations across semi-arid areas of Tanzania. Bars marked with different letters (*a* and *b*) are significantly different (Fisher's LSD, p < 0.05)

In non-strictly protected areas, baobab population density varied significantly across age categories ($F_{2,\,44}$ = 4.365, p = 0.001; Fig. 11). Population density was 1.26±0.11 plant/ha for adults, 0.36±0.25 plants/ha for sub-adults and 0.35±0.16 plants/ha for juveniles. Based on *post hoc* LSD multiple comparisons, adult and juvenile population densities differed significantly (p = 0.003), as did the adult and sub-adult populations (p = 0.001), but sub-adult and juvenile populations did not differ significantly (p = 0.98).

In unprotected areas, baobab population density varied significantly across age categories ($F_{2,\,44}$ = 5.022, p = 0.008). Population density was 1.43±0.14 plant/ha for adults, 0.96±0.19 plants/ha for sub-adults, and 0.34±0.35 plants/ha for juveniles (Fig. 11). Based on *post hoc* LSD multiple comparisons, adult and juvenile population densities differed significantly (p = 0.05), adult and sub-adult population densities differed marginally significantly (p = 0.45), but sub-adult and juvenile populations did not differ significantly (p = 0.125).

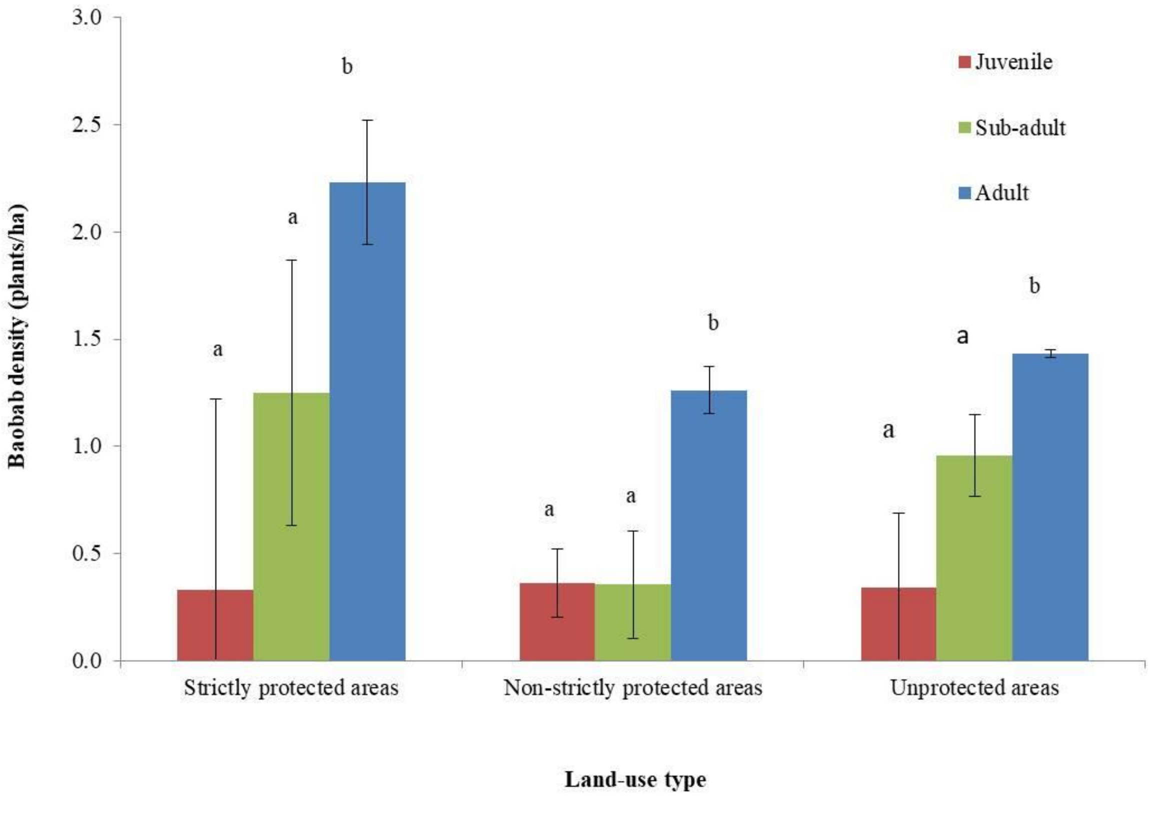

Figure 6: Density (mean ± SE) of juvenile, sub-adult and adult baobab populations in different land-use types. Bars marked with different letters (*a* and *b*) are significantly different (Fisher's LSD, p < 0.05)

(iii) Mature and juvenile baobab densities

The densities of mature baobabs were found to be higher than juvenile baobabs in all three land-use types, representing 70% of all recorded trees, with 72% in strictly protected areas, 70% in unprotected area. Baobabs was significantly ($F_{3,\ 20}$ = 3.177, p = 0.046) higher in strictly protected areas than in other land-use types, and lowest in unprotected areas, especially in cultivated lands. Paired t-tests showed significant differences between mature and juvenile baobab densities within strictly protected and non-strictly protect areas (p <0.05) but were not significantly different in unprotected areas. The differences between juvenile and mature baobab population density between all land-use types were not significant (p>0.05). In all land uses, there was a lack of regeneration because no seedlings were recorded in all land-use categories (baobab stem >1 cm DBH). The immature and mature stems ratios were 0.567 in strictly protected areas, 0.224 in non-strictly protected areas and 0.281 in unprotected areas (Fig. 12).

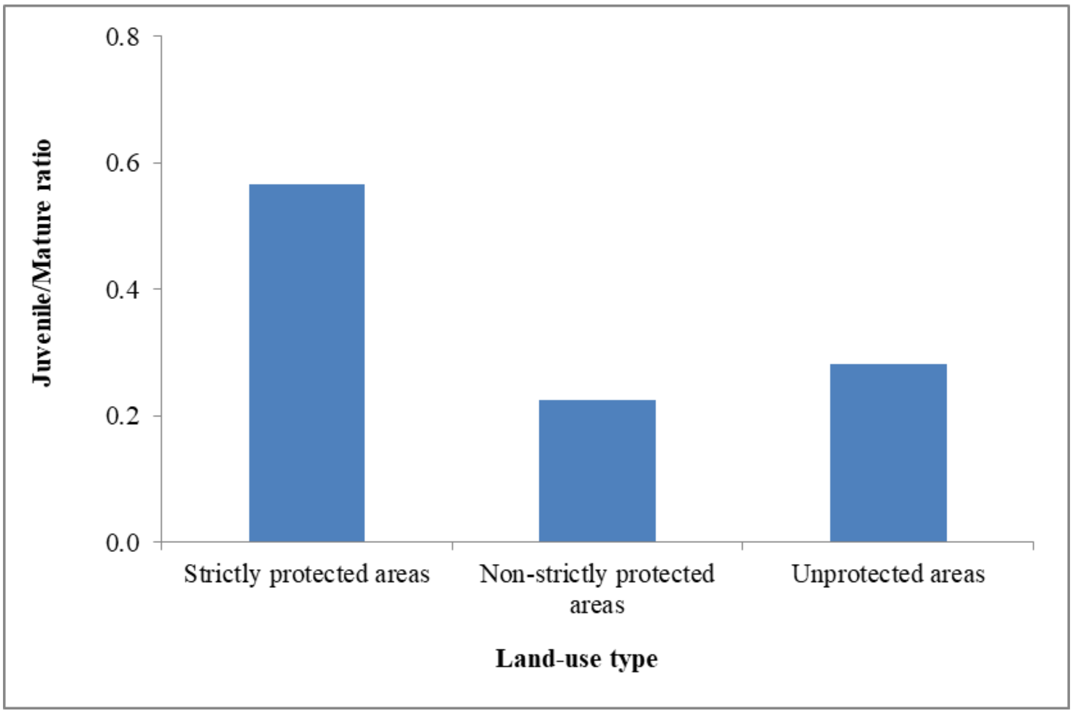

Figure 7: Baobab juvenile/mature ratio in different land-use types in the semi-arid areas in Tanzania

(iv) The health status of baobab stems from different land-uses

The health status of baobab populations in the three land-use types was assessed in terms of the presence of fruits and the number of dead trees and stem damage by elephants and people.

The difference between baobab trees with and without fruits was significant ($F_{2,\ 1026}$ = 5.332, p = 0.005). Baobab trees with fruit represented 84.4% of all trees, with 76.4% (188 trees) in strictly protected areas, 72.6% (146 trees) in non-strictly protected areas and 59.9% (348 trees) in unprotected areas. The difference between baobab trees with and without leaves was not significant ($F_{2,\ 1026}$ = 2.806, p = 0.061). Baobab trees with leaves represented 84.2% of all trees, with 99.6% (245 trees) in strictly protected areas, 96.0% (193 trees) in non-strictly protected areas and 97.1% (561 trees) in unprotected.

The difference between alive and dead baobab trees was strongly significant ($F_{1,\ 1029}$ = 68.332, p < 0.001), with an estimated 96.13% (993 trees) alive and only 3.87% (40 trees) dead (Plate 4B). About 57% of the dead trees were recorded in unprotected areas (death caused by human damages), with 83% of the dead trees in farmland, 35% in non-strict protected areas caused by both human and elephant damages, and only 7.5% in strictly protected areas, mainly caused by elephant damage in the parks.

The number of damaged baobab tree stems was higher than undamaged stems in all land uses. The main causes of baobab damage in the semi-arid area were fire, humans and elephants (Fig. 13). Human damages through debarking by machetes (Plate 4A) and use of fire were significantly different among the four levels of damage ($F_{2,\ 1029}$ = 18.951, p < 0.001). Severe stem damages (harvesting of bark) by humans were higher in non-strictly protected and unprotected areas, with more baobab stems harvested for bark in unprotected areas than other land-use types. The number of stems among the four levels of damage by elephants was significantly different ($F_{2,\ 1029}$ = 385.375, p < 0.001). Most baobab stems damaged by elephants and termites were observed in strictly protected areas, with severe elephant damages mostly observed in the Parks (Plate 4C).

Fire affected baobab populations in all land uses, with fire damage to the stem significantly different ($F_{2,\ 1032}$ = 30.784, p <0.001), with about 68% of fire-damaged stems at level 2 (severe damage-scars more numerous). The proportion of fire-damaged stems was 80.5% in strictly protected areas, 57.7% in non-strictly protected areas and 74.6%% in unprotected areas. The health status of baobab trees varied between land-use types, with 80.5% of baobab trees in strictly protected areas, 47% in non-strictly protected areas and 66.5% in unprotected areas in intermediate health status. In this study, human damages in unprotected areas and elephant damages in protected areas were the major threats to baobab populations.

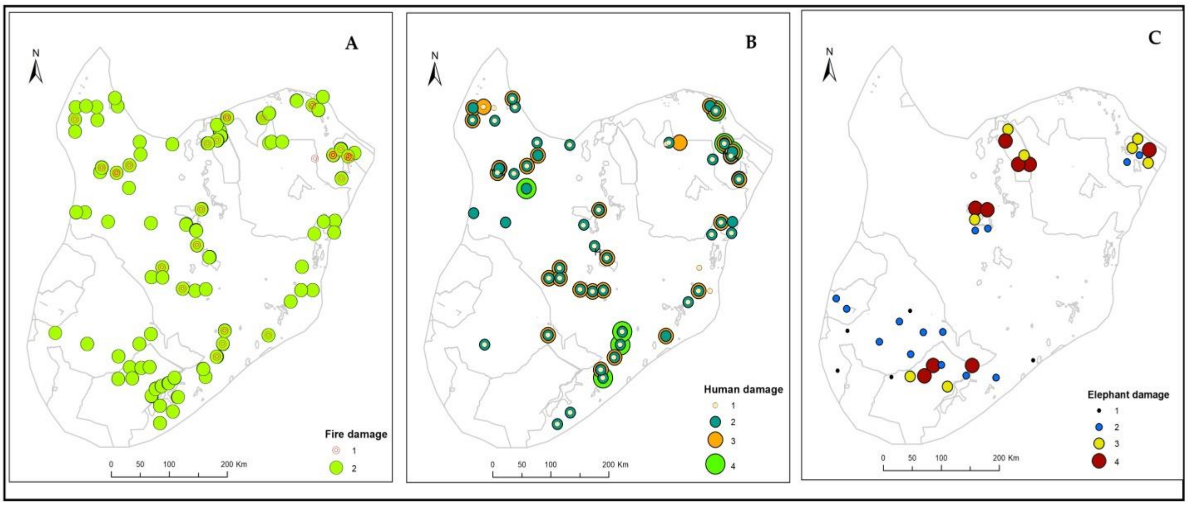

Figure 8: Maps showing baobab stems damage levels (A-Fire, B-Humans and C-Elephants) in the semi-arid areas in Tanzania

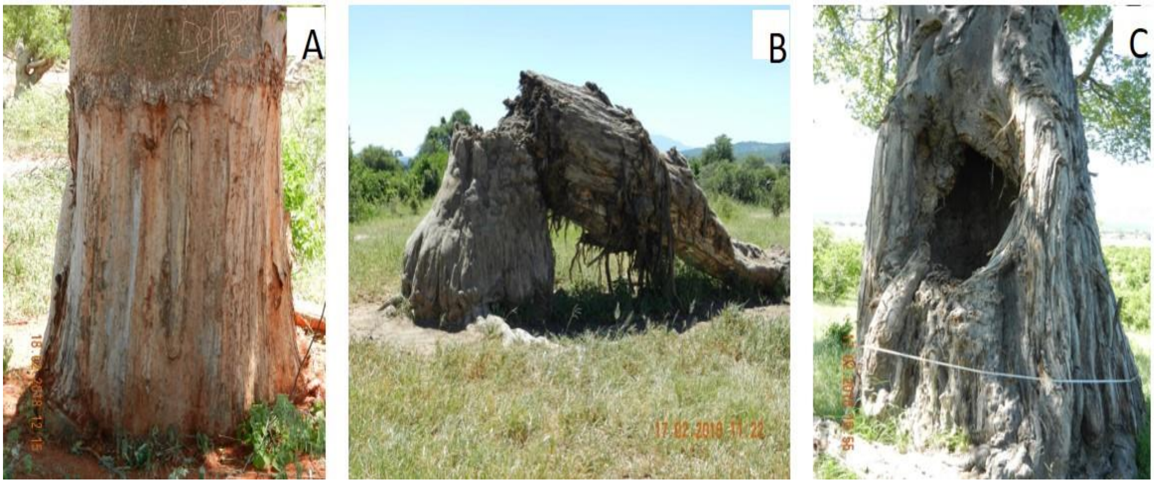

Plate 4: Baobab debarked by humans in Dodoma (A), killed by an elephant in Ruaha National Park (B) and damaged by an elephant in Tarangire National Park (C)

4.1.4 Characterization of baobab crude oil in the semi-arid areas of Tanzania

(i) Physico-chemical properties of baobab seed oil

The quality of crude baobab seed oil samples was determined by evaluating physico-chemical properties. The parameters analysed were free fatty acids (FFA), specific gravity, saponification value, unsaponifiable matter, peroxide value, and iodine value. Except for refractive index and unsaponifiable matter, no significant differences ($p > 0.05$) in the physico-chemical properties of baobab crude oil samples were observed from the three selected semi-arid regions of Tanzania (Table 6).

Table 6: Physico-chemical properties of baobab seed oil

Physiochemical properties	Region			
	Iringa	**Dodoma**	**Kilimanjaro**	**p-values**
FFA (meq/100 g oil)	1.03 ± 0.05	1.03 ± 0.05	1.06 ± 0.05	0.752
Specific gravity (g/ml oil)	0.928+ 0.001	0.928+ 0.001	0.928+ 0.001	0.47
Refractive index (at 26 ^{o}C)	1.05 ± 0.01	1.07 ± 0.00	1.04± 0.00	0.03
Saponified matter (meqNaOH/ g of sample)	196.87 ± 2.8	196.45 ± 0.77	186.83 ± 0.45	0.114
Unsaponifiable matter (g/100 g)	1.22± 0.06	1.17 ± 0.09	0.90 ± 0.08	0.001
Peroxide value (meq/Kg)	3.8 ± 0.61	3.69 ± 0.10	3.83± 0.35	0.742
Iodine Value (mEq Iodine/g)	87.16 ± 5.31	87.69 ± 0.61	90.70± 1.71	0.407

Free fatty acids

The obtained results for the free fatty acids showed that the average free fatty acids for the baobab oil samples were 1.03 ± 0.05, 1.03 ± 0.05 and 1.06 ± 0.05 for Iringa, Dodoma, and Kilimanjaro respectively (Table 6).

Refractive index

The results showed that, the average refractive indexes at 26 ^{o}C for the baobab crude oil were 1.05 ± 0.01, 1.07 ± 0.00 and 1.04 ± 0.00 for Iringa, Dodoma, and Kilimanjaro respectively.

Specific gravity of baobab crude oil

The specific gravity value is a good measure of purity of oils. Fatty acids in the oil affect the specific gravity of oil, therefore higher the value in the chain length of fatty acid present in oil, the higher the rise in the specific gravity of oils. The average specific gravity of baobab crude oil samples at 25 ^{0}C was 0.928 ± 0.001 in all the three sampled regions.

Saponification value

Baobab crude oil samples showed higher saponification values of 219.87 ± 2.8, 217.45 ± 0.77, and 210.83 ± 0.45 mg/KOH for Iringa, Dodoma, and Kilimanjaro regions, respectively (Table 2). The highest average value was obtained from Iringa region and the lowest value was obtained from Kilimanjaro regions.

Unsaponifiable matter

The study found that the average unsaponifiable matter values for baobab crude oil samples were 1.22 ± 0.06, 1.17 ± 0.09 and 0.90 ± 0.08 for Iringa, Dodoma, and Kilimanjaro regions, respectively (Table 2). The highest and the lowest values for baobab crude oil samples were obtained from Dodoma and Kilimanjaro regions, respectively.

Peroxide and Iodine values

The results showed that the average peroxide values of the baobab crude oil samples were 3.8 ± 0.61, 3.69 ± 0.10, and 3.83 ± 0.35 meq/kg for Iringa, Dodoma, and Kilimanjaro regions respectively. The highest values for baobab crude oil samples were obtained from Kilimanjaro and the lowest values were obtained from Dodoma region. In this study, the average iodine values for baobab oil were 87.16 ± 5.3, 87.69 ± 0.61 and 90.70 ± 1.71 g/100g for Iringa, Dodoma, and Kilimanjaro respectively.

(ii) Fatty acids composition in baobab crude oil

In this study, twelve fatty acids were identified and quantified from baobab seed oil collected from three different regions in the semi-arid areas of Tanzania (Table 7). Results found that the total composition of fatty acid in the baobab crude oil was 98.09 wt percent. The composition percentages of fatty acid in baobab crude oil were 68.59, 28.39, and 3.02 percent for unsaturated, saturated, and cyclic fatty acids respectively. There were no significant differences ($p > 0.05$) in the compositions of saturated, unsaturated, and cyclic fatty acids between the three regions in the semi-arid areas of Tanzania. However, there were significant differences ($F_{9,\ 125} = 236.252$, $p < 0.001$) in the composition of the twelve fatty acids identified in baobab seed oil in the semi-arid areas of Tanzania. Furthermore, there were significant differences ($F_{2,\ 153} = 11.335$, $p < 0.001$) in the compositions of saturated, unsaturated, and cyclic acids within the region. The numbers of fatty acid identified included five saturated fatty acids, five unsaturated, and two cyclic fatty acids.

Table 7: Fatty acid levels, expressed as % of total FAs in baobab seed oil

Group	Fatty acid name	Chemical name (systematic name)	Abbreviation (bonds)	Average composition (%)		
				Dodoma	**Iringa**	**Kilimanjaro**
Saturated fatty acids	Myristic	$C_{14}H_{28}O_2$	C14:0	0.28±0.13	0.32±0.14	0.34±0.13
	Palmitic	$C_{16}H_{32}O_2$	C16:0	18.38±5.87	14.99±6.87	20.48±5.98
	Palmitoleic	$C_{16}H_{30}O_2$	C16:1n-7	0.78±0.38	0.85±0.38	0.99±0.39
	Stearic	$C_{17}H_{35}CO_2H$	C18:0	1.341±1.11	2.16±1.6	1.15±2.13
	Arachidic	C20H40O2	C20:0	1.18±0.71	0.54±0.70	1. 3±0.82
			Total	**21.961**	**18.34**	**24.26**
Unsaturated fatty acids	Oleic	$C_{18}H_{34}O_2$	18:1 cis-9	24.86±3.97	21.20±3.87	21.69±3.97
	Vacenic	$C_{18}H_{34}O_2$	18:1 trans-11	2.81±0.34	2.4±0.24	2.52±0.01
	Linoleic	$C_{18}H_{32}O_2$	C18:2	3.92±2.18	3.64± 1.18	5.48± 1.18
	Linolenic	$C_{18}H_{30}O_2$	C18:3	21 .69±2.32	12.16± 1.34	26.14±1.92
	Arachidonic	$C_{20}H_{32}O_2$	C20:4	0.26± 0.20	0.733	0.53
			Total	**59.47**	**40.133**	**56.36**
Cyclic fatty acids	Sterculic	$C_{19}H_{34}O_2$		0.97±0.56	1.45	1.17
	Dehydrosterculic	$C_{19}H_{34}O_2$		1.19±0.65	0.80	1.29
			Total	**2.16**	**2.25**	**2.46**

The saturated fatty acids identified in the crude oil were Myristic, Palmitic, Pamitoleic, Stearic and Arachdic. There were no significant differences ($p > 0.05$) in saturated fatty acids compositions in baobab seed oil. The highest and the lowest compositions quantity values of saturated fatty acids were found for baobab oil samples collected from Iringa and Dodoma regions respectively. The average amount of saturated fatty acids were Myristic (0.28 - 0.34%), Palmitic (14.99 - 20.48%), Palmitoleic (0.78 - 0.99%), Stearic (1.15 - 2.16%), and Arachidonic (0.26 - 0.733%). The highest amount of Palmitic fatty acid, as opposed to other saturated fatty acids, was detected in baobab seed oil. Furthermore, Myristic acids were present in all the samples, through in low concentrations (<0.5%).

The unsaturated fatty acids identified were Oleic, Vaccenic, Linoleic, Linolenic, and Arachidonic. Baobab seed oil contained both mono (Oleic and Vacenic) and polyunsaturated fatty acids (Linoleic, Linolenic and Arachidonic). Furthermore, there were no significant differences ($p > 0.05$) in unsaturated fatty acids in baobab seed oil. The most abundant fatty acids were Palmitic, Oleic and Linoleic acids (Table 6). The range of the amount of unsaturated fatty acid found in baobab oil was Oleic (3.64 - 5.48%), Vaccenic (24.4 - 29.52%), Linoleic (21.20 - 24.86%), Linolenic (12.14 - 26.69%), and Arachidic (0.54 - 1.30%). Furthermore, the study identified two cyclic fatty acids: Sterculic (0.97-1.45%) and Dehydrosterculic (0.80 - 1.29%). There were significant differences ($F_{2,\ 23} = 13.30$, $p < 0.001$) in the compositions of cyclic fatty acids in baobab seed oil.

4.1.5 Effect of heating on the reduction of the concentrations of Cyclopropenoid Fatty Acids (CFPAs) in baobab crude oil from the semi-arid areas of Tanzania

(i) Effect of heating on fatty acids composition

Fatty acids (saturated, unsaturated and cyclic fatty acids) results from the three regions were pooled together and considered as one sample since there were no observed significant differences in fatty acids composition. There was no significant main effect on fatty acids compositions (p = 0.125) when the samples were subjected to heating at a temperature of 150 °C within 20 minutes. However, there was a significant main effect of temperature (200 °C) on fatty acids compositions (p = 0.15). Also, there was a significant main effect of temperature (250 °C) on fatty acids compositions (p < 0.001) within 20 minutes.

Effect of heating on saturated fatty acids composition

The results showed that heating temperature (range of the heating temperatures) influenced the fatty acid composition. There was a slight increase in temperature of up to 200 °C in most saturated fatty acids regardless of heating duration (Fig. 14). It was interesting to observe that, different saturated fatty acids compositions responded differently to changing temperatures. For example, a sharp increment of the percentage composition was observed during the first ten minutes of heating (at 150, 200 and 250 °C) for Palmitic acid and a slight increase was observed after 10 minutes of heating at different temperatures. However, Myristic**,** Stearic, and Palmitoleic acid percentage compositions decreased with an increase in temperature (> 250 °C). All saturated fatty acids compositions decreased at a temperature of 250 °C. There was a significant difference ($p < 0.05$) in Palmitic acid composition in all the three temperatures. No significant difference ($p > 0.05$) was observed in the heating temperature and composition of Myristic, Palmitoleic, Stearic, and Arachidonic.

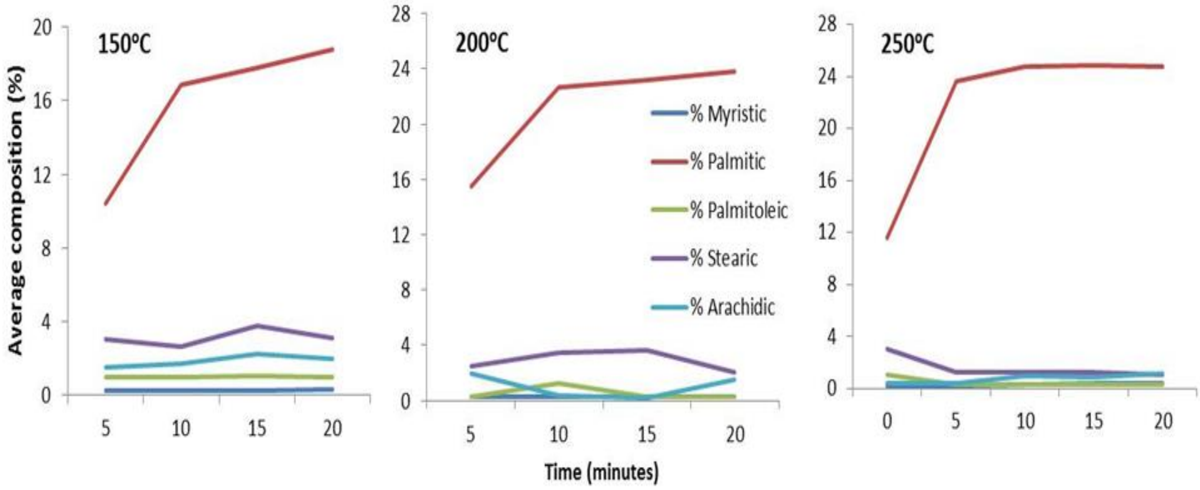

Figure 9: Percentage of Saturated Fatty Acids compositions with a variation of time and temperature

In this study, heating temperatures had a marked effect on the fatty acid compositions. The saturated fatty acids such as Palmitic, Stearic, and Arachidic show an increase in composition at 150 °C while Palmatoleic and Myristc remained almost constant with changing heating temperatures. For the saturated fatty acids, compositions increased with an increase in temperatures. Interestingly, Myristic, Palmitic, Palmitoleic, and Arachdonic increased with an increase in temperature.

Effect of heating on unsaturated fatty acids composition

In all three temperatures (150 °C, 200 °C and 250 °C), the quantity of unsaturated fatty acids decreased as the temperature increased probably due to the degradation of polyunsaturated fatty acid. Remarkably, the quantity of Oleic acid increased with an increase in temperature. The unsaturated fatty acids that decreased with an increase in temperature included Vacenic, Linoleic and Linolenic acids, and Arachidonic (Fig. 15). There were significant differences ($p < 0.05$) in Linolenic acid composition in the three temperatures. Furthermore, there were significant differences ($p < 0.05$) in oleic fatty acid composition in the three temperatures (150 °C, 200 °C and 250 °C). However, no significant differences ($p > 0.05$) were observed in the heating temperature and composition of Vacenic, Linolenicand, and Arachidonic.

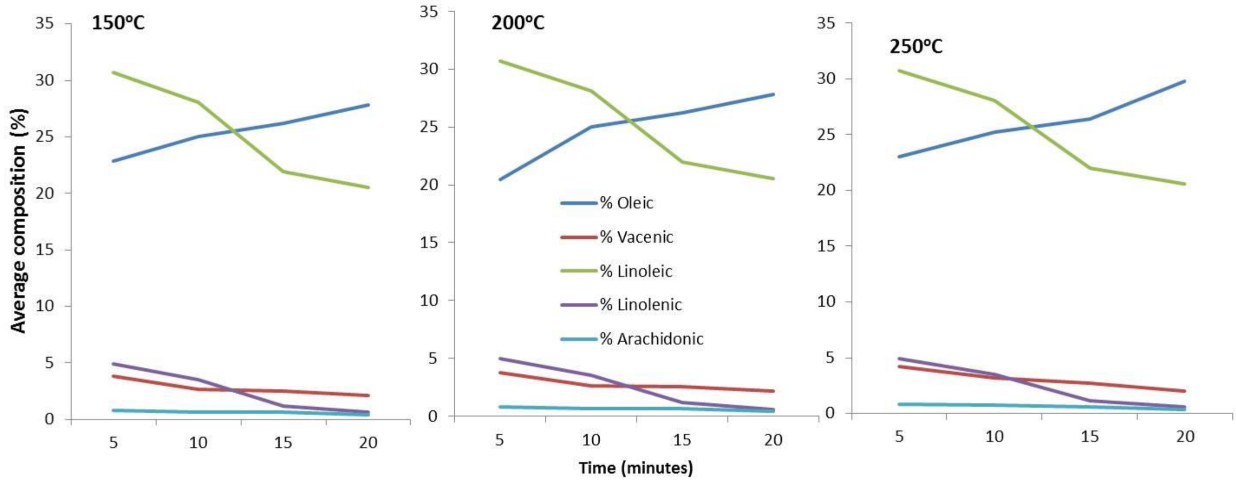

Figure 10: Percentage of Unsaturated Fatty Acids composition with a variation of time and temperature

Effect of heating and time on Cyclopropenoid Fatty Acids composition

The results show that the CFPAs compositions decreased with an increase in temperature (>150 °C). The decomposition of all cyclic acids was relatively higher at the temperature of 200 °C in 20 minutes (Fig. 16). The decomposition decreased by about 2 - 8 percent and 5 - 15 percent of the original concentration in Sterculic and Dehydrosterculic fatty acids respectively. There is a significant difference ($p < 0.05$) in Stercuric and Dehydrosterculic compositions in the three temperatures.

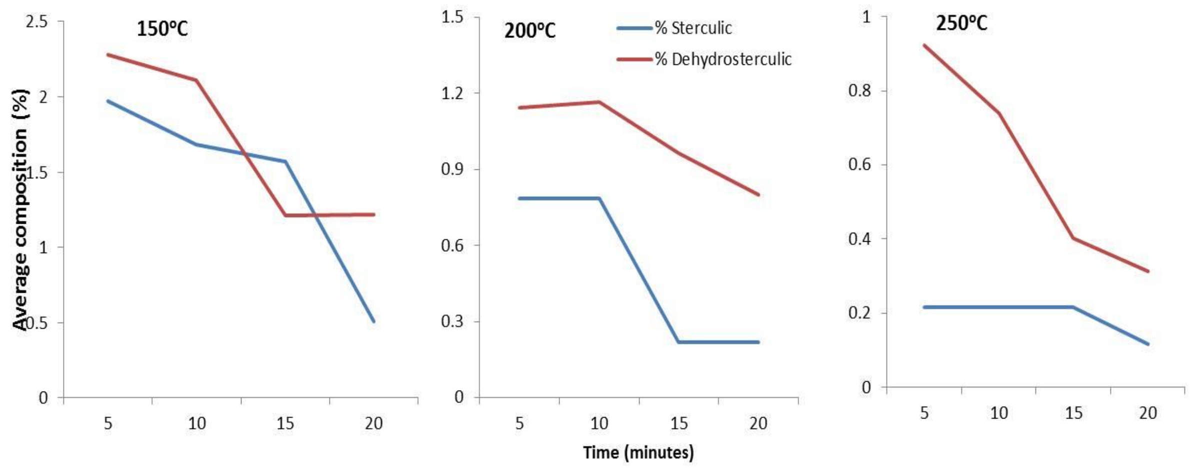

Figure 11: Percentage Cyclopropenoid Fatty Acids composition with a variation of heating time and temperature

(ii) Retention of essential Fatty acids on the Cyclopropenoid Fatty Acids removal

At 250 °C, the results show that CFPAs compositions decreased with time. Regarding essential fatty acids, Oleic and Palmitic acid increased while Linolenic decreased with heating time. Likewise, Dehydrosterculic and Sterculic acids decreased with heating time. After 15 minutes, the results show that all CFPAs had reached the composition below 0.4%, recommended by TFDA while the essential fatty acids were retained (Fig. 16).

4.3 Discussion

4.3.1 Distribution and abundance of baobab populations in different land-uses in the semi-arid areas of Tanzania

(i) Variations of baobab density with land use

The results indicate that baobab density and distribution are sensitive to both land-use types and environmental factors. Land-use intensification has been predicted to increase pressure on baobab populations in the future (Wilson, 1998; Schumann *et al.*, 2010; Schumann *et al.*, 2012). Land use is known to impact on baobab population structure (Venter & Witkowski, 2010; Schumann *et al.*, 2012). A study by Schumann *et al*. (2010) that compared stands in a protected area with those surrounding communal areas revealed that, the land-use type impacts the population structure of the baobab. I found an uninformed distribution of baobabs in the semi-arid regions of Tanzania. However, baobab density varied substantially and significantly across land-use types.

Most of the baobab populations concentrated in the central regions (Dodoma and Singida) which fall into unprotected areas running from the southern central parts (Iringa) to the northern central parts (Manyara and Kilimanjaro), which fall into protected areas. Dodoma and Singida areas had more baobab populations probably due to a combination of environmental factors that favour the growth of the baobab species and the protection due to economic and social importance of the baobab products to the local communities living in those areas (Sidibe & Williams, 2002; Aluko *et al.,* 2016).

The overall mean density for the three sampled land-use types was variable and ranged from 1.52 to 2.45 baobab stems per ha. This is within the range of recorded baobab densities in other African countries (Venter & Witkowski, 2010; Ndoro *et al.,* 2014). The observed lowest baobab density in unprotected areas is likely due to land-use changes resulting from increased human populations. Increased domestic animal numbers may also be responsible for low density of baobab in unprotected areas. Low densities of baobab in unprotected areas could be attributed to livestock browsing and trampling, clearing new fields, digging up seedlings to eat tap-roots, fire, and overharvesting of fruit and leaves. Other studies have found that low baobab densities in human-dominated areas were attributed to livestock browsing and trampling, clearing new fields, fire and overharvesting of fruit and leaves (Assogbadjo *et al.,* 2011; Chirwa *et al.,* 2006; Dhillion & Gustad, 2004).

Baobab trees in unprotected areas were widely spread with more exposure to disturbances due to high human densities, frequent domestic use of baobab fruit and lack of seedling protection. Abundant livestock in unprotected areas may account for the low baobab density in comparison to other land-use types. The people in central regions appear to have a stronger 'baobab culture' than the people in other regions which may be the reason for the high baobab populations in the central regions. Baobab culture means communities living in Dodoma and Singida have customs and social behavior with regards to baobabs. According to Duvall (2007) can aid in disappearing baobabs, foristance Manika-speaking people of West Africa effectively disperse baobab seed by collecting and using large quantities of fruit, the seeds of which are discarded around villages, where they germinate. There is also a culture of actively protecting seedlings from livestock thus increasing the recruitment success of baobabs near human habitation (Assogbadjo *et al.,* 2011; Dhillion & Gustad, 2004; Duvall, 2007). The protection is due to the benefits that the local communities derive from the mature trees (Lisao *et al.,* 2017).

It may be possible that in some parts within protected areas, lack of baobab recruitment was caused by elephants br owsing. Forestance, previous studies have documented that the distribution and population structure of *A. digitata,* which was determined by the elephant population densities (Wilson, 1998; Swanepoel, 1993; Barnes *et al.*, 1994). Likewise in their study, Barnes *et al.* (1994) revealed that baobab tree densities dropped between 1976 and 1982 due to elephant browsing in Ruaha National Park, Tanzania, while the same was reported in Lake Manyara in 1969 and 1981 (Dogulas-Hamilton, 1973; Owen-Smith, 1988). Elephants are highly associated with baobab populations and are believed to negatively affect baobab populations (Edkins *et al.,* 2008). They have been observed to reduce baobab densities by destroying young baobab trees by trampling or feeding on them (Barnes, 1980; Edkins *et al*., 2008; Ndoro *et al.*, 2014). According to the ICUC (2006), baobabs need to be protected against animals, especially during the juvenile stage. The semi-arid areas of Africa face intractable challenges related to practical pathways to social and environmental sustainability in rangelands. The rangelands make up ~90% of the habitat for the species. The rangeland area is currently undergoing enormous change including shifts from large communal to partitioned private tenure, coupled with climate change (Venter & Witkowski, 2010).

4.3.2 Main drivers of abundance and distribution of baobabs in semi-arid areas of Tanzania

(i) The effect of environmental factors on baobab distribution

I analyzed the distribution of baobabs in relation to environmental variables and determined the relative importance of rainfall and temperature to their distribution. Baobab distributions were more strongly influenced by rainfall than by temperature. The results suggest that out of the climatic variables investigated, rainfall is the main factor determining baobab distribution in Tanzania. Temperature also influences the distribution of many several species, although it explains much less of the variation. Insight into how environmental factors such as rainfall influence individual species' distribution and abundance is critical (Condit *et al.*, 2013). At a large scale, rainfall has been shown to influence species distribution (Engelbrecht *et al*., 2007; Toledo *et al*., 2012; Amissah *et al.,* 2014), whereas at smaller scales, soil fertility, topography and irradiance can affect species distribution (John *et al*., 2007; Mashapa *et al.,* 2013). Most tropical forests show seasonal variation in rainfall, and species drought performance and physiological drought tolerance have been found to determine the distribution of tropical species (Engelbrecht *et al.,* 2007; Baltzer *et al.,* 2008).

Other studies also found that rainfall is the main driver of large-scale distribution patterns of tropical plant and tree species (Bongers *et al.,* 1999; Maharjan *et al.,* 2011; Toledo *et al.,* 2012; Amissah *et al.*, 2014) while temperature may have an indirect effect on plant growth. Short-term leaf-level measurements in many tropical forest regions foristance showed that net carbon assimilation declines with an increase in daytime temperatures (Doughty & Goulden, 2008). In many countries where seasonal variability in temperature is large compared with daily variation, an increase in temperature may affect the distribution of a limited number of species (Vasseur *et al.*, 2014). However, in areas with larger temperature variation, temperature increases are likely to shift plant species (Toledo *et al.,* 2012; Amissah *et al.,* 2014).

Baobabs are dominant and originate in the dry tropical ecosystems. Sidibe and Williams (2002) argued that its relatively wide-ranging ecological tolerance probably determines the extent of the distribution of the baobabs. It usually grows at low altitudes (450-700 m), at mean annual rainfall of 150-1500 mm (Wickens, 1982). *Adansonia digitata* occurs on well-drained soils, from clay to sand and is often spared when land is cleared for cultivation (Wickens & Lowe, 2008). It has been demonstrated that vegetation structure and composition vary continuously along environmental gradients (Gauch & Whittaker, 1972; Oksanen & Minchin, 2002) especially when the gradient is long such as the rainfall gradient in Tanzania. The observed significant differences in baobabs stand density across the semi-arid regions of Tanzania were also related to environmental factors. The highest baobabs stem densities were observed in areas with a relatively medium annual rainfall (500 - 800 mm). High annual rainfall may, therefore, not necessarily be the primary factor in determining high baobabs densities. Wetter areas have relatively high baobab densities compared to dry areas (Edkins *et al.,* 2008; Mashapa *et al.,* 2013; Mpofu *et al.,* 2012). I found a significant main effect of rainfall on baobab density across the semi-arid region. It appears that baobab density declines with increasing rainfall above 800 mm. Regardless of land use, rainfall ranges of between 500 and 650 mm per annum are key to the distribution of baobabs in the semi-arid regions of Tanzania.

Studies that have evaluated the response of tropical plant species to individual environmental gradients have focused on soil nutrients, rainfall and water availability, but far less attention has been paid to the role of temperature (Amissah *et al.,* 2014). Seasonal temperature variation is minor across most tropical forests, but recent studies suggest that small temperature changes are likely to affect plant species distribution patterns (Wright, 2010; Amissah *et al.,* 2014), although there are still little data to support this point. Determination of individual species response curves to a range of climatic variables is imperative to identify the climatic variables that are biologically most relevant to individual plant species, as they can help to predict the possible consequences of climate change for tropical forests (Borchert, 1998; Amissah *et al.,* 2014). Although we did not found a significant main effect of temperature on baobab density, we learned that baobab density was highest in areas with a mean temperature between 28 ^{o}C and 30 ^{o}C (Fig. 5). Temperature seasonality is important for all plants species growth and hence for their distribution, because most annual net primary production of plants in seasonal forests is concentrated in the months with high rainfall and growth is likely to be most sensitive to temperature variability during this time of the year (Vlam *et al*., 2014; Amissah *et al.,* 2014). I also observed a significant main effect of elevation on baobab density suggesting that baobab density declines with increasing elevation (> 1000 m a.s.l).

(ii) Relationship between baobab population structure and climate in different land uses

Largely dry, the semi-arid extends well into highland zones to North and South and displays various elevation gradients due to the prevalence of volcanic and other activities below the Earth's surface (Millennium Ecosystem Assessment, 2005). Local landscapes at various scales are distinguished by substantial geological heterogeneity, dissected landforms, and resultant steep gradients of precipitation and vegetation, as reflected by results of baobab abundance and distribution. The consequent pronounced fragmentation of habitats and sharp juxtaposition of distinct landscape and use types, combined with climatic oscillations in geological time, may have contributed to major variations observed in this study. The study further indicates that baobab population and distribution are increasingly isolated and fragmented mainly within strictly protected areas of varying size, habitat and environmental diversity. Thus, the ability to sustain the species in the absence of active management is increasingly becoming constrained. The field survey in the study area recorded that wide spatial variations of baobab densities were distinct across land-use and environmental gradient. The most evident from the results are the varied densities and distribution and hotspots of baobab across the study area and in particular land use categories (Fig. 3).

In many of the semi-arid areas, a high density of baobab co-existed with extensive overlap in the land use/rainfall/extensive long-term elephant migratory routes, effectively clustered in strictly protected areas, known to harbour many elephants and located in and at extreme end of climate-elevation continuum (Wato *et al.*, 2018). The proportion of different intensities of occurrence/hotspot of baobab population indicated environmental/land use distinctions across the semi-arid regions. They have been described as being dissimilar mainly because of their use, structural, and boundary elevation. For example, residence and annual movements of the elephants delineate the semi-arid ecosystem, of which most of the time elephants are confined in the strictly protected areas and other non-strictly protected areas with sporadic movements between locations (Wato *et al.*, 2018). Consequently, elephants can act as dispersers more in the strictly protected areas where availability and access of baobab by elephants can be made. Elephants, for example, regularly migrate across the National Park boundaries to habitats that are not protected.

The geographic distributions of baobab are documented but less understood. On a local scale, this is the first and most comprehensive and rigorously quantitative study that measured its distribution and abundance in semi-arid regions of Tanzania concerning land-use types. Application of GIS technology to these data identified critical hotspots that segregated this population to various locations across environmental and land use types. The hotspots reflected a gradient of elevation, rainfall and land use types. Occupying in strictly protected areas, the management policies are designed to stabilize the densities in such land-use types. In contrast, disappearance and low densities may be traced to the activities of humans. However, some other background factors such as edaphic factors, dissected topography and dispersal agents (elephants) may be independent of human beings. Many protected areas are intensively managed; thus, claims of high plant and animal biomasses not unique. Elephant populations that have been censused regularly in these areas have indicated high numbers compared with other land use types, providing room for dispersal of baobab seeds within and around such areas lease (Owen-Smith, 1988; Swanepoel, 1993; Barnes *et al.*, 1994). The distribution of baobabs varies with geomorphology and climate in the semi-arid regions of Southern Africa including Tanzania (Wickens & Lowe, 2008). This suggests that most baobab populations tend to grow in arid-eutrophic soil types of savannas that are likely to be found in low rainfall, open grasslands (Wickens, 1982).

In the past, the herbivores in the semi-arid areas used to consist of particularly elephant (*L. africana*) and buffalo that then contributed 75% or more of total animal biomass interacting closely with baobab species and in areas where elephant populations had shown a sign of overpopulation, managers were posed with a dilemma for managing populations due to worries of regulating/reducing tree abundance (Douglas-Hamilton, 1973). While in the past, both trees and elephant densities were highest in strictly protected areas such as national parks (Douglas-Hamilton, 1973). Results of the present study suggest that elephants target large baobabs (girth ≥ 5 m) (Kupika *et al.*, 2014), signifying that damage of baobab by elephants in these areas is not necessarily detrimental to succumb to mortality. Baobabs act as the biomass of high quality forage and high density and principal forage plants for elephants. Baobab seeds are dispersed by elephants and can be transported long distances elsewhere they can germinate easily after passing through the alimentary canal of elephants. There is a potential for damage and clearance of plant species which could at some point if no action is taken lead to local extinction. The current land-use intensifications, likely due to increased cultivation, may lead to increasing pressure on baobab population in the future and display a conservation concern over the long-term. Therefore, there is a need to adopt management strategies that guarantee the continuous existence of this economically-important plant species.

4.3.3 Demography of baobab populations in different land uses in semi-arid areas of Tanzania

(i) The size class distribution across different land uses

Baobab trees with smaller diameters were observed in all land-use types. The size class distribution curve of strictly protected areas stands was an inverse '*J*-shape', which indicates good rejuvenation. In contrast, the curve of non-strictly protected areas and unprotected areas stands was bell-shaped, indicating a lack of recruitment. Schumann *et al*. (2010) revealed that the recruitment of baobab was higher inside the protected area than it was outside, despite human utilization and elephant presence in the park. This study found that land-use type has an impact on the population structure of the baobab. A *J*-shape describes a curve of many trees over DBH that is steeply and steadily declining (Rubin *et al.*, 2006). It was observed that the diameter distribution follows a reversed *J*-shape meaning the number of lower diameter class (young) trees is higher, an indication of adequate recruitment. In such cases, the frequency of small trees is higher compared to the old ones. That pattern indicates a balance between recruitment and mortality of baobabs (Wilson & Witkowski, 2003). This suggested that baobab recruitment in strictly protected areas was relatively high and represents a steady-state and transitional increasingly viable baobab population (Lykke, 1998), despite high elephant damage and high fire frequency within this particular land-use type. Biologists generally use the classic inverse-shaped size class distribution as an indication of a healthy, recruiting population, and deviation from this would typically be a cause for concern (Wilson & Witkowski, 2003). The argument is that a healthy, viable and potentially growing population has a reverse size-class distribution, with a mono-modal distribution in numbers from a maximum in the juvenile size class (Condit *et al.,* 1998; Edkins *et al.,* 2007). Baobab size class distribution in unprotected areas had a positively skewed-sized class distribution which indicated the existence of irregular growth patterns (Wickens & Lowe, 2008). Therefore, the present study highlighted and indicated a concern over the unbalanced size class structure distribution of baobabs in unprotected areas, which suggested a baobab recruitment bottleneck. This study displays the concept of regeneration niche (Grubb, 1977) that species-environment interaction may vary with plant life stage (size class); thus, juvenile baobabs could have different requirements from adults and may, therefore, have different distribution patterns from adults. However, a large number of seedlings were recorded in unprotected areas. Selective protection of bigger baobabs by communities may contribute to the high densities and occurrence of trees in bigger size classes compared to juveniles.

Bell-shaped size class distributions for non-strictly protected areas and unprotected areas may not necessarily indicate an unstable population. Baobab can sustain population levels with low or sporadic recruitment (Venter & Witkowski, 2013). The lack of baobab plants of < 2 m DBH in the semi-arid areas indicates high rates of seedling mortality that may be due to elephant damage and human use of baobab seeds. The lack of plants in some size classes may be a result of a natural disaster such as drought, flood, fire or diseases as this may result in the death of cohorts. Long-term monitoring of these populations may yield results that will help understand baobab population dynamics in the semi-arid areas of Tanzania.

The population status of baobab over the four-time period across the three land-use types suggest that some trees in the 'even'-aged cohort grow faster and some grow slower, and the height of the curve lowers because of differential growth and mortality, and different factors in each land use type caused mortality in the different land uses (Geldenhuys, 2010). It is speculated that this may relate to factors other than the specific land use such as different growth in rocky areas, and differential intensities and frequency in rainfall at a local level across the different parts of the landscape. In their study in Namibia, Lisao *et al.* (2018) found that the proportions of baobab damage by humans and wildlife (e.g. elephants) (herbivory) varied spatially and were as well influenced by resources (e.g. rainfall) distribution and amount. Overall, there seem to be enough younger trees in each land use. This might be due to a combination of biotic and abiotic factors occurring at a local level which may then have feedback into the local baobab population. These historical and emerging factors might act in time and space driving dynamics of baobab population in different land-use types differently, thus, contributing to better or poorer survival, such as people uprooting younger trees when cultivating fields, or higher mortality caused by larger numbers of elephant, or more fire damage.

(ii) Baobab spatial distribution and population density by age categories

Juveniles showed the lowest presence and density of the age categories, and most juveniles were observed at the edge of the protected areas. This is probably because juvenile baobabs are facing grazing pressure from both livestock and elephants during dry seasons. For example, in protected areas, juveniles are destroyed by elephants, and in unprotected areas, juveniles are destroyed by humans and browsed by livestock. Harvesting juveniles for food and medicine might be among the reasons for few juveniles in unprotected areas. Most of mature fruits are harvested and taken away with the seeds resulting in few seedlings in the unprotected areas. Sub-adult baobabs were mostly observed in unprotected areas. This might be due to land transformation resulting from agricultural activities and grazing. These activities are detrimental to baobab trees with large diameters.

It was observed that strictly protected areas supported few large parent baobab trees and reasonable seedlings of DBH less than 50 cm. Grazing and herbivory by both elephants and livestock, fire and debarking by humans were the main factors driving those DBH distribution categories in each of the land-uses. It is possible that outside these well-protected areas, cutting has removed most large trees and the remaining adults are small producing relatively few seeds. Furthermore, some general factors affecting recruitment include location and elevation perhaps indicative of higher precipitation might have influenced baobab age categories and population densities across the semi-arid areas.

Baobab size (i.e., stem diameter and plant height), a good indicator of photosynthetic growth, significantly differed across land-use types; baobabs in strictly protected areas were relatively larger and taller than in unprotected areas. This study observed the mean baobab density in the semi-arid areas ranged between 0.3 to 2.23 plants/ha. This is within the range of other recorded baobab densities in other African countries (Venter & Witkowski, 2010; Ndoro *et al.,* 2014; Msalilwa *et al.,* 2019a). The density of the baobab juvenile, sub-adult and adult populations varied across all land-use types in the semi-arid areas. The observed significant differences in stand density between different land uses were related to causal factors for the differences. These were assumed to be caused by differences in the land-use types and biological factors such as herbivory and fruit predation. Furthermore, the observed density differences in the baobab population probably resulted from edaphic factors such as differences in soil nutrients, soil depth, soil drainage, soil moisture, and climatic induced aridity droughts.

(iii) Mature and juvenile densities

Land-use type is a significant factor that impacts the population structure of baobabs (Schumann *et al.,* 2010; Venter & Witkowski, 2010). Agricultural cropping may result in fewer seedlings because baobab seedlings are usually removed when clearing new sites for growing crops, to reduce competition with their crops (Lisao *et al.,* 2018), with similar observations in other countries (Dhillion & Gustad, 2004; Venter & Witkowski, 2013). However, the adult trees are normally retained, resulting in more adult trees than those in the juvenile stages. Traditionally, important large trees, such as baobab, are protected by cultural norms in African communities (Sidibe & Williams, 2002; Lisao *et al.,* 2018). This may contribute to the high ratio of mature trees to juveniles. The same trend has been reported in other parts of Africa (Dhillion & Gustad, 2004; Edkins *et al.,* 2007; Cuni Sanchez *et al.,* 2010; Schumann *et al.,* 2010; Munyebvu *et al.,* 2018). Cattle and goats are common domestic animals that occur in the semi-arid areas. While these are dispersers, they may also destroy seeds when feeding and therefore negatively impact recruitment. Seeds may also be dispersed to areas where suitable germination conditions are not met and therefore fail to establish. Venter and Witkowski (2013) indicated that baobab seedlings might be destroyed by repeated browsing by livestock, contributing to a lack of juveniles. The lack of juveniles may indicate a high rate of destruction of seeds before the establishment or destruction of fruits before maturing, resulting in a reduction of viable seeds. Geminated baobab seedlings may likely be browsed by cattle, goats and donkeys which are found in high densities in those areas. Local communities in the semi-arid areas use oil extracted from baobab seeds and reduce the number of viable seeds that may potentially establish. Additionally, fire scars observed on stems may potentially destroy juveniles before recruiting into larger trees, which are more resilient to fire.

(iv) Baobab stems' health condition

The high rate of damage of stems in the semi-arid areas is a combination of stripping by elephants and harvesting of bark by humans. Most baobab stems were pruned and debarked in villages, croplands and settlements. Nearly all baobabs had fire scars and elephant damages in the strictly protected areas. Debarking and pruning by humans was somehow size specific. The pruning of the baobab tree of tree-size had a significant impact on fruit production. The bark is harvested by humans, mainly for administering various ailments (Munyebvu *et al.,* 2018; Lisao *et al.,* 2018). Baobab bark is the most important part of the baobab tree (Lisao *et al.,* 2018), but the use of baobab bark needs to be regulated. Sustainable harvesting is recommended with recovery periods of 8 years for bark thickness and 12 years for fibre quality (Romero *et al.,* 2001). The study identified that baobab populations in the non-strictly protected areas and unprotected areas might be exposed to local extinction. Investigation of seedling regeneration in unprotected areas is critical for the conservation of baobab. Regardless of the resilient nature of the baobab stems, excessive bark harvesting increases the vulnerability of the trees to diseases (Kassa *et al.,* 2014). The observed rates of damage to the baobab trees may not be sustainable. Recovery periods are recommended to allow the bark to recover before harvesting fully. Studies to investigate population genetics is critical to ensure genetic diversity is maintained and for better conservation strategies. Additionally, baobab trees play essential ecological roles as a keystone species. It has been shown by the presence of beehives and bird nests observed on the trees. Conservation of this species is therefore crucial in maintaining stability in the ecosystem.

Elephants are a significant contributor to baobab bark damage, especially in the dry seasons (Weyerhauser, 1985; Romero *et al.,* 2001; Msalilwa *et al.,* 2019b). As a succulent, it can serve as a source of water. Mudavanhu (1998) found a relationship between bark harvesting and sooty disease. Ndoro *et al.* (2014) observed that elephants damaged 98% of baobab trees in a National Park in Zimbabwe. Elephants strip damage the bark of older baobab trees, weakening the tree and making them more prone to disease infections and fire. A study in Zimbabwe has indicated that some trees may not produce fruits for up to four years due to depleted resources resulting from elephant damage to the bark (Swanepoel, 1993). Fire and elephant damage play a vital role in the dynamics of many similar woodlands in East Africa (Mwalyosi, 1990); both are common in the semi-arid areas. Furthermore, termite activity, which is a feature of many woodlands and dry forests (Menaut *et al.,* 1995), affecting soil characteristics such as structure, texture, moisture status and organic matter and hence vegetation productivity, structure, and dynamics, is quite frequent in the semi-arid areas. A study by Menaut *et al*. (1995) reported that fire, regeneration capacity, and the role of termites played a crucial role in the woodland dynamics. In general, animals are essential for seed dispersal and for shaping the woody vegetation through browsing. Heavy browsing and grazing of baobab trees by goats and cattle were observed in the semi-arid areas. It has been established that cattle browsing and trampling play a significant role in the early growth and subsequent development of the baobab population (Menaut *et al.,* 1995; Eshete, 2000).

4.3.4 Characterization of baobab crude oil in the semi-arid areas of Tanzania

(i) Physico-chemical properties of baobab crude oil

The physico-chemical properties from the three different regions, except for refractive index and unsaponifiable matter, did not show any significant differences ($p > 0.05$). This might be due to the fact that there were no variations in the environmental conditions in the regions where baobab fruits were collected.

Free fatty acids

The highest values of free fatty acids were obtained from Kilimanjaro region. However, the values from all the three regions were lower than the values of 2.6 for baobab oil reported by Ajayi *et al.* (2003). The low free fatty acids of baobab oil indicating that the oil may have a long-shelf life and can be stored for a long time (Passera, 1981). Baobab oil is extremely stable and with proper storage conditions, it can have a highly variable shelf life of up to 5 years (Raimondo *et al.,* 2009; Vermaak *et al.,* 2011). Furthermore, the fatty acid profile could significantly change due to the storage and climatic conditions; the profile could increase with a period of storage, air, heat, traces of metal, peroxides, light, or double bonds present in the oil and thus leading to the deterioration of the quality (Idris, 2020).

Refractive index

The results for the baobab crude oil refractive index from the three regions were lower than the results reported by Idris (2020), which indicated baobab oil refractive index values of between 1.436 and 1.459. Findings indicated slightly lower values than the values reported by Idris (2020) possibly because the oil solidified after exposure to air (Kadam, 2012).

Specific gravity (SG)

The obtained average SG for baobab crude oil values from the study are within the WHO limit of between 0.91 and 0.93 (Alimentarium, 1999). The values are approximately similar to the values reported by Idris (2020) for the baobab oil. These values are within the range for vegetable oil such as the specific gravity ranges recommended by WHO/FAO for niger seed, sunflower, and palm oils of 0.917 - 0.92, 0.919 - 0.923 and 0.891 - 0.899 respectively (Alimentarium, 1999). The specific gravity indicates the purity of the oil. The lower the SG value, the pure the oil and *visa versa*.

Saponification value

Saponification value determines the average chain length of the molecule and hence the estimated molecular weight of the fatty acid in the oil. Saponification equivalent is directly proportional to the average chain length of the fatty acid present (Pervina *et al.*, 2012). For example, the higher the saponification value, the lower the average molecular weight (O'Brien, 2008; Ekwu, 2004). The findings from the study are approximately similar to the findings in a study by Nkafamiya (2007) who recorded the saponification value of 196±0.05 mgKOH/g for the baobab oil. The observed values are within the range of the other edible oils (187 - 196 mgKOH/g) and are used in soap making (Eromosele & Eromosele, 1993). Ikhuoria (2007) observed that the saponification values of Pepper fruit (*Dennettia tripatala*) fruit oil was 159.33 mgKOH/g. Furthermore, a study by Nwinuka (2009) reported that, the saponification values of the African pear oil were 143.76 mgKOH/g. Higher unsaponifiable matter results in restively lower saponification value which implies that the oil is suitable for soap making (Ikhuoria, 2007). Baobab oil has been used in soap industries for many years in the world (Ikhuoria, 2007; Nwinuka, 2009).

Unsaponifiable matter

Unsaponifiable matter is that fraction of oils and fats which is not saponified by caustic alkali, but is soluble in ordinary fat solvents. Unsaponifiable matters such as hydrocarbon, pigments, waxes, higher molecular weight alcohols, and sterols do not react with bases during the formation of soap. The average values obtained for the unsaponifiable matter from the three regions are similar to the value (1.7) reported by Idris (2020). Also, Abubakar (2015) reported unsaponifiable matter value for baobab oil of 1.46. The low unsaponifiable matter indicates that the oil can be used for biodiesel production (Idris, 2020). The baobab seed oil has been reported as one of the most suitable feedstocks for biodiesel production, according to the fatty acid methyl ester profile that becomes one of the critical factors (Ali, 2013). Furthermore, low unsaponifiable matter of the baobab oil suggests that the oil could be edible because observed value of unsaponifiable mater (Table 2) was within the recommended range of edible oils.

Peroxide and Iodine values

Peroxide value of oil measures the deterioration of oil over time. The higher the peroxide values the lower the storage period of oil over time. The obtained average ranges for the baobab crude oil are within 0 – 10 mEq/kg stipulated for freshly prepared vegetable oil (Cooks, 1966). Adebisi and Olagunju (2011) demonstrated that peroxide values greater than 10 meq/kg was highly susceptible to auto-oxidation when exposed to moisture or trace elements. The obtained values in a study were close to the value obtained by Babiker (2017) who reported the peroxide value for baobab oil of 4.08 mEq/Kg. This suggests that the baobab oil has a higher resistance to lipolytic hydrolysis and oxidation, and with proper storage conditions, it can be stored between 2 and 5 years without undergoing rancidity.

The iodine value has been used as a measure of the susceptibility of the oil to oxidation (Zuleta *et al.*, 2012). The iodine value shows the amount of double bonds present and the degree of unsaturation of the fatty acids in the specific oil. The obtained average iodine value implies a low percentage of unsaturated fatty acids in the baobab seed oil. Results are similar to the results in a study by Nkafamiya (2007) who reported the baobab oil iodine value (IV) of 87.9 ± 0.02 g/100 g, groundnut oil (84 - 99 g/100 g), olive (79 - 90 g/100 g), and castor oil (81 - 91 g/100 g). These ranges of iodine values suggest that the oil contains a low degree of unsaturation and can, therefore, be classified as non-drying edible oil because a range of 80 – 100 g/100 g iodine has been suggested for most edible oils (Pearson, 1981).

(ii) Fatty acids composition in baobab crude oil

The compositions of the fatty acids did not vary in the three different regions. This implies that there were no variations in the environmental and soil conditions in the three regions. Conceivably, the evolution of baobab populations into ecotypes with the possibility of genetic drift, the seed oil FAs content pattern remained highly conserved. The results for the total fatty acid composition in baobab crude oil obtained in this study were similar to those reported by Idris (2020) who obtained 98.76 wt percent for the fatty acid composition. The compositions of Palmitic, Oleic and Linolenic, and Vaccenic fatty acids were higher compared to the compositions of other fatty acids. The higher fatty acid compositions of the baobab crude oil in this study were in the ranges of previous studies (Summers & Viljoen 2017; Azafimamonjison *et al*., 2017). Moreover, the oil contains CPFAs mainly Sterculic and Dehydrosterculic which is the characteristic property of Malvaceae family. Surprisingly, Malvalic acid was below the detection limit in the baobab crude oil, hence it deviates from the results reported in literature by Bianchini (1989). The absence of Malvalic acid could be attributed to the sample preparation method which involved oil extraction from baobab seeds using a pressing machine leaving out the seed coat during fatty acid quantification (Bianchini, 1989). The composition of the CFPAs found in the baobab crude oil Sterculic (0.97-1.45%) and Dehydrosterculic (0.80- 1.29%) was higher than the recommended quantity for human consumptions (TFDA, 2013).

4.3.5 Effect of heating on the reduction of the concentrations of Cyclopropenoid Fatty Acids in baobab crude oil from the semi-arid areas of Tanzania

The variation in the heating temperatures influenced the compositions of saturated, unsaturated, and cyclic fatty acids. The observed effects of heating on fatty acid compositions were the same as those observed by Alil (2017). The compositions of saturated fatty acids responded differently to the changing temperatures. During hearting of the baobab oil, chemical reactions occur. One of the reactions was that, oxygen with unsaturated fatty acids resulted in hydroperoxides. A study by Ludger (2014) observed that the geometrical isomerization of double bonds resulted in the formation of Trans fatty acids during the hearting of oils. For the saturated fatty acids, the compositions increased with an increase in temperatures in the study.

Unsaturated fatty acid compositions decreased with an increase in temperatures probably due to the degradation of polyunsaturated fatty acid. A similar observation was made by Ali *et al.* (2013) during Thermo oxidative degradation of canola oil. A decrease in unsaturated fatty acid was mainly due to the reaction of oxygen with unsaturated fatty acids resulting in hydroperoxides, which immediately degraded in further radical reactions at heating temperatures. The results are similar to the results in a study by Marr and Ingraham (1962) and Canvin (1965) who reported a decrease in the proportions of unsaturated fatty acids as temperature decreased. In a study, it was evident that heating temperatures had a noticeable effect on the CFPAs and fatty acid compositions. For example, heating reduced all CFPAs composition significantly below 0.4 percent. This is the recommended level for human consumption by TFDA (2013). The major breakdown of CFPAs in the baobab oil occurred at 200 °C and 250 °C. To reduce the CPFAs in the baobab oil, heat is needed for post-extraction treatments to make them fit for consumption (Andrianaivo-Rafehivola, 1995). These would be the best temperatures in the refining process of the baobab oil. Similar observations were made by Bianchini *et al.* (1983). Therefore, the heat might reduce cyclopropenic fatty acids from the baobab seed oils making them fit for human consumption. However, further studies on the composition of fatty acids and the physico-chemical parameters of baobab seed oil after the CPFA removal are necessary.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This thesis aimed to investigate abundance, distribution and structure of baobab population as well as their main drivers in semi-arid areas of Tanzania. By using bioclimatic data and land use types and their management practices as indicators and collecting environmental data at various spatial scales and in different land uses, this work contributes to the growing knowledge on factors controlling population structure and abundance and distribution of baobab species in their range areas. Furthermore, this thesis has highlighted the importance of accounting for temperature in reducing the CPFAs in crude oil of baobabs; an important aspect which is often overlooked in pharmacological studies of baobab products. This final chapter synthesizes the major findings of this thesis and its implications for both general benefits of babobab and the sustainable management of the species.

The study point out the emerging issues and challenges in baobab conservation which were categorized in three different ways namely emerging issues and challeges related to environment, herbivory and human.

The study found a significant variation both in density and occurrence of babobab trees among land uses with the highest baobab density being observed in strictly protected areas and the lowest density in non-protected areas, suggesting anthropogenic activities coupled with habitat fragmentation may be driving the abundance and distribution of baobab across the non-protected areas in Tanzania. In the advent of global demand on baobab products, the population of this species is expected to decline, and non-protected areas are expected to be the most affected parts of the species' hotspots.

Tackling this challenge would require a mix of actions across the spatial scales, including a shift in management strategy towards sustainability. This would include addressing land-use change unsustainable to baobab populations and application of breeding and other techniques that would address the problem of baobab recruitment and its ability to track climate change. Sustaining the population of baobab has both ecological and socio-economic dimensions. These must be understood if one endeavors to evaluate and implement best evidence-based management practices that can sustain the population in different land use systems at the level of spatial aggregation required for solving the problem of scarcity and species' persistence. The baobab is a semi-arid species, strongly seasonal, which thrives well as a drier deciduous woodland tree, generally function through adaptation to fire and/or grazing/browsing. It is important that in the course of establishing different management systems, when implemented, should be aligned with the ecological characteristics and management practices of the particular land use system and adaptive capacity of baobab in the targeted area.

Woodlands in tropical regions have much lower annual variation in temperature than those in temperate regions (Geldenhuys, 2010), but distinct dry/wet seasonality can produce dynamic trees and other plant species regimes which regulates how tropical trees grow and adapt. Seasonal variation in rainfall leads to differences in growth and recruitment of trees, which in turn affect population structure and community assemblages (Bond, 2008). It was one of the main aims of this thesis to provide a better understanding of how climate and land uses influence baobab population structure and health quality conditions in semi-arid areas of Tanzania.

The analyses from this study provide evidence for presence of strict conservation measures employed to conserve babobab in some of the land use types to be effective, as observed in National Parks and Reserves (Chapters 3 and 4). In chapters 3 and 4, I showed that baobab sizes and hotspots were higher in the National Parks, Forest and Game Reserves than in non protected areas, suggesting the strong effect of governance and conservation efforts in preventing decline and loss of baobab trees. These results are in line with other studies in tropical regions (Rahul *et al*., 2015; Lisao *et al*., 2018) which have demonstrated the decline in baobab populations as influenced by anthropogenic factors that negatively affect their recruitment and establishment. The findings from this study highlight particular management approaches more effective in preventing baobab loss and promote abundance gain and distribution, and provide valuable information for conservation efforts.

These findings suggest the need for more effective strategies for enforcing the existing policies to ensure that socio-economic benefits to local communities are maximized and national interests are sustained.

The initial hypothesis in Chapter 1, land-use (particularly agriculture) affects occurrence and distribution of baobabs therefore seem be to more prominent in the non-protected areas causing low hotspots that is likely to threaten baobab abundance. Accordingly, I suggested creating intact belts as buffer zones (at least 20 m from each side of the main agriculture fields) which can help to alleviate some of the observed negative effects of the land use (agricultural) activities and intensification on the baobab populations.

This study was also carried in oder to understand of baobab population hotspots in Tanzania which is of paramount importance if we are to sustainably conserve the species. The variations in land use types have been important in shaping their abundance and distribution. Unsustainable land use type conversions, changes in climate and anthropogenic activities have and are expected to play major roles in reducing abundance and distribution of baobab populations. The semi-arid regions of Tanzania harbor one of the important baobab populations in savannah regions which are continuously threatened by land use and unsustainable utilization of baobabs. Population variations both in density and occurrence was evidence among land uses with the highest baobab density being observed in strictly protected areas and the lowest density recorded in unprotected areas. The results suggest that anthropogenic activities coupled with habitat fragmentation and population pressure may be contributing to reduction and occurrence of baobabs populations in unprotected areas across the semi-arid savannah ecosystem.

A comparison of baobab density between non-strictly protected and unprotected areas showed a significant difference which suggests that environmental factors play a lesser role than land use and anthropogenic changes in influencing the observed variation in hotspots, distribution and densities within land use and across the landscape in semi-arid savannas. In long-lived species like baobabs, with less and slow recruitment rate, it takes long-time to bring population to recovery when substantial disturbance and overutilization. Therefore, there is need for management authorities to develop strategies that can ensure not only sustainable utilization of the species but also further implement actions protecting the species in all land use types. In the event of increased human population and pressure due to climate change and other triggers, unsustainable land use conversions are likely to drive the local extinction of baobabs in these fragmented populations. In the event of increased human population and pressure due to climate change and other triggers, unsustainable land use conversions are likely to drive the local extinction of baobabs in these fragmented populations.

The study assessed the baobab population structure in the semi-arid areas of Tanzania and found significant differences in DBH and height between different land-use types. The results revealed that there is a lack of baobab trees in the juvenile life stage in the semi-arid areas. Stem diameter class distributions revealed fewer young trees than adults in non-strictly protected areas and unprotected areas, whereas a higher number of young than adult trees were observed in strictly protected areas, indicating a young and stable population. This research has also revealed potential land use and other anthropogenic influence on the dispersal and population persistence of the species. However, if factors that affect regeneration are not monitored, the population of baobab may become threatened. Nevertheless, protection is accorded to adult trees by locals. Therefore, this contributes positively to the population structure of baobab. The study indicated that a significant number of trees had damaged stems, making them vulnerable to infections of the damaged stems. Though baobab recruitment is sporadic, factors that disturb and reduce numbers of baobab seedlings need to be monitored to ensure higher proportions of young trees in order to conserve baobab in the semi-arid areas of Tanzania.

This study further concludes that despite the land-use impact and the intense harvesting, baobabs are still well preserved in the semi-arid areas due to their longevity, extremely low adult mortality rates and traditional management practices. However, land-use intensification may lead to increasing pressure on baobab populations in the future. Therefore, improved management strategies are needed to guarantee the persistence of this vital species and to avoid a shortage of baobab products. Overall, the baobab population is currently considered stable in the semi-arid areas of Tanzania. However, factors that negatively impact the recruitment and establishment of baobab required to be controlled to ensure a higher proportion of young trees survive. Sustainable harvesting practices of baobab bark are recommended in unprotected areas. Active protection of established baobab seedlings and transplanting seedlings to desirable areas by local communities is recommended in order to ensure successful recruitment and maintain stable populations. This may also contribute to the conservation of the local genetic pool in future populations.

This study further identified a total of 12 fatty acids from the baobab oil. The physico-chemical properties values indicated that baobab oil is non-drying and edible. Fatty Acids profile of baobab seed oil is similar across all regions in the semi-arid zone of Tanzania. Oleic, Linoleic and Palmitic acids were found to be the major FAs and Stearic and Linolenic acids as minor FAs. The possible existence of similar environmental conditions in the semi-arid regions of Tanzania would not affect the FAs pattern but may influence the quantities of some FAs of the seed oil. There is a need to assess the pattern of FAs not included in this study in order to determine whether other FAs could be potential markers for baobab seed oil. The heating of baobab oil causes the increase of saturated fatty acid at temperature 150 °C and 200 °C. Sterculic and Dehydrosterculic fatty acids were the CFPAs detected during this study. Further studies should be carried out to investigate the presence of Malivalic acid in the baobab oil. It has been observed that a large major breakdown of CFPA was at 200 °C. The present results indicated that heating the baobab oil has an effect on the fatty acid composition as well as the amount of CFPAs. The temperature of 200 °C could be the optimal temperature in the refining process of the baobab oil.

5.2 Recommendations

The present study recommended that protected area management in the semi-arid areas of Tanzania should consider establishing long-term baobab monitoring programmes, i.e. monitoring plots in strategic baobab stands for conservation. Long-term continuous monitoring of baobab populations is necessary in order to identify the dynamics and the trend in the population structure.

Tropical biodiversity is foreseen to be critically threatened not only by climate change, but also by land-use changes (Sodhi *et al.*, 2009). Many animal and plant populations have declined in numbers, geographical distribution, or both. A few studies have addressed the potential consequences of the future climate changes on biodiversity in Africa. Knowledge of genetic parameters, especially for baobab plant traits that can be adaptive to changing biophysical conditions is almost absent, thus characterisation of genotypes is proposed for the population of this species in Tanzania.

Efficient vegetative propagation based on simple techniques that are based on local conditions and situation need to be undertaken and their efectiveness in terms of supporting recruitment and establishment of population in various local areas in order to secure immediate as well as long term gains. This process may combine both top-down and bottom-up approaches that would engage both land users and land owners, where the actual decision making by individual land users takes place.

Studies of biophysical land use systems in relation to performance of baobab recruitment trials to generating input for socio-economic evaluation under different scenarios of conserving baobab population while benefiting from their products and services would be useful in developing rewarding mechanisms that would be promoted to land owners/users and other stakeholders.

Establishing seed orchards and germplasm banks through vegetative propagation is recommended. Grafting and different micropropagation techniques can be developed, while genetic characterization and barcoding within and across populations can be done to establish best lines that can be both adaptive to climate change and rapid establishment in the areas when planted.

Domestication of fruit trees in the areas of their natural occurrence is recommended, and be tested in different local areas and upscaling this bassed on performance on their recruitment levels.

Training programme on how to propagate the baobabs and practice traditional agro-forestry system in order to restraint destruction of baobab juveniles during land tilling would be necessary. Trees collection and establishment of nurseries in different sites as sources of planting materials should be promoted across range areas. In addition, farmers may need training on identifying germinating baobab seedlings. In order to enhance baobab recruitment, protection of young seedlings in areas where the seedlings are easily monitored and better protected such as within fenced fields and villages is crucial. Where farmers have enough land size, the intentional growing of trees in combination with crops may be highly encouraged. Baobab species should be taken into consideration when revising agricultural and forest policies as a species of national importance for both food and conservation value. Areas not gazzeted as strictly protected areas are brought under pressure by agricultural land use systems increment and intensification. This should be controlled and regulated in order to avoid further transformation of most land cover types leading to loss and extinction of baobab species.

The interventions proposed by land use planners should address management practices that among others, promote sustainable management of baobab populations while mitigating the negative impacts to species persistence.

Studies on the effect of heating on the physicochemical properties should be carried out to investigate if there is change in physical chemical properties after heating of baobab's oil.

The study recommend refining of the baobab oil at higher temperatures ranging from 200-255 ^{o}C as the best way of reduing the CPFAs. Also other refining processes like hdrogenetion should be carried out.

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APPENDICES

Appendix 1: Field inventory form

Recorder: …………………. Date: ……………….. Study site name: ……………..……….

Belt transect No. ……..….. Land use type: ....………….…… GPS waypoint: ……………………………….

Sample No.	Plant status (*Alive/Dead*)	DBH (cm) *	Tree Height (m)	Elephant damage (0-4)**	Fire damage (yes/no)	Plant disturbance (debark, stump)	Fruit presence (yes/no)	Leaf presence (yes/no)

**Adult tree (dbh > 150cm), Sub-adult tree (dbh 1- 150cm), and Sapling (dbh < 1cm)*

*** Elephant damage: (0) - no damage, (1) - slight elephant damage-few scars, (2) - moderate damage-scars more numerous, (3) - severe damage-scarred deeply, and (4) - tree completely damaged-dead.*

Appendix 2: Physical chemical properties form

Sample name	FFA (meq/100g oil)	Specific gravity (g/ml oil)	Smoking temperature (^{o}C)	Saponified matter (meq NaOH/g of sample)	Unsaponifiable matter (g/100g)	Peroxide value (meq/Kg)	Iodine Value (mEq Iodine/g)

Appendix 3: Fatty acidy composition form

Temperature	Time	Regions	Values	% Compositions of fatty acid (1-12)
		Dodoma	Mean	
			Stdev	
		Kilimanjaro	Mean	
			Stdev	
		Iringa	mean	
0	0		stdev	
		Dodoma	mean	
			stdev	
		Kilimanjaro	mean	
			stdev	
		Iringa	mean	
	5		stdev	
		Dodoma	mean	
			stdev	
		Kilimanjaro	mean	
			stdev	
		Iringa	mean	
	10		stdev	
		Dodoma	mean	
			stdev	
		Kilimanjaro	mean	
			stdev	
		Iringa	mean	
	15		stdev	
		Dodoma	mean	
			stdev	
		Kilimanjaro	mean	
			stdev	
		Iringa	mean	
150	20		stdev	
		Dodoma	mean	
			stdev	
		Kilimanjaro	Mean	
			Stdev	
		Iringa	Mean	
	5		Stdev	
		Dodoma	Mean	
			Stdev	
		Kilimanjaro	Mean	
			Stdev	
		Iringa	Mean	
200	10		Stdev	

Temperature	Time	Regions	Values	% Compositions of fatty acid (1-12)
		Dodoma	Mean	
			Stdev	
		Kilimanjaro	Mean	
			Stdev	
		Iringa	Mean	
	15		Stdev	
		Dodoma	Mean	
			Stdev	
		Kilimanjaro	Mean	
			Stdev	
		Iringa	Mean	
	20		Stdev	
		Dodoma	Mean	
			Stdev	
		Kilimanjaro	Mean	
			Stdev	
		Iringa	Mean	
	5		Stdev	
		Dodoma	Mean	
			Stdev	
		Kilimanjaro	Mean	
			Stdev	
		Iringa	Mean	
	10		Stdev	
		Dodoma	Mean	
			Stdev	
		Kilimanjaro	Mean	
			Stdev	
		Iringa	Mean	
	15		Stdev	
		Dodoma	Mean	
			Stdev	
		Kilimanjaro	Mean	
			Stdev	
		Iringa	Mean	
250	20		Stdev	

RESEARCH OUTPUTS

Publications

Msalilwa, U. L., Makule, E. E., Munishi, L. K., & Ndakidemi, P. A. (2020). Physicochemical Properties, Fatty Acid Composition, and the Effect of Heating on the Reduction of Cyclopropenoid Fatty Acids on Baobab (*Adansonia digitata L.*) Crude Seed Oil. *Journal of Lipids*, *2020*, 1-13.

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Msalilwa, U. L., Munishi, L. K., Makule E. E. & Ndakidemi, P. A. (2019). Pinpointing baobab (*Adansonia digitata* [Linn. 1759]) population hotspots in the semi-arid areas of Tanzania. *African Journal of Ecology*, *58* (3), 455-467.

Poster presentation

Assessment of the status of african baobab populations and fatty acids composition of its crude oil in semi arid areas of Tanzania.