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Balanites aegyptiaca: A resource for Improving Nutrition and Income of Dryland Communities in Uganda

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Balanites aegyptiaca: A resource for Improving Nutrition and Income of Dryland Communities in Uganda

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ABSTRACT

Balanites aegyptiaca (L.) Del. (desert date), an important but neglected indigenous fruit tree in the drylands of Uganda was studied with the aim of understanding its local use and management as a prerequisite for its domestication and commercialisation for improved livelihoods of dryland communities. The specific objectives were to: (i) document local knowledge on use, management and conservation, (ii) determine the distribution and population status, (iii) assess its phenology, fruit yield and characteristics, (iv) document local processing and market potential of the leaves, fruits and oil, and (v) determine the nutritional composition of leaves, fruit pulp and kernel. The study was conducted in the semi-arid areas of Katakwi and Adjumani districts in Uganda where Balanites is commonly found and utilised. The two districts are geographically and ethnically different thus, providing a basis for comparison. Information on local knowledge was collected through household survey using a semi-structured questionnaire, focus group discussions and key informant interviews. A total of 150 respondents comprising an equal number of males and females were interviewed. Four populations of Balanites were inventoried in the wild and on-farm using plotless sampling and nearest neighbour techniques. Phenological events (leafing, flowering and fruiting) were monitored monthly over two years. Key informant interviews were conducted to capture information on local processing of Balanites products while a rapid market survey involving 45 traders and 50 urban consumers was carried out to assess market potential of the products. Forty five local leaders were interviewed using a self-administered questionnaire about policy related issues on management and promotion of Balanites in Uganda. Nutritional composition of Balanites leaves, flowers, and fruit pulp, and the fatty acid profile of the oil extracted from seed kernels were determined using standard procedures. The results revealed that both communities from Katakwi and Adjumani districts are heavily dependent on Balanites products during the dry season and have accumulated local knowledge regarding its use and management. Although the Iteso community in Katakwi district consume Balanites fruits, they mainly prefer its leaves as a vegetable. In contrast, the Madi community in Adjumani district highly value its fruits for consumption and often use the nuts to extract edible oil. All these products were traded in local markets and contributed about 12% of household incomes. The market was, however, limited by the products' short shelf life, poor processing and lack of a developed market. Both communities used concoctions made from various parts of Balanites tree to treat ailments such as, skin infections, stomach-aches and joint pains. Ecologically, Balanites is mainly found along rivers and swamps in Karamoja, Teso and West Nile sub-regions and in sites dominated by moderately acidic sandy clay soil. The population density of Balanites was higher in Adjumani (17 – 30 trees ha^{-1}) than in Katakwi (2 – 8 trees ha^{-1}). There was no significant ($P \leq 0.05$) difference in tree densities in the wild and on-farm. There are no clear management arrangements for wild Balanites trees while those on-farms are managed by land owners. Balanites was rarely planted although 51% of the farmers claimed that they retained and managed natural regeneration on farms. Regeneration is insufficient due to annual bush fires. Leafing and flowering mainly occur in the dry season (November – March) while fruiting starts during dry season and extends into early rains (April - May). Fruits take seven to eight months to develop in the rainy season, and ripen in the dry season (December – February). The method used for leaf harvesting is destructive as it involves cutting small branches bearing young leaves. Fruits are mainly collected after abscission. In Katakwi district, the leaves are boiled and sold in markets while in Adjumani district the fruits are sold fresh. The local method used by women in Adjumani district to process Balanites oil is similar to that used for processing shea butter/oil. Despite the high oil demand, its production is low due to difficulties in cracking nuts; hence only 5% of nuts are currently used for oil production. Nutritionally, Balanites leaves, flowers and fruit pulp are good sources of protein, K, Fe, Mn, Zn and Cu and in all cases, leaves and flowers were superior to fruit pulp. Kernel oil yield was 45% and the resulting oil contained four major fatty acids in the following order of magnitude: linoleic>oleic>stearic>palmitic. The level of unsaturated fats was higher (65.6%) than that of saturated fats (34.4%). There was no significant ($P \leq 0.05$) difference in fatty acid content of locally and solvent extracted oil. It is concluded that Balanites products are nutritionally and economically important for the rural dryland communalities in Uganda. There is a need to build upon the local knowledge documented in this study by developing techniques for cracking Balanites nuts to increase oil production. For the foreseeable future, work on Balanites should concentrate on value addition, product development, and sustainable management of wild and on-farm trees.

DEDICATION

This thesis is dedicated to:

My mother, Lucy Aanyu, who without attaining any formal education, supported and encouraged me throughout my studies,

and

My uncles; Prof. James Opolot and the late Christopher Opit Akais, who motivated and inspired me in various ways.

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ABBREVIATIONS AND ACRONYMS

ACORD	Agency for Cooperation and Research in Development
ANOVA	Analysis of Variance
AOAC	Association of Official Agricultural Chemists
CDRN	Community Development Resource Network
CIFOR	Centre for International Forestry Research
CSO	Civil Society Organisation
DBH	Diameter at Breast Height
DED	Department of Economic Development
DFS	District Forestry Services
DSOER	District State of Environment Report
FAME	Fatty Acid Methyl Esters
FAO	Food and Agricultural Organization of the United Nations
GC-MC	Gas Chromatography-Mass Spectrometry
GIS	Geographical Information Systems
GoU	Government of Uganda
ICRAF	World Agroforestry Centre (formerly - International Centre for Research in Agroforestry)
IFAD	International Fund for Agricultural Development
IFT	Indigenous Fruit Tree
IPGRI	International Plant Genetic Resources Institute - now Bioversity International
KADDAN	Katakwi District Development Actors Network
KDLG	Katakwi District Local Government
LC	Local Council
LK	Local Knowledge
m.a.s.l	Meters Above Sea Level
MC	Moisture Content
MDGs	Millennium Development Goals
MEA	Millennium Ecosystem Assessment
NAS	National Academy of Sciences
NEMA	National Environment Management Authority
NGO	Non Governmental Organisation
NRC	National Research Council (US)
NRI	Natural Resources Institute
NTFP	Non Timber Forest Products
PEAP	Poverty Eradication Action Plan
PMA	Plan for Modernization of Agriculture

PUFA	Poly Unsaturated Fatty Acid
RDA	Recommended Daily Allowance
RI	Adeqaute Intake
RMA	Rapid Market Appraisal
RPM	Revolutions Per Minute
SACCO	Savings and Credit Cooperative Society
SFA	Saturated Fatty Acid
SME	Small and Medium Scale Entrepreneur/Enterprise
SPSS	Statistical Package for Social Scientists
UBOS	Uganda Bureau of Statistics
UFA	Unsaturated Fatty Acid
UGX	Uganda Shilling
UIFT	Underutilized Indigenous Fruit Tree
UNCCD	United Nations Convention to Combat Desertification
UNDP	United Nations Development Programme
UNESCO	United Nations Education Scientific and Cultural Organization
UTM	Universal Transverse Mercator
WHO	World Health Organization
WIPO	World Intellectual Property Organization

CHAPTER ONE: GENERAL INTRODUCTION

This chapter introduces the context of the study on *Balanites aegyptiaca*, which is a little known but highly versatile and dependable dryland indigenous fruit tree of considerable socio-economic value. The global and regional context of indigenous fruit trees is presented in section 1.1 and points out the uniqueness of *B. aegyptiaca* in spite of being neglected as a valuable crop for the drylands of Africa. The problem statement, objectives and the conceptual framework are presented in sections 1.2 and 1.3, respectively. The significance of the study is given in section 1.4 and gender and ethical considerations in section 1.5. The study sites are described in section 1.6 and the thesis outline is presented in section 1.7.

1.1 Background to the study

The drylands of Africa are geographically complex and made up of dynamic ecosystems that house a wide variety of plant and animal species of critical importance to humans and for environmental resilience. Most of the drylands are communally owned and grazing on natural pasture is the main economic activity. However, major socioeconomic changes are occurring in the drylands and these have affected the ecosystem in various ways. For instance, increase in both human and livestock populations over the years have placed enormous pressure on the land leading to intensive degradation and loss of valuable tree species in many places. Trees are essential component of the environment in dryland farming because they play a critical role in ameliorating the effects of climate in addition to providing a wide range of products, including food for people, fodder for livestock, medicines for both people and livestock and goods of commercial, cultural and scared value. For these reasons, trees constitute a major component of the traditional dryland farming systems in Sub-Saharan Africa that successfully ensures food supply under variable and adverse conditions (NRI, 2004).

Trees are woody perennial crops that can be used in production systems that are less reliant upon agro-chemicals, assist in stabilization of agro-ecosystems, enhance biodiversity and contribute to carbon sequestration (NRI, 2004). Indigenous fruit trees (IFTs) are abundant in many parts of Africa, particularly in the arid and semi-arid areas where they play a dominant long-term role in sustaining the livelihoods of millions of smallholder farmers. According to Hughes and Haq (2003), IFTs are underutilized yet they are an important source of food and nutrition. Marketing of their products can provide an additional source of income for farmers and traders (Hughes and Haq, 2003; NRI, 2004). In addition, IFTs play vital roles in food and nutritional security in Sub-Saharan Africa, especially during periods of famine and food scarcity (Saka *et al.*, 2002; 2004; Akinnifesi *et al.,* 2004), and are becoming increasingly important as a main source of food to supplement diets in better times (Akinnifesi *et al.*, 2006).

Many reports have recognized the importance of IFTs in poverty reduction (e.g. Leakey, 1999; Poulton and Poole, 2001; Russel and Franzel, 2004; Garrity, 2004; Schreckenberg *et al.*, 2006; Mithofer and Waibel, 2008; Ham *et al.*, 2008). According to Akinnifesi *et al.* (2006), there is clear evidence that indigenous fruits and their products improve the livelihoods of small-holder farmers in southern Africa. However, this is often not acknowledged in national reporting (Schreckenberg *et al.*, 2006). This reflects a lack of official and scientific interest in the many so-called "Cinderella species" which have provided poor people with a wide range of essential everyday products (Leakey and Newton, 1994).

Schreckenberg *et al.* (2006), drawing on evidence from West Africa, argued that domestication of IFTs can contribute to raising some of the poorest people, particularly women, above the poverty line where they live on less than one dollar a day. Furthermore, the benefits of domesticating IFTs include the potential for better nutrition for the poor, maintenance of biodiversity and environmentally sustainable agricultural systems. For all these to be realized, there is a need for national governments to recognize the income contribution of IFTs in order to create a favourable market environment and provision of micro-credits for IFT-based enterprises. Moreover, farmers need multidisciplinary extension support that covers all aspects from production to commercialization and a more participatory research focus to improve management practices and productivity, and identify new opportunities for adding value and commercializing indigenous fruit tree products.

In the past, most dryland fruit trees in Africa were perceived to be abundant, slow growing and inappropriate for domestication. According to Akinnifesi *et al.* (2006), this perception has been aggravated by the limited understanding of the natural variability, reproductive biology, propagation and the lack of techniques for adding value and cultivation. Therefore, management of IFTs in the wild and/or their cultivation on-farm is generally environmentally beneficial. Akinnifesi *et al.* (2006) provided insights into the potential of integrating IFT cultivation into smallholder production systems in ways that contribute to livelihoods, biodiversity conservation and sustainable land productivity.

A large proportion of the population in the drylands of Eastern Africa face food insecurity, live in marginal environments and are highly vulnerable to the impact of common diseases including HIV/AIDS. According to Gari (2003) and Akinnifesi *et al.* (2004), indigenous fruit tree resources can play a role in reducing the impact of HIV/AIDS through improved nutrition and use of these trees for medicine. Ramadhani (2002) pointed out that IFTs contribute to both food and cash income and yet they are harvested with little regard to establishing and managing them as a renewable resource. However, IFTs and other wild food and medicinal plants are recently gaining prominence as demonstrated by a number of studies and development projects dedicated to such plants (e.g. Teklehaimanot, 2004; Chikamai *et al.,* 2004; FORRI, 2004; Okia, *et al.,* 2005; Akinnifesi *et al.,* 2006).

In southern Africa, Maghembe *et al.* (1998) reported that indigenous fruits have long been used to compliment or supplement diets because they contain vital nutrients and essential vitamins especially for growing children, who are often prone to malnutrition and related diseases. In Eastern Africa, rural farm households depend on indigenous fruits for additional income and food (Chikamai *et al.,* 2004; Teklehaimanot, 2005; Jama *et al.,* 2008) because they provide important nutrients and vitamins in diets that are dominated by cereals. The trees fruit during the late dry season and early wet season, when stocks of cereal crops are usually low and they provide an additional source of income. IFTs also play a crucial role in tapering the effects of hot climate and in facilitating crop and pasture growth beneath their crowns. It is therefore, evident that the consumption and marketing of indigenous fruits is one of the strategies adopted by communities in arid and semi-arid areas in order to survive in harsh environments.

Farmers selectively retain IFTs when farmlands are established by clearing natural woodlands. For these reasons, they constitute a major component of many African agricultural systems that successfully ensure food supply under adverse climatic and edaphic conditions. In Uganda, indigenous fruits are popular in the drylands, especially in the northern and north eastern parts of the country (Okia *et al.,* 2008). Many communities in these areas rely on indigenous fruits for food, especially during dry periods when other cultivated food crops are in short supply. Some of the fruits also generate income for rural households.

Despite their importance, the role of indigenous fruits in diversifying income generation and sustaining rural livelihoods is overlooked and receives little recognition from the development and research community (NRC, 2008). According to Teklehaimanot (2004) and Scoones *et al.* (1992), the reasons for neglecting IFTs centre around lack of information and reliable methods for evaluating their contribution to farm households and the rural economy, irregular production of fruit from wild sources, lack of quality standards, lack of international markets, production incentives related to markets and technology (low prices offered by local and international industries may discourage collection and processing of these fruits) and bias in favour of large-scale agriculture. Indigenous fruit tree resources are, however, fast disappearing as a result of deforestation by an ever-increasing population that is opening up new farmland, harvesting wood for fuel and construction and converting forest land to irrigated agriculture (UNCCD, 1998; Scoones *et al.,* 1992).

Balanites aegyptiaca (L.) Del. is one of the underutilised indigenous fruit trees (UIFTs) in the drylands of Africa (NRC, 2008). As such, it is a wild food plant. According to Hughes and Haq (2003), UIFT refers to trees bearing fruits that are not highly researched and which are generally ignored by the commercial sector. Little research has been carried out on these species and information documented about their basic biology, growing habits, management practices, processing and utilisation is scanty and scattered. Research on UIFTs is often carried out by isolated groups of researchers with their findings restricted to academic journals and dissemination of information to a wider audience, especially the farming communities is poor (Hughes and Haq, 2003). Some of the general reports on *B. aegyptiaca* include its monograph (Hall and Walker, 1991) and its potential as a lost crop of Africa (NRC, 2008). Throughout its belt in the arid and semi-arid parts of Africa, *B. aegyptiaca*, is grossly underutilized yet it is one of the dominant trees in these areas and has potential to contribute towards environmental stability, food security and poverty alleviation. Tabuti *et al.* (2004) noted that utilisation of wild food plants (including *B. aegyptiaca*) in Uganda is inefficient due to lack of knowledge on appropriate post-harvest technologies and even where information is available, it is usually scattered and users are unaware of where to get it.

1.2 Problem statement

The drylands of Africa are well-known for production of a wide range of indigenous fruits. However, due to increased human and animal population pressures, IFTs are continuously being destroyed. As a result, the critical role that these trees play in terms of ecological services, food security and health are diminishing. Consequently, communities in the drylands of Africa remain the poorest and most food insecure in the world (IFAD, 2001), and yet they have plenty of wild plant resources. There have been limited attempts geared towards providing livelihoods options for dryland communities through promotion of on-farm cultivation of indigenous trees yet this holds a great socio-economic and environmental potential. According to Leakey *et al.* (2003), domestication of IFTs is of strategic importance to poverty alleviation and sustainable development worldwide, especially in dryland Africa.

Chikamai *et al.* (2004) and Teklehaimanot (2008) have reported the potential contribution of IFTs to household food, nutrition and rural economy in eastern Africa. They have also revealed that *B. aegyptiaca* is very popular among the dryland communities in this region and it is ranked high for integration into agroforestry systems. *Balanites aegyptiaca* in Uganda is mainly found in the wild (savannas) in the north and north eastern parts of the country. Despite its wide utilization in these areas by rural and peri-urban communities for food, fodder, income and medicine, there is a dearth of information on its management, stocking densities and economic potential.

In addition, there is limited understanding of the phenology and propagation techniques of the species. The local knowledge and potential of *B. aegyptiaca* for commercialisation have not yet been explored. Furthermore, there are research gaps in the processing, marketing and nutritional value of *B. aegyptiaca* products (fruits and leaves). The purpose of study is to augment the local people's desire in Uganda and eastern Africa to generate knowledge for improved management and utilization of *B. aegyptiaca*. The findings of this study are expected to enhance ways in which Balanites products can promote food and nutritional security, increase household incomes and diversify farming systems and rural economy.

1.3 Objectives and conceptual framework

1.3.1 Overall objective

To understand the local use and management of *B. aegyptiaca* as a prerequisite for its domestication and commercialisation for improving livelihoods among dryland communities in Uganda.

1.3.2 Specific objectives

The specific objectives were to:

i. Document local knowledge on use, management and conservation of *B. aegyptiaca;*
ii. Determine the distribution and population status of *B. aegyptiaca*;
iii. Assess the phenology, fruit yield and fruit characteristics of *B. aegyptiaca*;
iv. Document the local harvesting and processing of *B. aegyptiaca* leaves, fruits and oil and explore their marketing prospects; and
v. Determine the nutritional composition of *B. aegyptiaca* leaves, fruit pulp and kernel oil.

1.3.3 The conceptual framework

A clear understanding of the wealth of undocumented local knowledge on *B. aegyptiaca* was found to be an essential entry point into exploring opportunities for improved use and management of the species. The ultimate goal was to contribute to improved nutrition and income of dryland communities through better and sustainable use of *B. aegyptiaca* and other IFTs that are abundant in the drylands of Africa. The conceptual model for the study is given in Figure 1.1.

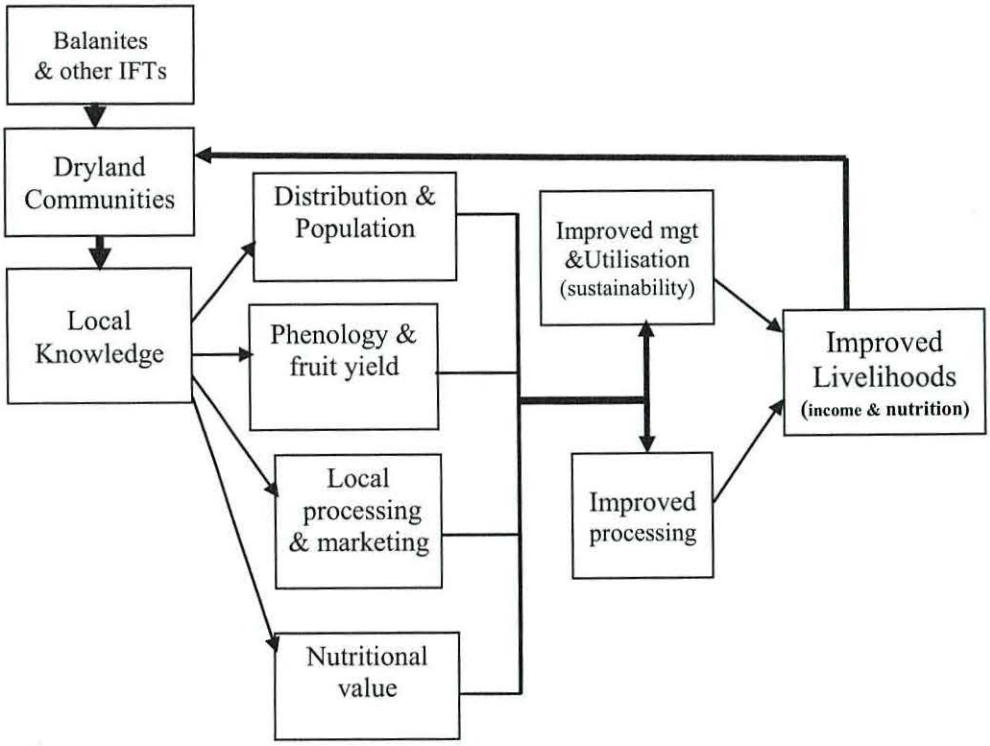


Figure 1.1 The study conceptual framework

1.4 Significance of the study

Balanites aegyptiaca is a native tree species of Eastern Africa providing fruits and leaves that are consumed and traded locally. The use of *B. aegyptiaca* for diversifying income and improving livelihoods of dryland communities in Uganda and other countries in the Balanites range can help to ensure environmental sustainability and reverse the loss of biodiversity. The study has generated knowledge that contributes to improved use and management of *B. aegyptiaca*. Ultimately, national and district-level decision-makers in government and NGOs will be expected to apply this knowledge to diversify income and improve livelihoods of the rural people.

Research from drylands of Africa reveals that rural people are incredibly resourceful even when they face extreme hardships. They need to be offered choices and a range of livelihood opportunities, and access to technologies, practices and information in an environment that makes their efforts worthwhile (CIFOR, 2003). This study has provided a foundation for empowering local people with knowledge to manage and sustainably use *B. aegyptiaca* instead of leaving the responsibility in the hands of government agencies or non-governmental organisations. Participation by local people in the study inspired and motivated the local people in Balanites rangelands and has given them the opportunity to apply the findings to manage and conserve the species.

The study was also in line with the Tunis Declaration on research priorities to promote sustainable development in drylands (UNESCO, 2006). The declaration requested both the national decision-making bodies and the scientific community to increase their efforts in implementing research for development projects in close collaboration with and for the benefit of local dryland communities, integrating modern technologies with traditional knowledge with a view to achieving sustainable development in drylands.

The study specifically addressed two of the eight United Nations Millennium Development Goals (MDGs): MDG 1 on eradication of extreme poverty and hunger by providing results which can enhance the livelihoods of rural smallholder farmers in the drylands of Uganda and beyond, and MDG 7 on ensuring environmental sustainability by providing livelihood options that ensure environmental protection and conservation of biological diversity (UN, 2005). At the national level, the study has directly contributed to Uganda's Poverty Eradication Action Plan (PEAP) and the Plan for Modernisation of Agriculture (PMA) through empowering communities in dryland areas with alternative income sources using resources that are locally available to them. This is hoped to promote community environmental stewardship thereby minimising deforestation and effects of climate change that are already evident in the drylands of Uganda.

1.5 Gender and ethical considerations

The study took into account the significant gender issues in the use and management of *B. aegyptiaca*. For instance, it is well known that most families in Uganda are patriarchal, and men have predominant control over land and natural resources, household revenues and decision-making. However, it is clear that women play a significant role in production and utilisation of indigenous fruits. Although women are the prime producers and users of *B. aegyptiaca* products, they would be the most disadvantaged when the natural populations of the species decline. Already, they travel long distances to collect wild fruits of Balanites and other trees. Therefore, the participation of women was given a special emphasis in this study.

1.6 Study area

1.6.1 Selection of study sites

A review of literature on *B. aegyptiaca* in Uganda (e.g. Eggeling, 1940; Katende *et al.*, 1995; Katende *et al.*, 1999; Madrama, 2006) and specimens in Makerere University herbarium revealed that the species is commonly found and widely utilized in Karamoja, Teso, and West Nile sub-regions. These sub-regions are located in the semi-arid areas of Uganda. Two sub-counties in Adjumani district in the West Nile sub-region and two in Katakwi district in Teso sub-region (Table 1.1) were selected for the study after a reconnaissance survey that was conducted in May and June 2007. The study sub-counties and villages were selected in consultation with the respective district forestry officials, local leaders, civil society organisations and some farmer groups. The selection criteria were based on the availability of *B. aegyptiaca* trees coupled with demonstrated use of the tree's products, mainly fruits, leaves and kernel oil.

Table 1.1 Study districts, sub-counties and villages

District	Sub-county	Villages
Katakwi	Ngariam	Acoite
	Katakwi	Aputoon
		Aboiboi
Adjumani	Dzaipi	Egge
	Adropi	Nyeu

During the reconnaissance survey, district and civil society officials, local leaders and some farmer groups were sensitised about the study and their participation was solicited. The communities and district leaders welcomed the study because it documented their knowledge on Balanites that is a source of food and income thus contributing to their livelihoods. Permission was sought from the local administration of the two study districts. The two districts vary culturally and belong to different agro-ecological zones, thus making it possible to compare the research results. Katakwi is occupied by the Iteso while Adjumani is dominated by the Madi ethnic group. The study sub-counties were selected in a manner that permitted representation of different *B. aegyptiaca* populations. The biophysical attributes and population characteristics of the two study districts are summarized in (Table 1.2).

Table 1.2 Biophysical attributes and population characteristics of Katakwi and Adjumani districts

Attribute/characteristic	District	
	Katakwi	Adjumani
Biophysical attribute		
Size of district (km^2)	2,505	3,128
Altitude above sea level (m)	1,036 – 1,127	900 – 1,500
Latitude	33°48'E – 30°14'E	31°24'E – 32° 4'E
Longitude	1°38'N – 2°20'N	2°53'N – 3° 37'N
Mean annual rainfall (mm)	1,000 – 1,500	750 – 1,500
Mean annual min & max temperatures (^{0}C)	18 - 31	19 - 36
Population characteristic		
Population density (per sq. km)	65	69
Number of males per 100 females	93	98
Annual population growth rate (%)	6.2	6.4
Average household size (persons)	4.6	5.1

Sources: NEMA, 2005; UBOS, 2007; ADLG, 2008; KDLG, 2007

1.6.2 Location and size

Adjumani district is located in north western Uganda (Fig. 1.2) in the West Nile sub-region. The other districts in the sub-region are Moyo, Arua, Nebbi and Yumbe. Adjumani district was carved out of Moyo in 1997 and it is separated from Moyo by River Nile. Adjumani is bordered by republic of Sudan to the north east, Gulu district to the east and south and Arua, Moyo and Yumbe districts to the west. It covers a total area of 3,128 km^2 of which 46.8 km^2 is water (Adjumani DSOER, 2008). It lies at an altitude ranging from 900 to 1,500 m.a.s.l. (Adjumani DSOER, 2008). Administratively, Adjumani district comprises only one county (East Moyo), two town councils (Adjumani and Pakele) and six sub-counties, namely; Adropi, Adjumani Town Council, Ciforo, Pakele Dzaipi and Ofua (GoU, 2006a).

Katakwi district is located in the Teso sub-region in north eastern Uganda (Fig. 1.1). The other districts in the sub-region are Soroti, Amuria, Kaberamaido, Kumi, Bukedea, Palliasa and Budaka. Katakwi was carved out of Soroti district in the 1970s when it was known as North Teso district. The district status was cancelled in the 1980s and reinstated in 1997 (KDLG, 2007). In 2005, Amuria district was carved out of Katakwi and left the current Katakwi district with only Usuk County while Amuria district consists of Kapelebiyong and Amuria counties

(KDLG, 2007). Katakwi is bordered by the districts of Moroto in the north, Nakapiripirit in east, Amuria in the west and northwest, Soroti in the southwest and Kumi in the south. It comprises of only one county (Usuk), one town council (Katakwi) and nine sub-counties, namely; Usuk, Katakwi, Katakwi Town Council, Omodoi, Kapujan, Toroma, Magoro, Ngariam and Ongogoja (KDLG, 2007).

Katakwi district has a total area of 2,507 km^2, of which 87% is land. About 29% of the land is cultivated, only 1% is forest while the rest is savanna woodland and grassland mainly used for communal grazing. There are two minor lakes (Bisina and Opeta) along its border with Kumi district and River Kiriik - a seasonal river that flows from neighbouring Karamoja. Katakwi district has many wide swamps.

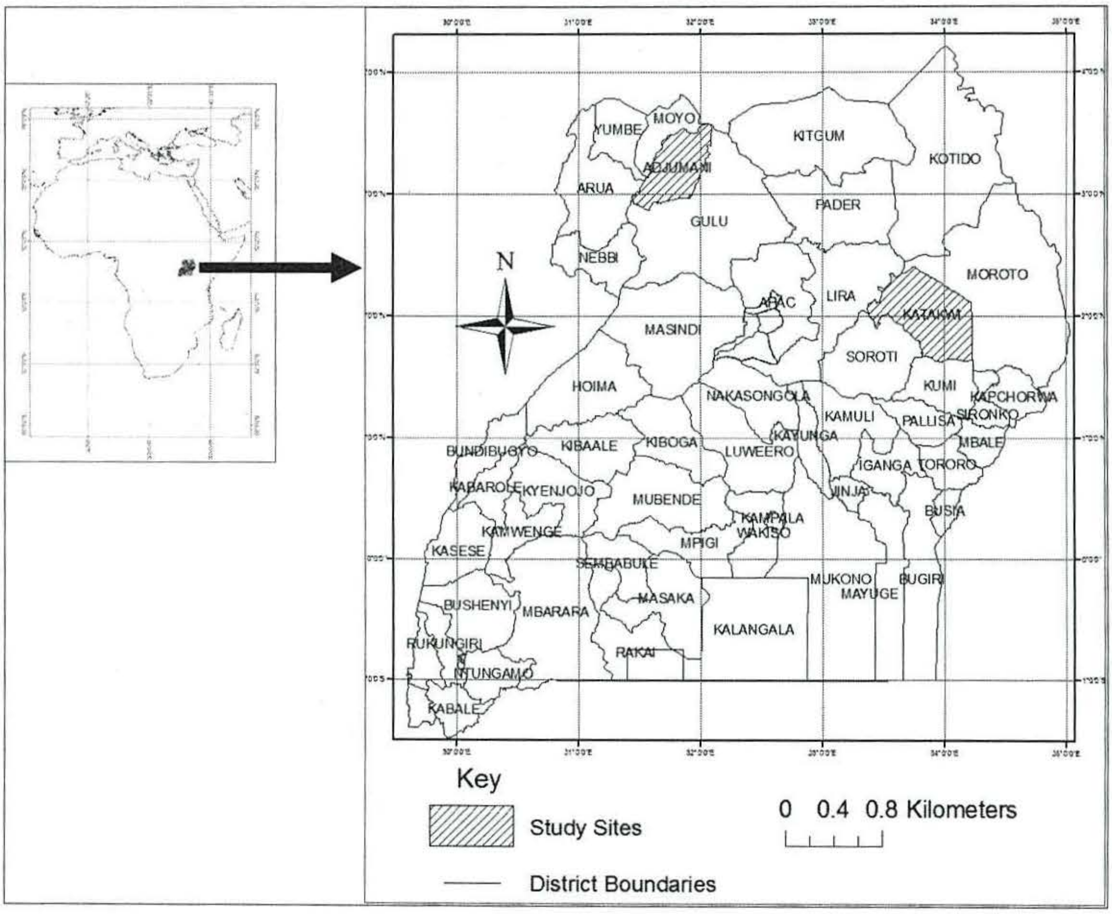


Figure 1.2 Map of Uganda showing the location of the study districts, Adjumani and Katakwi

1.6.3 Climate, topography, vegetation and natural resources

Adjumani experiences a bi-modal rainfall pattern with an annual average of 750 mm - 1,500 mm. The rainfall seasons are April to June, and August to November. There are relatively high rates of evaporation, particularly in the Nile valley area, and these are highest between December and March when temperatures reach up to 36°C. The humidity is about 80% in most parts of the district with the exception of 50% in December to February. Drainage occurs towards the Nile, through a series of seasonal rivers. Most of Adjumani district lies on a coarse layered rock and soils are generally considered moderately fertile (NEMA, 1997; 2008). A large percentage of soils cannot sustain intensive farming without special care to supplement nutrients and organic matter. According to NEMA (1997), the major soil types in Adjumani are vertisols, lithosols, alluvial deposits, ferruginous tropical soils and ferralitic soils. Both the sub-counties used for this study (Adropi and Dzaipi) lie along the river Nile and as such are dominated by alluvial deposits.

Much of the vegetation in Adjumani is mainly savanna woodland and grassland with only one forest, Zoka in the southwest. It is occupied by a vast stretch of dry savanna dominated by *Combretum, Acacia* and *Hyperrenia* species (NEMA, 1997; NEMA, 2008). A high refugee population was created in Adjumani district as a result of the political and civil unrest that pre-dominated the neighbouring Southern Sudan in the recent past. According to NEMA (1997; 2008), the refugee influx and population increase (refugees constitute 36% of the population) has degraded the vegetation in Adjumani district due to high demand for more farmland and wood for construction and fuel (GoU, 2006a). Furthermore, some of the refugee camps were located in marginal areas of the district that have been severely degraded. Generally, there is no quantified information on the impact of refugee influx on the environment in the West Nile sub-region.

Katakwi district has two climatic seasons; the wet season is from March to October and the dry season is from November to February. The mean annual rainfall varies from 1,000 to 1,500 mm. The rainy season has a major peak around March - June and a minor peak around August - October. The district receives unreliable and unpredictable rainfall (KDLG, 2007) and December and February are the driest. The mean annual maximum and minimum temperatures are 31^0C and 18^0C, respectively. Relative humidity ranges from 66 – 83% at 0600 GMT and reduces to 35 -57% at 1200 GMT. Much of Katakwi lies between 1,036 and 1,127 m above sea level.

The landscape in Katakwi is generally a plateau with gently undulating slopes. The soils are ferralitic and mainly of sandy sediments and sandy loam that are well drained and friable. The swamps contain widespread alluvial deposits (NEMA, 1997). Generally the soils in Katakwi are considered to be moderately fertile with the most productive areas found in the north to eastern parts of the district. The basement complex is made of granites, gneiss, schists and quartzites (NEMA, 1997). The vegetation is savanna grassland dotted with shrubs and trees. It is dominated by *Acacia, Combretum, Piliostigma, Vitellaria* and *Hyperrenia* species (KDLG, 2007). *Balanites aegyptiaca* and *Acacia* species are common along swamps.

1.6.4 Population, household characteristics and economic activities

According to the 2002 Population and Housing Census, Adjumani district has a total population of about 200,000 people out of which 49.5% are male and 50.5% female. Most of the people (94%) live in rural areas (UBOS, 2002). The district has a large Madi speaking community that makes 55.2% of the population. The other ethnic groups are Lugbara, Acholi, Kuku, Zande and Bor. During the peak of the civil war in Southern Sudan, Adjumani district had the largest population of refugees in Uganda, totalling to 78,668 or 36.4% of the resident population (GoU, 2006a). Land is mainly communally owned, and primarily based on small land holdings. Ownership of customary land is tied to lineage or clan. Land can be owned only by men, although it can be used by all family members. Family members and clan elders administer customary land. A man's land is inherited by the elder sons of all his wives, who share their portion with their other brothers.

Agriculture is the main economic activity for over 87% of the people in Adjumani district (NEMA, 1997; 2008). The sector is dominated by labour-intensive low-technology smallholder agricultural production. Livestock husbandry complements subsistence crop production, and plays an important role in the social and economic systems in the district. Most households in rural areas grow sweet potatoes, cassava, sorghum, sesame, maize, groundnuts, millet and cow peas. In general, men's work is seasonal, whereas women perform most of the daily chores in addition to farming (GoU 2006a). Over 97% of the households use firewood for cooking while about 2.3% use charcoal, mainly in urban areas. Fuelwood gathering and charcoal burning is steadily leading to loss of vegetation especially around settled areas (NEMA, 1997).

In Katakwi district, the 2002 Population and Housing Census revealed that there were 118,928 people out of which 48.2% were male 51.8% female (UBOS, 2002). The population density is low with 65 persons per Km^2 which is below the national average of 123 persons per sq. km (GoU, 2006b and KDLG, 2007). Katakwi has a total of 25,811 households, 95% of which are rural while only 5% are urban. The average household size is 4.6 persons which compares well with the national figure of 4.7. Over 38% of the population lives in concentration camps in Katakwi and Usuk sub-counties due to insecurity from cattle rustling by the Karamojong. Over 98% of the population in Katakwi district are the Iteso. The other tribes are the Langi and Bakenye. Children less than 18 years constitute about 56% of the population while the literacy rate for persons aged 10 years and above is 55%. Only 12% of the economically active population are paid employees, 43% are self employed, 40% are unpaid family employees and 5% are unemployed. Over 97% of households use firewood while only 2% use charcoal for cooking. This poses a big challenge to the district that has a sparse vegetation cover. According to KDLG (2007), there are currently no measures to control tree cutting for firewood and charcoal burning. *Balanites aegyptiaca* and *Vitellaria paradoxa* are indiscriminately being cut to provide woodfuel.

Over 86% of households in Katakwi district depend on subsistence farming using traditional methods of animal traction and the hand hoe. Modern scientific methods of farming have not fully been adopted. About 95% of the people own land under the customary land tenure system. According to KDLG (2007), this posses challenges to agricultural modernization since customary land tenure tends to be traditional or communal in nature. The major crops grown are groundnuts, sorghum, cassava, millet and sweet potatoes while the major livestock reared are goats, cattle, pigs, and sheep. Cattle rustling by the neighbouring Karamojong and rebel activities in the recent past created insecurity that affected agricultural activities thus making some areas of the district food insecure (KDLG, 2007).

1.7 Thesis structure

This thesis is divided in to eight chapters. Chapter One is the introduction to the study and Chapter Two gives the current state of knowledge on *Balanites aegyptiaca* with a focus on its use and management. Chapters Three to Seven present the findings under five study objectives; Chapter Three dwells on local knowledge; Chapter Four focuses on the distribution, population and associated species; Chapter Five is devoted to phenology, fruit yield and fruit characteristics; Chapter Six presents the findings on local processing and marketing prospects for *B. aegyptiaca* products (leaves, fruits and kernel oil); and Chapter Seven is centred on nutritional value of *B. aegyptiaca* products (leaves, fruit pulp and kernel oil). The General discussion, Conclusion and Recommendations are presented in Chapter Eight.

CHAPTER TWO: STATE-OF- KNOWLEDGE ON *BALANITES AEGYPTIACA* (L.) DEL.

This chapter presents the current state of knowledge on *Balanites aegyptiaca* based on the available literature. It starts with an overview of the significance of *B. aegyptiaca* in the drylands of Africa (section 2.1). The taxonomic history of species is given in section 2.2, the morphology in section 2.3 and the distribution and ecological requirements in section 2.4. Section 2.5 focuses on the phenology and reproductive biology of *B. aegyptiaca* while section 2.6 covers its propagation and cultivation. Section 2.7 is dedicated to its uses including local, medicinal and industrial uses while the chemical and nutritional composition of *B. aegyptiaca* products (leaves, fruits and kernel) are covered in section 2.8. The conclusion of the review is presented in section 2.9.

2.1 Introduction

Balanites aegyptiaca, commonly known as desert date, is an important food and medicinal tree found in most African countries, stretching from arid and semi-arid regions to sub-humid savanna. Its fruit has an edible mesocarp and a hard woody endocarp enclosing an edible oil-rich seed kernel. The leaves are eaten as a vegetable in the dry season in many countries throughout its range in dryland Africa. According to Mbah and Retallick (1992), *B. aegyptiaca* is a promising economic plant for both the arid and semi-arid regions of tropical Africa, the Middle East and India. As a multipurpose tree, *B. aegyptiaca* offers food, medicines, cosmetics, fodder, fuelwood and pesticides valued for subsistence living in the arid and semi-arid areas where other options are few (NRC, 2008). The fruit of *B. aegyptiaca* has been the basis of an active trade for many centuries in countries where the species grows (von Maydell, 1990). The seed kernel oil is rich in saturated fatty acids and is used as cooking oil (Hall and Walker, 1991; FAO 1992; NRC, 2008). It also contains steroids (saponins, sapogenins, diosgenins) used as raw material for industrial production of contraceptive pills, corticoids, anabolisants and other sexual hormones (UNIDO, 1983). Retallick and Sinclair (1992) noted that the genetic resources of *B. aegyptiaca* are in danger of depletion due to destruction of habitat and over-exploitation of the species. The situation is compounded by the low rate of natural regeneration and a slow growth rate – flowering after five to seven years (von Maydell, 1986; 1990). There is, therefore, a need to conserve, develop and utilize the existing *B. aegyptiaca* germplasm.

For many tree species which are characteristic of the semi-arid Africa so far studied, it is believed that *B. aegyptiaca* has the most organised and specialised use that has been sustained for a long time (Hall and Walker, 1991; Hall, 1992; Sands, 2001). *B. aegyptiaca* has a long history of use as a resource throughout its range, especially in Africa. It has been cultivated in Egypt for over 4,000 years; stones of its fruits have been found in pharaohs' tombs (placed as votive offerings) dating back to at least the 12^{th} dynasty in ancient Egypt (Hall and Walker, 1991; Sands, 2001; NRC, 2008). The tree is also reported to have biblical connections where it is believed to be the source of one of the ingredients of spikenard perfume (Holland, 1922). Accounts of the earlier use of *B. aegyptiaca* in various parts of Africa have been given by several authors e.g., Eggeling (1940), Abu-Al-Futuh (1983), Burkill (1985), Hall and Walker (1991), Hall (1992), Katende *et al.* (1995), Maundu, *et al.* (2001), Madroma (2006). The feasibility of commercial exploitation of *B. aegyptiaca* for pharmaceutical and food industry in the Blue Nile Province of Sudan was shown in the early 1980s by Abu-Al-Futuh (1983). In this region of Sudan, the species was reported to make up a third of the total tree population, estimated to have a million *B. aegyptiaca* trees.

Even in the 21^{st} century, *B. aegyptiaca* has continued to play diverse traditional and cultural roles in many societies across its range. Besides its earlier roles, additional and even more important values of this versatile dryland tree have emerged. For instance, industrial potential as source of steroid and other drugs (Hall and Walker, 1991; Chapagain and Wiesman, 2005), highly valued oil (NRC, 2008), production of bio-diesel from its kernel oil (WIPO, 2006 a&b) and alcoholic drinks from its fruit pulp (FAO, 1992) have been reported. A report by the US National Research Council (NRC) (2008) ranked *B. aegyptiaca* high among the 24 priority "lost crops" of Africa and called for a concerted effort to develop its true potential using modern capabilities. The report observed that although *B. aegyptiaca* produces the necessities of life in one of the world's most difficult zones of existence (drylands), it is surprising that the species is still considered a "lost" crop of Africa. In addition, *B. aegyptiaca* helps to stabilize life and environment in the most severely drought-challenged regions of the world. A recent priority setting exercise to indentify indigenous fruit trees (IFTs) with domestication potential in the drylands of five countries in eastern Africa (Ethiopia, Kenya, Sudan Tanzania and Uganda) was conducted by Teklehaimanot (2005; 2008). The results showed that *B. aegyptiaca* was among the eight priority species and it was ranked second after *Adansonia digitata*. The kernel oil is used for cooking and the leaves are the only vegetable available at the peak of the dry season in Katakwi district, Uganda. The leaves were a commercial commodity in the area and sold at US$ 0.01 per 250 ml cup (Teklehaimanot, 2005; 2008).

Except for the species monograph (Hall and Walker, 1991) and a recent account of its potential (NRC, 2008), *B. aegyptiaca* is seldom, included in textbooks of African food production and it is little known to horticultural and food technology science. It is argued that improved processing of *B. aegyptiaca* oil could form part of rural poverty alleviation strategies in the drylands of Africa (NRC, 2008). However, Balanites oil processing is greatly constrained by lack of an appropriate technology for nut cracking (FAO 1992; SPORE, 1992 and Aviara *et al.*, 2005). Besides, there is limited information on its population status, phenology, propagation and management. Other research gaps related to the development of *B. aegyptiaca* include development of its products for wider markets and understanding the nutritional value of its major products such as fruit pulp, kernel oil and leaves.

2.2 A taxonomic history of *Balanites aegyptiaca* (L.) Del.

2.2.1 Species name and family

*Balanites aegyptiaca (*L.) Del. is a small to medium-sized dryland tree or shrub belonging to the family Zygophyllaceae (Balanitaceae). It is reported to have been first described in the sphere of western science by Prosper Alpinus in 1592 who named it *Agihalid* (Hall, 1992). In 1753, Linnaeus applied conventional binomial system to name it *Ximenia aegyptiaca* using a specimen collected from Egypt (Sands, 1990). Michel Adanson in 1763 thought the plant was a different species and named it *Agialid senegalensis* applying an epithet collected from Senegal. Sprague (1913) noted that Adanson's name was however, not adopted in the botanical world. Later in 1813, Alire Delile replaced the name *Agihalid* (derived from the Arabic name for the tree 'heglig') with Balanites (from the Greek word for acorn, referring to the fruit) and reduced Adanson's *Agialid senegalensis* to synonymy within species (Hall and Walker, 1991; Hall, 1992). The conservation of the name Balanites was proposed by Harms (1904) and formally adopted at the Vienna Botanical Congress in 1905 (Briquet 1906). The name Balanites, though not the oldest valid generic name has since been formally conserved (Hall, 1992). This explains, the use of the current species name with two authorities (LINNAEUS and DELILE), thus, *Balanites aegyptiaca* (L.) Del.

According to Sands (2001) and Hall (2008), there have been conflicting views regarding the family placement and suprageneric affinities of *B. aegyptiaca* in the major classification systems for many years. These contradicting views can be seen from several reports e.g. Sheahan and Cutler (1993), Maksoud and El Hadidi (1988), Sheahan and Chase (1996 and 2000), Savolainen *et al.* (2000) and Stevens, (2001). Opinion today (Judd *et al.*, 2002), based on gene sequencing, recognizes Balanites as a member of the Eurosid I clade and within this as a genus of the Zygophyllaceae, and not as a monotypic family (Balanitaceae). Sheahan and Chase (1996), who examined *B. maughamii*, refer the genus to sub-family Tribuloideae, although with reservations, suggesting a need to extend sequencing action to further species. Despite the debate, Balanites for the time being has been included in the zygophyllaceae family under the class Tribuloideae with the Synonymy of Agialidaceae and Balanitaceae (Sheahan and Chase, 2000; Judd *et al.*, 2002).

2.2.2 Revision of the genus Balanites

Sands (2001) completely revised the genus Balanites and with the help of a number of newly recognised characters, mostly associated with the spines, nine species and eleven infra-specific taxa of Balanites are now recognised. The nine species within Balanites are (1) *B. wilsoniana* Dawe & Sprague, (2) *B. maughamii* Sprague, (3) *B. triflora* Tiegh., (4) *B. roxburghii* Planch., (5) *B. aegyptiaca* (L.) Delile (6) *B. pedicellaris* Mildbr. & Schltr., (7) *B. angolensis* (Welw.) Welw, (8) *B. rotundifolia* (Tiegh.) Blatt., and (9) *B. glabra* Mildbr. & Schltr. There is a proposed tenth species from Ethiopia currently only described under a provisional name, *B.* 'Omo Valley' (Sands, 1983; Sands 2001). All but two of the species are African. Sands (2001) noted that many earlier works covering the Indian species of Balanites erroneously identify it as conspecific with the African *B. aegyptiaca*.

Out of the 20 formally described taxa currently recognized in Balanites, *B. aegyptiaca* accounts for five: *B. aegyptiaca* vars *aegyptiaca* (widespread), *ferox* (Guinea Bissau, Mauritania, Senegal), *pallida* (Djibouti, Ethiopia, Somalia), *quarrei* (Democratic Republic of Congo, Tanzania, Zambia), *tomentosa* (Tanzania) (Sands, 2001; Hall, 2008). These varieties are distinguished from each other by indumentum, pedicel, petiole and spine details. Sands (2001) developed a multi-access key to these varieties (Table 2.1).

According to Hall (2008), three of the five described varieties of *B. aegyptiaca* occur only in eastern and north-eastern Africa, and three other species are similarly restricted. Sands (2001) suggests that in the absence of fossil evidence, the geographic origin of Balanites is presumed to be in Africa or south Asia, with current patterns of diversity suggesting eastern Africa south of the equator as a strong possibility.

Table 2.1 Key to the varieties of *Balanites aegyptiaca*

No.	Description	Variety
1.	Leaflet indumentum sparse and/or early-glabrescent or minutely puberulous	2
	Leaflet indumentum conspicuous and/or dense	5
2.	Pedicels 3- 5 mm long and, like the calyx, closely puberulous to tomentellous; always flowering at spineless nodes	**a.** var. **aegyptiaca**
	Pedicels 6- 17 mm long and, like the calyx, tomentose; flowering at spinous or spineless nodes	3
3.	Pedicels 6 - 7 mm long; leaflets narrowly to broadly cuneate; always flowering at spineless nodes	**a.** var. **aegyptiaca**
	Pedicels 8 - 17 mm long, or if less than 8 mm, then the flowers mostly arising at spinous nodes and/or the buds clearly apiculate; leaflets rounded, truncate or occasionally broadly cuneate ..	4
4.	Petiole 0 - 7 mm long; inflorescence 1 - 6-flowered at either spinous or spineless nodes	**a.** var. **aegyptiaca (southern forms)**
	Petiole 7 - 37 mm long; inflorescence 6 - 11-flowered, nearly always at spinous nodes	**d.** var. **quarrei**
5.	Spines more than 3 cm long	6
	Spines 3 cm long or less	7
6.	Pedicels and calyx tomentose; styles 2 - 3.5 mm long	**b.** var. **ferox**
	Pedicels & calyx closely puberulous to tomentellous; styles 0.75 - 1.9 mm long ..	**c.** var. **pallida**
7.	Leaflets not tomentose, usually densely grey-puberulous; flowering always at spineless nodes	**c.** var. **pallida**
	Leaflets tomentose, flowers mostly if not always at spinous nodes	**e.** var. **tomentosa**

Source (Sands, 2001).

2.2.3 Balanites in Uganda

Besides *Balanites aegyptiaca,* the other Balanites species found in Uganda are; *B. pedicellaris* in Karamoja and Acholi; *B. rotundifolia* in Karamoja and *B. wilsoniana* in Mabira, Budongo and Kibale forests (Eggeling, 1940; Katende *et al.*, 1995, Sands, 2001). *Balanites orbicularis* (Sprague) which was earlier regarded as one of the Balanites species found in Karamoja, Uganda (Eggeling, 1940) was reduced by Sands (1983) to synonymy and justification given by Sands (2001). Although none of these other Balanites species seems to offer promise as a fruit crop like *B. aegyptiaca*, each is an interesting plant in its own right and is worth some horticultural attention. According to NRC (2008) other Balanites species typically provide fodder for livestock but along with *B. aegyptiaca*, they could perhaps prove useful in food-security interventions for the drylands of Africa.

2.3 Morphological description of *Balanites aegyptiaca* tree and its major parts

Balanites aegyptiaca has been variably described in many reports (e.g. Eggeling, 1940; Adams, 1967; Hall and Walker, 1991; Hall, 1992; Sands, 2001). The most recent description of the species was provided by Sands (2001) who examined hundreds of specimens while reviewing the genus Balanites. The description given here is presented in terms of; the mature tree, spines, leaves, inflorescence flowers and fruits (Figure 2.1) and (Table 2.2).

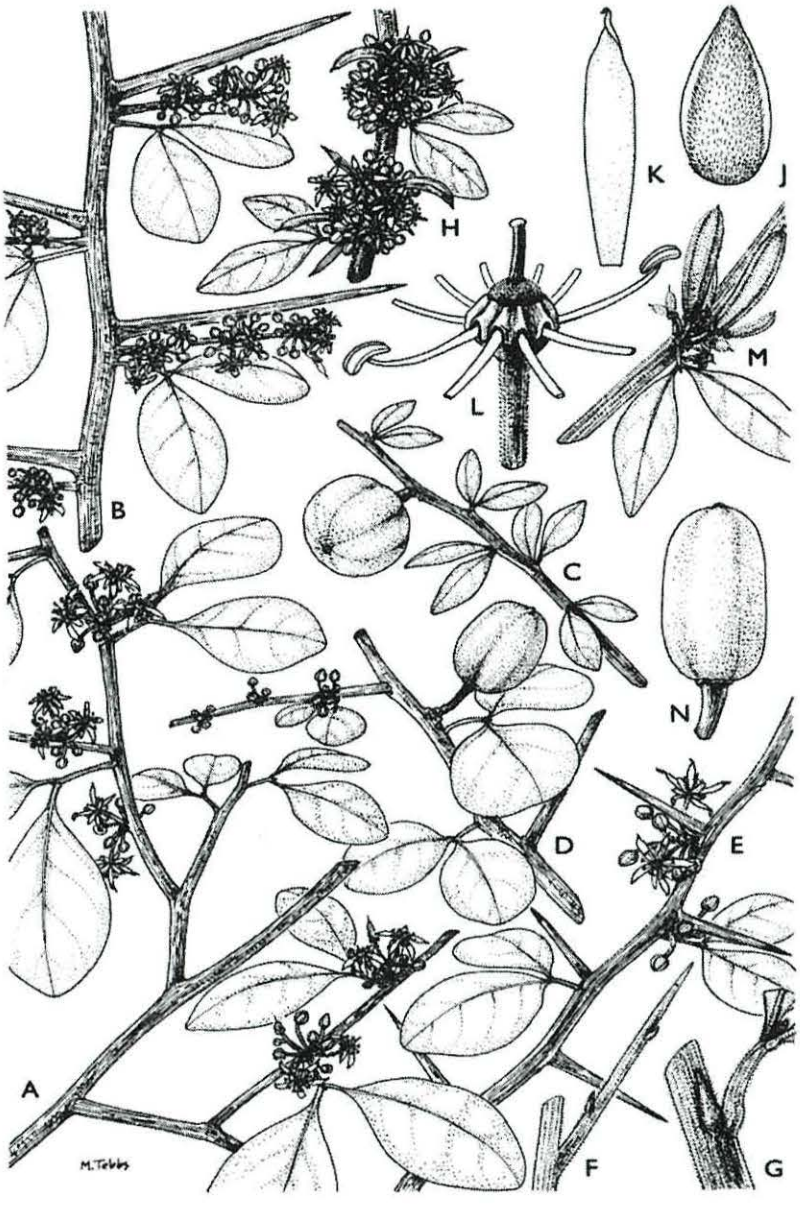


Figure 2.1 *Balanites aegyptiaca* var. *aegyptiaca*.

A - E habit x 0.7, **A** spineless flowering branch, **B** stem with stout spines and flowers on condensed shoots of short internodes, **C** stem with sessile leaves, small, narrow leaflets and small, rounded fruit, **D** stem with small fruit and broad, rounded leaflets, **E** stem with dark-tipped spines and inflorescences at spinose nodes (southern form - Malawi); **F** young spine bearing scale leaves x 2.7; **G** petiole and stipule x 6.7; **H** dense fascicles of many flowers, with young fruits elongating in early development x 0.7; **J** sepal, abaxial x 6.7; **K** petal, adaxial x 6.7; **L** stamens, disc, ovary and style x 6.7; **M** developing fruits x 0.7; **N** mature fruit x 0.7.

Source: Sands (2001).

Table 2.2 Botanical description of *Balanites aegyptiaca* var *aegyptiaca*

Part	Description
Tree	A semi-evergreen or sometimes deciduous, usually spiny, shrub or small tree up to 12(- 15) m high, extremely variable in many of its characters. Bole usually straight, to 60 cm diam, often fluted, the branches spreading irregularly or pendulous, sometimes forming a rounded crown; bark hard, becoming rough, corky and deeply fissured, dark grey, inner bark and sapwood pale yellow to light brown, wood hard and fibrous. Branchlets and spines greyish green becoming light brown, at first minutely puberulous to tomentellous, usually glabrescent.
Spines	(0.4 -)2 - 8(- 11.5) cm long, 2 - 6 mm diam. at the base, borne at a wide angle to the parent stem, (0.6 -)1.2 - 3(- 3.2) cm apart, axillary or 0.1 - 0.4 cm above the axil, straight or slightly curved, terete with a sharp tip or subulate, without leaves or flowers, only very rarely bearing a short branch-spine. Scale-leaves occasional on young spines, 0.75 - 1 mm long.
Leaves	Sub-sessile or with a petiole (0.3 -) 1.1 - 2(- 3.5) cm long; stipules 0.5 -1 mm long, triangular, caducous, finely puberulous, glabrescent. Leaflets (0.6 -) 1.2 - 6.4(- 6.8) x (0.3 -)0.4 - 4.2(- 5) cm, sessile or with petiolules 0.1 - 0.6 (- 1) cm long, very variable, narrowly spathulate or elliptic to broadly ovate or obovate, sometimes very broadly spathulate or almost orbicular and eccentric, thin to coriaceous, closely and minutely puberulous, often glabrescent, or sometimes densely tomentellous or tomentose, apex bluntly acute to obtuse or rounded, occasionally emarginate, cuneate or narrowly decurrent at the base; foliole (1 -)1.5 - 2.5 mm. long, often caducous, sometimes persistent, linear and bent.
Inflore-scence	(never on the spines) of (1 -)2 - 15(- 20 or more) flowers variously arranged in cymose fasicles at spineless or spiniferous nodes, or closely arranged on shoots of short internodes, sometimes more or less spiciform, finely tomentellous to tomentose. Peduncle, if present, 2 - 8 mm long; bracts to 1 mm long, rounded or broadly triangular; pedicels 0.4 - 1.1 (- 2) cm long, thickening to 2.5(- 3) mm diam. in fruit.
Flowers	5-merous, sweet-scented, buds rounded or apiculate. Sepals 3.5(-5.5) x 1.5-2(-2.5) mm, ovate, acute to acuminate, tomentellous to tomentose on the outside, becoming spreading to reflexed, sometimes early-caducous. Petals 4.5 - 6.5(- 7) x 1 - 2(- 2.5) mm, lanceolate or narrowly elliptic to obovate-oblong, rounded or obtuse to acute, sometimes contorted at the apex, glabrous within, spreading, sometimes reflexed, green to pale yellow or creamy white. Stamens 10, spreading; filaments 2 - 3(- 3.5) mm long, filiform or tapering, anthers (0.75 -)1 - 1.5(- 1.8) x 0.4 - 0.7 mm, oblong-ovoid. Disc 1 - 1.5 mm high, 2.2 mm diam., shallowly conical, enclosing the lower part of the ovary and persisting as a cup. Ovary 0.75 - 1 mm high, 1 - 2 mm diam., hemispherical, puberulous or pubescent to tomentose, sometimes glabrous at the base of the style; style 1.5 - 3.5 mm long, subulate with a small, often slightly swollen stigma.
Fruit	(2.3 -)2.8 - 4(- 4.7) x (1.3 -)1.7 - 2.8 cm, elongating markedly in very early development, very variable when mature, sub-spherical or ovoid to ellipsoidal, rounded, truncate or sometimes sulcate at both ends or the apex tapering, conical, ripening greenish brown to yellow; exocarp at first leathery, becoming brittle and cracking, up to 1 mm thick; mesocarp yellowish brown, fibrous and oily (bitter-sweet), to 2 mm thick; endocarp, containing the seed, hard, woody and fibrous, up to 5 mm thick, eventually splitting from the apex to form 5 flanges.

Source: Sands (2001).

2.4 Distribution and ecological requirements for *B. aegyptiaca*

2.4.1 Distribution

According to Hall (1992), few African species are as widely distributed as *B. aegyptiaca*, which occurs in almost every African country north of the equator and several countries in the southern hemisphere (Figure 2.2). Its native range extends through the hottest and driest parts of the African continent: from the Atlantic coast at Mauritania and Senegal to the Red Sea at Somalia, Sudan, and Eritrea as well in Yemen and the Jordan valley (Hall and Walker, 1991; Sands, 2001). The area extending through Sub-Saharan Africa from Senegal to the Sudan is described as the main belt for the species (Hall and Walker 1991; Hall, 1992). The latitudinal extremes of range in Africa are Zimbabwe (19°S) and the Middle East (35°25') and the longitudinal extremes are Mauritania (16°30'W) and Somalia (49°E). The species range is fairly continuous although occurrence becomes increasingly closely linked to coastal and rift valley conditions in the Middle East and the adjacent part of Africa. The most disjunct occurrence appears to be that in Angola where, in the absence of more information on the circumstances, the possibility that the species was introduced cannot be ruled out (Hall, 1992).

In Uganda, *B. aegyptiaca* is common in the north eastern, lowland areas of West Nile along the River Nile, the flat plains of Butiaba along Lake Albert, and the dry margins of Queen Elizabeth National Park (Eggeling, 1940; Kerfoot, 1962; Langdale-Brown *et al.,* 1964; Katende *et al.*, 1995). It is also found along the shores of Lake Kyoga (Landale-Brown *et al.*, 1964; Obua, Pers. Com. 2008). Just like throughout its range in Africa, *B. aegyptiaca* is known by various local names in Uganda. This perhaps demonstrates the local importance that has been attached to this species for generations. The various local names for *B. agyptiaca* in Uganda include: Ecomai (Ateso); Ekorete (N'gakarimojong); Logba/Lugba (Madi and Lugubara); Logwat/To (Luo); Thoo (Alur); Musongole (Muruli), Comiandet (Sebei); Zomai (Lugishu) and Kinacoma (Lugwere) (Eggeling, 1940; Langdale-Brown *et al.*, 1964; Katende, *et al.,* 1995; Katende *et al.*, 1999; Sands, 2001).

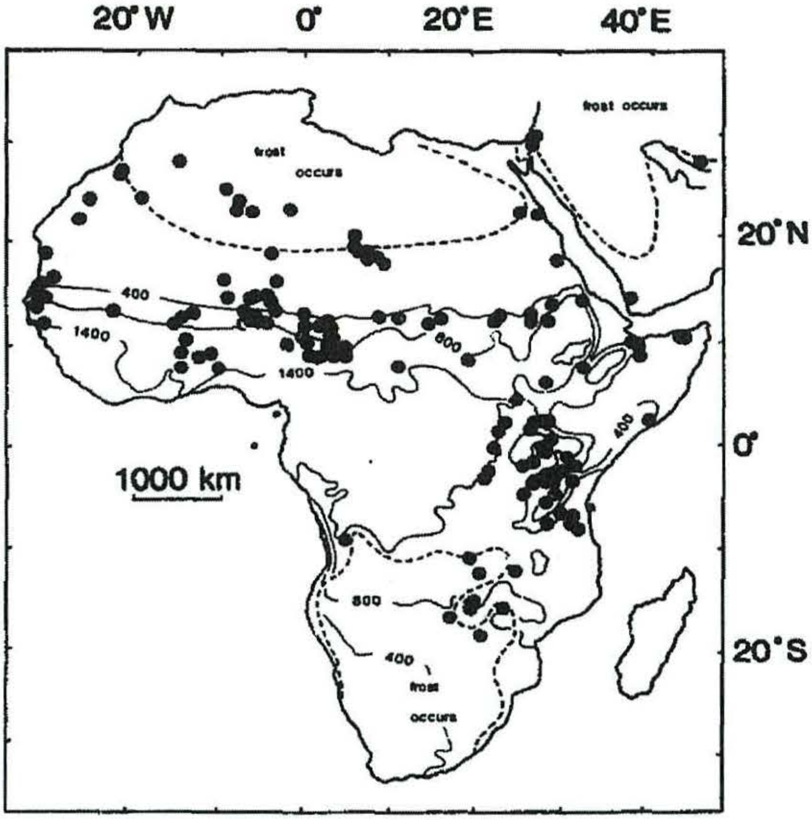


Figure 2.2 *Balanites aegyptiaca:* distribution in Africa

Dots represent the species in relation to rainfall (400, 800 and 1,400 mm isohyets shown). Areas at low elevation subject to frost are demarcated by broken lines.
Source: Hall, 1992.

2.4.2 Ecological requirements

Rainfall: The most comprehensive review of the ecology of *B. aegyptiaca* was provided by Hall and Walker (1991) and Hall (1992) and has been supplemented by Sands (2001) with variety specifications. According to Sands (2001), Hall and Walker's treatment covers the species as a whole. *Balanites aegyptiaca* is a versatile species growing in various ecological conditions in the arid and semi-arid to sub-humid savanna. It is generally common in areas with a rainfall of 400 – 1,000 mm year^{-1} in semi-arid and arid zones of tropical Africa (Hall and Walker 1991; Hall, 1992; Sands, 2001). The species is also present, but less frequently, under only 250 – 400 mm year^{-1} annual rainfall and where ground water compensates, it even grows under mean annual rainfall < 250 mm, as in parts of the Sahara area (Hall, 2008). It however, prefers valley, floodplain or watercourse sites where seasonally high water tables or groundwater compensate for low rainfall (Sands, 2001). Aubreville (1950) indicated the 1000 mm year^{-1} rainfall isohyet as the natural limit to *B. aegyptiaca* range in West Africa. However, Hall (1992) reported that under conditions of disturbance (and probably by conscious introduction), the species has spread beyond this limit. He points out that isolated occurrences under mean rainfall 1,300 - 1,400 mm year^{-1} in Guinea Bissau and the Central African Republic.

Altitude and temperature: Natural populations of *B. aegyptiaca* are recorded at frost-free elevations from sea level to 2,000 m, generally with mean annual temperature >20°C (Hall, 2008). It is sensitive to low temperatures, especially frost but easily withstands high temperatures. Frost is very rare within *B. aegyptiaca* range, occurring only in the Saharan mountains and parts of Zambia and Zimbabwe (Sands, 2001). Within the main belt, absolute maximum temperatures are 40-46 ° C (Hall, 1992).

Soil: *B. aegyptiaca* is found on various soils ranging from deep sands in the drier parts of the Sahel zone (250 - 450 mm annual rainfall), to sandy loams or clays, where rainfall is somewhat higher (450 - 900 mm), as in parts of the Sudan (Sands, 2001). However, vigorous populations occur in relatively fertile, low-lying sites with deep sandy soil and uninterrupted access to water but it also grows well on heavier, fertile vertisolic soils, provided salinity is low (Hall, 2008). However, it clearly prefers clay, and when it is found on pure sand there is usually an underlying layer of clay (NRC, 2008). Although the plant readily survives periodic inundation, it does not tolerate prolonged water logging (Hall and walker, 1991; Sands, 2001; NRC, 2008). Hall (1992) noted that in the climatic conditions which appear most favourable for *B. aegyptiaca,* the soils concerned are acrisols, arenosols, luvisols and a "vertisolic' complex (fluvisols, gleysols, planosols and vertisols - in the strictest sense).

Despite its wide ecological amplitude in terms of soil type and climate, *B. aegyptiaca* is reported to grow best in deep clayey or gravel soils such as valley floors, river banks and foot of rocky slopes (Snolnozi, 1985; Hall and Walker, 1991; Katende, *et al.,* 1995; Sands, 2001). Hall (1992) notes the ability of the species to attain large sizes on heavy vertisolic clay subject to prolonged flooding. Maximal development of *B. aegyptiaca* as an individual tree is on low-lying, level alluvial sites with deep sandy loam soil and uninterrupted access to a source of water. According to Burkhill (1985) establishment of *B. aegyptiaca* along water courses and on flood plains ensures periodic nutrient replenishment where soils would not otherwise sustain vigorous growth. *B. aegyptiaca* has only modest tolerance to salinity (Hall, 1992).

Stocking levels: According to Hall and Walker (1991) and Hall (1992), except where proliferation of root suckers occasionally leads to thicket formation, *B. aegyptiaca* is typically a woody species of open parkland or grassland and does not form dense stands. Individuals occur singly and full crown exposure is typical, particularly as the species is often taller than any of its associates. In its range in the Sahel (400 - 500 mm per year mean rainfall), *B. aegyptiaca* is a constituent of bush land and thicket communities (Hall and Walker, 1991). In Kenya (White, 1983) and Uganda (Thomas, 1943) *B. aegyptiaca* is reported to occur as widely dispersed individuals in bush land and thicket. Hall (1992) noted that available reports on stocking of *B. aegyptiaca* lack consistency in diameter size classes used and areas assessed thus making comparison difficult. The reports are also based on few individuals because the plot sizes are small and estimates are not statistically robust (Hall, 1992). Furthermore, unless individuals <5 cm diameter at breast height are counted, it is unusual for numbers to exceed 25 trees ha^{-1} (Hall, 1992). However, in the Blue Nile province of Sudan, Balanites was estimated to be occurring at a density of 34 trees ha^{-1} (Hall and Walker, 1991) and in Uganda a study in Moyo district (Madrama, 2006) reported a stocking density of 39 trees ha^{-1}.

Associated species: In White's (1983) vegetation characterisation terminology, *B. aegyptiaca* is associated with bush and shrub land, wooded grassland and lands with open canopies. Typical, although not ubiquitous, trees associated with *B. aegyptiaca* include; *Acacia senegal, A. seyal, A. tortilis, Sclerocarya birrea* and *Ziziphus mauritiana* (Hall, 1992). *B. aegyptiaca* is always widely dispersed but it is prominent in vegetation where it occurs because of its dense crown, ever-green or briefly semi-deciduous phenology and height (Hall and Walker, 1991). Where well-represented it can account for more than 20% of individuals exceeding 10 cm diameter at breast height (Hall, 1992). In Sudan, *B. aegyptiaca* was reported as one of the longest-lived savanna trees (more than 100 years) (Bourliere and Hadley, 1983). Under typical current burning regimes and levels of grazing pressure it is thought that populations of *B. aegyptiaca* would persist longer than those of most associated woody species (Hall, 1992).

2.5 Phenology and reproductive biology

2.5.1 Phenology

Available reports indicate variable phenological patterns for *B. aegyptiaca* across its main range in Africa. In humid conditions *B. aegyptiaca* is an evergreen tree, for instance in Zambia and Zimbabwe (White, 1962). It is believed to shed most of the foliage in the dry season (Jackson, 1973) and sometimes all the foliage is shed (Wickens, 1976). First flowering and fruiting takes place at the age of 5-7 years (von Maydell, 1986) and full fruiting potential is reached at around 25 years (Abu-Al-Futuh, 1983). Schmidt and Jøker (2000) reported a shorter time (15-25 years) for attainment of maximum fruit production.

B. aegyptica exhibits variable, extended and diffuse flowering and fruiting behaviour across its range (Schmidt and Jøker, 2000). In the Sahel region, von Maydell (1986) reported that there is no definite flowering time but also pointed out that the dry season is the most likely flowering period. This is supported by Hall and Walker (1991) although Wickens (1976) observed that there appears to be two flowering periods in *B. aegyptiaca*; no other report supports this observation. Schmidt and Jøker (2000) noted that in areas with pronounced seasonal climate (northern and southern part of the distribution range) fruit maturation occurs before the rainy season. In the Sahel region, the main flowering season is between October and March while the main fruiting season is between December and April. In southern Africa (Zambia-Zimbabwe) flowering is reported in September – December while fruiting is between April and August. Flowering in Nigeria varies between November and April, fruits ripen in December and January and occasionally from March to July (Schmidt and Jøker, 2000).

A study on the reproductive biology of *B. aegyptiaca* conducted in Senegal by Ndoye *et al.* (2004) focused on phenological events in the species over a 12 months period and determined the relative length of each phenophase. This study revealed that leafing in Senegal began in May and ended in December and from December to March all *B. aegyptiaca* populations were partially defoliated, most likely due the effects of the dry season. It was found that flowering was heterogeneous but delineated in two distinct periods. The first flowering period lasted from December to March and concerned only 25% of the population. The second period, with 90% of the individuals, took place between March and September with a flowering peak in

July. Flowering is usually followed by fruiting, but some trees due to their situation and own specificities, failed to produce fruits. The second flowering period leads to the fruiting phase. Flowers pollinated from May to August produced ripe fruits from December to January (Ndoye *et al.*, 2004). Generally, records on fruiting and fruit ripening periods vary apparently due to the long time taken by the fruits to mature and ripen (at least one year) but many generally seem to indicate the dry season as the peak fruit ripening period (Hall and Walker, 1991; Schmidt and Jøker, 2000).

2.5.2 Reproductive biology

The Floral details of *B. aegyptiaca* have been described by Sands (2001). Ndoye *et al.* (2004) reported that *B. aegyptiaca* flowers are small and gathered in several types of inflorescence (clusters, fascicles or glomerules) and carried by lateral branches. The green-yellowish flowers are hermaphroditic, scented, actinomorph and without access restriction to either anthers or stigma. About 70% of the flowers open during the night between 3 and 6 a.m. and pollen is released in big quantities (22,600 per flower) with 91% viability which last for about four days.

B. aegyptiaca also shows a synchronization between male (internal stamina cycle) and female phase, thus, asynchrony of flowers opening, the quick loss of pollen viability and the high frequency of Diptera, slightly mobile, all lead towards geitonogamy, a main strategy developed in *B. aegyptiaca* (Ndoye *et al.*, 2004). However, they noted that a low ratio of allopollination (37%) was related to the wind and also to the presence of Hymenopterae which may be very mobile. This strategy helps to maintain a level of heterozygoty in a very challenging environment (Sedley *et al.*, 1992 cited in Ndoye *et al.*, 2004). Diptera and Hymenoptera were the main pollinators found on Balanites inflorescences. The breeding system of *B. aegyptiaca* was found to be partially auto-compatible with a low fruit/flower ratio resulting into high fruit abortions interpreted as an active screening of the progeny best fitted to the environment. Only a few fertilized flowers (5-10%) produce mature fruits. The main vectors of pollination are Dipterae, Hymenopterae and Coleopterae (Ndoye *et al.*, 2004). The high rate of abortion is reported to be usual in the Sahelian environment where trees produce a great number of flowers to attract pollinators (Tybirk, 1991) and after fertilization, according to resources allocated (Lloyd, 1980; Bawa and Webb, 1984), select the most competitive fruits for maturation.

After fertilization the ovary lengthens, the developing fruit tending to fill out only as the final length is attained (Sands, 2001; Ndoye *et al.*, 2004). In the Indian *B. roxburghii* Planch., fruits were found to develop and ripen over 190-250 days (Amalraj and Shankaranarayan, 1995). Ndoye *et al.* (2004) reported a similar period for *B. aegyptiaca* in Senegal and the fruits tend to reach maturity in the dry season. *B. aegyptiaca* trees are reported to be heavy fruiters, with a single tree producing about 10,000 fruits year^{-1} (Von Maydell, 1986; von Maydell, 1990). However, Hall and Walker (1991) argued that this could have been a heavy fruiting situation. Abu-Al-Futuh (1983) reported 100-150 kg of ripe fruit per tree year^{-1} while Piot (1980) reported 45 kg per adult tree. Whereas Teel (1984) reported *B. aegyptiaca* fruits to be always produced even in dry years, Hall and Walker (1991) pointed out lack of clarity on whether individual trees fruit annually. It appears that the quantity of fruits produced by *B. aegyptiaca* is determined by the prevailing environmental conditions which dictate the size of the mature tree and amount of resources available for fruit development.

2.6 Propagation and cultivation

Whereas *B. aegyptiaca* is basically uncultivated, individual trees have been reported to be planted for centuries and in recent times tiny plantations have been established in Niger, Chad, northern Nigeria, Egypt and Israel (Hall and Walker, 1991; Chapagain and Wiesman, 2005; NRC, 2008). From these, it is known that Balanites is easily established by direct seeding. It also naturally regenerates by direct seeding, root suckering and coppicing (NRC, 1983; von Maydell, 1986; Hall and Walker, 1991).

2.6.1 Propagation by seed

Several reports indicate that *B. aegyptiaca* is mainly propagated from seed (e.g. NRC, 1983; Von Carlowitz, 1986; von Maydell, 1986; Hall and Walker, 1991; NRC, 2008). According to Hall and Walker (1991) this may be by direct seeding or seedling production in the nursery but the latter is more appropriate. Seed can easily be extracted from fruits used for other purposes or collected directly from under trees, or animal resting places (Abu-Al-Futuh, 1983; von Maydell, 1986; Hall and Walker, 1991). If whole ripe fruits are collected, the seeds (stones) can be separated by soaking in water for some hours and stirring vigorously to remove the pulp/mesocarp.

When the mesocarp is removed and seeds air-dried before storage, they can retain near-full viability for up to a year (Booth and Wickens, 1988; Mahony, 1990). Hall (2008) also reported that cleaned endocarps kept away from insects can be stored for at least a year, and whole fruit can also be dried and stored. von Maydell (1986) reports 500 - 1,500 seeds kg^{-1} of cleaned and air-dried (15% MC) seed while NRC (2008) reported 500 – 2,500 seed kg^{-1} citing information from Eden Foundation. On the other hand, Hall (2008) reported 80 - 250 kg^{-1} considering whole endocarps. A major problem noted during storage of *B. aegyptiaca* seed is their susceptibility to insect attack (seed borers). Short boiling (which may also serve as a pre-treatment before storage), insecticides or storage in CO_2 may kill present insects and further attack is prevented by storage in air-tight containers (Schmidt and Jøker, 2000). Seed dispersal is mainly attributed to free-ranging domestic stock, such as goats, sheep, cattle and camels that consume fruits when they drop and discard, regurgitate or evacuate the stone (Booth and Wickens, 1988; von Maydell, 1986; Hall, 1992). The camels are however reported to crush the nut and kernel in the course of feeding (Booth and Wickens, 1988).

2.6.2 Seed pre-treatment and germination

Von Maydell (1990) noted a need to break seed dormancy in *B. aegyptiaca* seed before sowing. However, seeds that have passed the digestive tract of ruminants are said to germinate well without pre-treatment. Fresh seeds need no pre-treatment but seeds that have been stored will normally need manual scarification (Hall, 1992). Methods reported to improve *B. aegyptiaca* seed germination include; intestinal scarification (von Maydell, 1986), boiling for 7-10 minutes and left to cool slowly (IBPGR-KEW, 1984; Booth and Wickens, 1988), soaking in hot water for 12-18 hours (ICRAF, 1988; von Maydell, 1986), soaking in warm water for 24 hours or overnight soaking in warm water (NRC, 1983; Weber and Stoney, 1986) and soaking in water at room temperature for 24 hours (NRC, 1983; Schmidt and Jøker, 2000). Manual scarification followed by 24 hours of soaking and also soaking for 12 hours in 30°C water are also reported as possible pre-treatment methods (NRC, 2008). At Bangor University, seeds were successfully germinated after soaking for 12 hours at 20°C (night) and 12 hours at 30°C (day) for up to 48 hours (Hall and Walker, 1991). Most of these reports do not however indicate the associated germination rates.

There appears to be a contradiction regarding an appropriate position for placing the seed/stone in a planting hole. Booth and Wickens (1988) and ICRAF (1988) report that *B. aegyptiaca* seed should be sown vertically with the proximal (stem or funicular) end down and just covered with soil while in their *B. aegyptiaca* handbook for extension workers, Shanks and Shanks (1991) indicate that the stones should be planted in vertical position with the sharp end (distal) pointing down. There may be a need to re-examine this since this could have an effect on the rate of germination. According to NRC (2008), *B. aegyptiaca* seeds can be directly sown at 3 cm depth (twice its diameter) after rains have properly started.

Because of the strong tap roots, square plastic pots measuring 9 x 9 x 12.7 cm were found ideal for green house culture of Balanites seedlings (Hall and Walker, 1991). Germination takes 1 – 4 weeks (Teel, 1984) however; few records have reported the germination rate. Weber and Stoney (1986) reported 61% over a 1 - 4 week period while Herlocker *et al.* (1981) reported only 33% in 52 days. A few days after sowing, the endocarp of viable seeds splits into five segments at its distal end (characteristic of the species – Sands, 2001) where the root radical emerges (Hall and Walker, 1991). Seedlings require shade initially (Hall, 2008). A study in Senegal (Bâ *et al.*, 2000) revealed that no inoculum is needed for *B. aegyptiaca* seed since the species is not dependent on mycorrhizal symbionts. Seedlings are recommended to be kept in the nursery for about 3 – 6 months before planting out (Teel, 1984; IBPGR-KEW, 1984; Weber and Stoney, 1986; ICRAF, 1988; Hall, 2008). According to IBPGR (1984) delayed transplanting affects the field establishment of *B. aegyptiaca* seedlings since the tap root may become too long.

2.6.3 Vegetative propagation

Vegetative propagation of *B. aegyptiaca* has been demonstrated (e.g., Gosseye, 1980; Ladipo, 1989; El Nour *et al.*, 1991; Mbah and Retallick, 1992; Ndoye *et al.*, 2003). Ladipo (1989) reported that stem cuttings of *B. aegyptiaca* can root with up to 60% success without any treatment with root promoting hormones. NRC (2008) noted that success in vegetative propagation presents an opportunity for raising elite specimens of *B. aegyptiaca*. Root cuttings have been used to form hedges in the Sahel (NRC, 2008).

A report by Siddique and Anis (2008) described successful direct plant regeneration from nodal explants of *B. aegyptiaca.* Rooting of shoots was achieved on Murashige and Skoog medium augmented with 1.0 lM IBA plus 0.5% activated charcoal followed by their transfer to half strength MS basal medium. The in-vitro raised plantlets with well developed shoots and roots were also successfully established in earthen pots containing garden soil and were grown in greenhouse with 70% survival rate. A recent report by Anis *et al.* (2009) demonstrated the feasibility of plantlet formation from nodal segments of a mature *B. aegyptiaca* tree using in-vitro propagation. The best results with regards to frequency of root formation, number of roots and root length was obtained on half strength Murashige and Skoog (MS) medium containing 1.0 l M Indole-3-Butyric Acid (IBA). The regenerated plantlets were potted and acclimatized successfully in a growth chamber and then moved to the greenhouse. This method provides a possibility for conservation and an effective way of propagating *B. aegyptiaca* and other woody tropical tree species. However, no reports of attempts to graft *B. aegyptiaca* have been seen (Hall, 2008).

2.6.4 Growth and management

B. aegyptiaca seedlings grow slowly at first, making it vulnerable to grazing animals, grass fires and weed competition in fertile soils (NRC, 2008). Herlocker *et al.* (1981) reported a height of 16 cm over 148 days, 39% survival and initial height growth of 0.29 m $year^{-1}$. Adams (1967) also reported slow growth of seedlings but noted that they are however less susceptible to mechanical, physiological or chemical disturbance compared to other dryland trees, thus, making it a species worth considering for difficult sites. Information available on growth rates in planted *B. aegyptiaca* trees (Table 2.3) does not give details of management regimes applied.

Table 2.3 Reported growth rates for *B. aegyptiaca*

Age	Growth	Location/Reference
6 years	1.4 m tall; 0.9 cm DBH	Machakos, Kenya (Bashir *et al.*, 1989)
3.5 years	0.7 m tall	Delwaulle (1979)
8 years	2 – 5 m tall (43 trees)	Puerto Rico (NRC, 1983)
23 years	6 m tall; 20 cm DBH (average)	Geidan Nigeria (Aubreville, 1950)
2 - 3 years	1 – 3 m tall (coppice shoots)	Israel (NRC, 1983)
148 days	16 cm tall, 39% survival	Herlocker *et al.* (1981)

Source: (Hall and Walker, 1991).

Since *B. aegyptiaca* trees are vulnerable to browsing, fire and competition from weeds during the juvenile phase, planted seedlings should be protected for the first three years (NRC, 1983;

von Maydell, 1986; ICRAF, 1988). Once past the establishment phase (3 years), the plants need no protection as they show excellent persistence and appear immune to almost all natural injuries (NRC, 2008). Established *B. aegyptiaca* trees are said to be slow growing as well (NRC, 1983) but very resilient (von Maydell, 1986). In dry areas pruning helps the trees survive drought because they coppice readily, and bounce back without lasting damage even after heavy pruning (NRC, 2008). The first fruit yields can be expected in 5- 8 years, depending on plant and location but once fruiting begins, the tree can go on producing annually for at least 75 of its 100-year lifespan. For all those decades it can be extremely productive with reported average yield of 125 kg of ripe fruit per tree (NRC, 2008). Hall (2008) observed that *B. aegyptiaca* has apparently escaped formal horticultural attention; however, recovery from pollarding and opportunistic lopping of branches (generally for fodder) indicates resilience.

Whereas various organisms have been reported to be associated with *B. aegyptiaca,* none has yet been confirmed as a serious or widespread pest or pathogen (Hall, 2008). However, the most frequently mentioned pests and diseases are seed borers - bruchid beetles (Kama, 1990), phytophagas locust and beetles, leaf galls, bugs and scales (Grouzis and Sicot, 1980) and defoliating *Bunea alcinoe* (Momoh and Akanbi, 1977). Hall and Walker (1991) note that *B. aegyptiaca*'s ability to attract and act as a haven for numerous insects could potentially be used in pest control in agroforestry systems with the tree acting as a trap crop.

Hall (2008) observed that no systematic efforts have been undertaken to improve *B. aegyptiaca* through selection and breeding but preliminary trials are now underway in several countries, particularly in the Sahel region. According to NRC (2008), there are no detailed studies on optimum cultivation methods for *B. aegyptiaca,* hence there is much scope for improving yields. For example, studies into seed viability, optimum planting times, spacing distances, soil fertility and watering could all lead to improvements. There is also little understanding of its reproductive biology in different sites across its range and there is scanty information on pests and diseases. A clear understating of all these aspects could further unlock the potential of this dryland fruit and vegetable tree.

2.7 Uses of *B. aegyptiaca*

2.7.1 Local uses

The value of *B. aegyptiaca* has been known for a very long time throughout much of its range in Africa. A wide range of uses have been reported for the different parts of *B. aegyptiaca*, often playing some locally important cultural role. Extensive reviews of known and potential uses of this versatile though neglected dryland tree are given by Burkill (1985), NRC (1983), Hall and Walker (1991), FAO (1992), Sands (2001) and NRC (2008). According to Sands (2001), most parts of the plant yield food products. For instance, the fruits are eaten raw or processed to provide a variety of items such as soup, flavouring or sweetmeats. As reported by von Maydell (1986) and Teklehaimanot (2008), *B. aegyptiaca* produces fruit even in dry years which makes it a highly appreciated food source in the drylands of Africa. The fruits are eaten like candy and sold as "desert dates" and pounded fruits make a refreshing drink which becomes alcoholic if left to ferment (FAO, 1992; NRC, 2008). The ripe fruits are commonly eaten by children; however, when there are food shortages they are also eaten by adults (NRC, 2008).

The leaves are eaten as a vegetable in many countries across *B. aegyptiaca* range in Africa. During food shortages, dryland communities cut the newly grown succulent shoots and leaves, which are then cooked as a vegetable (Katende *et al.*, 1999, Teklehaimanot, 2008). *B. aegyptiaca* leaves also make very good mulch and the tree is said to be nitrogen fixing (FAO, 1992). A resin from the tree bark may be sucked or chewed or used as a gum to fix arrow and spearheads and repair cracks in tool handles among pastoralists in Uganda and Kenya (Katende *et al.*, 1995; Maundu *et al.*, 1999; Egadu *et al.*, 2007). The hard seeds/stones are used as rosary beads, the bark yields a strong fibre, and charcoal and ash is used in dyeing or to make an ink (NRC, 2008).

The light yellow wood is hard, heavy and resistant to insects and is therefore, sought for tool handles and wooden household items (Hall and Walker, 1991; FAO, 1992; Sands, 2001). It is also an excellent fire wood, and yields good charcoal since it produces almost no smoke and has a calorific value of 4,600 kcal per kg (Webb, 1984). The thorny branches are good for fencing and the protein rich young leaves and shoots which are always growing during the dry season are an excellent source of fodder (NRC, 2008).

B. aegyptiaca also provides fish poison (stem and root bark), medicine (roots, fruit, bark), fodder (shoots, fruit), mulch, shade, windbreak, gum and fencing (cut thorny branches) (Bekele *et al.*, 1993; Katende *et al.*, 1995; FAO, 1992 and Maundu *et al.*, 1999). Table 2.4 gives a summary of reported general uses of the different parts of *B. aegyptiaca.* NRC (2008) noted that, despite the fact that *B. aegyptica* has been eaten for years, more toxicological testing is necessary before its products can be wholeheartedly recommended as a major food source. The report further notes that it seems likely that the traditional methods for preparing *B. aegyptica* products rely on leaching out the soapy ingredients (saponins). While unpleasant to eat, these saponins are not toxic to humans.

Traditionally, most parts of *B. aegyptiaca* have been used medicinally and although the efficacy of such treatments has rarely been proven, there is no doubt that the plant yields useful steroidal saponins from which, notably, sapogenin and diosgenin, can be extracted for use in the pharmaceutical industry (Sands, 2001). Extracts from the fruit and bark have been found to contain saponins, which are very toxic to fish and fresh water snails- carriers of bilharzia (schistosomiasis), and water fleas *(Cyclops)* which serve as an alternate host to guinea-worm (Tredgold, 1986; Iwu, 1993; Katende *et al.*, 1995; FAO, 1992; Maundu *et al.*, 1999; NRC, 2008). Extracts can be added to drinking water because the saponins are non toxic to humans (Katende *et al.*, 1995; FAO, 1992). In some parts of Africa, trees planted close to a well or irrigation channel have reduced the occurrence of bilharzias (FAO, 1992; NRC, 2008). Bark extracts of *B. aegyptiaca* have been reported to be used by communities in west Nile and Acholi sub-regions, Uganda for poisoning fish (Eggeling, 1940; Madrama, 2006). According to Ufodike and Omoregie (1994), the death of the Nile tilapia, *(Oreochromis niloticus)* from bark extract of *B. aegyptiaca* is due to both fatigue and direct toxic effects of the plant extracts on the fish tissues.

Table 2.4 Summary of uses of *B. aegyptiaca*

Part	Use
Fruits	Ripe fruits are eaten raw or sun-dried as snacks and can be safely stored like dates. Pulp is macerated in water to create a tonic, can also be fermented into forms that are more potent. Pulp juice often mixed into porridges to liven up the flavour and add a touch of sweetness.
kernels	Kernels extracted from seed have an enticing aroma when roasted and can be pounded and added to soups and to various cereal products enjoyed in Senegal, Nigeria, Chad, Uganda, and Sudan.
Seed oil	Human consumption and cosmetics. Highly prized especially in Sudan where it is rated to be over cottonseed oil and equal to peanut oil. Others have compared it to olive oil. Also used as a fuel in lamps - burns with a bright flame.
Resin	Collected from fresh wounds, the globs are full of fluid and pleasant to suck like sweets. Some are made into drinks and also used as glue.
Flowers	In parts of West Africa boiled Balanites flowers (*dobagara*) are added to couscous, often at ceremonial meals. Also eaten with *dawadawa*, a fermented cheese-like food prepared from locust beans. Flowers provide important forage for honeybees and children also suck the nectar.
Leaves	Young leaves are eaten as a vegetable, but only after thorough cooking (like spinach). Reported in Niger, Burkina Faso, Ethiopia, Sudan and Uganda. Boiled and added to crushed peanut balls or to sauces or relishes. Considered a dependable dry season/famine food in some areas. Also valued for feed, especially during the dry season. Relished by all types of stock despite the tree's thorny nature.
Kernel Cake	Seedcake left after the oil has been extracted from the kernels is nutritious enough to replace cottonseed cake in animal rations. A promising locally produced "concentrate" for drylands of Africa. Has been used for fattening sheep because of high in protein (37%) and low in fiber (6%).
Wood	Often-crooked though useful. Heartwood is attractive, easily worked, fine grained, durable, and resistant to insects, including termites. Can be made into bowls, troughs, tool handles, walking sticks, gunstocks, cabinetry, other farm implements, furniture, and mortars and pestles, parts of camel and donkey saddles. Specially valued for fuel, burns with little smoke and also yields charcoal of high energy content, thus, suited for use as indoor fuel.
Nut shells	Shells are hard, dense, and highly combustible thus make good fuel as well as good charcoal and particleboard.
Branches	Spiny branches are often piled together to form thorny brushwood barriers in West and East Africa. Especially suitable for cattle kraals.

Source: Hardman & Sofowora, 1972; El Khidir, *et al.*, 1983; Webb, 1984; Tredgold, 1986; von Maydell, 1986; Hall & Walker, 1991; FAO, 1992; Dirar, 1993; Azene Bekele *et al.*, 1993; Katende *et al.*, 1995; Neuwinger, 1996; Neuwinger, 2004; Maundu *et al.*, 1999; Chapagain & Wiesman, 2005; WIPO 2006 a & b; Teklehaimanot, 2008; Aluka database, 2008; NRC, 2008; 2008; Hall, 2008).

According to FAO (1992), the fruits have been used in the treatment of liver and spleen diseases. The roots are used for abdominal pains and as a purgative. The bark and roots are used as laxatives and for colic pains. The bark is also used for sore throats, and as a remedy for sterility, mental diseases, epilepsy, yellow fever, syphilis, and tooth aches (FAO, 1992). Maundu *et al.* (1999) reported that *B. aegyptica* root decoction is used to treat malaria, oedema and stomach pains by the Pokot and heart burn by the Kamba people in Kenya. Chapagain and Wiesman (2005) reported aqueous extracts of root and bark of *B. aegyptiaca* to be very effective against the larvae of the *Culex pipens* mosquito. They further asserted that these larvicidal properties could be developed and used as natural insecticides for mosquito control. The active substances in *B. aegyptiaca* (sponins) have now been isolated and widely studied (e.g. Neuwinger, 1996; Wiesman and Chapagain, 2005; Chapagain, 2007; Chapagain *et al.*, 2008). These studies have given credence to most of the earlier reported medicinal uses of *B. aegyptiaca*. Neuwinger (1996), for instance, covers the chemistry, pharmacology and toxicology of *B. aegyptiaca* extracts in detail.

Fruit mesocarp of *B. aegyptiaca* is commonly used in Egyptian folk medicine as an oral anti-diabetic drug (hypoglycemic agents) (Gad *et al.,* 2006). This appears to be re-enforced by earlier findings by Kamel *et al.* (1991) and Saeed *et al.* (1995) who found that aqueous extract of Balanites fruit mesocarps exhibits a prominent anti-diabetic activity in diabetic mice. The same extracts were also found to induce improvement in the blood cholesterol, triglycerides and creatinine levels of diabetic rats (Kamel *et al.,* 1991). In Uganda, oil extracted from *B. aegyptiaca* is an important food as well as medicinal item for communities in the West Nile and Karamoja sub-regions (Eggeling, 1940, Katende *et al.*, 1995; Madrama, 2006). Table 2.5 summarizes the major reported medicinal uses of *B. aegyptiaca.*

2.7.3 Industrial potential of *B. aegyptiaca*

Commercially, *B. aegyptiaca* is reported to be a potential diosgenin and yamogenin source for the manufacture of cortisone and corticosteroid drugs (Hardman and Sofowora, 1972; von Maydell, 1989; Hall and Walker, 1992; Dirar, 1993). Mohamed *et al.* (2002) estimated that more than 400,000 tons of *B. aegyptiaca* fruits are produced in the Sudan annually, thus a significant quantity of this can be used for oil extraction and production of other useful substances such as diosgenin/saponins. According to Chapagain and Wiesman (2005), the seed kernel of *B. aegyptiaca* would be an alternate for diosgenin extraction in the global market. There has been an increasing demand for steroid-based drugs, such as; corticosteroids, contraceptives, sex hormones, and anabolic steroids since about 1960s (Hall and Walker, 1991).

Table 2.5 Reported medicinal uses of *B. aegyptiaca*

Part used	Use	Reference
Fruits	Purgative, vermifuge/de-wormer, chills, rheumatism, liver complaints, spleen complaints, stomach disorders as a catharthic/laxative/purgative, colds, arrow poison antidote, as a hypoglycaemic and as a hypocholeasterolmic.	1, 3, 5, 8, 9, 10, 11, 12, 13
Oil	Sores on camels, rheumatism/joint pains, trypanasomiasis, skin parasites, shield against secondary infection, joint and bone pains.	2, 3, 5, 9, 11, 12
Leaves	Rheumatism, open wounds, septic carbuncles, boils, infusion for fevers, infusion to cause vomiting, an anti-helminthic.	5, 6, 11, 12
Resin	Colds, chest complaints, pneumonia, bronchial troubles.	11, 14
Root	Laxative for constipation, tranquillizer for colics, syphilis, anti-helminthic, galactogogue, jaundice.	1, 5, 7, 11, 12, 16
Bark	Colds, fumigant for circumcision wounds, infusion as an abortifacient, laxative for constipation, stomach disorders as a catharthic/laxative/ purgative, tranquillizer for colics, stomach aches, sterility, mental disease and insanity, epilepsy, yellow fever, syphilis, toothache, bronchial troubles, angina/chest pains, snake bites, liver complaints, spleen complains and anti-helminthic.	1, 4, 5, 7, 9, 10, 12, 13, 14, 16
seeds	Malaria, stomach disorders, febrifuge (reduce fever).	8, 9, 10, 11, 12, 15,16

1. FAO (1992) 2. Holland (1922) 3. Suliman & Jackson (1959) 4. Irvine (1961), 5.Watt and Breyer-Brandwijk (1962) 6. Bernus (1979) 7. Seida *et al.* (1981), Liu and Nakanishi (1982), 9. Abu-Al-Futuh (1983) 10. Baumer (1983) 11. Burkhill (1985) 12. von Maydell (1986) 13. El-Saadanay *et al.* (1986) 14. Booth and Wickens (1988) 15. Zarroug *et al.* (1990) 16. NRC (2008).

Adapted with modifications from Hall and Walker (1991)

To date, diosgenin and related steroidal saponins have been commercially obtained from the tubers of various *Dioscorea* species; however, Chapagain and Wiesman (2005) argued that the seed kernel of *B. aegyptiaca* can be an alternate source of diosgenin for the global market. They further pointed out that *B. aegyptiaca* selected from provenances with higher percentages of both oil and diosgenin, could be a resource for germplasm for the future. This might help to make this neglected plant species economically competitive with tubers of *Dioscorea,* the traditional source of diosgenin used for the synthesis of steroid drugs, and ultimately help the domestication process of *B. aegyptiaca*.

B. aegyptiaca extracts are reported to exhibit anti-diabetic and anti-tumor action which presents an opportunity for industrial development. Gad *et al.* (2006) reported that *B. aegyptiaca* extract reduced blood glucose level by 24% and significantly decreased liver glucose-6-phosphatase activity in diabetic rats. Attempt has also been made to characterize the anti-cancer activity of a mixture of steroidal saponins: balanitin-6 (28%) and balanitin-7 (72%)

(referred to as bal6/7) isolated from *B. aegyptiaca* kernels (Gnoula *et al.*, 2008). Bal6/7 demonstrated appreciable anti-cancer effects in human cancer cell lines *in vitro*. *In vivo* bal6/7 was found to increase the survival time of mice bearing murine L1210 leukemia grafts to the same extent reported for vincristine. Gnoula *et al.* (2008) noted that, *in vivo* anti-tumor effects obtained with bal6/7, although modest, are nevertheless statistically significant. Thus, it may be possible to generate novel hemisynthetic derivatives of balanitin-6 and -7 with potentially improved *in vitro* and *in vivo* anti-cancer activity and reduced *in vivo* toxicity, hence markedly improving the therapeutic ratio (Gnoula *et al.*, 2008).

Bio-diesel can be produced from *B. aegyptiaca* oil or crushed nuts. The bio-diesel obtained is reported to have a composition of triglycerides of mainly C16:0 and C18:0 saturated and unsaturated fatty acids, with a very high content of linoleic and oleic acids, and it further contains Balanites saponins, acting as surfactants, which reduce the rate of corrosion and improve the performance of an engine (WIPO, 2006a & b).

2.8 Nutritional value of *B. aegyptiaca* fruit pulp, kernel oil and leaves

2.8.1 Fruits and leaves

Many parts of *B. aegyptiaca* provide food but the most notable edible products include the kernel oil, fruit pulp and leaves. Several reports (e.g. Hussain, *et al.*, 1949; Wu leung *et al.*, 1968; Giffard, 1974; Abu-Al-Futuh, 1983; El Khidir *et al.*, 1983; NRC, 1983; Booth and Wickens, 1988; Jain and Banerjee, 1988; Mohamed *et al.*, 2002) have indicated varying nutritional value of different *B. aegyptiaca* products. The value of the oil and saponins, present particularly in the fruit, has been recognised for some time and these and many other properties and uses have been recorded by Dalziel (1937), Hussain *et al.* (1949) Burkill (1985), Booth and Wickens (1988), Jain (1988), Hall and Walker (1991), Hall (1992), Mohamed *et al.* (2002).

According to NRC (2008), the pulp seems quite nourishing with a carbohydrate (notably sugars) content ranging from 40% (fresh-picked) to 70% (fully dry). The dried pulp also contains about 5% protein and 0.1% fat. School children in parts of West Africa have been reported to suck 15-20 Balanites fruits a day seemingly without ill effect (NRC, 2008). Koko *et al.* (2005) reported that *B. aegyptiaca* fruit mesocarp could be considered as a highly effective antischistosomal remedy. Chapagain and Wiesman (2005) found a higher *B. aegyptiaca* oil yield from Israel (46.12%) followed by Africa (44.17%) and then India (39.20%). They also found a positive correlation ($R^2 = 0.849$) between the diosgenin content in the seed kernel and oil content. *B. aegyptiaca* selected from provenances in Bet-Shean (Israel) were found to contain high percentages of both oil and diosgenin, and they concluded that since both these parameters are desirable characteristics, this relationship may play a vital role in germplasm selection for future domestication of *B. aegyptiaca*.

Cook *et al.* (1998) investigated the nutritional content of *B. aegyptiaca* from Niger and found the fruit mesocarp to contain 7.10% protein and 13 amino acids. Though the amino acids were in lesser quantities than WHO standards, they were noted to be contributing to the nutrition of the Sahelian inhabitants who were facing food shortage. The pulp contained 14.1% fat and 0.93 mg/g dry wt. of dienoic (an essential fatty acid). Cook *et al.* (1998) found *B. aegyptiaca* to provide useful amounts of zinc (8.3 mg/g dry wt.), critical trace mineral for the maintenance of body immune systems. They noted that this was good for the dryland communities, especially children, who are at risk for a variety of microbial and parasitic infections. *B. aegyptiaca* mesocarp was also found to have four fatty acids: palmitic (1.31), stearic (0.47), oleic (0.75) and linoleic (0.93) mg/g dry wt. Though Cook *et al.* (1998) did not determine the fatty acids in the seed kernels, similar fatty acids have been reported in kernels by others (e.g. Jain and Banerjee, 1988; Hall and Walker, 1991; Mohamed *et al.* 2002).

In a study of *B. aegyptiaca* samples from two different regions in Sudan, Nour, *et al.* (1985) reported that the edible mesocarp contained 1.2-1.5% protein and 35-37% total sugars of which 81.3-91.1% is present as reducing sugars. On the other hand, the kernels contained 45.0 - 46.1% oil. Palmitic, stearic, oleic and linoleic acids were reported to be the main fatty acids present in the seed kernel. The fat content of the kernels was high, levels of 40-46% edible oil having been reported (Abdel-Rahim *et al.*, 1986). Although the different reports have indicated a high nutritive value, just how good a food the kernels are remains in doubt. Sometimes they are steeped 3 to 4 days before being eaten, and whether this is necessary, precautionary, or reflective of just certain types is currently unknown. However, seed meal tested on rats showed no gross toxicity.

Mohamed *et al.* (2002) also investigated the chemical composition of *B. aegyptiaca* seed kernels and kernel cake and reported crude fat (49.0%) and crude protein (32.4%) (dry weight basis), as the two major constituents of the kernel flour. The proximate composition and mineral content of *B. aegyptiaca* leaves, fruit pulp and seed kernel are shown in Tables 2.6. and 2.7 respectively.

Table 2.6 Proximate values of *B. aegyptiaca* fruits and leaves (% dry weight basis)

Parameter	Pulp* (% dry wt)	Pulp** (% w/w)	Kernel** (% w/w)	Leaves* (% dry wt)	Leaves*** (mg/100g)
Dry matter	90.90	-	-	5.69	-
Moisture	-	-	-	-	13.11
Ash content	7.42	2.4 – 6.9	3.0	12.37	9.26
Protein	7.88	1.2 – 6.6	27.6	-	15.86
Fats	1.34	0.1 – 0.4	48.3	3.34	2.90
Fibre	5.83	0.4 – 4.4	0.3	26.07	30.75
Carbohydrate	73.29	88.0	20.8	-	32.38
Vitamin C	-	0.9 – 1.6	-	-	-

*Lockett *et al.* (2000)
** Hall and Walker (1991) – citing several sources
***Kubmarawa *et al.* (2008)

Table 2.7 Mineral content of *B. aegyptiaca* fruit pulp, seed kernel and leaves

Mineral	Fruit pulp* µg/g dry wt.	Seed kernel* µg/g dry wt.	Fruit pulp** mg/100g	Leaves** mg/100g
Al	94	2.9	-	-
Ca	1,050	1,910	20.00	1,580
Cr	3.5	1.3	-	-
Cu	2.4	1.4	0.62	1.10
Fe	120	11	5.80	57.93
Mg	930	800	81.37	296
Mn	5.4	3.9	0.65	4.73
Mo	ND	0.4	-	-
Zn	8.3	7.7	2.92	2.27
P	ND	ND	78.57	159

* Cook *et al.* (1998)
** Lockett *et al.* (2000)
ND – not detected

2.8.2 Kernels

In an earlier study of oil from the *B. aegyptiaca* kernels from Sudan (Hussain *et al.,* 1949), the kernels which amount to 9 to 10% of the fruit were found to contain approximately 46% oil. The oil was corresponding to 43.8% linolein, 30.5% olein, 23.7% saturated acid glycerides, and 2.0% unsaponifiable matter. The colour of *B. aegyptiaca* oil (golden/light yellow) was due almost entirely to the presence of alpha-carotene (Hussain *et al.,*1949). Other reports have confirmed the presence of four fatty acids in *B. aegyptiaca* kernel; linolein, olein, stearic and palmitic acid, though in varying yields and quantities (Table 2.8). Cook *et al.* (1998) reported similar fatty acids in the fruit pulp being: 1.31, 0.47, 0.75, and 0.93 mg/g dry wt. for linoleic, oleic, stearic and palmitic, respectively. Of all the reports seen, only Mohamed *et al.* (2002) has reported presence of alpha linolenic acid in *B. aegyptiaca* seed kernel though in a rather small proportion (1.7%). It appears that the difference in method of extraction used (hand press as opposed to solvent) and improvement in the scientific equipment could have enabled detection of alpha linolenic in the seed kernel.

Table 2.8 Composition of *B. aegyptiaca* kernel oil (% w/w)

Component	Hussain *et al.* (1949)	Giffard (1974)	Abu-Al-Futuh (1983)	Mohamed *et al.* (2002)
Linoleic acid	43.8	38.6	40-48	35.0
Oleic acid	30.5	33.7	30-40	38.1
Stearic acid	(Saturated	11.3	9-10	12.5
Palmitic acid	glycerides) 23.7	16.4	10-12	12.7
α-Linolenic acid	-	-	-	1.7

Oil yield has been reported to be good [e.g., Hussain *et al., 1949* (46%), Jain and Banerjee, 1988 (45%); Mohamed *et al.,* 2002 (49%)]. In a study of *B. aegyptiaca* seed oil from India (Jain and Banerje, 1988) reported oil yield, 45%, acid value, 0.58; iodine value, 56.5 and saponification value, 172.7. A more detailed profile of the fatty acids in *B. aegyptiaca* oil was recently conducted by Chapagain, *et al.* (2009) who identified up to 17 fatty acids (Table 2.9). linoleic (47.8%), oleic (22.2%), palmitic (16.9%) and stearic (11.7%) were the dominant fatty acids.

Table 2.9 Detailed fatty acid profile of *B. aegyptiaca* oil

Fatty acid	Structure	Percentage
Myristic	14:0	0.050
Pentadecenoic	15:1	0.003
Pentadecanoic	15:0	0.046
Palmitoleic	16:1	0.027
Palmitic	16:0	16.683
Margaric	17:0	0.106
Linoleic	18:2	47.847
Oleic (9)	18:1	22.187
Oleic (10)	18:1	0.620
Stearic	18:0	11.67
Nonadecenoic	19:1	0.175
Nonadecenoic	19:0	0.032
Gadoleic	20:1	0.061
Arachidic	20:0	0.340
Behenic	22:0	0.059
Tricosanoic	23:0	0.012
Tetracosanoic	24:0	0.042

Source: Chapagain et al. (2009)

The leaves, pulp and kernel (oil) are said to be nontoxic and containing thirteen amino acids (Table 2.10). Cook *et al.* (1998) reported 18 amino acids in *B. aegyptiaca* fruit pulp excluding asparagine and glutamine reported in kernel oil (Jain and Banerje, 1988*)* but including additional seven: phenylamine, methionine, isoleucine, leucine, tryptophan, arginine and alanine. Jain and Banerje (1988) pointed out that the oil could be a good source of oleic and linoleic acids since they were found to be the major constituents in the lipid, noting that natural sources of linoleic are significant because it is an essential fatty acid.

Table 2.10 Amino acid composition of *B. aegyptiaca* leaves and fruit pulp

Amino acid	Leaves (g/100g protein) Kubmarawa *et al.* (2008)	Pulp (mg/100g dry wt) Cook *et al.* (1998)	Kernel (mg/g of nitrogen) Abu-Al-Futuh (1983)
Alanine	1.80	2.90	100
Arginine	4.20	3.00	394
Aspartic acid	7.86	4.3	1200
Cysteine	0.79	1.65	106
Glutamic acid	10.80	7.10	1520
Glycine	9.65	2.52	1106
Histidine	2.83	0.80	119
Isoleucine	3.50	1.87	256
Leucine	6.23	3.04	331
Lysine	4.51	1.64	319
Methionine	0.73	0.60	94
Phenylamine	4.80	1.90	194
Proline	1.85	30.80	113
Serine	2.01	1.80	525
Threonine	2.88	2.17	100
Tryptophan	NR	0.70	63
Tyrosine	3.16	1.84	113
Valine	4.07	2.23	263

2.8.3 Anti-nutritional factors in *B. aegyptiaca* products

A study in Nigeria (Kubmarawa *et al.*, 2008) revealed that *B. aegyptiaca,* one of the vegetables consumed in Adamawa state, can contribute useful amount of nutrients including amino acids to human diet and interestingly the anti-nutritional contents (phytic acid, tannins and oxalates) were much lower than is obtainable in most Nigerian vegetables. They however, pointed out that nutrient loss is of great concern during blanching and cooking of vegetables, thus, suggesting the need to study the effects of cooking and processing procedures on nutrient availability of the vegetables.

2.9 Conclusion

Information so far available indicates that *B. aegyptiaca* is a versatile species with great local and international importance. Although the species has various uses ranging from food to ethnobotanical, many reports have considered it as one of the most neglected tree species in the drylands of Africa (Hall and Walker, 1991; Chapagain and Wiesman, 2005; Teklehaimanot, 2008; NRC, 2008). According to NRC (2008), the several Balanites products with industrial potential need and deserve further development. These include diosgenin, oil, and various fermentation products. The same can be said for its by-products (such as protein-rich kernel cake), which may end up becoming vital resources for many of the world's most needy nations. It has been pointed out that the principal obstacle to extensive commercial exploitation of *B. aegyptiaca* is the lack of suitable technology for cracking its hard nuts. According to NRC (2008), a research breakthrough in this area could transform the potential of this dryland species.

It has also been noted that research is urgently needed to determine how good the various *B. aegyptiaca* products are as medicinals, pest-control agents, skin treatments, animal feeds, and chew sticks. Such research would be interesting and justified because the tree grows in the arid and semi-arid areas where few or no other sources for such products exist. Additionally, *B. aegyptiaca* leaves are a dependable dry season vegetable in many African countries such as Niger, Burkina Faso, Ethiopia, Sudan and Uganda. Earlier literature tended to refer to Balanites leaves as a famine food. The current emerging consensus however, suggests that, much as Balanites leaves are available deep in the dry season, dryland communities regard them as a dependable dry season food which is used in both years of food abundance and scarcity. It is therefore necessary to understand the nutritional value of Balanites leaves so as to appreciate their contribution to household food and nutritional food security of dryland communities. This could perhaps partly explain why some of these communities have always survived amidst the severe droughts and food shortages that have characterised many dryland areas. Ways of improving processing and packaging of Balanites leaves for long-term storage should also be explored. This is needed to guide their wider utilisation and marketing, thus improving incomes of dryland communities.

CHAPTER THREE: LOCAL KNOWLEDGE ON USE AND MANAGEMENT OF *BALANITES AEGYPTIACA* IN UGANDA

This chapter documents the local communities' knowledge on the use and management of *Balanites aegyptiaca* in Uganda. Section 3.1 gives a general introduction and the role of local knowledge in development of indigenous fruit trees (IFTs). The objectives and research questions which guided the study are outlined in section 3.2 while materials and methods are described in section 3.3. The results are presented in section 3.4 on the characteristics of the study population, Balanites as a source of food among indigenous fruits and vegetables, silviculture and management of Balanites, contribution of Balanites to household diets and institutional constraints and opportunities for improved use and management of Balanites. The results are discussed in section 3.5.

3.1 Introduction

There is evidence across the drylands of Africa that local communities have for a long time utilized indigenous fruit trees (IFTs) for their livelihoods (Aluma, 2004; Steiner and Oviedo, 2004). This dependence can be explored so as to increase the contribution of these foods in rural economies. Nevertheless, IFTs have received limited recognition from the development community and have not been subjects of scientific research until very recently. There is therefore a dearth of information to permit sound management and propagation. It is now widely accepted that research aimed at indigenous tree improvement is likely to be most effective when local people are involved (Dewalt, 1994). As such, IFTs research needs to embrace 'local' or 'indigenous' or 'traditional' knowledge. Mukapa (2004) noted that indigenous knowledge (IK) is a resource that can help to solve local problems and contribute to global development. This observation strengthens the above position.

Given the negative connotations that have been associated with 'indigenous' and 'traditional' knowledge (FAO, 2005), the word 'local knowledge' has been adopted in this study although the three have been used interchangeably. The concept of traditional knowledge implies that people living in rural areas are isolated from the rest of the world and that their knowledge systems are static and do not interact with other knowledge systems. IK systems on the other hand are often associated with indigenous people and tend to limit policies, projects and programmes seeking to work with rural communities in general. In some countries, the term 'indigenous' has a negative connotation, as it is associated with backwardness or has an ethnic and political connotation (FAO, 2005). Lingill (1999) noted that the word indigenous appears to be too narrow because it excludes peoples who may have lived in an area for a long time but are not the original inhabitants. This has led to widespread use of the term local knowledge (LK) - a broader concept which refers to the knowledge possessed by any group living off the land in a particular area for a long period of time. On this basis, it is not necessary to know if the people in question are the original inhabitants of an area, rather it is important to learn how people – indigenous or non-indigenous - in a particular area view and interact with their environment, in order that their knowledge can be mobilized for the design of appropriate interventions.

According to Warburton and Martin (1999), LK is regarded as a collection of facts and relates to the entire system of concepts, beliefs and perceptions that people hold about the world around them. This includes the way people observe and measure their surroundings, how they solve problems and validate new information. It also includes the processes whereby knowledge is generated, stored, applied and transmitted to others. World Bank (2006) regards LK as knowledge and practices developed over time and maintained by people in rural areas who interact with their natural environment. This complex knowledge forms part of the cultural practices used in the management and use of natural resources to sustain livelihoods. LK is also considered to be dynamic, and unique to a given culture and society and it forms the basis for local-level decision making in agriculture, healthcare, food preparation, education, natural resource management and other activities (Wold Bank, 2006).

Mukapa (2004) observed that communities are eager to learn from the scientific community so as to improve their livelihoods. On the other hand, they are also eager to share the knowledge which their environment has been teaching them on a daily basis for a long time. Therefore, the very process of learning from the community recognizes the community and bearers of local knowledge as partners in development who bring as much, if not more to the process. Integration of modern science with local knowledge makes incremental changes to the existing local systems thus enabling sustainable development and poverty alleviation in the drylands (Waser, 2007). One of the questions among Suderland's hundred scientific questions that, if answered, would have the greatest impact on conservation practice and policy is 'what mechanisms best promote the use of local ideas and knowledge in conservation programmes in ways that enhance biodiversity outcomes? (Suderland *et al* (2009). As noted by Aveling

(2009), this question clearly demonstrates the increasing importance of local knowledge and the fact that research is re-focusing on how local knowledge can be translated into better outcomes for biodiversity within modern conservation practice.

According to Simons (1996) and Maghembe *et al.* (1998), groups of IFT collectors who include children and women have useful information on taste, availability and fruit size that can help in guiding the domestication of IFTs. Oduol, *et al.* (2008) pointed out that LK is a very important resource for rural communities in fighting poverty, and by implication the attainment of objective one of the Millennium Development Goals (MDG1). They further noted that LK enables the development of enterprises and for the local people to participate in decision making and sustainable development yet this knowledge is being eroded and lost. Documentation of LK is therefore a necessary starting point for strengthening the capacities of local people for developing their own knowledge and methodologies that promote activities to improve and sustain their livelihoods (Oduol, *et al.*, 2008). Kwesiga *et al.* (2000) reported that LK should form the basis for policy development and research on domestication of IFTs. The role of LK in rural development was earlier discussed by Chambers (1983) who called for reversals in learning, that is, 'putting the last first'. According to him this can take many forms including sitting, asking, listening and learning from the poorest and learning indigenous technical knowledge and then conducting joint research and development.

In addition to LK, information on existing local institutional and legal opportunities and constraints regarding the use and management of *B. aegyptiaca* and other IFTs needs to be taken into account to develop options for their enhanced use and management. Even if know-how and high quality trees are available, it is no sure deal that local people will use them unless there is favourable legal and institutional environment in the community. The legislation on forestry and trees in Africa dates back to colonial times and has a strong protective focus (Ribot, 2001). Even in cases where new legislation has been put in place, local people are not aware of it; for instance, farmers in Cameroon were uncertain whether or not they needed permission before harvesting bark from their own *Prunus africana* trees (Cunningham, *et al.*, 2002). Trees and the use of trees are regulated by traditional institutions in some places and farmers have managed their trees for a long time (Boffa, 1999).

Whereas legislation varies from one country to another, traditional regulation of trees is much more variable (with site and ethnic group). The effects of these differences on use and management of IFTs have not been studied or described in the literature. While it is impossible to obtain a complete picture of these regulations, it is necessary to understand at least the basis of how they affect tree use and management if recommendations regarding trees are to be of use. Campbell *et al.* (2001) reported that there is need to understand the evolution and dynamics of institutions in order to develop IFTs. There is increased appreciation of a need to integrate formal institutions with traditional moral and political legitimacy at the local level to provide a more stable and effective approach for managing trees and other natural resources (Oduol *et al.*, 2008).

Any attempt towards increasing the contribution of *B. aegyptiaca* and other IFTs to household food security and incomes requires a clear understanding of the wealth of local knowledge on their use, management and conservation. Shanley (2006) noted that local knowledge can offer an irreplaceable foundation for research and development. Besides documenting LK, this study also sought to understand the contribution of *B. aegyptiaca* to rural household diets by looking at the quantities of the products (leaves, fruits and oil) collected and consumed. Such information will be vital in understanding the importance of *B. aegyptiaca* to rural livelihoods and thus promote its integration into dryland farming systems.

3.2 Objectives and research questions

The overall objective was to collect and analyse local knowledge on use and management of *B. aegyptiaca* and its contribution to rural diets and incomes. The specific objectives were to:

i. Document and analyse local people's use and management of *B. aegyptiaca*,
ii. Assess the contribution of *B. aegyptiaca* to household diets.
iii. Identify institutional constraints and opportunities for improved use and management of *B. aegyptiaca*.

The study was guided by the following research questions:

Objective	Questions
(i) Document and analyse local people's use and management of *B. aegyptiaca.*	• What is the priority status of Balanites among indigenous fruits and/or vegetables in the study areas? • What are the uses of Balanites and which parts or products are the most commonly used? • What are the sources of Balanites trees? • How are Balanites trees managed under different land use systems?
(ii) Assess the contribution of *B. aegyptiaca* to household diets.	• How frequently do local people utilize Balanites products and during which months/periods of the year? • Who in a household collects and uses Balanites products?
(ii) Identify institutional constraints and opportunities for improved use and management of *B. aegyptiaca.*	• Which institutions (traditional and government) are involved in the management of Balanites and other IFTs? • What are the institutional constraints and opportunities for improved use and management of Balanites in Uganda?

3.3 Materials and Methods

3.3.1 Data collection

The study was conducted in Adjumani and Katakwi districts in Uganda (described in chapter 1). These districts were selected because of the prominence of *B. aegyptiaca* and its significant use as a source of food and income for local communities. Five villages were selected for the study by local communities based on the density of Balanites trees and their product use. The villages were Nyeu and Egge in Adjumani district and Aboiboi, Apuuton and Acoite in Katakwi district (Table 1.1). Preliminary survey in some of the study villages, especially in Katakwi had earlier been conducted by Teklehaimanot (2005) and a follow up preliminary survey in all the study villages was carried out by the researcher between April and June 2007.

Systematic random sampling as described by Ott and Longnecker (2001) was used for selecting participating households using village lists obtained from district administration offices. After constructing the sampling frame for each site (village), the sampling interval was calculated based on the required sample size for each village. The starting household was randomly selected based on a number lying between one and the sampling interval. Subsequent households were selected systematically by addition of the sampling interval to the preceding sample until a required number of households were selected for each village. In each village, the 20% minimum sample size as recommended in social surveys recommended by Hetherington (1975) was ensured. Within the selected households, either a man or a woman was interviewed depending on availability and/or their preference.

In each study district, one research assistant was identified to work with the researcher in data collection. These were trained forestry technicians with knowledge of the social dynamics in the study sites. According to Barker and Cross (1992) selecting appropriate community researchers is critical to the success of any study. Although a high level of education and literacy enables interviewers to grasp the complexity of some of the survey questions, community researchers should also have a high level of curiosity and analytical capacity; an understanding of their own culture and how research among their own people should be conducted. von Geusau *et al.* (1992) also observed that a good traditional education and the confidence and respect of the local people are key for community researchers.

Data for fulfilling the three objectives were collected using a combination of structured and semi-structured interviews. The sample questionnaire and interview guide used are shown in Appendix 3.1 and 3.2, respectively. Structured interviews involved using a set of predetermined questions and standardised techniques of recording responses while semi-structured interviews had some flexibility in the responses provided (Kothari, 2004). In addition to interviews using a questionnaire, three focus group discussions involving men, women and children/youth were held in each village. This was done to encourage spontaneity and to minimize inhibitions caused by codes of expected behavior in communities. Oduol (1996) noted that to achieve this, a researcher can identify discussion groups on the basis of gender, age, educational status, interests and ethnicity. Group discussions permit a high rate of information generation and the accuracy of the information generated. As noted by Grenier (1998), groups also act as information dissemination sessions since the less knowledgeable participants learn something new from those who are more knowledgeable. The splitting of the groups by gender and/or age helped to reduce domination of the discussion by some influential members. Interviews were also conducted with key informants such as district, sub-county and village leaders and community members with specialised knowledge including Balanites products collectors, processors, traders as well as elders.

Respondents were asked to provide information on a wide range of issues regarding *B. aegyptiaca*, such as, availability of trees and a historical use of tree products in the area, management of wild and on-farm trees, quantities of products harvested for home consumption and sale, gender disparities in the tree management, collection, utilization and marketing of products and households' dependence on Balanites products (fruits, oil and leaves). Focus group discussions based on the interview guide and involving men, women and youth, explored and probed key aspects related to management, conservation and utilisation of Balanites. Additional information captured included the extent of tree planting by farmers and the type and sources of planting materials used. According to Patton (2002), interview guides are essential for conducting focus group interviews because they keep the interactions focused while allowing individual perspectives and experiences to emerge. Nichols (1991) pointed out that key informants provide detailed information on factual issues regarding the subject under investigation. Information from key informants, focus group discussions and secondary sources were used to triangulate and back-up that collected using questionnaires. According to CDRN (2000), key informant interviews help to close gaps on data collected using questionnaires and community meetings.

Traditional and institutional frameworks that govern the use and management of trees in the wild and on-farms were captured during the interview. Existence of extension services and ownership of trees in different settings was inquired and institutional issues related to land and environmental policies were also captured. Traditional tree management systems were investigated and included issues such as, traditional systems in place and their effectiveness and weaknesses; and prospects for strengthening or reviving traditional tree management systems to fit the current conditions. In general, a total of 150 respondents (households), 15 focus groups and 25 key informants were interviewed in the two study districts.

3.1.2 Data analysis

Data were corded, entered and analysed in SPSS statistical package (Version 16). Percentages, totals and means of selected variables were generated using descriptive statistics and cross tabulation for either single or multiple responses. Multiple responses were combined by defining the new sets and specifying whether responses where dichotomous or categorical. Analysis on such multiple responses was then run using either frequencies or cross tabulations. The results generated were presented in form of tables, pie charts and graphs. Information gathered from focus group discussions and key informant interviews was integrated into the results and discussion.

3.4 Results

3.4.1 Demographic and socio-economic characteristics of respondents

The demographic and socio-economic characteristics of the respondents are presented in Tables 3.1 and 3.2, respectively. Fifty five percent of the respondents were from Katakwi while 45% were from Adjumani. The sample was made of an equal number (50%) of both male and female respondents who were mostly from two ethnic groups, Iteso (55%) and the Madi (43%). Respondents were mainly aged between 36 and 50 years (37%) and attained primary level of education (47%). Only a few (13%) had attained tertiary level of education (Table 3.1). The average number of people per household was eight and six for Katakwi and Adjumani respectively. Respondents had settled in the study area for about 20 to 32 years in Adjumani and Katakwi, respectively.

About 62% of the respondents were engaged in subsistence farming as the main livelihood source while a few (3%) were engaged in fishing, especially along the River Nile in Adjumani district. The majority (78%) had landholdings ranging from 1 to 4 ha with an average land size of 2.5 ha in Katakwi and 4 ha in Adjumani. The land was mainly acquired through inheritance (68%) with communal system of ownership; nonetheless, some (13%) reported having bought their land. Most of the respondents were generally poor with about 62% living on less than one dollar per day (Table 3.2).

Table 3.1 Demographic characteristics of respondents in the two study districts (n = 150)

Variable	%
District	
Adjumani (n=68)	45.3
Katakwi (n=82)	54.7
Sex	
Male	50.0
Female	50.0
Ethnicity	
Iteso	54.7
Madi	42.7
Kuku	2.6
Age group (years)	
< 20	4.4
20 – 35	29.3
36 – 50	37.3
51- 65	16.7
> 65	12.3
Education level	
None	19.6
Primary	46.6
Secondary	20.9
Tertiary	12.8

Table 3.2 Socio-economic characteristics of respondents (n=150)

Variable	Percentage (%)		
	Katakwi	Adjumani	Mean
Livelihood source			
Farmer	90.2	33.8	62.0
Employed	7.3	29.2	18.3
Business	2.4	30.8	16.6
Fishing	0.0	6.2	3.1
Land size (ha)			
1 - 2	57.3	27.4	43.8
3 – 4	33.3	32.3	32.8
5 – 6	4.0	11.3	7.3
7 – 8	4.0	16.1	9.5
> 8	1.3	12.9	6.6
Means of land acquisition			
Inherited	65.3	71.2	68.3
Allocated (resettled)	8.0	27.3	17.6
Bought	25.3	1.5	13.4
Borrowed	1.3	0.0	0.7
Annual income level (UGX)			
< 100,000	26.0	1.5	13.8
100,000 - 400,000	35.6	10.4	23.0
400,000 - 700,000	11.0	40.3	25.6
> 700,000	27.4	47.8	37.6

(Exchange rate: 1 USD = UGX 2,000)

3.4.2 Main food and cash crops grown in Katakwi and Adjumani

The main food crops grown in Adjumani and Katakwi districts were cassava (*Manihot esculenta)*, maize (*Zea mays)*, peanuts (*Arachis hypogaea)*, sorghum (*sorghum bicolor*) sweet potatoes (*Ipomoea batatas)* and millet (*Eleusine coracana)* (Table 3.3). The main cash crops grown in the two districts in descending order of rank were *Zea mays*, *Arachis hypogaea*, sesame *(Sesamum indicum)*, *Manihot esculenta* and *Eleusine coracana* (Table 3.4).

Table 3.3 Main food crops grown in Adjumani and Katakwi districts (n=150)

Crop	Adjumani		Katakwi	
	Mean score	Rank	Mean score	Rank
Manihot esculenta	1.29	1	1.86	1
Zea mays	1.60	2	3.50	6
Arachis hypogaea	2.00	4	2.20	2
Sorghum bicolor	3.00	5	2.29	3
Ipomoea batatas	1.83	3	3.17	4
Cajanas cajan	3.14	8	-	-
Eleusine coracana	-	-	3.29	5
Sesamum indicum	3.00	5	3.53	7
Vigna unguiculata	3.13	7	3.80	8

Table 3.4 Main cash crops grown in Adjumani and Katakwi districts (n=150)

Crop	Adjumani		Katakwi	
	Mean score	Rank	Mean score	Rank
Zea mays	1.31	1	2.50	4
Arachis hypogaea	2.00	3	1.39	1
Sesamum indicum	1.74	2	2.67	5
Manihot esculenta	2.50	5	2.17	2
Eleusine coracana	2.46	4	2.30	3
Sorghum bicolor	2.80	6	2.67	5
Ipomoea batatas	3.00	7	2.82	7
Cajanas cajan	3.00	7	3.00	8
Vigna unguiculata	-	-	3.09	9

3.4.3 Priority status of *B. eagyptiaca* among indigenous fruits and vegetables in Adjumani and Katakwi districts

During the questionnaire pre-testing, it was realised that whereas some communities valued *B. aegytiaca* as a fruit tree, others regarded it as a vegetable tree. It was, therefore, deemed necessary to establish the priority status of the *B. aegytiaca* in these two major use categories. *B. aegytiaca, Vitellaria paradoxa, Vitex doniana, Tamarindus indica* and *Carissa edulis*, in that order were the five priority IFTs in Adjumani while in Katakwi *T. indica, V. paradoxa, C. edulis, Holslundia opposite* and *B. aegytiaca,* respectively were the five priority IFTs (Table 3.5).

Table 3.5 Priority indigenous fruit trees in Katakwi and Adjumani districts (n=150)

Fruit tree	Adjumani		Katakwi	
	Mean score	Rank	Mean score	Rank
Tamarindus indica L.	1.89	4	1.52	1
Balanites aegyptiaca (L) Del.	1.10	1	3.30	5
Vitellaria paradoxa C.F. Gaertn.	1.50	2	2.02	2
Carissa edulis Vahl.	1.90	5	2.96	3
Holslundia oppositae Vahl.	-	-	3.13	4
Vitex doniana Kotschy & Peyr.	1.86	3	3.45	6
Rhus vulgaris Meikle	-	-	3.60	7
Strychnos innocua Del.	-	-	4.00	8
Diospyros mespiliformis Hochst	-	-	4.00	8
Annona senegalensis Pers.	-	-	4.00	8
Ximenia Americana L.	-	-	4.21	11
Vangueria apiculata K. Schum	-	-	4.30	12
Mimusops kummel Bruce	-	-	4.50	13

The five top ranked indigenous vegetables in Adjumani were *Sesamum calycinum*, *Leptadenia hastate, Hibiscus sabdariffa, Corchorus olitorius* and *Cleome gynandra,* correspondingly. Balanites *aegyptiaca* was ranked as a top priority indigenous vegetable in Katakwi. It was followed by *Senna bicapsularis, Tribulus terrestris, Hibiscus sabdariffa* and *Asystasia mysorensis* in that order (Table 3.6).

Table 3.6 Wild vegetables collected in Adjumani and Katakwi districts (n=150)

Species	Adjumani		Katakwi	
	Mean score1	Rank1	Mean score 2	Rank 2
Sesamum calycinum	1.26	1	-	-
Leptadenia hastata	1.36	2	-	-
Corchorus olitorius	1.67	4	-	-
Balanites aegyptiaca	-	-	1.91	1
Senna bicapsularis	-	-	1.98	2
Hibiscus sabdariffa	1.40	3	2.73	4
Tribulus terrestris	-	-	2.33	3
Cleome gynandra	2.50	5	-	-
Asystasia mysorensis	-	-	2.83	5
Vigna unguiculata	-	-	3.11	6
Emolodok- Ateso (Unknown)	-	-	3.13	7
Basella alba	-	-	3.18	8
Oxygonum sinuatum	-	-	3.57	9
Cyphostemma adenocaule	-	-	3.72	10

3.4.4 Uses of *B. aegyptiaca* in Adjumani and Katakwi districts

Balanites has been used by local communities in Adjumani and Katakwi districts for generations. The Iteso people in Katakwi district and the entire Teso sub-region call Balanites tree *Ecomai* while the Madi in Adjumani call it *Logba* or *Lugba*. Except for the Balanites fruit which is locally known as *irorokony* among the Iteso and the oil referred to as *edu* by the Madi, no specific local names were reported for the other Balanites products. Most of the names were rather a description of the products in the local dialects (Madi and Ateso). The majority (99%) of respondents had at least used Balanites tree or its products in one way or another.

3.4.4.1 Main uses and users of *B. aegyptiaca* products

The main uses of Balanites were leafy vegetable (47%), snack food (27%) and oil (27%). The parts used included young leaves, fruit pulp and seed kernels, respectively. In Adjumani, the main uses of Balanites were oil extraction (53%) and snack food (44%) while in Katakwi its major use was leafy vegetable (91%) (Figure 3.1). These products were mainly used by children (54%) and women (37%) (Figure 3.2).

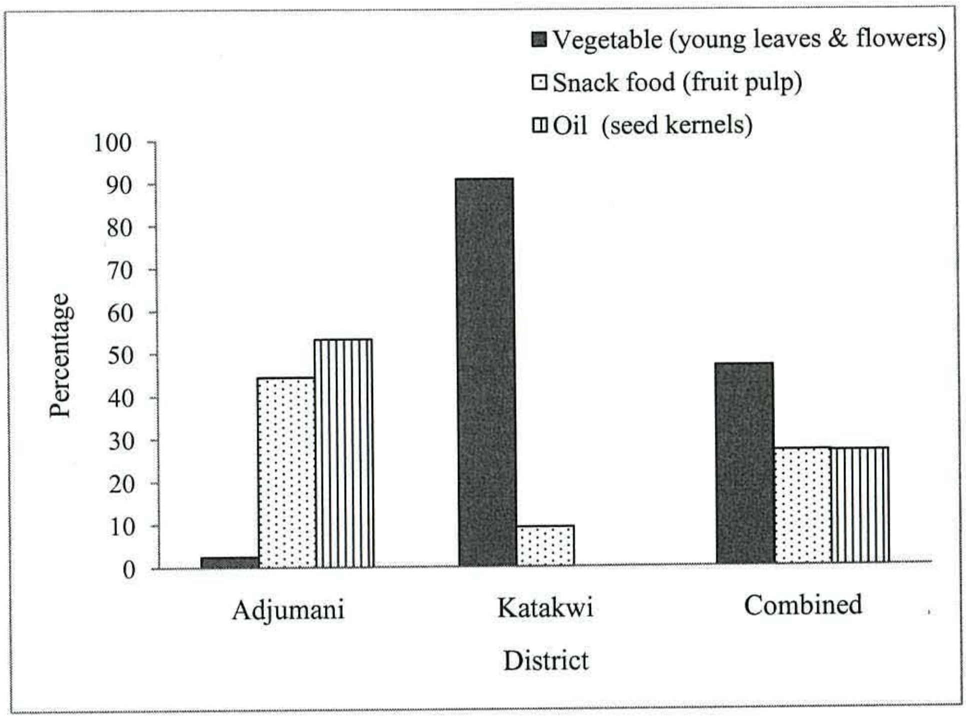


Figure 3.1 Main uses of Balanites products in Adjumani and Katakwi districts, Uganda

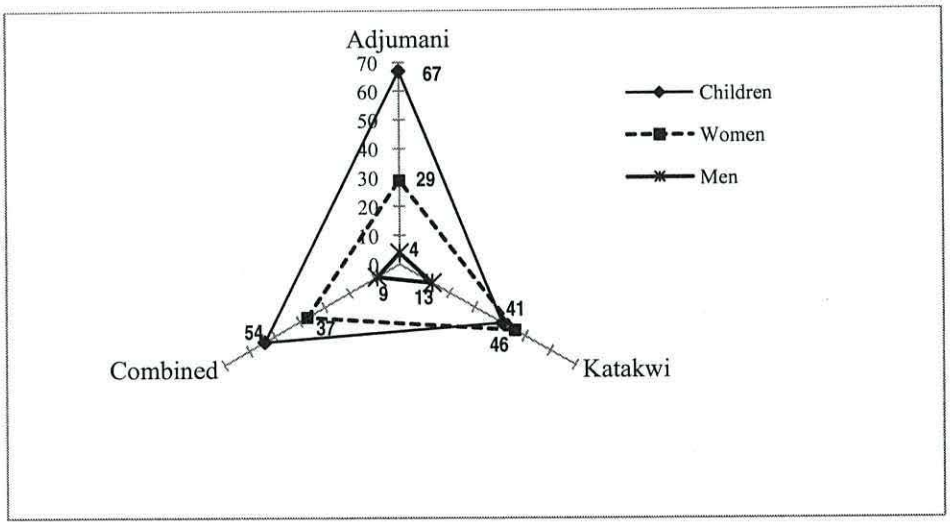


Figure 3.2 Main users of Balanites products in Adjumani and Katakwi districts, Uganda

3.4.4.2 Other uses of Balanites products in Katakwi and Adjumani districts

Households used Balanites tree or its products in other numerous ways, however, fuelwood (firewood and charcoal) and medicines were the other prominent uses (Table 3.7). Several parts and products were used, ranging from whole tree for provision of shade to use of thorns for removing sand flea (*Tunga penetrans*) locally called jiggers from infected body parts, especially in the feet. The medicinal uses of Balanites were further inquired during the focus group discussions and key informant interviews. This was aimed at documenting the purported ailments treated with the different products or parts of Balanites. The main parts/products used were the root and stem bark, oil, fruit pulp and kernel cake (Table 3.8). Several ailments were reported to be treated with these products but generally included; body pains, stomach upsets, malfunctioning of internal body organs (liver and spleen), malaria, snake bites, skin diseases and de-worming children.

Table 3.7 Other uses of Balanites products in Adjumani and Katakwi districts

Use	Part used	% of responses
Firewood	Stem, braches, nut shells	47.3
Charcoal	Stem and braches	23.7
Medicine	Stem/root bark and wood ash	21.6
Building	Poles from stem and branches	8.1
Tools/crafts	Stem and branches	8.1
Gluing	Bark exudates	7.4
Condiment	Wood ash	7.4
Shade	Whole tree	2.0
Fodder	Leaves and twigs	1.4
Remove jiggers	Thorns	1.4
Lubricant	Oil	1.4
Fencing	Thorny branches	1.4
Fish poison	Stem and bark extract	1.4

Table 3.8 Current medicinal uses of *B. aegyptiaca* in Adjumani and Katakwi districts

Use	Part used
Anti-diabetic	Fruit pulp
Cataracts (in animals)	Bark ash
Chest pains	Gum from stem bark
De-worming (children)	Oil and fruit pulp
Joint pains	Bark
Liver and spleen disorders	Raw fruit
Malaria control	kernel cake poured in mosquito breeding places
Malaria treatment	Root bark extract
Mosquito repellant	Smoke from nut shells
Skin diseases	Oil
Snake bites	Root and stem bark mixed with other herbs
Sore throat	Bark
Stomach pains	Stem and root bark
Tooth ache	Bark
Yellow fever	Bark

3.4.4.3 Sources of Balanites products

The current source of Balanites products was mainly (84%) wild trees with on-farm trees contributing only 14% (Table 3.9). The distance travelled to collect Balanites products was generally short (1 – 2 km) (93%) and there appears to be a small change in distance covered to the Balanites source compared to a decade ago (1 – 2 km by 78%). This change was attributed to increased demand for Balanites products and increasing alternative uses of the tree and its products. On-farm retention of Balanites trees was pointed out as another contributory factor for a small change in distance travelled to collect Balanites products. However, over 92% of the interviewees in Adjumani lived within the Balanites belt.

Table 3.9 Sources of Balanites products in Adjumani and Katakwi districts

Variable		Percentage	
	Adjumani	Katakwi	Mean
Current source of Balanites products			
On-farm	24.6	4.9	13.7
Wild	70.8	93.8	83.6
Fallow land	3.1	1.2	2.1
Around home	1.5	0	0.7
Current distance of source from home (km)			
<1	95.5	53.7	72.3
1-2	3.0	35.4	20.9
3-6	1.5	11	6.8
Distance of source from home 10 year ago (km)			
<1	92.5	35.4	61.6
1-2	6.0	25.3	16.4
3-6	1.5	32.9	18.5
7-10	0.0	5.1	2.7
>10	0.0	1.3	0.7
Reason for change in location			
Increased demand of products	-	43.75	43.75
Alternative uses of Balanites trees	-	37.5	37.5
On-farm retention	-	12.5	12.5
Poor harvesting methods	-	6.25	6.25

3.4.5 Growing and management of *B. aegyptica*

3.4.5.1 Growing of *B. aegyptica*

B. aegyptiaca was reported to have been planted by a few (7%) households, however, many (51%) retained and protected natural regeneration on their farms and another 42% regarded it as God given, thus no need to plant (Table 3.10). Among those who planted, seeds (46%) and wildings (36%) were the main sources of planting materials. Cuttings were reported to be used in establishment of cattle enclosures though this was not seen during the present study. Planting niches were mainly on farms (55%) and near homesteads (43%). Balanites tees were, however, more retained near homes (56%) than scattered on farm (31%). The trees were reported by 57% of the respondents to devrease yield of associated agricultural crops although 31% reported Balanites trees as having no effect on associated crops and another 10% reported an increase in yield. About 49% of the respondents said that planting of Balanites was worthwhile, however, the major, reason for limited planting was the lack of knowledge and skills on its propagation (Table 3.10). On average, three Balanites trees were regarded suitable to be retained in one hectare of land. Balanites trees were said to take about 12 years to fruit and respondents expressed the desire to reduce this period by half.

Table 3.10 Planting of *B. aegyptiaca* trees

Variable	Percentage
How do you establish Balanites trees?	
Retaining natural regeneration	51.2
Not grown (God given)	41.9
Planting	7.0
Planting material used	
Seed	45.5
Wildlings	36.4
Cuttings	18.2
Source of planting material	
Wild	83.3
Friend	16.7
Planting sites/niches	
Scattered on farm	55.1
Near home	42.9
Farm boundary	2.0
Sites where Balanites trees are normally retained	
Near home	56.0
Scattered on farm	30.8
Farm boundary	13.2
Effects of Balanites on yield of associated crops	
Decrease	56.8
Increase	10.0
No effect	31.0
Don't know	2.2
Constraints in growing Balanites trees	
Lack of knowledge & skill on propagation	66.7
Lack of seed	30.0
Slow growth	3.3
Opinion on commercial growing of Balanites	
Worthwhile	49.3
No need to plant	36.0
Don't know	14.7

3.4.5.2 Management of *B. aegyptiaca*

Wild trees were reported to benefit from the annual bush burning (42%) which cleared other vegetation leaving the resistant Balanites trees. Those on-farms benefited from weeding of associated crops (43%) while trees around homesteads were normally pruned (50%) (Figure 3.3). Many (54%) respondents reported that Balanites trees in the wild were not managed and few said trees on farms and around homes (25% and 18%, respectively) were not managed.

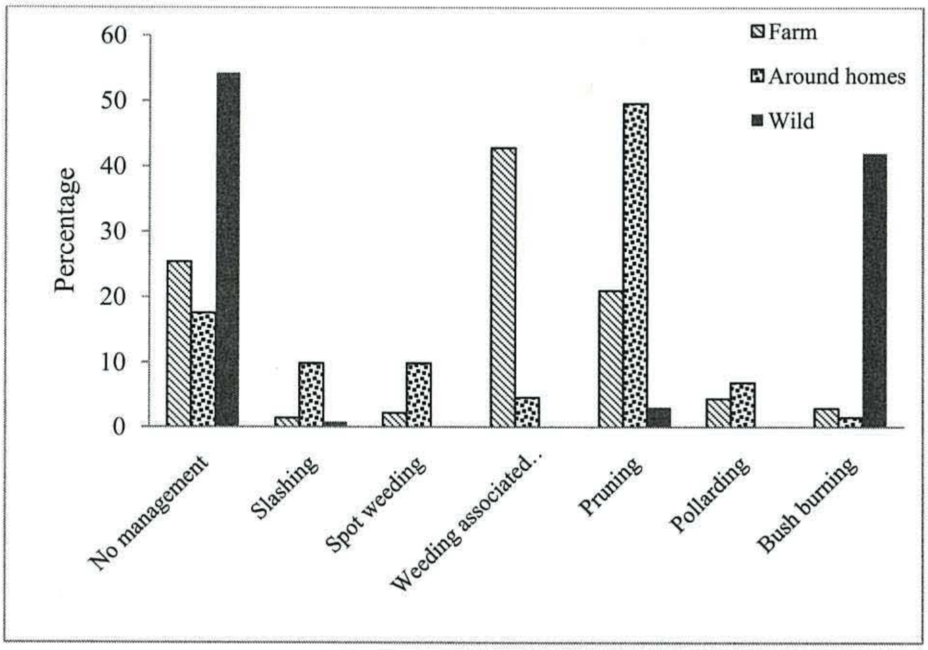


Figure 3.3 Management practices applied to Balanites trees in different land use types

Besides retention of at least three trees per acre, communities also reported that the negative effects of Balanites on associated crops could be minimized through management of the tree itself, such as crown pruning and ring barking of the stem. Furthermore, planting of shade tolerant crops as well as complete avoidance of the area under shade were reported (Table 3.11).

Balanites were mainly found in the wild, especially in communal areas. As such they are in most cases an open access resource. Nonetheless, trees retained on farm and those found around homestead were treated as private property controlled by the farm or home owner. Wild trees were reported to be controlled by the community (43%) and government local authorities (41%) especially, the district forestry services (Table 3. 12).

Table 3.11 Management practices for minimizing negative effects of Balanites on associated crops

Practice	Percentage
Cutting some down	64.7
Crown pruning	27.4
Ring barking	3.1
Plant shade tolerant crops	2.4
Avoid planting crops under shade	2.4

Table 3.12 Control of access to Balanites trees in different land use types

Controller	Wild	On-farms	Around homes
Owner	-	45.9	60.3
Government local authorities	41.2	17.0	9.6
Community	43.4	31.1	26.5
Uganda Wildlife Authority	0.7	-	-
None	11.8	3.7	1.5
Uncertain	2.9	2.2	2.2

The results presented in Table 3.13 show that there were more IFTs retained on farms in Katakwi district (10) than in Adjumani district (5). Ranking of the major IFTs retained on farms revealed that *B. aegyptiaca* is priority rank one and seven for Adjumani and Katakwi districts, respectively. Overall, it was the third most common IFT retained on farms (Table 3.13). The most common exotic fruit trees grown by households were oranges, citrus, pawpaw and jack fruit, in that order (Figure 3.4).

Table 3.13 IFTs retained on-farm in Katakwi and Adjumani districts (n=150)

Tree species	Adjumani		Katakwi		Overall	
	Mean score	Rank	Mean score	Rank	Mean score	Rank
Vangueria apiculata	-	-	0.71	1	0.71	1
Tamarindus indica	2.00	3	1.43	2	1.52	2
Vitellaria paradoxa	1.50	2	1.59	3	1.58	3
Balanites aegyptiaca	1.04	1	3.00	7	1.58	3
Holslundia opposita	-	-	2.00	4	2.00	5
Carissa edulis	2.00	3	2.36	5	2.34	6
Vitex doniana	2.00	3	3.00	7	2.67	7
Diospyros mespiliformis	-	-	2.75	6	2.75	8
Ximenia americana	-	-	3.25	9	3.25	9
Mimusops kummel	-	-	3.50	10	3.50	10

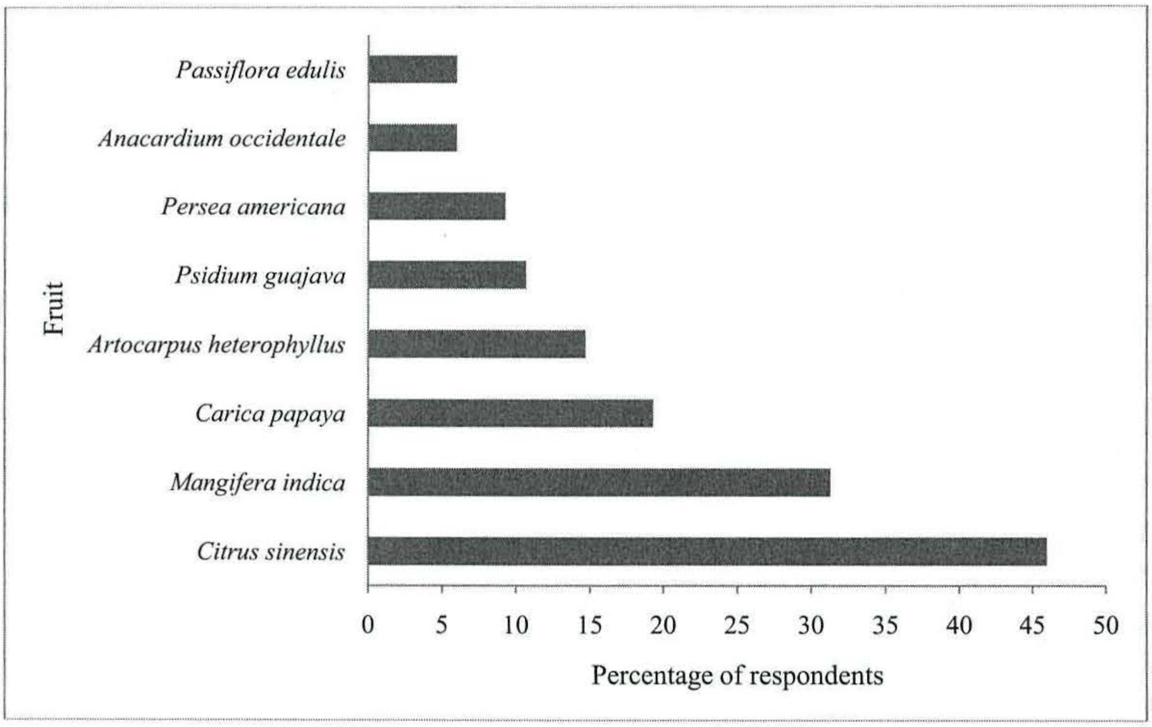


Figure 3.4 Common exotic fruits grown by respondents

3.4.5.3 Harvesting of *B. aegyptica* products

Women and children were the major collectors of Balanites products (Table 3.14). In Adjumani, women and children mainly collected fruits and nuts while in Katakwi they collected leaves and fruits. Just like leaves in Adjumani, no nuts were collected in Katakwi.

Table 3.14 Collectors of Balanites products in household

Product	Product	% responses	
		Adjumani	Katakwi
Women	Leaves	-	59.6
	Fruits	48.0	34.0
	Nuts	47.4	-
Children	Leaves	-	32.1
	Fruits	49.0	47.2
	Nuts	49.5	-
Men	Leaves	-	8.3
	Fruits	3.1	18.9
	Nuts	3.2	-

The method of leaf and fruit collection was more or less the same for both wild and on-farm trees. Leaves were mainly collected by climbing the tree and cutting branchlets and twigs (Plate 3.1) while fruits where generally collected after they have fallen under the tree (Plate 3.2). Nuts were collected from under the parent trees (60%) and in animal resting places (Figure 3.5). Some accidents were reported to be encountered during the harvesting of Balanites leaves in Katakwi (Plate 3.1). Some of these included falling from trees and injuries inflicted by the sharp Balanites thorns.

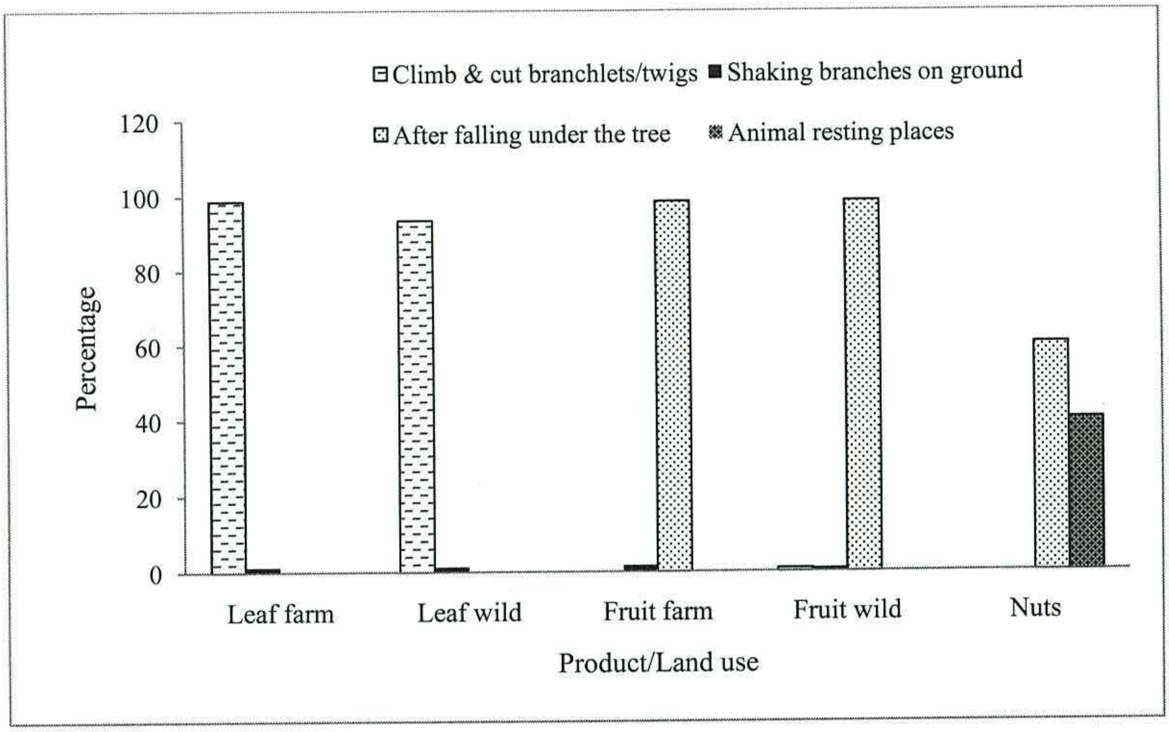


Figure 3.5 Method of harvesting Balanites leaves and fruits products

The reasons for harvesting Balanites leaves by cutting of branchlets and twigs included the ease of picking leaves from below, time saving and avoidance of accidents (Table 3.15). Other reasons were to encourage coppicing of more shoots for next season's harvest and a need to avoid biting small black ants which are always present in many trees.

Table 3.15 Reasons for harvesting Balanites leaves by cutting young branches/twigs

Reasons	Percentage
Trees are thorny/easy to pick from delow	25.9
Time saving	21.0
Avoid accidents	16.0
Carried and leaves picked under shade/at home	13.6
Encourage coppicing	12.3
Presence of biting small blank ants	11.1

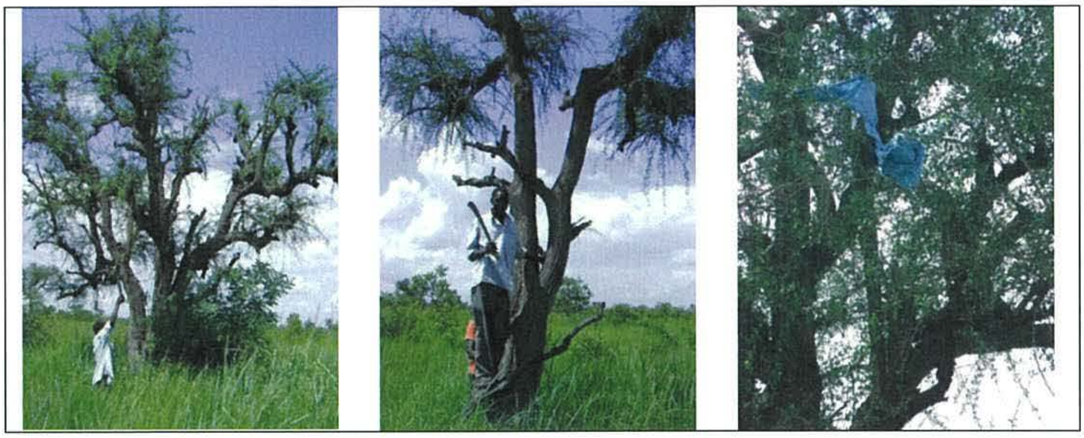


Plate 3.1 Balanites leaf harvesting in Katakwi district

A community leader showing a Balanites tree harvested during the past dry season- notice the excessively cut branchets (left), demonstrating how women and children use improvised ladder to climb tall Balanites trees (middle) and Balanites tree where a child's cloth (apparently school uniform) was caught and torn by thorns and left on the tree (right)

Plate 3.2 Collection of ripe Balanites fruits fallen under a tree

Ripe Balanites fruits fallen under the tree (left) and children with some collected fruits of Balanites, Egge Village Adjumani district

Much as communities reported that this leaf harvesting practice increased leaf yield, they were also aware of the negative effects of the practice on the tree as a whole as well as yield of some products. For instance, the cutting of branchlets and twigs was reported to decrease tree vigour and fruit and/nut yield (Figure 3.6).

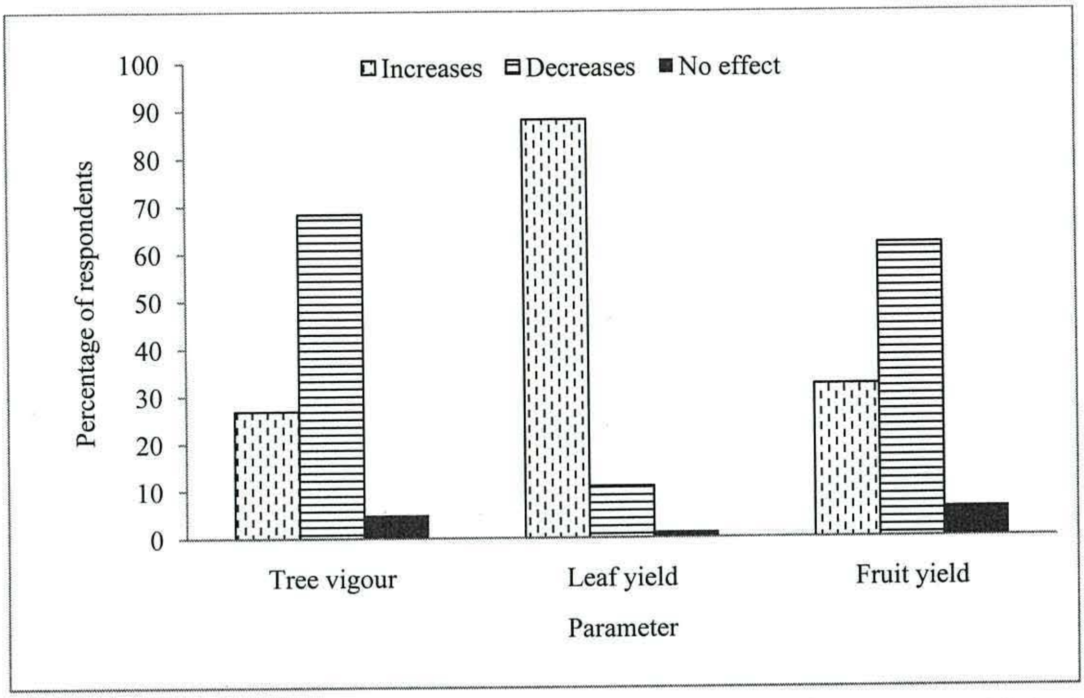


Figure 3.6 Perceived effect of cutting branchlets and twigs on tree vigour and leaf and fruit yield in Katakwi district

3.4.6 Contribution of *B. aegyptiaca* to household diet

3.4.6.1 Collection and use of Balanites products by households

In order to understand the contribution of Balanites products to households' diets and incomes, time of collection in a year and collection frequency of the major products were inquired. In addition, quantities collected and consumed or marketed and frequency of use in households was used to compute annual household consumption and income. Children and women were the major collectors of all the Balanites products – leaves, fruits and nuts (Figure 3.7).

Fruits and nuts were collected in Adjumani and leaves were collected in Katakwi for both household consumption and sale. However, the overall analysis showed that all the products were mainly collected for household use (52%, 89% and 50% for Leaves, fruits and nuts, respectively) (Table 3.16).

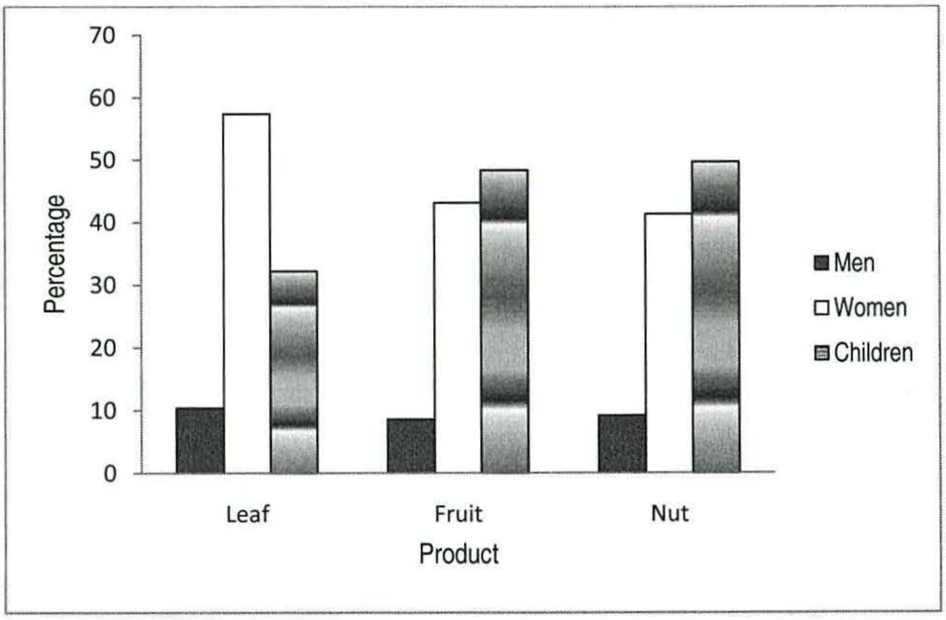


Figure 3.7 Collectors of Balanites products in household

Table 3.16 Purpose for collection of Balanites leaves, fruits and nuts

Purpose	Frequency (% of cases)		
	Leaves	Fruits	Nuts
Household use	52 (34.7)	89 (59.3)	50 (33.3)
Household use & Sale	30 (20.0)	20 (13.3)	10 (6.7)
Total	82 (54.7)	109 (72.7)	60 (40)

Values in brackets are the respective percentage of cases (n=150)

Figure 3.8 shows that Balanites leaves, fruits and nuts were more or less collected during the same months of the year. The collection started around September, picked up in October and November reaching maximum in December and there after it reduced between January and February and again reached a second maximum around March and finally ended in May. There was almost no collection of products from June to August. These results are closely comparable with the phenology monitoring results (Chapter 4).

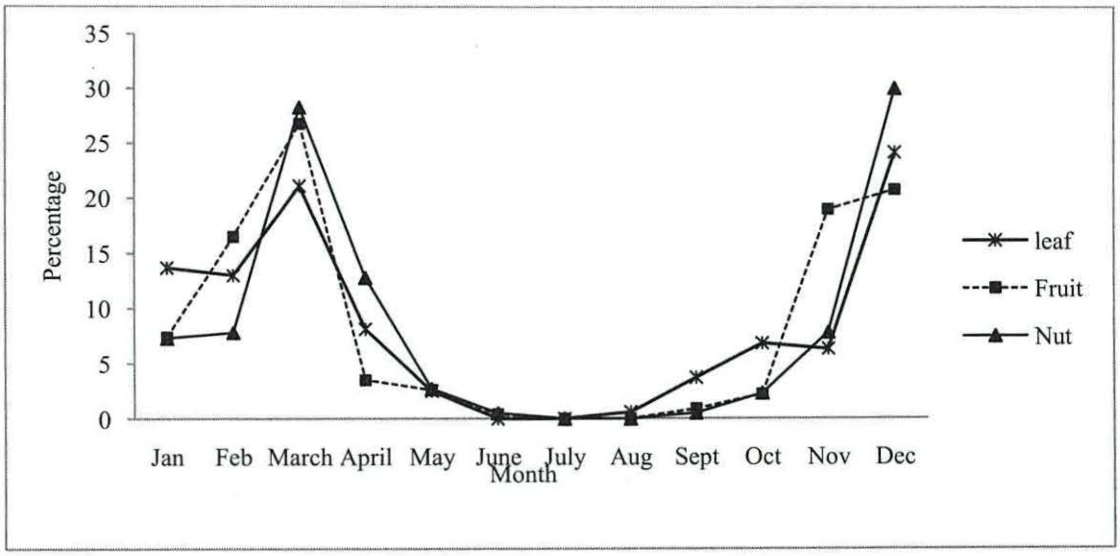


Figure 3.8 Months in a year when Balanites leaves, fruits and nuts collected

3.4.6.2 Household consumption

Balanites leaves were consumed in all households interviewed in Katakwi district and almost all (98%) were involved in leaf harvesting. A household collected leaves about four times a week and a total of about 30 kg per month. Thus, over the five months leaf collection period in each year, the 82 households interviewed in Katakwi collected about 49,200 kg of Balanites leaves. Most of the leaves were used for household consumption (Table 3.16). Balanites leaves were reported to be the priority dry season (November – March) vegetable. During this period, households consumed Balanites leaf as a sauce for 3-5 times a week. A majority (80%) consumed the leaves four (4) times a week over the five months leaf collection period. It was also reported that a family of six people consumed about 2 kg of Balanites leaves per meal. This implied that such a family consumed 32 kg of leaf per month or 160 kg over the five months period. Again at current market value of Balanites leaves (UGX 600 per kg), this level of dependence could save a family UGX 96,000 ($ 57) every year.

Balanites leaves used as food are mixed with groundnuts and sesame and eaten with cassava or potatoes as a traditional delicacy. The oil is also used for baking pan cakes and frying different foods. It was also used as a lubricant for bicycles and motorcycles. As medicine, Balanites oil was used as a remedy for abdominal and chest pains, skin infections, spleen and liver disorders, skin diseases and snake bites. After oil extraction, the waste residue (kernel cake) was used in various ways including; varnishing or polishing wooden objects (e.g. chairs and hoe handles), as manure in the back yard gardens, feeding goats and chicken and as a larvicide in standing water around homes. The nut shell (stone) in a few instances was used as a fuel for cooking using the local mud stoves. The other uses of Balanites in both Adjumani and Katakwi district were fuelwood, medicine and building poles.

3.4.7 Institutional constraints and opportunities for improved use and management of *B. aegyptiaca*

3.4.7.1 Institutions involved in management of *B. aegyptiaca* and other IFTs

Traditional, government and civil society organisations were all playing some role in the management of IFTs including Balanites. However, elders' councils and traditional leaders were the only two traditional institutions reported while there were a number of government and civil society organisations involved. District Forestry Services (DFS) and Lutheran World Federation (LWF) were leading government and non-government institutions respectively (Table 3.17).

Table 3.17 Institutions involved in the management of Balanites and other IFTs as perceived by respondents

Category	Percentage of cases
Traditional institutions	
Elders councils	70.0
Traditional leaders	40.0
Government institutions	
District Forestry Services	74.7
District Agriculture Department	33.3
District Environment Department	28.0
National Agricultural Advisory Services	18.7
Local Councils	16.0
Northern Uganda Social Action Fund	2.7
National Forestry Authority	2.7
Village Environment Committees	1.3
Restocking project	1.3
Civil Society Organisations (CSOs)	
Lutheran World Federation	75.0
Soroti Catholic Diocese Integrated Development organization	70.4
ACTION AID	20.6
SACCOS	5.9
Women's League	5.9
DED	2.9
ACORD	2.9
KADDAN	2.9

3.4.7.2 Institutional arrangements for management of *B. aegyptiaca* and other IFTs

Although more (33%) interviewees said that Balanites and other IFTs were not managed in the past, some (28%) reported use of controlled burning and another 16% pointed out use of pruning as past management practices (Table 3.18). There was also mention of restrictions on cutting of IFTs whether on farms or in the wild since they benefited the whole community.

Table 3.18 Past traditional practices used for management of *Balanites* and other IFTs

Practice	Percentage
None	32.8
Controlled bush burning	28.0
Pruning	16.4
Restricted cutting of IFTs	5.5
Benefited from agric activities	5.5
Uncertain/don't know	4.7
Strict conservation	3.9
Retaining on farms	1.6
Grazing animals around them	0.8
Ring barking	0.8

Many (56%) respondents were unaware and another 20% were uncertain of any government regulation on IFTs. On the other hand, only 10% reported of no cutting of IFTs and 9% talked of controlled cutting of IFTs supplemented by double replacement of whatever is cut as current government regulation on IFTs (Figure 3.9a). A mere 4% were aware of the actual existing policy on trees in general, that is, all trees on non state land belong to the people and must be used in a sustainable way to benefit the present and future generations. At the local (district and sub-county) levels, some by-laws had been put in place to regulate IFTs and these included; no cutting down of IFTs, no bush burning, harvesting fruits from one's own trees only and planting two if one ever cuts one (Figure 3.9b).

Penalties for community members breaking by-laws ranged from being fined in local courts to receiving a caution. About 30% of the respondents, however, reported non existence of penalties (Table 3.19). The majority (62%) said the by-laws put in place were ineffective since IFTs have continued to be cut for other uses and are still regarded as God given resources. Thirty four percent reported that the by-laws were somehow effective.

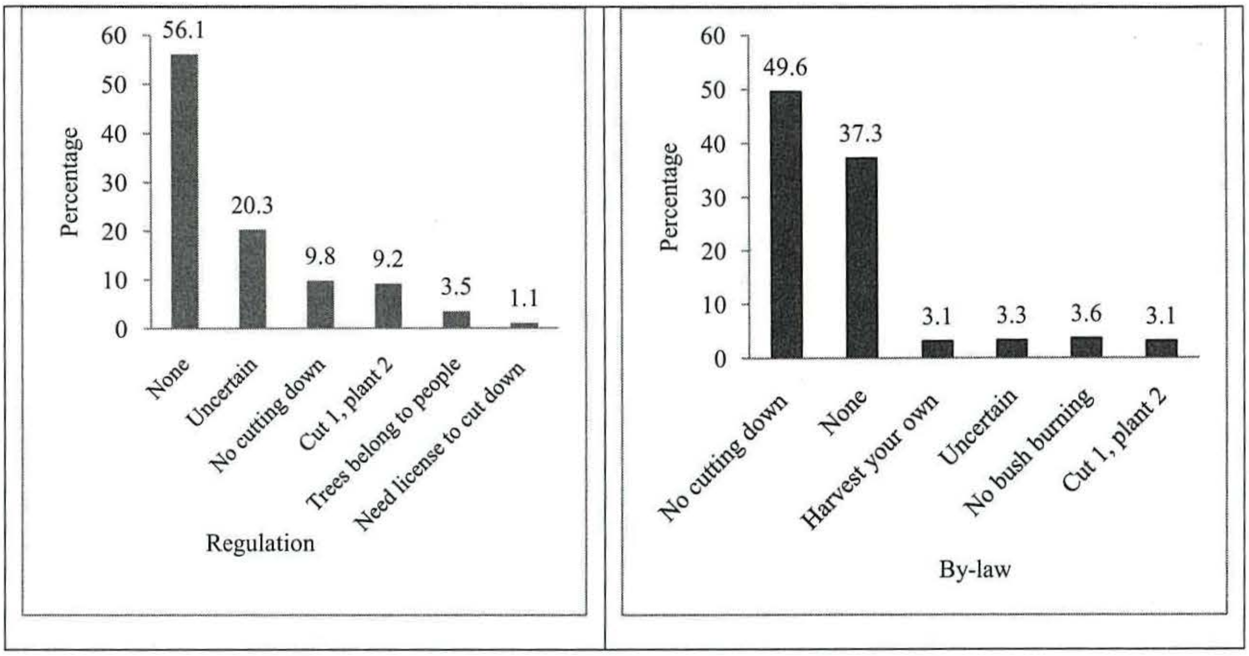


Figure 3.9 Government regulations and local by-laws on Balanites and other IFTs.

Table 3.19 Penalties in place for offenders

Penalty	Percent of respondents
Fined in local courts	60.4
None	29.7
Cautioned	5.0
Don't know/not aware	2.0
Asked to plant more of the cut IFTs	2.0
Detention in police cells	1.0

3.4.7.3 Constraints and opportunities for improved use and management of *B. aegyptiaca*

Tables 3.20 and 3.21 present constraints and opportunities identified by communities during group discussions as important for improved management of Balanites and other IFTs in the study sites.

Table 3.20 Constraints for improved management of *B. aegyptiaca* in Uganda

Constraints	District	
	Adjumani	Katakwi
Increasing human population - clearance of more land +swamps	x	x
Increased grazing pressure–affecting natural regeneration.	x	
Limited knowledge and skills on propagation	x	x
Limited knowledge and skills on value addition to Balanites products	x	x
Increasing intensity of bush fires - killing some trees & destroying fruit before ripening	x	x
Increasing demand for fuelwood	x	x
Balanites only does well along swamps - limiting its on-farm integration		x
Communal ownership of Balanites belts –common pool resource (difficult to manage)	x	x
Thorny nature of Balanites tree - makes it less suited for on-farm retention	x	x
Long juvenile phase of the Balanites tree – 12 years to produce first fruits		
Trees seen as obstacles to farm operations – e.g. ploughing, also reduce crop yields	x	x
Limited awareness about the value and potential of Balanites and other IFTs.	x	x
Limited or localized markets for Balanites products and low prices	x	x
Lack of institutions promoting value addition to natural products	x	x

Table 3.21 Opportunities for improved management of *B. aegyptiaca* in Uganda

Opportunities	District	
	Adjumani	Katakwi
High demand for Balanites oil	x	
High demand for Balanites leaves		x
Availability of local knowledge on Balanites leaf processing		x
Availability of local knowledge on processing of Balanites oil	x	
Positive local attitude towards Balanites as a potential income generating tree	x	x
High density of Balanites trees in the drylands	x	x
Heavy fruiting ability of Balanites - guaranteed even in very dry years.	x	x
Communities' long association with Balanites due to its multiple benefits.	x	x
Coppicing ability of the Balanites tree	x	x
Increasing awareness about the importance of IFTs and natural products.	x	x
Availability of some by-laws for conservation of IFTs	x	x
Balanites grows along swamps - already protected by existing wetland laws	x	x
Balanites trees are long-lived (over 70 years)	x	x
Available natural regeneration both on-farms in the wild	x	x
Presence of government conservation structures at lower levels	x	x
Presence of some CSOs with interest on natural resources	x	x

3.5 Discussion

3.5.1 Local knowledge on use and management of *B. aegyptiaca*

3.5.1.1 Priority status of *B. aegyptiaca* among indigenous fruits and vegetables in Adjumani and Katakwi districts

Balanites aegytiaca was a highly valued tree in the two study sites. In Katakwi district, however, it was more regarded as a leafy vegetable tree while in Adjumani it was regarded as a fruit tree as well as a source of highly valued oil. Though both communities consumed Balanites fruits as a snack food, only the Adjumani communities extracted oil from its seed kernels. Likewise, almost no Balanites leaf eating was reported in Adjumani. Both the Katakwi and Adjumani communities were surprised to learn about each other's unique use of the two Balanites products. This divergence in the major use of Balanites could be partly explained by the fact that the two districts are occupied by different ethnic groups. Adjumani is dominated by the Madi while Katakwi is occupied by the Iteso. The Iteso regarded Balanites as their dependable dry season vegetable and likewise communities along the River Nile in Adjumani cherished Balanites fruits for being available at the peak of the dry season. It was therefore not surprising that Balanites was ranked as the first priority fruit tree in Adjumani.

Similar findings have been reported for other IFTs, for instance, Muok *et al.* (2000) observed that within the drylands of Kenya, what is edible fruit in one ethnic group may be considered not edible in another. They pointed out the case of the Kamba community who did not consider *Boscia coriacea* an edible fruit while among the Pokot community, this fruit is not only edible but also regarded as a source of survival during droughts and at times of food scarcity. For the case of Balanites fruit in Katakwi district and Teso sub-region as a whole, it appears that communities must have lost the art of oil processing in the near past. This was observed during focus group discussions where some elderly members of the community said that oil processing was practised in the past. In addition, the neighbouring Karamojong who are regarded as the Iteso ancestors process Balanites oil and also cherish the fruits (Katende *et al.*, 1995).

Like other reports on IFTs in the drylands of Africa have shown (e.g. Jama, *et al.*, 2008; Franzel *et al.*, 2008; Teklehaimanot, 2008; Akinnifesi *et al*, 2008; Okia, *et al.*, 2008), prioritisation of IFTs is a dynamic process that changes from one region, country or community to another. The identification of one IFT as priority for two or more differing areas may therefore be difficult to realise except for some species such as *Sclerocarya birrea* in Southern Africa (Franzel, *et al*., 2008), *Vitellaria paradoxa* and *Tamarindus indica* in Uganda (Okia *et al*., 2008), *Adansonia digitata* in West Africa (ICRAF, 2003) and in Kenya (Muok *et al*., 2000). Surveys in Burkina Faso, Mali, Niger and Senegal showed that people could not survive without the products that trees provide and topping the long list of essential trees was baobab (*Adansonia digitata*) for its fruits and leaves (ICRAF, 2005).

Be it as it may, communities in Katakwi were eager to engage in Balanites oil processing for both domestic use and income generation. Promotion of such an activity among the Katakwi communities may be easier because some of them are already involved in shea oil processing with more or less similar processes to Balanites oil. Communities in Adjumani were, however, not enthusiastic about eating Balanites leaves. This divergence in use of the two major Balanites products (leaves and fruits/nuts) could be exploited in efforts to improve rural livelihoods through Balanites.

3.5.1.2 Uses of *B. aegyptiaca* in Adjumani and Katakwi districts

Communities in Adjumani and Katakwi have a long history of Balanites use. Balanites tree was very popular among all age categories and had names: *Ecomai* in Katakwi (Iteso) and *Logba* or *Lugba* in Adjumani (Madi). The fruits were referred to as *irorokony* among the Iteso while the oil was known as *edu* among the Madi. Communities throughout the drylands of Africa have been reported to refer to Balanites tree or its parts/products by various local names. Detailed lists of such names have been presented in reports such as Burkill (1985); Hall and Walker (1991); Neuwinger (1996); Sands (2001) and NRC (2008). For instance, Balanites tree: *Ga, Kaha, Higlig* (Sudan), *Gacona, Giuli, Gosa, Guza, Gunyanda* (Tanzania), *Bedena* (Ethiopia- Amharic), *Aduwa* (Nigeria – Flani); Balanites fruit: *Arraronyit* (Kenya-Turukana), *Betto* (Nigeria and Niger), *Hegligh* (Egypt- Arabic), *Heglik* (Ethiopia), *Lalob* (Sudan). These names seem to reflect the local importance attached to this fruit and vegetable tree throughout its range in Africa. One of the villages in Amuria district (neighbouring Katakwi) is named "Acomai" – derived from the local name of the Balanites tree – *ecomai*. According to elders, this village had a high density of Balanites trees in the near past. The practice of naming places after the most predominant vegetation or tree species is common among the Iteso people.

The two study districts are semi-arid and have frequent food shortages during the dry season (November – March). All respondents had used Balanites tree or its products in one way or another, the main uses were a vegetable (leaves and flowers), oil (seed kernels) and snack food (fruit pulp). All household members utilised Balanites leaves in Katakwi while the fruits were more frequently consumed by children and women in both districts. The elderly valued Balanites products highly whereas oil processing was unique to Adjumani.

Guinand and Lemessa (2000) reported the importance of *B. aegyptiaca* tree (*bedena* in Amharic) among communities in southern Ethiopia. Children eat the ripe fruits and during food shortages both children and adults eat the fruits. The new shoots, which continuously grow during the dry season, are commonly used as animal forage. During food shortages, households cut the newly grown succulent shoots and leaves, which are cooked (Guinand and Lemessa, 2000). Lockett *et al.* (2000) reported use of fruits, leaves and nuts of Balanites (*aduwa*) among the Fulani of northern Nigeria. Like in the drylands of Uganda, these products were mostly used by the Fulani during the dry season and with more intensive usage in drought periods or years. Consumption of wild plants is common and widespread in food insecure areas and among low-income households (Barnett 2001; FAO, 2003). This linkage has given rise to the notion of famine-foods that include plants that are eaten at times of food stress and are indicators of famine conditions (Guinand and Lemessa, 2000).

Local people in Adjumani and Katakwi districts know the importance and the contribution that Balanites makes to their livelihoods, especially during the dry season. They also know of the possible health hazards, such as minor stomach upsets that may occur after eating Balanites leaves or fruits. Such hazards occurred at the beginning of usage/season and were not long-lived. Balanites is usually a semi-deciduous tree in the drylands of Uganda, however, due to the dry season bush fires that are common in the area, they are sometimes forced to shed off almost all their leaves and within a period of two weeks or so, new tender leaves which are used as a leafy vegetable emerge. In addition, flowering is initiated within one to two months after fire and these are collected along with the young leaves and twigs. In older trees, the thorns may be few or even absent at the growing tips and this facilitates picking of leaves together with flowers by stripping branchelets between the thumb and fingers. Balanites leaves picked this way are locally called "ekuruta" and are highly sought after (Plate 3.3).

Plate 3.3 A mixture of boiled Balanites leaves and flowers

An indication of having been picked by pulling between thumb and fingers - "Ekuruta"

Leaf collection lasts from middle of the dry season (November) when all other vegetables are not available to the beginning of rains (March). As a result, the locals said that no household in Katakwi district lacks sauce in the dry season because of Balanites. Similarly in Adjumani, it is believed that no child lacks a fruit in the dry season because of Balanites. Related to this, Iwu (1993) while reporting on the uses of Balanite*s* in West Africa documented a Bornu proverb which extols Balanite*s* - "*abito* tree and a milk cow are just the same" - referring to the many uses of Balanites products.

When there is sufficient food from normal crop harvests, the use of wild foods is ignored and people who eat them are considered "inferior" (Barnett, 2001). All households interviewed in Katakwi reported that they depended on Balanites products, especially the leaves every year. Balanites is a dry season vegetable which is depended upon even in years of plentiful crop harvest. The only variation reported was the increased intensity of use in years of food shortage or famine. As such, the use of Balanites leaves as vegetable was never under-looked. This has helped in the conservation of the tree since all community members appreciated its use. It also presents an opportunity for participatory domestication and on-farm integration of Balanites. This has been achieved with the baobab tree (*Adansonia digitata*) in West Africa where the fruits and leaves are eaten (ICRAF, 2003).

The use of Balanites fruits, leaves and flowers has been reported in other dryland countries in Africa (Burkill (1985; Sands, 2001; Guinand and Lemessa, 2000). However, extraction of Balanites oil appears to be highly specialised and restricted to a few communities. Besides Uganda, available reports indicate that Balanites oil extraction is also carried out in Burkina Faso (UNDP, 2009) and the Sudan (Nour *et al.*, 1985; Gebauer *et al*, 2002). Women groups in Burkina Faso have gone further to utilise Balanites oil as an ingredient for manufacture of indigestion syrup, soap and a range of skin soothing creams (UNDP, 2009).

In addition to leaves and oil, local communities in Adjumani and Katakwi districts used Balanites tree or its parts for fuelwood and medicines. The root, stem bark oil, fruit pulp and kernel cake have medicinal properties. Most ailments treated were similar to those reported by local communities in the Balanites range. However, the use of Balanites for treatment of snake bites and de-worming children seem to be unique to communities in Adjumani district.

According to Sands (2001), most parts of Balanites have traditionally been used medicinally and although the efficacy of such treatments has rarely been proven, there is no doubt that the plant yields useful steroidal saponins from which, notably, the sapogenin and diosgenin can be extracted for use in the pharmaceutical industry. Extracts are also used as a pesticide, the active ingredient being a saponin which is very toxic to cold-blooded animals. Communities' local use of Balanites for malaria treatment seems to be supported by Chapagain and Wiesman (2005) who reported aqueous extracts of root and bark of *B. aegyptiaca* to be very effective against mosquito larvae. NRC (2008) has reported a wide range of uses of various Balanites products. Iwu (1993) reported that Balanites features prominently in Hausa (West Africa) ethnomedicine and is also very useful for other household purposes. The oil from the fruit kernel is used for dressing wounds and as embrocation in rheumatism while the root is used for treatment of malaria, herpes zoster and venereal diseases. The saponins occurring in the roots, woodchips and fruits facilitate their use for washing clothes (Iwu, 1993).

The increasing use of Balanites for fuel (firewood and charcoal) was reported to be decreasing the tree numbers. Balanites is valued as a fuel because it burns with minimal smoke and produces more heat. Webb (1984) reported a calorific value of 4600 kcal per kg. The shells (stones) left after the kernel is removed provide good fuel used by communities in Adjumani. The use of these materials and charcoal from Balanites has also been reported by women in Burkina Faso (UNDP, 2009).

3.5.1.3 Sources of *Balanites* products

The main source of Balanites in both study sites was the wild (84%) and the stocks are reported to be declining over the years due to land clearance for agricultural purposes. The destructive uses of Balanites such as, cutting of trees for fuelwood and poor harvesting techniques for the leaves in Katakwi pose a threat to the species. Balanites grow along swamps and rivers and in other well drained sites but with access to ground water. About a decade ago most of these areas were not used for human settlement but the current increase in both human and animal population has forced some people to move into such areas. This has reduced the distance travelled to collect Balanites products in Adjumani (Plate 3.4 a&b). Much as this was a positive development among the children who said they were now living within a close reach to Balanites fruits, older people said that Balanites population is declining due to uncontrolled cutting for fuelwood and increased grazing pressure which hampers regeneration. In Adjumani district, the situation was further complicated by increased human settlement in the Balanites belt by immigrant fishing communities from neighbouring districts and with limited regard to Balanites and other IFTs. As such, Balanites was now being cut for use as a fuel for cooking, fish smoking and brick baking (Plate 3.5a & b).

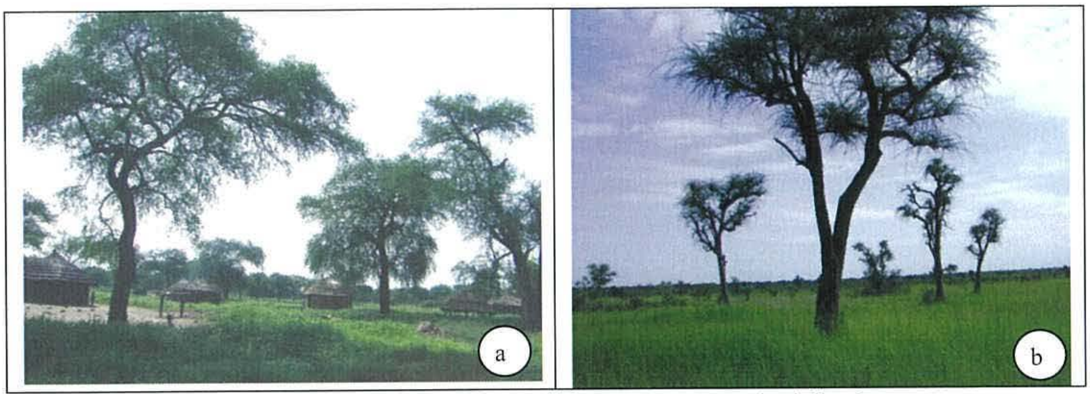


Plate 3.4 Balanites trees in different land settings in Adjumani and Katakwi districts

(a) Balanites trees in Nyeu Village Adjumani - Notice human settlement within Balanites belt in well drained site along R. Nile.
(b) Balanites trees in Acoite Village Katakwi - Notice the swampy site with no human settlement.

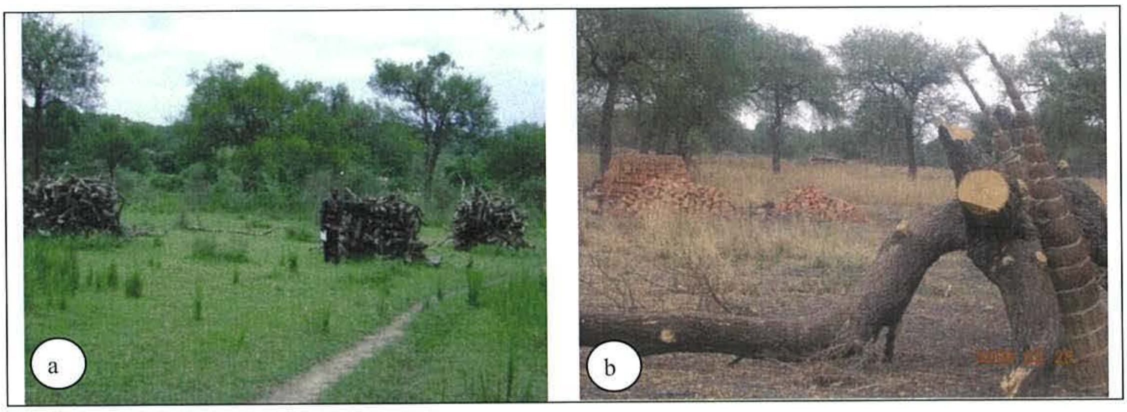


Plate 3.5 Balanites trees cut for fuelwood in Nyeu village, Adjumani district.

(a) Balanites trees cut to provide firewood for sale
(b) Balanites trees cut for baking bricks

The women and children of the new fishing community have also taken on the consumption of Balanites fruits and oil. Since women are in charge of preserving fish, their use of Balanites for consumption and income generation could be a good starting point for raising awareness about the tree and its commercialisation. Another important development brought about by the immigrants is the demonstration of the agroforestry potential of Balanites in Adjumani district. Initially, the area was mainly used for grazing but now some patches, especially near homesteads are cultivated (Plate 3.6). The main crops observed in immigrants' gardens were maize, sesame, sweet potatoes, sorghum and pumpkins.

Plate 3.6 Balanites trees retained on-farms, Nyeu village, Adjumani district

3.5.1.4 Cultivation and management of *B. aegyptica*

Much as a majority (93%) of the households interviewed did not plant Balanites, many (51%) had retained the trees on their farms. This demonstrates the importance these communities attach to Balanites since only useful trees are retained on farms. Although some still regarded Balanites trees as 'God given' with no need to plant, decreasing levels of wild trees coupled with increasing dependence on the tree products was a driving incentive for on-farm retention of the species along with other useful IFTs such as *Vitellaria paradoxa*. Akinnifesi *et al.* (2006) also observed that although many rural households rely on IFTs as sources of cash and subsistence in the Southern Africa, there has been little effort to cultivate, improve or add value to these fruits.

Shackleton (2004) noted that wild harvested products can be very unreliable in the quantities and qualities due to the vagaries of the weather. Quantities may also be affected by the existence of competing opportunities for producers, for whom indigenous fruit production typically contributes just a small part of their income (Belcher and Schreckenberg, 2007). Akinnifesi *et al.* (2006) noted that as a result of the dwindling access to forest products, an increasingly higher proportion of households are finding it necessary to explore options to plant trees for supplying household requirements. In this regard, IFTs are always among the first trees to be planted. Balanites was found to be planted or retained near home, scattered on-farm or along farm boundaries. Similar findings have been reported in the miombo region of Southern Africa (Akinnifesi *et al.*, 2006).

Balanites trees were reported to have no effect on yield of cereals, especially, maize, sorghum and millet but with some negative effect on yield of pulses and tubers such as groundnuts and sweat potatoes and cassava. Local communities were aware of tree management to minimise negative effects on associated crops, such as shoot pruning just before sowing. These practices can be built upon in efforts to improve dryland agroforestry in these areas. In both Katakwi and Adjumani districts, Balanites trees were among trees left when clearing land for farming. In some areas, this has created the impression that Balanites and other IFTs are dominant on farms. According to Kang and Akinnifesi (2000) the retention of a low density of valuable trees in parklands of the semi-arid areas is a common practice to improve the yield of understory crops. In southern Tanzania, Akinnifesi *et al.* (2006) reported that farmers spare fruit trees such as *Uapaca kirkiana* and *Parinari curatellifolia* because of their importance to households. This process makes IFTs the dominant trees on farms. Ramadhani *et al.* (1998) reported that IFTs constitute about 71% of the trees on farmers' fields. Constraints to growing Balanites such as lack of seedlings, and lack of knowledge and skills on its propagation need to be addressed by building the agronomic capacity of these dryland communities.

Harvesting of leaves in Katakwi by cutting young branches and twigs though appropriate from the harvesters' (mainly women and children) point of view is endangering the trees. This practice has negatively affected trees with some of them dying due to over-harvesting. Increasing intensity of annual bush fires compounded with the old age of most trees makes the over-harvested Balanites trees succumb to mortality. Such incidences were observed in Katakwi district (Plate 3.7). In West Africa, women and children found trouble climbing the giant baobab trees in natural stands thus making leaf picking a risky venture. This prompted scientists to initiate on-farm cultivation of baobab for leaf production (ICRAF, 2003). Unlike the baobab whose leaves have to be harvested when they are growing during the short three-month rainy season (ICRAF, 2003; Maranz *et al.*, 2008), the young edible Balanites leaves are always available during the dry season.

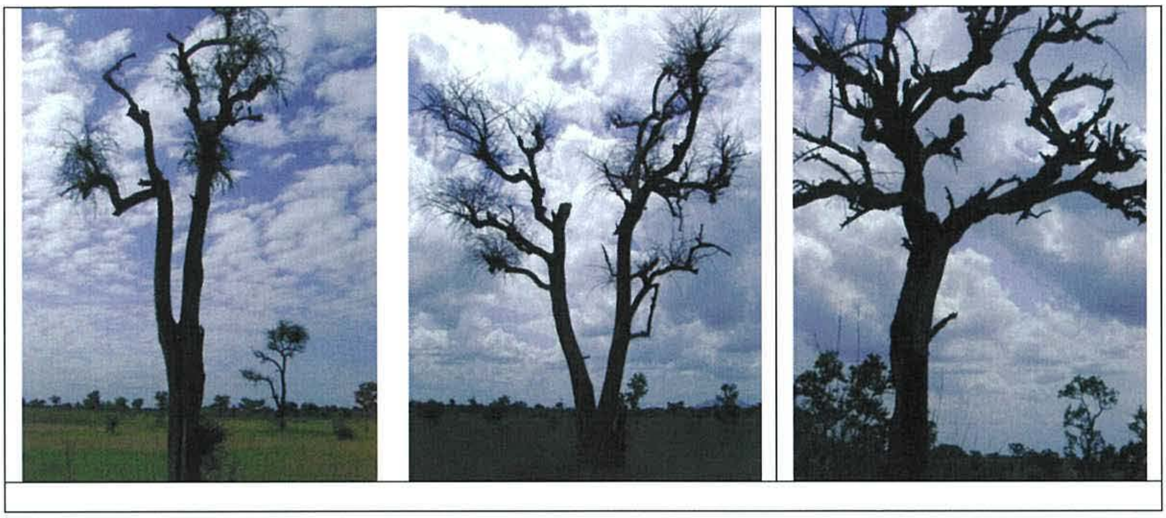


Plate 3.7 Balanites trees loosing vigour and sometimes drying up

Dead Balanites tree (right) – effect of leaf over-harvesting and increased intensity of annual bush fire in tall grasses, Acoite Village, Katakwi district.

Although most of the fruits from IFTs harvested from the wild support household food security, this could be significantly enhanced if improved varieties and production, harvesting, and storage techniques could be made available to the rural poor. Thus, a pro-poor strategy involves moving away from depending on wild harvesting to domestication. Such a strategy has already been demonstrated in southern and western Africa and it involves participatory domestication - genetic improvement that includes farmer-researcher collaboration, and is farmer-led and market-driven (Akinnifesi, *et al.* 2006).

3.5.2 Contribution of *B. aegyptiaca* to household diet

Women and children were the major collectors of Balanites, although these products were used by all members of the household. UNDP (2009) reported a similar situation in Burkina Faso where women and children were the main collectors, harvesting as much as 40 kg of Balanites fruits per day in December and January. Women often have more specialized knowledge of wild plants used for food, fodder and medicine than men. Children mostly collect and eat the fruit from wild plants. In this study Balanites leaves, fruits and nuts were mainly collected by children and women and prepared by the latter in all the areas surveyed. Women frequently collected Balanites products as they performed other daily duties such as, collecting firewood, on their way to fetch water or when walking home after farm work. They even collected fruits for the men to eat.

In the dry season, men in Adjumani site spent most of their time fishing in the river or migrated to find work in urban centers while women and children remain behind to manage Balanites. Therefore, women and children are the main actors in the collection, preparation and consumption of Balanites and other IFTs. Some women said "as we wait for fish to be brought by men, we depend on Balanites fruits". Given the thorny nature of Balanites tree (difficult to climb) children forage Balanites trees to collect fruits that have fallen under ripening trees. More ripe fruit was reported to fall during the night so it was necessary for children visit the trees early in the morning or else they were deprived of the fruit by roaming livestock. Short of climbing, children also used long sticks or stone throwing to dislodge ripe Balanites fruits.

In normal times, young rural males eat more wild foods than the older generation although, when there is a food shortage, all ages and both sexes eat wild foods. Women generally have the primary responsibility of providing their families with food, water, fuel, medicines, fibre, fodder and other products. As a result, rural women were the most knowledgeable about the patterns and uses of local biodiversity. Rural households in Adjumani mainly eat Balanites fruits and used its kernel for oil extraction. Although the fruit was eaten as a snack by all people in a household, it was reported to be very popular among children/youth and women. It was eaten on a daily basis throughout the fruit fall period (November – March) and children normally consume about 10-20 fruits daily, without any reported side effects. Balanites oil extraction was popular among women in Adjumani district. The oil is highly valued by the communities for cooking and used as medicine for treating skin diseases and intestinal worms. Balanites fruits were eaten among communities in Katakwi but their consumption was only popular among children. The leaves were popular in Katakwi and used by all respondents. Balanites oil is not extracted by communities in Katakwi. However, it was popular among the neighbouring Karamojong.

Balanites leaves and fruits play an important role in rural diets in both study sites while the oil extracted from the seed kernels is a commercial commodity in Adjumani district and most parts of West Nile sub-region. The fruit pulp is a source of food for animals, especially, sheep, goats and cows. Ripening of *Scelocarya birrea* and *V. paradoxa* fruits was followed by

Balanites. Cows spend at least 2-3 hours while goats and sheep spent about 3-4 hours daily feeding on Balanites fruits (Plate 3.8). Availability of the fruits during this period also makes Balanites shade the most preferred resting place for livestock. Both goats and cows do not swallow Balanites nuts; goats spit the nuts after steeping the pulp while cows regurgitate them. In Adjumani, the animal resting places had a lot of nuts, and were convenient nut collection points.

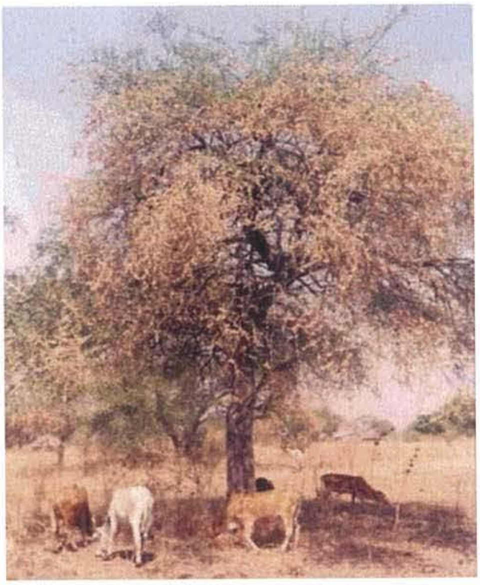


Plate 3.8 Cows feeding on Balanites fruits in Adjumani.

3.5.3 Institutional constraints and opportunities for improved use and management of *B. aegyptiaca*

3.5.3.1 Institutional arrangements for management of *B. aegyptiaca* and other IFTs

Much as the DFS and some CSOs were involved in management of Balanites and other IFTs in the two study districts, communities felt that IFTs were given very little attention. They noted that district authorities were not controlling the cutting of IFTs because the charcoal was needed in urban centres. It was also noted that large scale use of IFTs was brought about by immigrants who specifically cut Balanites for firewood or charcoal for income. The DFS seemed to be constrained by both human and financial resources to carry out their work. In both districts, DFS had one person, the District Forestry Officer, running all the forestry related activities of the district. Among all the CSOs encountered in the two districts, forestry in general and IFTs in particular was not their core business but rather formed a small component.

They mainly promoted multiplication and growing of exotic fruits, such as citrus and mangoes and in a few cases timber trees. This left the communities with no technical help on management of IFTs. Communities also expressed a desire to go into small scale processing of indigenous fruits but they lacked technical support, especially in oil processing.

On the other hand, elders' councils that used to guide communities in sustainable use of trees are no longer effective since they are not respected. On the other hand, government has in place village environmental committees but these were reported not to be operational in the study areas. Members of such committees reported that their roles were not clear and had no motivation to perform such roles. They noted that communities do not recognise some conservation measures put in place by such committees. It was also noted that traditional leaders if empowered with relevant information on IFTs could play a great role in mobilising communities to conserve them and add value to IFTs products. There is also a lowest level of government, the Local Council (LC 1), with one of the committee members in charge of environment but communities reported that environmental issues are of little concern in these committees.

Respondents were generally unaware of government regulations on IFTs and other trees in the drylands. This partly stems from limited capacity of the DFS to disseminate information to rural communities. Some bylaws which had been put in place, such as no cutting of fruit trees or cut one plant two are not respected due to break down in social cohesion. Penalties set for offenders were also not deterrent enough and rarely enforced. IFTs in the wild have therefore continued to be destroyed with little regard while those on farms are protected to some extent. The future of Balanites and other IFTs therefore, appears to lie on their integration into traditional dryland farming systems.

It can therefore be inferred that both traditional/local and state systems for management of Balanites and other IFTs are currently weak and non-existent in some communities. This posses a great challenge to these resources that have supported the livelihoods of local people for generations. With increasing impacts of climate change already being experienced in the study sites, for instance the 2007 floods in Katakwi and the constant annual drought in the drylands in general, loss of IFTs could mean loss of a livelihood for many communities. Improved management and utilisation of IFTs could be easily achieved through building the capacity of local institutions with some technical support being provided by DFS and local-based CSOs.

3.5.3.2 Institutional constraints and opportunities for improved use and management of *B. aegyptiaca*

A number of constraints and opportunities for improved management and utilisation of Balanites were identified. The key constraints were increasing human and animal population in the Balanites growing areas, uncontrolled bush fires, alternative uses of Balanites –especially as fuelwood, limited knowledge and skills on propagation and value addition and the long juvenile phase of Balanites. However, several opportunities were also identified and they included; high local demand of Balanites products including their tradability, high density of Balanites trees found in the study areas, availability of local knowledge on some processing, and presence of some local institutions willing to play a role in improving the management of Balanites and other IFTs.

To overcome most of the constraints cited above, it is important for the research and development community to work with local dryland communities, especially women groups to add value to Balanites products. In this regard, oil processing seems to offer greater promise given the high unsupplied market and its high market value. This could raise the status of Balanites leading to its protection as it has already happened with *V. Paradoxa* (Okullo, 2004). This would later lead to increased demand for planting and thus kick-start a participatory domestication process as it has been done with other IFTs such as *S. birrea* in southern Africa (Hall *et al.*, 2002; Shackleton, 2004; Akinnefesi *et al.*, 2006) and *A. digitata* in western Africa (ICRAF, 2003). Participatory domestication would then solve the problem of long juvenile phase through vegetative propagation and also improve fruit characteristics (Akinnefesi *et al.*, 2006). In the short run, the method of leaf harvesting in Katakwi and control of bush fires in all the study sites need to be addressed to sustain the resource base. Furthermore, community sensitisation is needed for raising awareness about the potential role of Balanites and other IFTs in the dryland of Uganda for livelihood improvement. According to Teklehaimanot (2004), some socio-economic conditions need to be addressed for the potential of IFTs to be realized. Some of these include; a change in land use and forest policies to give farmers ownership of parkland trees and production incentives related to markets and technology.

CHAPTER FOUR: DISTRIBUTION AND POPULATION STATUS OF *BALANITES AEGYPTIACA* IN UGANDA

The distribution and population status of *Balanites aegyptiaca* in the drylands of Uganda are presented in this chapter. Section 4.1 introduces the chapter, the objectives, hypotheses and research questions are presented in section 4.2 and methods are described in section 4.3. Results are presented in section 4.4 under the following headings: distribution of Balanites and soil characterisation; population status; health status of Balanites trees; and other tree species associated with Balanites. The discussion is given in section 4.5.

4.1 Introduction

Balanites aegyptiaca is ranked highly by dryland communities in the north-eastern parts of Uganda (Teklehaimanot, 2008). Organised collection of fruits and products from *B. aegyptiaca* trees can create employment, particularly for women, children and the landless poor. This is because dryland fruits, like most wild food products, are usually free and easy to access by the local communities (FAO, 1988; Somnasang and Moreno-Black, 2000). In addition to its fruit, *B. aegyptiaca* is an important source of vegetable, fodder and fuelwood, and has many medicinal and industrial uses. However, intensive and uncontrolled exploitation of the tree combined with low rate of natural regeneration is causing drastic depletion of this important resource. This is further complicated by the long juvenile phase of Balanites, reported to be about five to seven years (von Maydell, 1990). Since *B. aegyptiaca* is one of the most useful trees in the semi-arid areas of Uganda, such as, West Nile, Karamoja and Teso sub-regions, there is an urgent need for improved management and utilization of the resource. As noted by Peters (1996), sustainable management and utilization of a species requires a detailed knowledge about its population structure. According to Peters (1996), population structure provides a picture of the future prospects of a resource and can indicate how it might be managed and utilized in a sustainable way.

Unlike timber trees, most indigenous fruit trees (IFTs) have limited appeal and have been disregarded in formal inventories. Hall and Walker (1991) pointed out that *B. aegyptiaca* has been no exception to this and as a result, quantitative estimates of abundance are secured from only small sample areas during localised research studies. In fact, in most cases it is just mentioned in passing as one of the tree associates in inventories of other 'important' timber tree species. Interpretation of available data is hampered because lower size limits are not specified (Ramsay, 1958; Bunting and Lea, 1962; Grondard, 1964), total number of individuals observed in small areas is negligible (Brookman-Amissah *et al.,* 1980 – one tree per hectare), species ranges overlap and taxa are aggregated (Kerfoot, 1962 – 156 individuals 10-15 cm DBH of Balanites spp. on 335 ha, in Karamoja Uganda). It is not always clear how many actual observations were made and according to Hall and Walker (1991), extrapolation to per hectare stocking levels is inevitably imprecise when actual numbers observed in a survey are very low.

There is no reliable information on the distribution and population structure of *B. aegyptiaca* in eastern Africa in general yet such information is required to guide its management, conservation and development as a tree crop in the arid and semi-arid areas where it is commonly found. In Uganda, a recent preliminary inventory of *B. aegyptiaca* covered two villages in Moyo district (Madrama, 2006). The communities in the study area were heavily dependent on *B. aegyptiaca* products, especially its fruits and nuts. Given the small sample size of the tree inventory used in this study, its findings on stocking level (34 trees ha^{-1}) may not be accurate. There were more *B. aegyptiaca* trees in woodlands (wild) than farmlands. As a result of limited information on the tree in Uganda, the distribution and population status and the implications for management are largely unknown.

In addition, there is scanty researched information on the association between *B. aegyptiaca* and other tree species across its range in the drylands of Africa. Hall and Walker (1991) noted that many reports lack assessment of the prominence of *B. aegyptiaca* and many others offer lists by ecological zone rather than plant community. Seventy nine tree species have been reported to show some association with *B. aegyptiaca* (Hall, 1992). Out of these, *Acacia* spp, *Combretum* spp, *Erythrina abyssinica, Sclerocarya birrea* and *T. indica* seem to be common. Information on other species, especially IFTs associated with *B. aegyptiaca* would be useful in developing a comprehensive strategy for promotion of dryland indigenous fruits for diet improvement and income generation to local communties. In an attempt to close these knowledge gaps, this study focused on understanding the distribution, population and health status of *B. aegyptiaca* and its tree associates in the drylands of Uganda.

4.2 Objectives, hypotheses and research questions

The objectives of the study were to:

i. Map the distribution of *B. aegyptiaca* in Uganda and characterise soil in the growing sites.
ii. Determine the population status of *B. aegyptiaca* in different study sites in terms of stocking levels, distribution patterns, size-class structure and health status.
iii. Record other tree species associat*ed* with *B. aegyptiaca* in different sites.

The following hypotheses were tested:

Ho: There is no difference in stocking density of Balanites between study sites
Ho: There is no difference in distribution pattern of Balanites in different sites
Ho: There is no difference in the morphological attributes of *B. aegyptiaca* (DBH, height and crown volume) between different sites.

Answers to the following questions were sought:

a) In which areas in Uganda is *B. aegyptiaca* found?
b) What are the soil characteristics in *B. aegyptiaca* growing areas?
c) What is the regeneration status of *B. aegyptiaca* in the study areas?
d) What is the health status of *B. aegyptiaca* trees in the study sites?

4.3 Materials and methods

4.3.1 Distribution of Balanites in Uganda

To establish the geographical locations of *B. aegyptiaca* in Uganda, a combination of methods was employed. First, literature on Balanites in Uganda was reviewed to identify areas where Balanites was reported to grow. Some of the information in this regard was collected from reports, for example, Eggeling (1940), Langdale-Brown *et al.* (1964), Katende *et al.* (1995), Katende *et al.* (1999), Teklehaimanot (2005), Madrama (2006), Egadu *et al.* (2007), Teklehaimanot (2008) and Okia *et al.* (2008). A list of places, mainly districts, where Balanites was reported to be found and used was generated. Information was also collected from *B. aegyptiaca* specimens in Makerere University herbarium. Additional information on herbarium specimens of *B. aegyptiaca* in Uganda was extracted from the Kew Bulletin on the revision of the genus Balanites (Sands, 2001). Key informant interviews were conducted with some forestry officials who had worked in the listed districts to provide details on the sub-counties and parishes (second smallest administrative unit in Uganda) where Balanites was found in the respective districts. This generated an expanded list of districts and parishes where Balanites is found. Some of the listed districts were visited to verify information collected and to geo-reference the areas. For some of the locations where GPS coordinates could not be recorded, the name of the parish was used to generate the GPS coordinates from the data files available within the ARC GIS Programme. The coordinates (parishes) were captured in Excel and then digitized on the map of Uganda using Arc GIS Version 9.1 to show areas where *B. aegyptiaca* grows. This generated a distribution map of Balanites in Uganda.

4.3.2 Population of *B. aegyptiaca*

4.3.2.1 Study sites

The study was conducted in two sub-counties in Adjumani and two in Katakwi district. In each sub-county, two sites each representing a wild savanna woodland and a farmland were selected, thus giving a total of eight sampling points (Table 4.1).

Table 4.1 Balanites populations studied in Katakwi and Adjumani districts, Uganda

District	Balanites population (sub-county)
Katakwi	Ngariam
	Katakwi
Adjumani	Dzaipi
	Adropi

4.3.2.2 Soil characterisation

The soil of the studied Balanites populations was characterised by digging soil profile pits. One soil profile pit was dug in each of the four populations. Each soil profile was described in terms of depth, number of horizons, width of each horizon and boundary distinctness between horizons. A linear tape was used to measure the profile depth while distinctness of the horizon boundaries was described as abrupt (a), gradual (g), clear (c) and diffuse (d). A munsell colour chart was used to provide standard descriptions and colour name for each horizon. The Munsell colour system describes or specifies colour based on three colour dimensions: hue (predominant spectral colour), value (lightness and darkness against a neutral gray scale) and chroma (purity or richness) (Cleland, 1921; Lindbo *et al*., 2000). In each horizon, about 500 g of soil was sampled by chiselling. Samples were double labelled and transported to Makerere University Soil Science laboratory for drying, preparation and subsequent analyses. Routine soil analyses were performed using standard procedures described by Okalebo *et al.* (2002). Parameters determined included pH, N, OM, K, Ca, Mg and Na.

Given the limitation of the field method for determination of soil texture (human error), particle size analysis was performed in the laboratory using the pipette method. Since soil texture refers to the relative proportions of sand, silt, and clay particles in a mass of soil, this method applies Stokes' Law to measure settling rates of different soil particles in a given soil sample (Okalebo *et al.* 2002). The proportions of sand, clay and silt in each soil sample were then applied to the soil textural class estimation chart (texture triangle) to derive the respective textural classes (Cleland, 1921). The textural classes were recorded as sand (s), loam (l), loamy sand (ls), clay loam (cl), sandy loam (sl), clay (c), sandy clay loam (scl), silt (si), sandy clay (sc), silt loam (sil) silty clay loam (sicl), and silty clay (sic).

4.3.2.3 Population status

To determine the population status of *B. aegyptiaca* in both wild and on-farm sites, one plot was established in each site following a modification of the plotless sampling and nearest neighbour technique (Clark and Evans, 1954; Cottam and Curtis, 1956). According to Ludwig and Reynolds (1988), plotless sampling methods are more efficient than fixed area plots when organisms of interest are sparse and counting of individuals within plots is time consuming. Sparks *et al.,* (2002) recommended using a combination of fixed radius plot and variable radius plot (plotless) methods when sampling stems of all sizes in woodlands of variable densities. They pointed out that variable radius plot method is time efficient and relatively accurate at sampling larger stems of DBH $\geq$ 11.4 cm while the fixed radius plots are relatively accurate at sampling small stems and seedlings. To ensure that the same quantity of data was collected from both low and high density stands, a modification of the plotless method by Cottam and Curtis (1956) was used based on a fixed count approach technique (Sheil *et al.*, 2003). According to Lessard *et al.* (1994), even where populations are not uniformly distributed, fixed count approach remains useful and biases are negligible when compared with normal sampling variability.

To begin sampling in each site, one Balanites tree (≥10 cm DBH) was randomly selected and used as a starting point. Other 99 nearest mature trees (nearest neighbours) (DBH ≥ 10 cm) to the starting tree were then included by moving progressively outward so that the sample is expanded by adding more individuals, but kept compact, until it included 100 individuals, that is, 100 percent sampling points (Cottam and Curtis, 1956). This meant that the diameter of the plots varied at different sampling points depending on the stocking density of Balanites trees. The 100 trees in each site were numbered serially using small aluminium tags and their coordinates recorded using a GPS (12XL Garmin, USA). The nearest neighbour distance was recorded for each pair of trees close to each other irrespective of direction. As noted by Cottam and Curtis (1956), many of the values were duplicates, since paired neighbours (which have each other as nearest neighbours) make up a significant portion of the total population. Within each site, the 100 tagged *B. aegyptiaca* trees were assessed for DBH, height, crown diameter and health status.

Crown diameter was measured by projecting the edges of the crown to the ground and measuring the length along one axis from edge to edge through the crown centre. According to (Brack, 1999), crown diameter can be used to estimate sectional area of a tree (used in crown surface area and volume calculations) by obtaining the average of two axes. In this study, the diameters of two axes perpendicular to each other (N-S and E-W) were measured and averaged using arithmetic mean. Crown depth, length along the main axis from the tree tip to the base of the crown, was determined using a hypsometer by taking the height of the lowest complete branch whorl or major branch that forms part of the canopy and subtracting from the height to the tip of the tree. Crown depth was expressed as "crown length ratio" (crown length divided by total tree height). Crown volume (C_v) was estimated from crown diameter (D) and crown depth (L) using the equation: $\mathbf{C_v = \pi D^2 L/12}$ (Brack, 1999).

The easting (x) and northing (y) coordinates for the 100 Balanites trees in each plot were recorded in meters using the Universal Transverse Mercator (UTM) system. The coordinates were entered in MS Excel spread sheet to produce scatter plots depicting spatial distribution of trees in the field. Plot diameter and radius were also calculated thus, enabling computation of plot area using the formula: **Area** = πr^2, where **r** is the plot radius in meters.

To determine the distribution pattern of Balanites trees, a series of nearest neighbour distances measured for the 100 trees in each site was used in the computation based on Clark and Evans (1954). Briefly, in a population of ***N*** individuals with known density ***d*** and the distance ***r*** from each individual to its nearest neighbour, the mean observed distance is represented as:

$r_o = \sum r/N$ .... (i)

The mean distance which would be expected if this population was distributed at random, r_e, has a value equal to:

$r_e = 1/2\sqrt{d}$ .... (ii)

The degree to which the observed distribution approaches or departs from random expectation with respect to the distance to nearest neighbour is expressed as ratio (***R***) as follows:

$R = r_o/r_e$ .... (iii)

According to Clark and Evans (1954), ***R*** has a limited range: $0<R<2.1491$. Clark and Evans (1954) and Petrere (1985) showed that when ***R*** = 0, there is a situation of complete aggregation; when ***R*** = 2.1491 there is completely uniform pattern resulting in a triangular lattice. On the other hand, when ***R*** =1, the pattern of distribution of individuals is random. Thus, in any given tree population distribution, the mean observed distance to the nearest neighbour is ***R*** times as would be expected in a random distribution of the same density. The ratios calculated for the different populations and sites were compared with one another as a measure of their relative departure from random expectation. Whenever the value of ***R*** indicated that a given population was not randomly distributed, the significance of the departure of $\mathbf{r_o}$ from $\mathbf{r_e}$ (**C**) was tested by the normal curve using the formula:

$C = r_o - r_e/\ \delta r_e$ ....(iv)

Where **C** is the standard variate of the normal curve (Mather, 1947) and δr_e is the standard error of the mean distance to nearest neighbour in a randomly distributed population of the same density as that of the observed population. The value of δr_e for a population of density ***d*** is represented by:

$\delta r_e = 0.26136/\sqrt{Nd}$ .... (v)

Where N is the number of measurements of distance made. The **C** values of 1.96 and 2.58 represent 5% and 1% levels of significance respectively (Clark and Evans, 1954).

In order to determine the health status of *B. aegyptiaca,* extent of crown damage, mainly through leaf harvesting activities, and search for fodder and fencing materials as well as incidences of pests and diseases in different parts of the tree were examined. Crown damage was coded as 5 = no sign of lopping, 4 = 25% of branches lopped, 3 = 50% of branches lopped, 2 = 75% branches lopped, and 1 = all branches lopped. Pest and disease incidence was coded as 5= healthy, 4= only leaves affected, 3= leaves and branches affected, 2= leaves, branches and stem affected and tree starting to dry, and 1= tree dry/dead.

4.3.2.4 Regeneration

Balanites saplings (< 10 cm diameter and ≥ 1 m tall) and seedlings (< 1 m tall) in each site were enumerated in five regeneration plots of 40 x 40 m nested within the main plot of 100 trees. These five plots were systematically laid out in centre, north, south, east and west of the main plot. Saplings were assessed in the 40 x 40 m plot while seedlings were recorded in two diagonal sub-units of 20 x 20 m within the regeneration plot. Therefore, saplings and seedlings were assessed in areas equivalent to 0.8 and 0.4 ha respectively (Figure 4.1). Population inventory data were recorded in pre-designed and tested data sheets (Appendix 4.1 and 4.2).

4.3.3 Trees associated with *B. aegyptiaca*

To determine other trees species which were associated with *B. aegyptiaca*, all other trees (DBH ≥ 10 cm) in each plot (area occupied by 100 Balanites trees) were recorded. Dendrometric measurements were not taken on associated trees since the focus was on species names and frequencies. Associated species were identified using the book Useful Trees and Shrubs of Uganda by Katende *et al.* (1995). Specimens were also collected, pressed and taken to Makerere University herbarium for identification. Associated species were recorded in a separate field data sheet (Appendix 4.3).

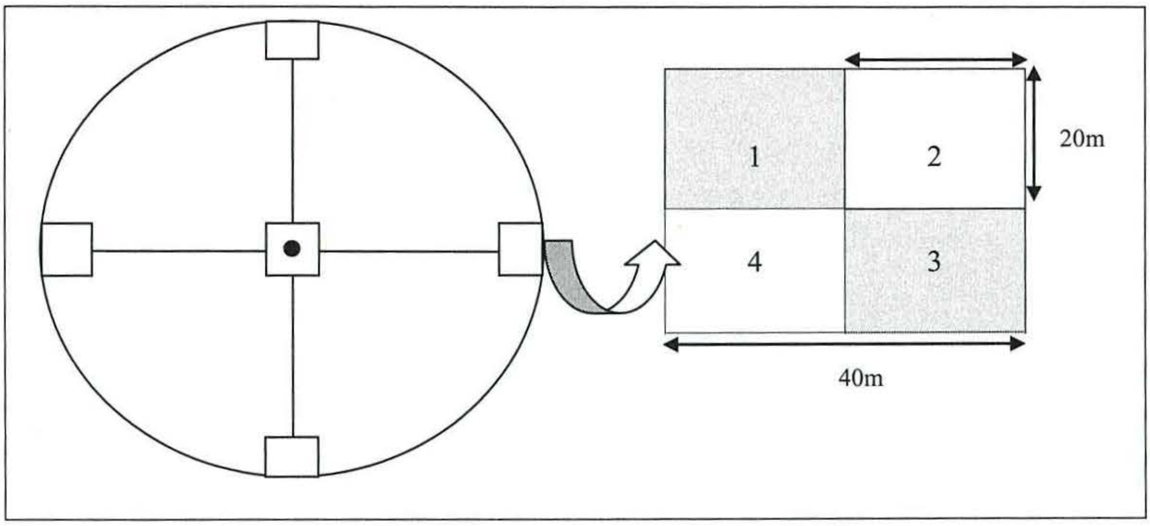


Figure 4.1 Nested sampling design for enumeration of saplings and seedlings.

4.3.4 Data analysis

Inventory data were entered in and analysed using SPSS Version 16. Exploratory data analysis was performed to show the patterns in the data in terms of center, spread, shape, gaps and outliers (LeBlanc, 2004). Descriptive statistics including means and percentages were used to generate tables and graphs while parametric tests were performed on key variables after checking for normality and equality of variance. Results were compared across the two study districts and between the four Balanites populations. Independent samples t-test was used to compare DBH, height and crown volume between the two study districts and significance levels determined at $p \leq 0.05$. One-way analysis of variance (ANOVA) was used to show population variations in the sub-county or site. Tukey's significant difference test (due to equal sample size) was used to separate means (test for homogeneity of means) (Kleinbaum and Kupper, 1978; Christine *et al.*, 2007).

4.4 Results

4.4.1 Distribution of *B. aegyptiaca*

Literature on *B. aegyptiaca* in Uganda and information from herbarium specimens revealed that the species is commonly found and widely utilized in Karamoja, Teso, and West Nile sub-regions. All these sub-regions are located in the semi-arid areas of Uganda. Herbarium specimens dated as far back as 1904 to 2006 although most of the specimens did not bear GPS locations (Table 4.2). Outside its main range in Uganda (West Nile, Teso and Karamoja), Balanites sparsely grew in other districts such as, Kamuli, Tororo, Kasese and Bulisa.

Table 4.2 Areas where *B. aegyptiaca* herbarium specimens had been collected

District	Site/locality description
Karamoja	• Napak, 1,219 m above sea level (a.s.l.)
	• Karasuk, Napaupass, $2^{0}25'$N $34^{0}57'$E
	• Lothea, Bokora County, $2^{0}06'$N$34^{0}13'$E, 1,220 m a.s.l.
Moroto	• Moroto town near Moroto Rest house
	• Lia River, Moroto
Adjumani	• Ajugopi, 609 m a.s.l.
Gulu	• Paimol, Acholi near Ilibi, 1,219 m a.s.l.
Moyo	• Itula
	• Laropi camp, west Madi, 611 m a.s.l.
Masindi	• Bukumi , Butiaba escarpment
Pallisa	• Agen swamp, Bugwere/Budaka
Kasese	• 5 km south of Kasese town, 950 m a.s.l.
Kotido	• Kibero, Agora, S.E Imatongs, 304 m a.s.l.
Kamuli	• Nasere village Kamuli district, Gadumire sub-county $33^{0}33'$E $1^{0}06.5'$N, 1,060 m a.s.l.

The areas/parishes where Balanites was found are presented in Appendix 4.4. Figure 4.2 shows Balanites site map for Uganda. The map confirmed that Balanites is found in northern, north eastern and north western parts of Uganda in Adjumani, Moyo, Arua and Nebbi districts in the West Nile sub-region; Katakwi, Soroti and Kumi in Teso sub-region and Moroto and Kotido in Karamoja sub-region.

4.4.2 Soil characteristics of Balanites populations

The soil profile pit in each Balanites population/sub-county is shown in Plate 4.1. The distance between the soil profile pits in Katakwi and Adjumani was 13.3 and 13.5 km, respectively. The depth of the pits ranged from 1.3 to 1.5 m and each had four recognizable horizons (Table 4.3).

Table 4.3 Location of soil profile pits in four Balanites study populations

District	Sub-county/ Balanites population	Land use	GPS points (UTM system)	Profile depth *(m)*
Adjumani	Adropi	Farm	0371027E 0388813N	1.4
	Dzaipi	Wild	0381866E 0380848N	1.4
Katakwi	Katakwi	Wild	0604543E 0209164N	1.3
	Ngariam	Farm	0617141E 0213248N	1.5

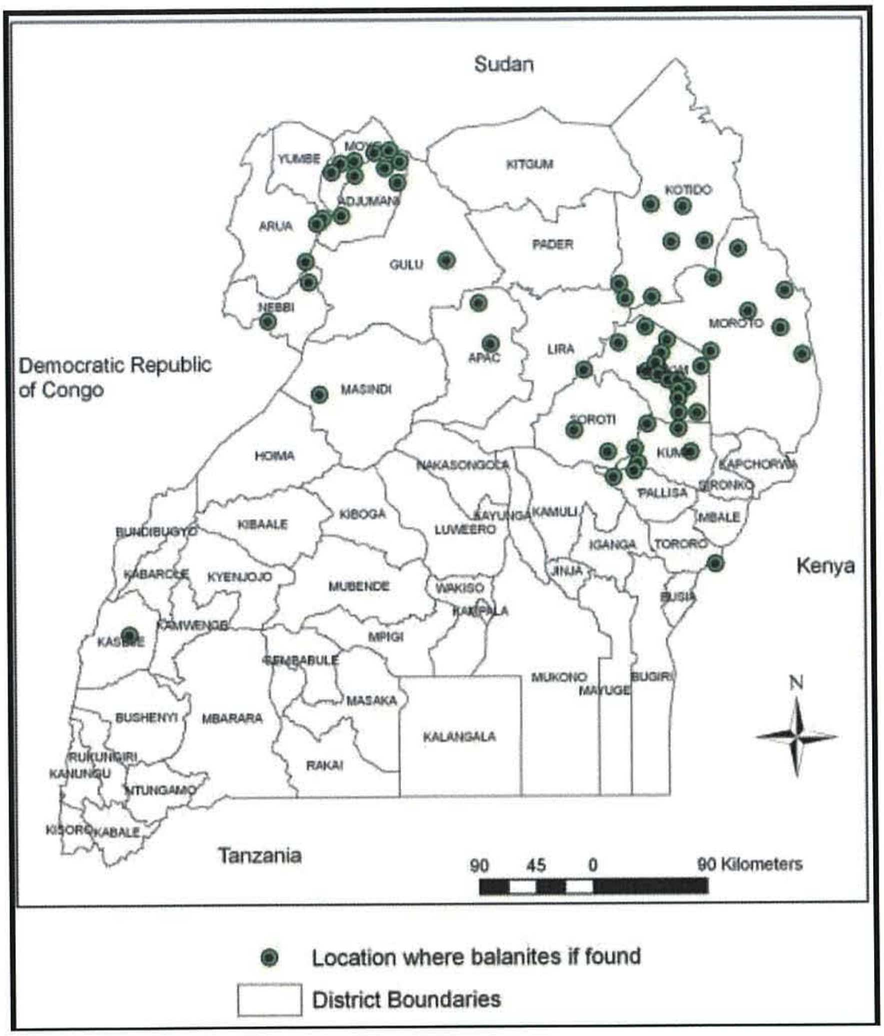


Figure 4.2 Map of Uganda showing the distribution of *B. aegyptiaca*

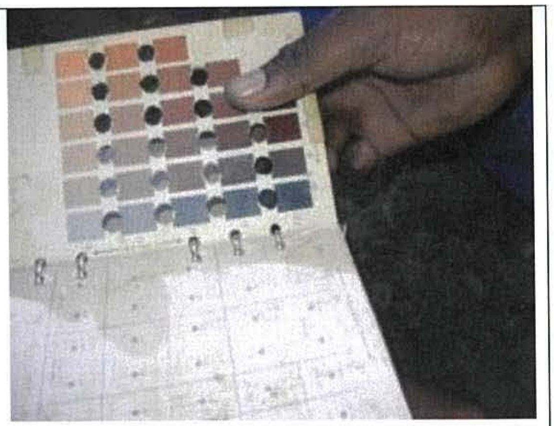



Plate 4.1 Description of a soil profile, Abela village, Katakwi district

The average depth or thickness of the horizons was 29.4, 24.5, 34.9 and 43.1 cm for H1, H2, H3 and H4, respectively. Horizon boundaries were abrupt, clear, gradual and diffuse in some cases. Soil hue was generally uniform at 2.5Y with a few exceptions of 2.5YR and 5Y. The soil values increased from 2.5 in the top to 3 in the mid horizons and to 4 and 5 in the fourth horizons. Soil chroma increased downwards in Katakwi where it was between zero and 2.0. There were no clear patterns in soil colour; nonetheless, the soil in the top horizon was generally black, while soil in the lower horizons was brown, grey or yellow (Table 4.4). The upper horizon was deep (27-30 cm) and the boundaries varied from abrupt to clear.

The soils were dominated by sand, clay and sandy clay loam. The upper horizon (H1) had mainly sandy, mid horizon (H2) had sandy clay while the lower two horizons (H3 and H4) had sandy clay (Table 4.5). The clay content was generally high in the lower horizons (H2 -H4)

Table 4.4 Field characteristics of soil in different *Balanites* populations/sites

Site*-Horizon**	Horizon thickness (cm)	Boundary Distinctness***	Colour code	Colour name
AD-H1	30.8	g	2.5YR 2.5/0	Black
AD-H2	20.2	d	5Y 2.5/1	Black
AD-H3	30. 9	a	2.5Y 3/2	Very dark greyish brown
AD-H4	40.1	a	2.5Y 4/2	Dark greyish brown
DZ-H1	26.5	c	2.5YR 3/3	Dark olive brown
DZ-H2	27.0	d	2.5YR 4/4	Olive brown
DZ-H3	45.0	a	5YR 4/6	Yellowish red
DZ-H4	57.0	a	5YR 5/6	Yellowish red
KA-H1	30.0	a	2.5Y 2/0	Black
KA-H2	25.0	d	2.5Y 3/0	Very dark grey
KA-H3	32.0	g	2.5Y 3/2	Very dark greyish brown
KA-H4	43.0	a	2.5Y 4/0	Dark grey
NG-H1	30.2	c	2.5Y 3/2	Very dark grenish brown
NG-H2	27.0	d	2.5Y 5/6	Light olive brown
NG-H3	62.5	d	2.5Y 6/8	Olive yellow
NG-H4	32.3	a	2.5Y 5/4	Light olive brown

**AD = Adropi, DZ= Dzaipi, KA= Katakwi, NG= Ngariam*
***H1 to H4 = Soil horizons 1 – 4 in a particular profile pit*
**** Abrupt (a), gradual (g), clear (c) diffuse (d)*

Table 4.5 Soil textual classes

Site*-Horizon**	% of sand	% of clay	% of silt	USDA textual class***
AD-H1	67	14	19	sc
DZ-H1	68	22	10	scl
KA-H1	69	15	16	sl
NG-H1	75	15	10	sl
Mean	**70**	**17**	**14**	**sl**
AD-H2	63	18	19	sl
DZ-H2	54	36	10	sc
KA-H2	52	41	7	sc
NG-H2	68	23	9	scl
Mean	**59**	**30**	**11**	**scl**
AD-H3	62	21	17	scl
DZ-H3	45	48	7	sc
KA-H3	70	23	7	scl
NG-H3	39	59	2	c
Mean	**54**	**38**	**8**	**Sc**
AD-H4	59	25	16	scl
DZ-H4	40	51	9	c
KA-H4	59	35	6	scl
NG-H4	35	59	6	c
Mean	**48**	**43**	**9**	**Sc**

**AD = Adropi, DZ= Dzaipi, KA= Katakwi, NG= Ngariam*
***H1 to H4 = Soil horizons 1 – 4 in a particular profile pit*
**** Sandy loam (sl), sandy clay (sc), sandy clay loam (scl), clay (c)*

N, P, OM, Na were low in all the horizons while Mg was high in all horizons. While the level of potassium was low in all the horizons in Katakwi (<0.4 meq/100 g), in Adjumani it was less in the surface horizon, moderate in second and high in third and fourth horizons (0.75 – 0.78 meq/100 g). On the other hand, the amount of Ca in surface horizon in Katakwi was very low (2.1 meq/100 g) while it was medium in Adjumani (5 meq/100 g). The level of Ca in the rest of the horizons in both districts was moderate (5 – 9 meq/100 g) (Table 4.6 and Appendix 4.5).

Table 4.6 Basic soil properties in Balanites growing sites in Adjumani and Katakwi districts

Property	Adjumani				Katakwi				Overall
	H1	H2	H3	H4	H1	H2	H3	H4	Mean*
pH	5.20	5.45	6.00	6.35	4.95	5.20	5.50	6.70	5.67 (0.64)
N (%)	0.07	0.07	0.05	0.05	0.05	0.04	0.04	0.04	0.05 (0.01)
O.M (%)	1.12	1.17	0.83	0.50	0.96	0.71	0.58	0.38	0.78 (0.27)
P (ppm)	9.86	1.02	0.58	0.15	0.73	0.37	0.29	0.80	1.33 (1.63)
K (meq/100g)	0.30	0.39	0.75	0.78	0.06	0.20	0.25	0.34	0.38 (0.18)
Ca (meq/100g)	4.96	5.92	5.64	7.29	2.07	4.54	5.37	9.08	5.61 (1.93)
Mg (meq/100g)	1.24	1.48	1.41	1.83	0.52	1.14	1.35	2.27	1.40 (0.48)
Na (meq/100g)	0.11	0.08	0.08	0.10	0.33	0.68	1.02	1.58	0.50 (0.26)

**Values in parentheses are standard error of the mean*

4.4.2 Population of *B. aegyptiaca*

4.4.2.1 Stocking density

Stocking density of *B. aegyptiaca* in the eight study plots is presented in Table 4.7. An area of about 121 ha was inventoried, with a total of 800 *B. aegyptiaca* trees. A much bigger area was covered in Katakwi district (102 ha) than Adjumani district (19 ha) to sample 400 trees in each case. There were more *B. aegyptiaca* trees in the wild than on-farm but the populations in the two landuse types were the same in Katakwi. Wild population in Adropi, Adjumani district, had the highest stocking density (30 trees ha^{-1}) while on-farm population in Ngariam, Katakwi district, had the lowest stocking density (2 trees ha^{-1}). The two populations in Adjumani district had the highest stocking densities (30 – 17 trees ha^{-1}) compared to 2 - 8 trees ha^{-1} for the two populations in Katakwi district.

In addition, 71 Balanites stumps were encountered in the eight plots inventoried with an average of nine stumps per plot. The highest number of stumps (16) was encountered in an on-farm site in Dzaipi, Adjumani district, while the lowest (4) was found in a wild site in Ngariam, Katakwi district (Figure 4.3 and Plate 4.2).

Table 4.7 Density of Balanites trees in the eight inventory sites in Adjumani and Katakwi districts

District	*Site/plot	Plot radius (m)	**Area (m^2)	Area (ha)	Trees ha^{-1}
	Adropi wild	102.5	32884.56	3.3	30
Adjumani	Adropi farm	118.0	43582.12	4.4	23
	Dzaipi wild	134.5	56622.48	5.7	18
	Dzaipi farm	139.0	60474.73	6.0	17
			(193563.90)	(19.4)	
	Katakwi wild	201.5	127085.04	12.7	8
Katakwi	Katakwi farm	203.0	128984.17	12.9	8
	Ngariam wild	328.0	336737.92	33.7	3
	Ngariam farm	369.0	426183.93	42.6	2
			(1018991.06)	(101.9)	

**Each site/plot had 100 B. aegyptiaca trees*
*** Area calculated from $A=\pi r^2$ where r is the plot radius*
Values in parentheses are the total area inventoried in each district.

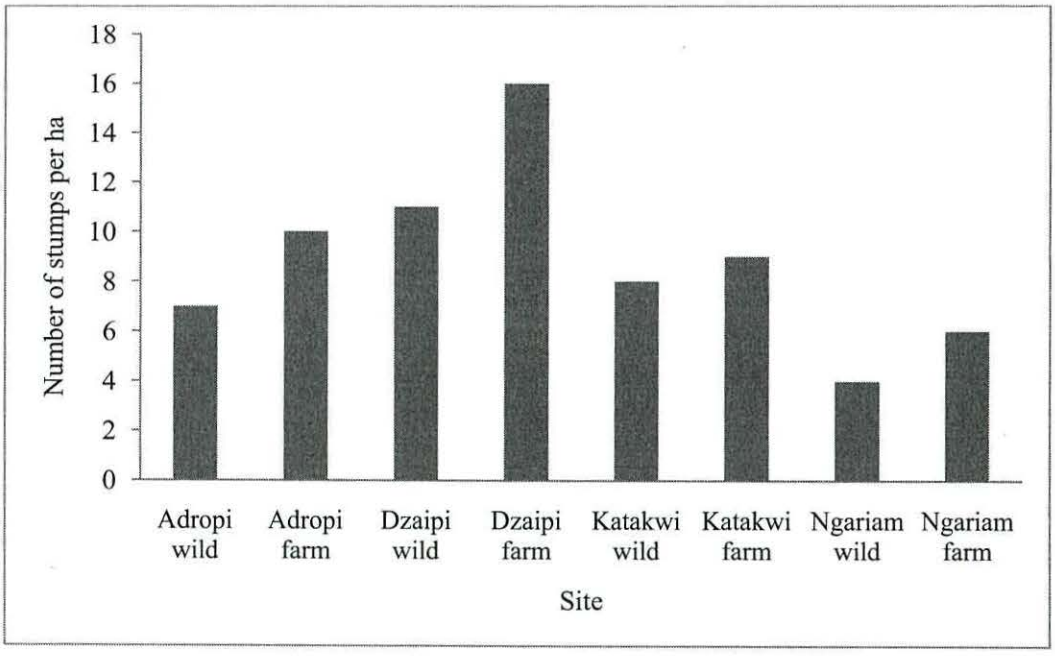


Figure 4.3 Level of Balanites tree harvesting in eight sampling points

Plate 4.2 Cutting of Balanites trees in Adjumani district

Balanites stumps cut during previous year (a) and recently cut stump for charcoal burning (b) in Ege village.

4.4.2.2 Distribution pattern of *B. aegyptiaca*

Scatter diagrams showing the spatial distribution of 100 *B. aegyptiaca* trees in each of the eight sites are presented in Figure 4.4 a&b). The altitude of the study sites in Katakwi district was higher (1,064 – 1,076 m) than in Adjumani sites (621 – 663 m).

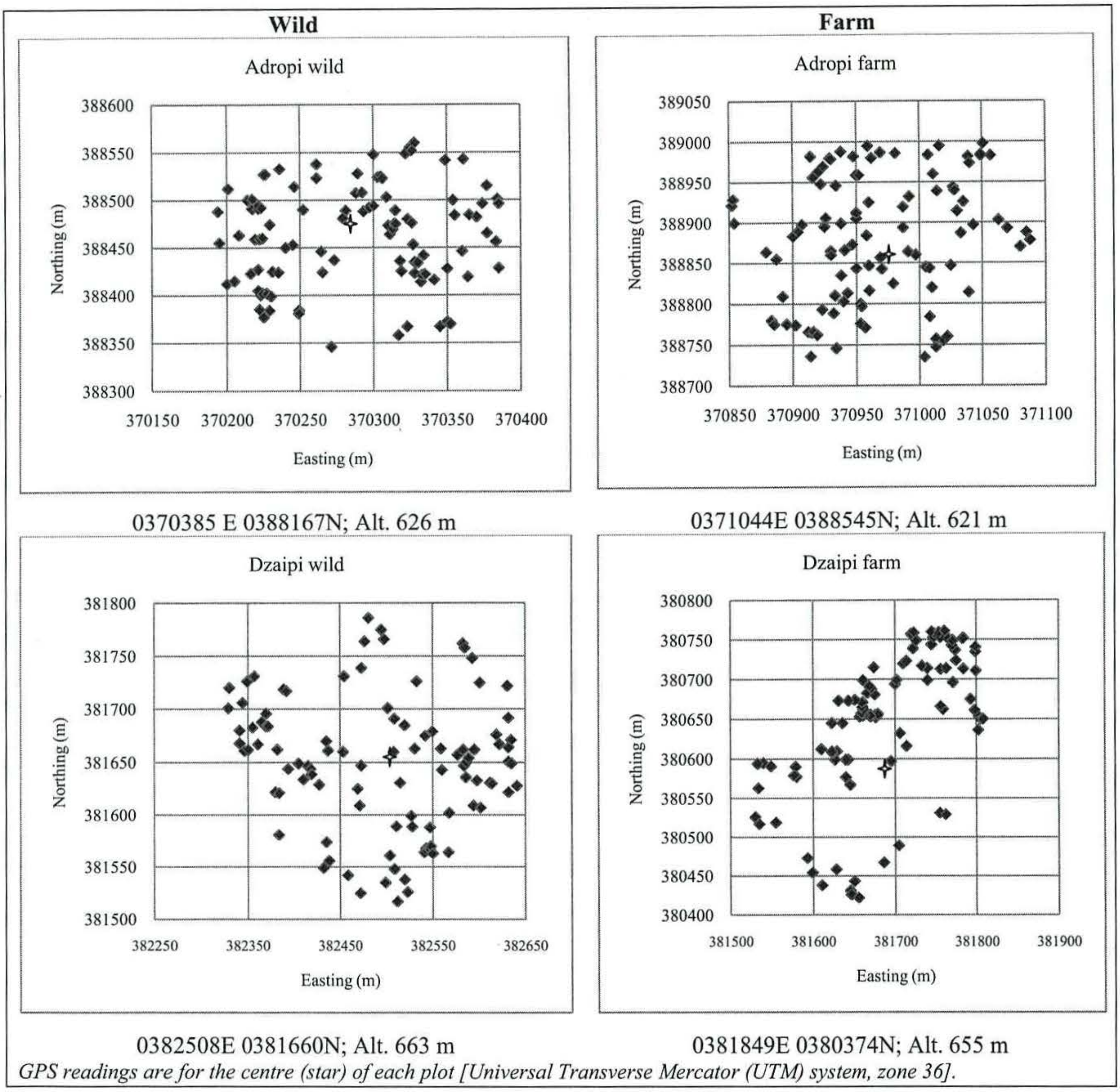


Figure 4.4 (a) Spatial distribution of 100 *B. aegyptiaca* trees in the wild and on-farm in Adjumani district, Uganda.

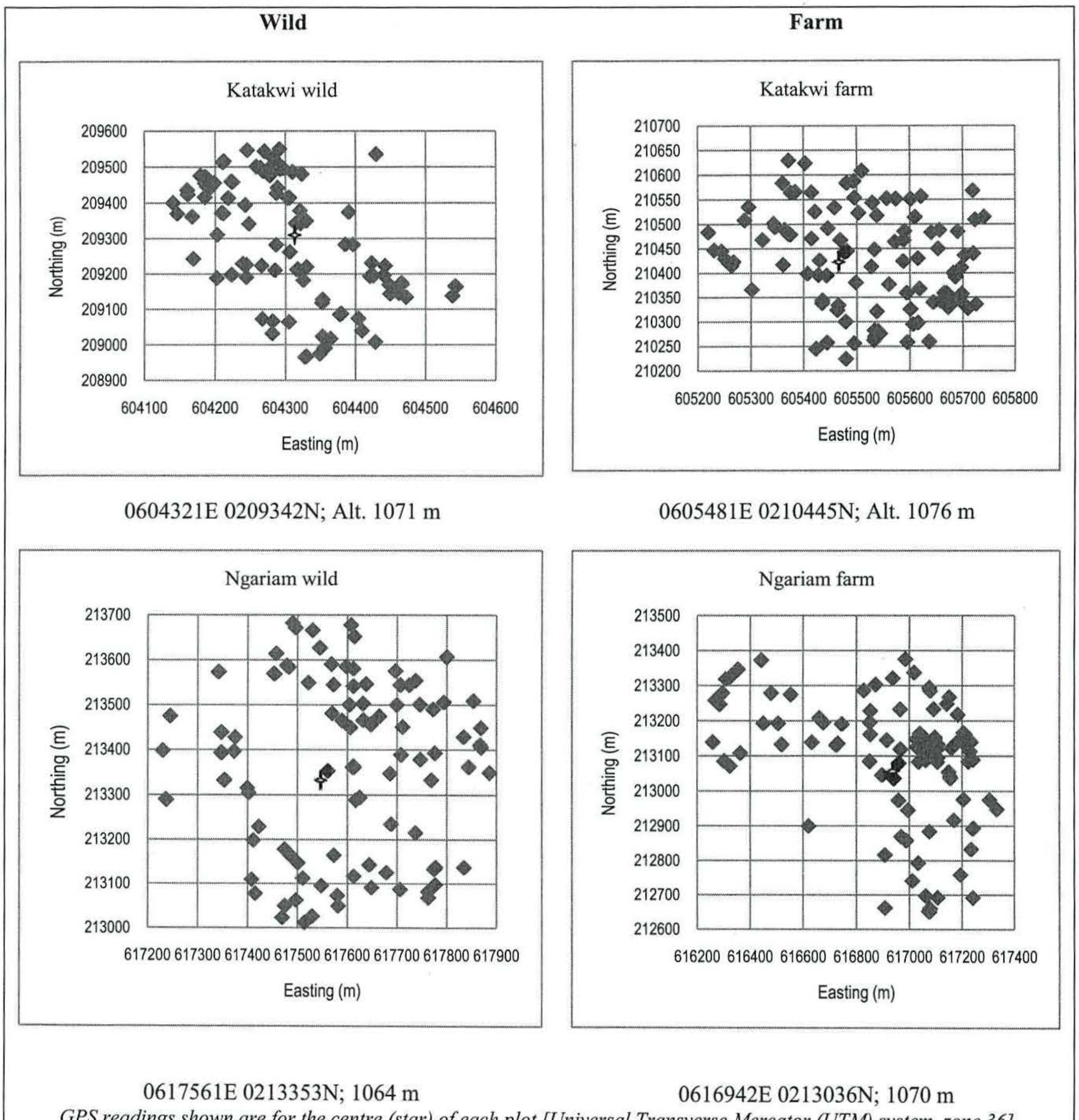


Figure 4.4: (b) Spatial distribution of 100 *B. aegyptiaca* trees in the wild and on-farm in Katakwi district, Uganda.

Table 4.8 shows the tree density (***d***), observed nearest neighbour distance ($\mathbf{r_o}$), expected nearest neighbour distance ($\mathbf{r_e}$) and measure of the degree to which the observed distribution approaches or departs from random expectation (***R***) for eight Balanites sites. The mean observed nearest neighbour distance ($\mathbf{r_o}$) was shorter in Adropi and Dzaipi sites (Adjumani) (8.15 – 12.08 m) than in Katakwi and Ngariam sites (Katakwi) (15.09 – 35.67 m).

Table 4.8 Distribution pattern of *Balanites* trees in the eight study sites in Katakwi and Adjumani districts

Site/plot	Plot area (m^2) [A]	Trees/m^2 [*d*]	Observed NND (m) [r_o]	Expected NND (m) [r_e]	Ratio [R]
Adropi wild	32884.56	0.00304	8.15	9.07	0.9
Adropi farm	43582.12	0.00229	11.05	10.44	1.1
Dzaipi wild	56622.48	0.00177	12.08	11.90	1.0
Dzaipi farm	60474.73	0.00165	9.59	12.30	0.8
Katakwi wild	127085.04	0.00079	15.09	17.82	0.8
Katakwi farm	128984.17	0.00078	21.88	17.96	1.2
Ngariam wild	336737.92	0.00030	27.98	29.01	1.0
Ngariam farm	426183.93	0.00023	35.67	32.64	1.1
		$d = N/A$	$ro = \sum r/N$	$r_e = 1/2\sqrt{d}$	$R = r_o/r_e$

N = number of *Balanites* trees in each plot (N=100)
NND = nearest neighbour distance

The observed distribution ($\mathbf{r_o}$) also closely approached the expected distribution ($\mathbf{r_e}$) thus, pushing the ***R*** values closer to 1.0 in all the eight plots. The ***R*** value ranged from 0.8 – 1.2, implying random distribution (Table 4.8). Comparison of mean observed nearest neighbour distance (one-way ANOVA) showed that all the four plots in Katakwi district were significantly ($p \leq 0.05$) different from each other while those in Adjumani were not (Figure 4.5).

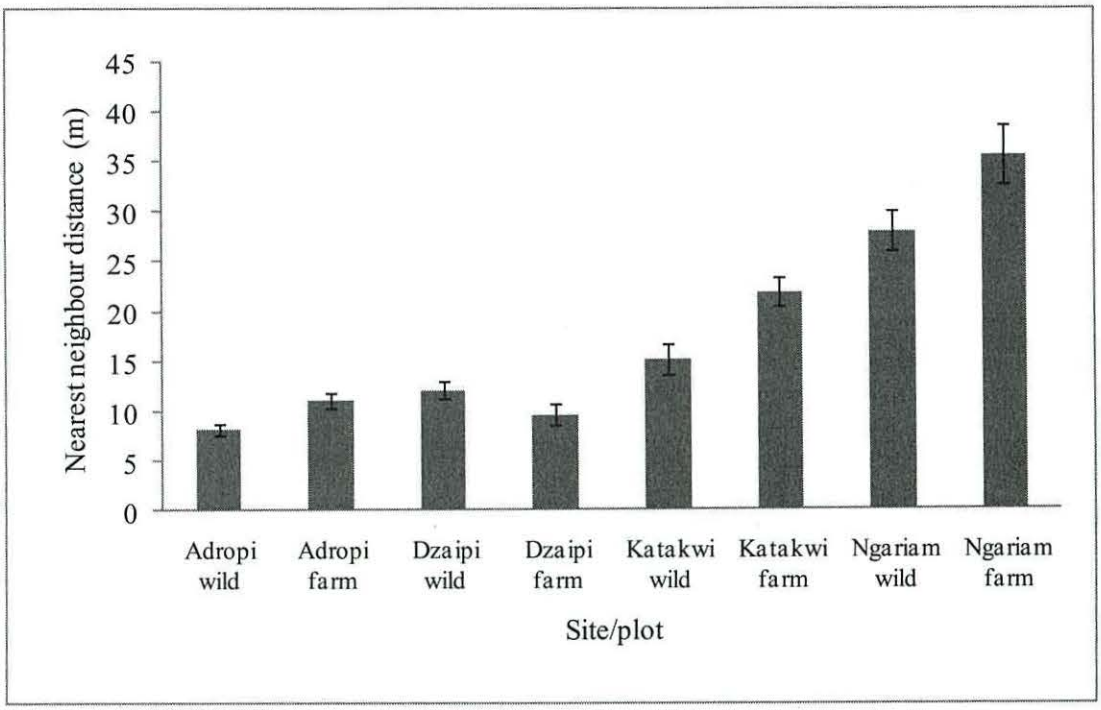


Figure 4.5 Comparison of the mean nearest neighbour distance between eight plots.
Vertical lines on bars are standard deviations.

4.4.2.3 Variation in DBH, height and crown volume between the study districts

Comparison of DBH, height and crown volume between the eight study sites did not reveal significant differences between wild and on-farm trees except in Adropi population where on-farm trees had significantly ($p \leq 0.05$) higher DBH than wild trees (50 and 44 cm, respectively). The 800 trees assessed in the two districts had a mean; DBH of 39 cm, height of 7.5 m and crown volume of 20.6 m^3 (Table 4.9).

Table 4.9 Variation in mean DBH, height and crown volume of the of Balanites trees among study districts

Parameter	Katakwi (n=400)	Adjumani (n=400)	Mean (n=800)
DBH (cm)	37.53	40.56	39.04
Total height (m)	6.63	8.30	7.47
Crown volume (m^3)	12.24	28.87	20.55
Crown/height ratio	0.51	0.60	0.55

Independent samples t-test for equality of means of the above dendrometric parameters revealed significant variations ($p \leq 0.05$) between the two districts (Table 4.10). This implies that Balanites trees in Adjumani were generally bigger than those in Katakwi. For instance, trees in Adjumani were about 3 cm bigger in DBH, 1.6 m taller and their crowns were 16.6 m^3 bigger than those in Katakwi district.

Table 4.10 T-test for comparison of mean DBH, height and crown volume between Katakwi and Adjumani districts

Tree dimensions	t	df	Sig. (2-tailed)*
DBH (cm)	2.849	798	0.005
Height (m)	8.233	798	0.005
Crown diameter (m)	16.679	798	0.005
Crown depth (m)	12.646	798	0.005
Crown volume (m3)	15.639	798	0.005
Crown/length ratio	11.834	798	0.005

**All parameters were significant at both $\alpha = 0.05$ and 0.001.*

4.4.2.4 Variation in DBH, height and crown volume between study populations

Balanites trees in Adropi population were the largest (47.1 cm DBH), tallest (9.10 m high) and had the biggest crown volume (34.87 m^3). Though trees in Katakwi were the second largest (38.75 cm DBH), they were much shorter (6.85 m) than those in Dzaipi which were 7.49 m tall and with lowest DBH, 34.06 m. (Table 4.11).

Table 4.11 Variation in Balanites tree morphological characteristics between study populations

District	Population	Mean (SE)		
		DBH (cm)	Total height (m)	Crown volume (m)
Katakwi	Ngariam (n=200)	36.30 (1.03)	6.42 (0.16)	10.25 (0.54)
	Katakwi (n=200)	38.75 (0.96)	6.85 (0.13)	14.22 (0.74)
Adjumani	Adropi (n=200)	47.06 (0.84)	9.10 (0.15)	34.87 (1.20)
	Dzaipi (n=200)	34.06(1.19)	7.49 (0.19)	22.87 (1.36)
Overall	N=800	39.04 (0.16)	7.51 (0.10)	20.55 (0.61)

Figures in parenthese are the standard error of the mean (SE)

One-way ANOVA showed that all the three tree morphological parameters varied significantly ($p \leq 0.05$) between the four Balanites populations (Table 4.12). Tukey's test revealed that the crown volumes of the two Balanites populations in Ngarian and Katakwi (Katakwi district) varied significantly ($p \leq 0.05$). All the three parameters varied significantly ($p \leq 0.05$) between the two populations in Adjumani district (Figure 4.6). Across the four Balanites populations, DBH and height for trees in Adropi were significantly ($p \leq 0.05$) more than the rest of the populations. Like other parameters, crown volume was generally in the order of Adropi>Dzaipi>Katakwi> Ngariam.

Table 4.12 A one-way ANOVA for DBH, height and crown volume between the four Balanites populations

Tree parameter	Sum of Squares	df	Mean Square	F	Sig.
Tree DBH (cm)	19339.111	3	6446.37	31.439	0.001*
Tree total height (m)	789.059	3	263.02	37.956	0.001*
Crown volume (m3)	71328.676	3	23776.23	115.022	0.001*

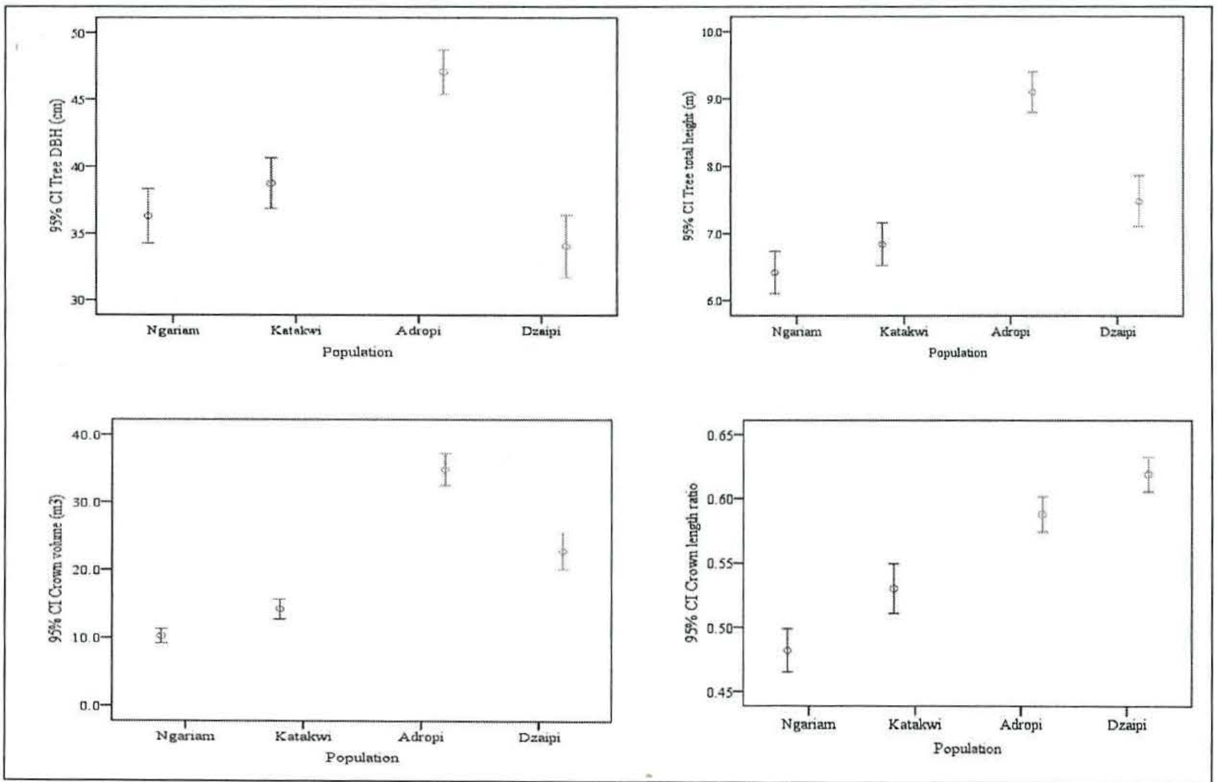


Figure 4.6 Variation in Balanites DBH, height, crown volume and crown/length ratio

4.4.2.5 Variation in Diameter class between study populations

Diameter class of *B. aegyptiaca* trees in the two study districts is presented in Figure 4.7. There were fewer trees in the lower (10 – 29 cm) and upper (≥ 50 cm) diameter classes but more trees in the mid diameter classes (30 to 49 cm). However, there were more trees in the higher diameter classes (≥ 50 cm) in Adjumani than in Katakwi district.

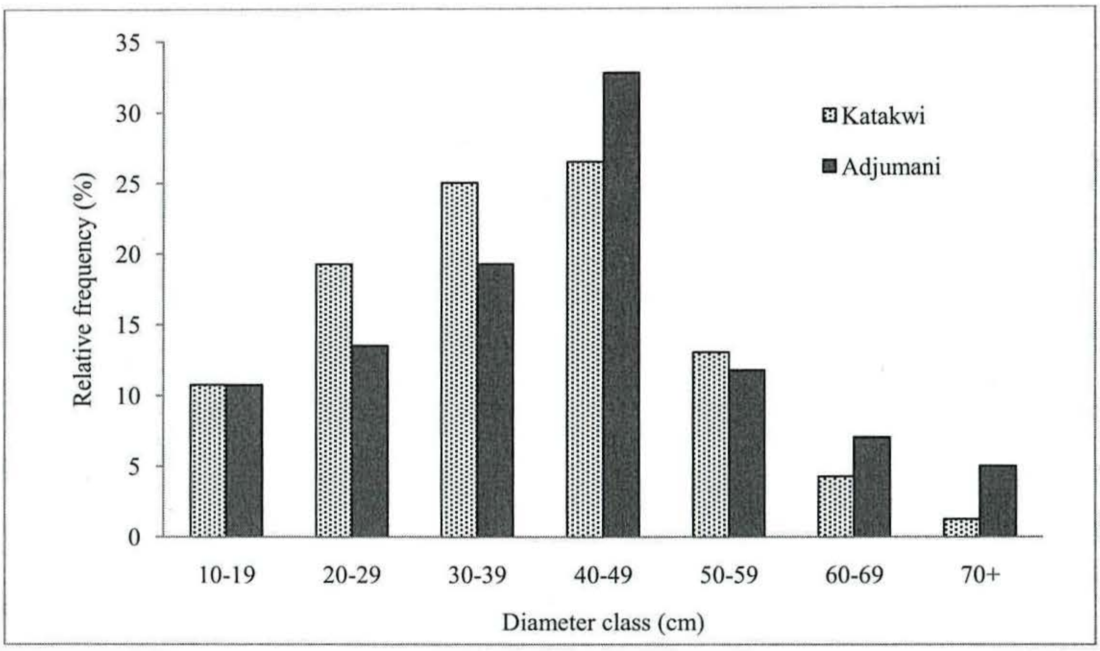


Figure 4.7 Diameter class for *B. aegyptiaca* in Katakwi and Adjumani districts.

4.4.2.6 Regeneration mode and regeneration success under different land use types

Balanites aegyptiaca regenerated from seeds and coppices in wild and on-farm. There were more seedlings regenerating from seed than coppices. At the sapling stage, there was more regeneration through coppicing than seed (Figure 4.8). Fire and over-grazing hindered regeneration and growth of Balanites seedlings and saplings. This was especially serious in Ngariam population.

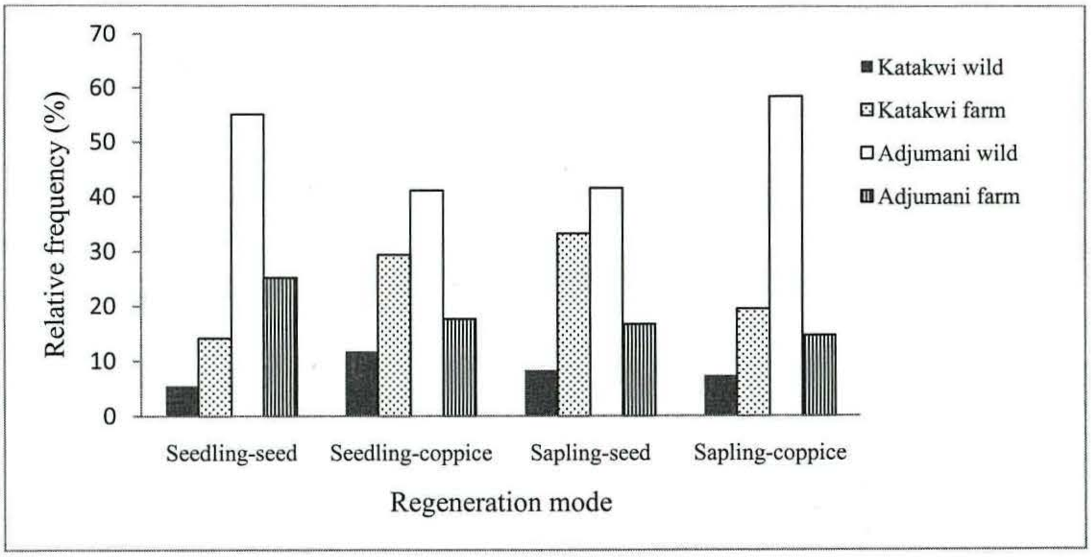


Figure 4.8 Regeneration mode for *B. aegyptiaca* under different land uses

Figure 4.9 shows that there was higher regeneration in Adjumani than Katakwi district and highest under wild conditions. The density of both seedlings and saplings was higher on-farm than in the wild in Katakwi district. In contrast, there were more trees than saplings on farm in Adjumani than in Katakwi district.

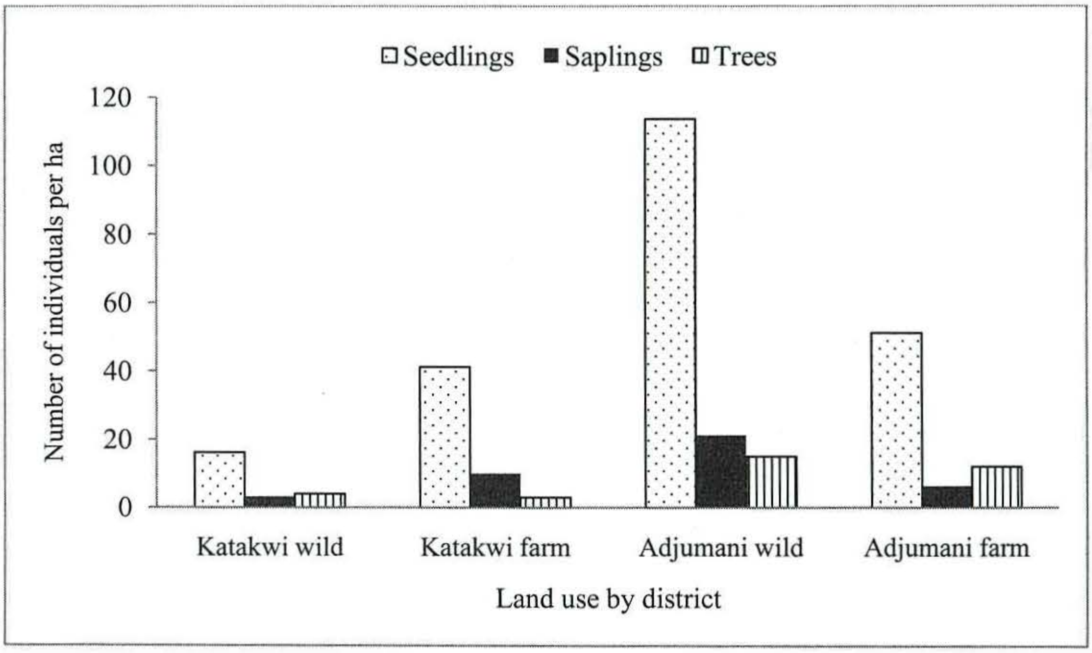


Figure 4.9 Regeneration of *B.aegyptiaca* in the wild and on farm.

4.4.3 Health status of *B. aegyptiaca* trees

Most of the trees (93%) in Adjumani had no sign of lopping while in Katakwi only a few trees (30%) were not lopped. About 42% of the trees in Katakwi had all their crowns lopped while the rest were lopped to varying levels (Table 13 and Plate 4.3). Balanites trees were generally healthy in all the study sites, 83% and 79% in Katakwi and Adjumani districts respectively (Table 13, Plate 4.3 and 4.4).

Table 4.13 Health status of *B. aegyptiaca* trees in Katakwi and Adjumani districts

Parameter	District (%)	
	Katakwi	Adjumani
Level of lopping (crown)		
All branches lopped	42.0	3.3
75% of branches lopped	8.3	0.8
50% of branches lopped	8.5	1.3
25% of branches lopped	11.3	2.3
No sign of lopping	30.0	92.5
Pest and disease incidence (whole tree)		
Dry/dead	2.2	0.0
Severely affected & drying up	3.5	0.0
Leaves & branches affected	1.2	0.5
Only leaves affected	10.1	21.0
Healthy (no sign of pest & disease)	83.0	78.5

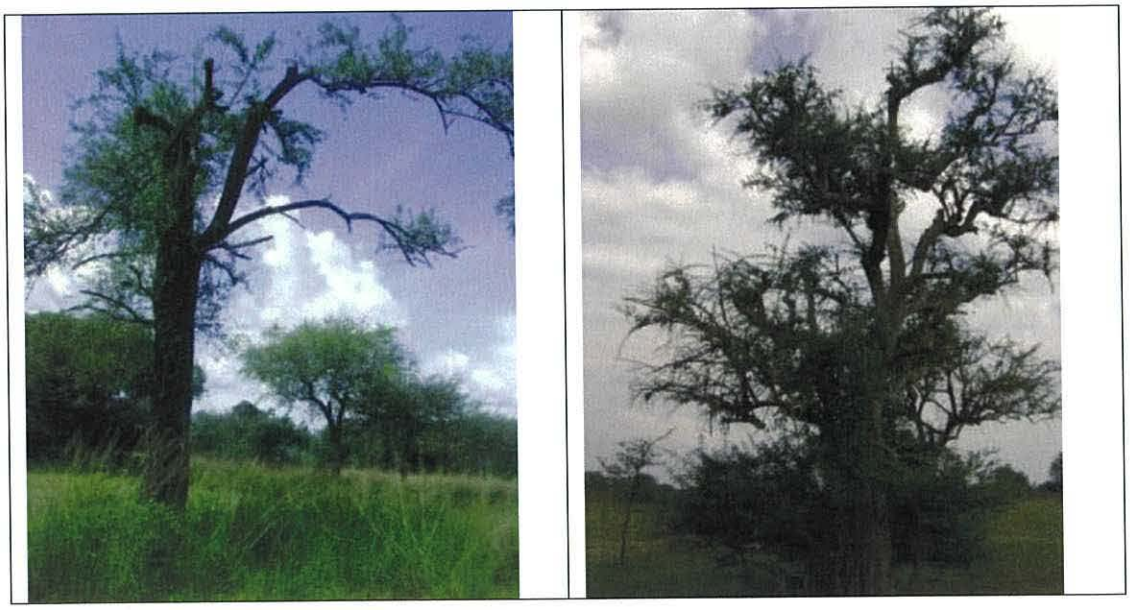
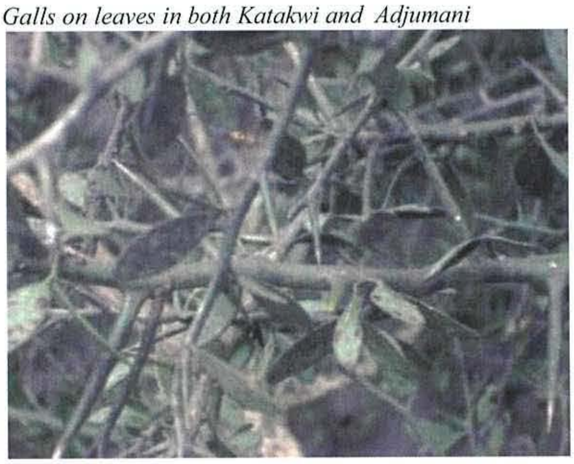


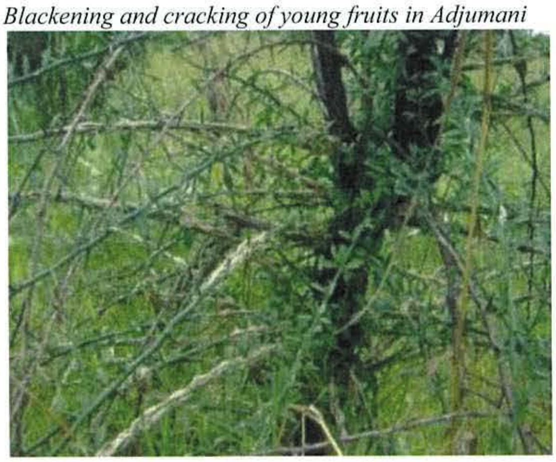
Plate 4.3 Balanites branches cut for fencing Adjumani district (a) and branchlets cut during leaf harvesting, Katakwi district (b).

Galls on leaves in both Katakwi and Adjumani

Blackening and cracking of young fruits in Adjumani



Blackening of leaves in Katakwi



Swellings(canker) in small branches in Katakwi

Phymateus viridipes

Defoliators observed on both wild and on farm trees in Katakwi district

Plate 4.4 Signs of pests and diseases observed on *B. aegyptiaca* trees in Katakwi and Adjumani districts

4.4.4 Tree species associated with *B. aegyptiaca*

In both study sites, *B. aegyptiaca* was the most dominant species. It was more abundant in Adjumani district where it constituted over 72% and 58% of the tree population in the wild and on farm respectively. In Katakwi district, *B. aegyptiaca* constituted 40% and 42% of the tree population in the wild and on farm respectively (Tables 4.14 and 4.15). In Adjumani, *B. aegyptiaca* was commonly associated with *Lannea schwenfurthii, Tamarindus indica, Acacia sieberiana, Sclerocarya birrea, Combretum collinum* and *Ziziphus abyssinica*. In Katatwi, it was associated with *Combretum schumanii, Acacia sieberiana, Acacia seyal, Acacia gerrardii, Euphorbia candelaberum, Lannea barteri* and *Tamarindus indica* (Plate 4.5).

Table 4.14 Balanites and common associated tree species in Adjumani district

Wild	%	Farm	%
1. Balanites aegyptiaca	72.2	*1. Balanites aegyptiaca*	58.3
2. Tamarindus indica	4.3	*2. Lannea schwenfurthii*	9.0
3. Lannea schwenfurthii	4.0	*3. Tamarindus indica*	4.4
4. Acacia sieberiana	4.0	*4. Sclerocarya birrea*	3.8
5. Sclerocarya birrea	3.6	*5. Combretum collinum*	2.9
6. Ziziphus abyssinica	2.2	*6. Ziziphus abyssinica*	1.7
7. Acacia hockii	1.8	*7. Acacia sieberiana*	1.7
8. Acacia senegal	1.8	*8. Gardenia sp.*	1.7
9. Ziziphus mauritiana	1.4	*9. Acacia hockii*	1.7
10. Combretum collinum	1.1	*10. Combretum molle*	1.5
11. Others*	3.6	11. Others*	13.3

**Abundance of each of the other species was less than the 10^{th} species listed in each case.*

Table 4.15 Balanites and common associated tree species in Katakwi district

Wild	%	Farm	%
1. Balinites aegyptiaca	40.1	*1. Balanites aegyptiaca*	42.4
2. Combretum schumanii	7.2	*2. Combretum schumanii*	11.2
3. Acacia seyal	5.4	*3. Acacia sieberiana*	6.6
4. Acacia sieberiana	5.2	*4. Acacia seyal*	4.9
5. Acacia gerrardii	4.4	*5. Euphorbia candelabrum*	4.2
6. Lannea barteri	3.8	*6. Tamarindus indica*	3.6
7. Lannea humilis	3.4	*7. Lannea barteri*	3.6
8. Combretum molle	3.2	*8. Combretum molle*	2.1
9. Tamarindus indica	3.2	*9. Piliostigma thonningii*	2.1
10. Lannea fulva	2.2	*10. Lannea humilis*	2.1
11. Others*	21.9	11. Others*	17.2

**Abundance of each of the other species was less than the 10^{th} species listed in each case.*

Tamarindus indica *Sclerocarya birrea*

Plate 4.5 Common IFTs associated with *B. aegyptiaca* in Katakwi and Adjumani districts.

4.5 Discussion

4.5.1 Distribution of *B. aegyptiaca* in Uganda

The findings of the present study revealed that *Balanites aegyptiaca* in Uganda commonly grows in the semi-arid areas of Karamoja, Teso and West Nile sub-regions. The Kew Bulletin on Balanites (Sands, 2001) indicated the herbarium specimens of *B. aegyptiaca* from Uganda held in the Kew Botanical Gardens, United Kingdom to include; Paimol hill, Gulu 1947, Dawkins 309; near Imatong hills, Agoro, 1945, Greenway and Hummel 7325; Near L. George, Kasese 1968, Ferreira and Lock 397; Serere 1933, Chandler 1110; and Lwampanga, Nakasongola, 1954, Langdale- Brown 1256. Similar information exists in Eggeling (1940), Landale-Brown *et al.* (1964) and Katende *et al.* (1995 and 1999). Though some of these reports indicate occurrence of *B. aegyptiaca* outside Karamoja, Teso, and West Nile sub-regions, the species was found to be scanty and sometime scarce in such areas.

The old information on *B. aegyptiaca* dating as far back as 1904 has been expanded with the current information in this study and used to produce the first distributional map for *B.aegyptiaca* in Uganda. The three sub-regions where *B. aegyptiaca* was found to be commonly growing in Uganda were generally semi-arid with low altitude (600 – 1,370 m.a.s.l.). Mean annual rainfall is 900 – 1,500 mm and mean annual temperatures > 25 °C. According to Hall and Walker (1991); Hall (1992), Sands (2001) and Hall (2008), *B. aegyptiaca* is generally common in areas with a rainfall of 400 – 1,000 mm year^{-1} in semi-arid and arid zones of tropical Africa. In all the sites visited in Uganda, *B. aegyptiaca* was generally found growing along swamps as was the case in Teso and along the River Nile in west Nile. In areas with no surface water bodies, the water table was high, evidenced by shallow wells. Hall (1992) and Sands (2001) noted that *B. aegyptiaca* prefers valley, floodplain or watercourse sites where seasonally high water tables or groundwater compensate for low rainfall. Annual rainfall range in *B. aegyptiaca* growing areas in Uganda (800 – 1,500 mm) is higher than that reported in its range in West Africa where a 1,000 mm year^{-1} rainfall isohyet is said to be its natural limit (Aubreville, 1950). However, the Ugandan scenario is supported by Hall (1992) who reported that under conditions of disturbance (and probably by conscious introduction), the species can spread beyond the 1,000 mm year^{-1} limit, making occurrences under mean rainfall 1,300 - 1,400 mm year^{-1} possible as is the case in Guinea Bissau and the Central African Republic. The altitude and temperature ranges are within the limits reported elsewhere (Sands, 2001 and Hall, 2008). It was noted that *B. aegyptiaca* was the most abundant and prominent tree species in these semiarid conditions in Uganda. It is, therefore, important to draw attention of forest and other environmental agencies towards management of Balanites in these fragile areas so as to maintain their environmental resilience.

4.5.2 Soil characteristics of the studied populations

The deep first horizon (27-30 cm) and abrupt or clear boundaries between horizons suggest that the soils are highly weathered and have experienced minimum anthropogenic disturbance. Noteworthy was the relatively low hue of the soil profiles (2.5Y, 2.5YR and 5Y) indicating that the areas experience periodic flooding (aquic moisture regime). The soils were generally dominated by sand and clay and the most common textual class was sandy clay loam. The fact that upper horizon was mainly sandy while the mid and lower two horizons were dominated by clay suggests higher water holding capacity of the lower horizons. Increased water holding capacity of the lower horizons coupled with flat terrain of the sites is responsible for periodic flooding of Balanites growing areas. This is confirmed by the general greyish colour of the soil, which indicates hydromorphism (CDA, 1976). According to Sands (2001), *B. aegyptiaca* grows in various soils ranging from deep sands in the drier parts of the Sahel zone (250 - 450 mm annual rainfall), to sandy loams or clays, where rainfall is somewhat higher (450 - 900 mm), as in parts of the Sudan. Hall (2008) however, reported vigorous populations of *B. aegyptiaca* in relatively fertile, low-lying sites with deep sandy soil and uninterrupted access to water as well as on heavier, fertile vertisolic soils, provided salinity is low. Balanites also survives periodic flooding (Hall and walker, 1991; Sands, 2001; NRC, 2008) and grows best in deep clayey or gravel soils such as valley floors, river banks and foot of rocky slopes (Snolnozi, 1985; Hall and Walker, 1991; Sands, 2001). According to Hall (1992), the maximal development of *B. aegyptiaca* as an individual tree is on low-lying, level alluvial sites with deep sandy loam soil and uninterrupted access to a source of water. Burkhill (1985) noted that establishment of *B. aegyptiaca* along water courses and on flood plains ensures periodic nutrient replenishment where soils would not otherwise sustain vigorous growth.

In Katakwi the surface soil pH was strongly acidic pH <5.1(4.5) while in Adjumani the soils were moderately acidic (5.2). According to Marx *et al.* (1999) and Sullivan and McQueen (2007), most agricultural crops grow best in soils with pH between 6.0 (somewhat acidic) and 7.5 (slightly alkaline). On the other hand, the soils in mid and lower horizons in both districts had moderately to slightly acidic pH (5.2 – 6.0) except for the lower horizon in Adjumani that tended to be neutral (6.7). Maximum nutrient availability occurs when pH is optimal. When soil pH is outside of optimal range, nutrients can be less available to plants, potentially resulting in deficiencies (Marx *et al.*, 1999). The findings of the present study agree with Hall (2008) who reported that *B. aegyptiaca* tolerates low salinity. In agroforestry terms, the acidic surface soils in Balanites growing sites would require some amendment with lime to support most agricultural crops that can grow alongside Balanites. Furthermore, the low levels of the other plant nutrients and organic matter call for additions of organic or inorganic fertilizers to increase crop yields beyond what is currently possible. Soils that are low in organic matter (less than 2%) usually have lower micronutrient availability (McKenzie, 1992). There were generally no marked differences between soil from farm and wild conditions. This suggests that soils in Balanites growing areas are generally low in nutrients. It also reflects the general nature of the semi-arid areas in northern and north eastern Uganda.

4.5.3. Population status of *B. aegyptiaca*

4.5.3.1 Stocking density

Balanites trees were sparsely distributed in Katakwi (2 - 8 trees ha^{-1}) and densely distributed in Adjumani (17 - 30 trees ha^{-1}). In each district, there was variation in stocking level between the Balanites populations that decreased in the order: Adropi> Dzaipi>Katakwi>Ngariam. The stocking density in the wild and on-farm did not differ much. This suggests that Balanites could have been spared and retained on-farms due to its importance to rural households. According to Hall and Walker (1991) and Hall (1992), *B. aegyptiaca* is typically a woody species of open parkland or grassland and does not form dense stands. Individuals usually occur singly with full crown exposure being typical. Hall (1992) noted that unless individuals <5 cm DBH are included; it is unusual for Balanites stocking density to exceed 25 trees ha^{-1}. Much lower stocking levels (about 1 tree ha^{-1} or less) have been reported in some areas, such as NE Ghana (Brookman-Amissah *et al.,* 1980); Karamoja, Uganda (Kerfoot, 1962); Eastern Tanzania (Welch, 1960) and the drier parts of Darfur, Sudan (Ramsay, 1958). This indicates generally sparse stocking of *B. aegyptiaca* in the drier parts of its range. The Ngariam stocking level (2 trees ha^{-1}) in the present study is, therefore, above that reported in other Balanites growing areas in Africa.

The high stocking level along the R. Nile in Adropi, Adjumani can be attributed to unrestricted access to underground water. There was also less human interference in Adjumani sites than in Katakwi. In agreement with the findings of this study, Madrama (2006), reported higher Balanites stocking levels (39 trees ha^{-1}) across the R. Nile in the neighbouring, Itula sub-county, Moyo district, Uganda. It therefore appears that Balanites belt in Adjumani and other districts along the R. Nile in West Nile sub-region of Uganda have higher stocking levels than other areas in Uganda. Such a stocking level (17 - 30 trees per ha^{-1}) is also higher than that reported in other countries in the Balanites range, except probably in some parts of Sudan. Occurrence of higher densities of Balanites along water courses has been reported elsewhere. For instance, in Darfur, Sudan, Ramsay (1958) reported a higher stocking >20 ha^{-1} in the riparian sites than on sands where the stocking was only 10 trees ha^{-1}. On the other hand, higher stocking levels were reported in earlier literature in other countries, for example, 72 trees ha^{-1} in Somalia (Gilliland, 1952), 100 trees ha^{-1} in Dori, Burkina Faso (Menaut, 1983) and 200 tree ha^{-1} in Chad (Grondard, 1992). However, Hall (1992) pointed out that lack of specificity on the lower size limit could have been responsible for such high stocking levels with individuals of up to 1 m in height being included in some inventories. Studies on other indigenous fruit trees in African parklands have found low stocking levels. Okullo (2004) reported 18 – 34 trees ha^{-1} for *Vitellaria paradoxa* ($\geq$ 10 cm DBH) in the parklands of northern Uganda while Nghitoolwa *et al.* (2003) reported as low as 1 tree ha^{-1} for *Sclerocarya birrea* ($\geq$ 20 cm DBH) in the drylands of northern Namibia.

Cutting down of Balanites trees was more prevalent in Adjumani where 44 stumps were encountered in 19.1 ha compared to only 27 stumps observed in 101.9 ha in Katakwi. While the trees were considered abundant with no need to protect in Adjumani, the local communities in Katakwi highly valued Balanites trees and elders considered their cutting to be socially unacceptable. This was attributed to long time dependence on Balanites leaves as a vegetable in Katakwi. However, local communities in Adjumani only depended on Balanites fruits which were eaten as a snack and oil was extracted from the kernels. It was noted that only a small quantity of nuts was used for oil extraction due to the laborious nature of the process. This has, in a way, contributed to increased felling of Balanites trees in Adjumani for fuelwood thought to generate more income while in Katakwi they are somewhat protected by social controls.

4.5.3.2 Distribution pattern

The spatial distribution of the 100 *B. aegyptiaca* trees in each of the plots revealed that the trees in Adjumani occupied a smaller area (hence high stocking) than in Katakwi (Figure, 4.4 a&b). Similarly, the mean nearest neighbour distance ($\mathbf{r_0}$) was significantly ($p \leq 0.05$) shorter in Adjumani than in the Katakwi populations. Furthermore, $\mathbf{r_0}$ for the different plots in Katakwi was significantly ($p \leq 0.05$) different. This can be explained by site differences, for instance, while the study site Ngariam sub-county experiences longer flooding periods each year (2-4 months), the site in Katakwi only experiences flooding for up to 2 months a year. In contrast, all the sites in Adjumani were not prone to flooding but close to R. Nile. These findings indicate that in sites where there is periodic flooding, Balanites trees tend to be scantily distributed while it is possible to have dense stands in riparian sites. This is consistent with Ramsay's (1958) observation in Darfur, Sudan.

However, the degree to which the observed distribution approaches or departs from random expectation (***R)*** for all the eight plots was close to 1.0, implying random distribution of individual trees (Clark and Evans (1954). This is because the observed distribution (r_o) was close to the expected distribution (r_e), and ***R*** being a ratio between the two ($R = r_o/r_e$). This may seem contradictory given the significant difference between the districts and also the Katakwi plots. As pointed out by Cottam and Curtis (1956), this is possible given that many of the values can be duplicates since paired neighbours (which have each other as nearest neighbours) make up a significant portion of the total population. This implies that even if the 100 Balanites trees in each of the Katakwi plots occupied a bigger area, the trees were close to each other. In this case, the empty spaces in the plot (Figure, 4.4 a&b) have no effect on the nearest neighbour distance. Thus, two conclusions may be drawn from the random distribution of Balanites trees observed in both wild and on-farm sites; (i) the species' natural distribution pattern is random, and (ii) human activities have had limited effect on the species distribution pattern.

4.5.2.3 Variation in diameter, height and crown volume

Balanites aegyptiaca trees in the two study districts in Uganda had 39 cm DBH, 7.5 m height and crown volume of 20.6 m^3. However, trees in Adjumani had bigger DBH (>40cm), were taller (> 8 m) and had larger crowns (> 28 m^3) than those in Katakwi district. The difference in tree size can be attributed to disparity in environmental factors in the two districts and/or the specific study sites. As pointed out earlier, there is unrestricted access to underground water by trees in Adjumani district thus favouring their growth. Additionally, trees in Katakwi were severely lopped to provide leaf vegetable. Periodic reduction of foliage due to leaf harvesting can potentially affect the tree's biological processes, especially the rate of photosynthesis, thus negatively affecting growth. According to Hall and Walker (1991), published reports on Balanites height vary widely. The heights reported in this study are in conformity with those earlier reported in West Africa [6-10 m, rarely 12 m] (Burkhill, 1985). Eggeling (1940) and Katende *et al.* (1995) reported that *B. aegyptiaca* in Uganda is usually 4 - 6 m tall and sometimes attaining 10.7 m. Other reports have indicated taller trees in some countries, such as 15 m in Angola and Tanzania (Exell and Mendonca, 1951), 17 m in Sudan (Adams, 1967). Sands (2001) reported that *B. aegyptica* is usually a shrub or small tree growing up to 12 to 15 m high and extremely variable in many of its characters. von Maydell (1986 and 1990) pointed out that site conditions, and treatment, especially lopping or heavy browsing imposes dwarfing on Balanites in the Sahel resulting in tree of about 6 m tall and rarely 10 m. Hall (2008) reported the species reaching 6 -17 m in height, depending on variety and growing conditions.

More than half (52%) of the Balanites trees were in the 30 – 49 cm DBH range thus leaving a few (27%) in the lower diameter classes (10-29 cm) and only (21%) in higher diameter classes (≥ 50 cm). Whereas the proportion of lower diameter trees (10 – 19 cm) was the same in both Katakwi and Adjumani districts (10.8%), there were more (5%) larger diameter trees (≥ 70) in Adjumani than in Katakwi (1.3%) district. For a given tree species, diameter is usually directly related to height and crown volume, thus taller Balanites trees with bigger crown volume also had larger DBH. According to Hall and Walker (1991), reports on diameters attained by *B. aegyptiaca* trees are fewer but the maximum of 40 – 50 cm is reported in cases where trees attain heights in excess of 12 m. von Maydell (1990) reports stem diameter of 30 cm in the Sahel. In this study however, a dominant DBH range of 30 - 49 cm was found for correspondingly shorter trees (7.5 m tall).

4.5.2.4 Regeneration status

Balanites regenerated from seeds and coppices under wild and on-farm conditions, though regeneration by seed was more prevalent (84.6%) than coppices (15.4%). Propagation through stakes has been reported in West Africa (Burkhill, 1985) however, this was not observed in this study. Hall and Walker (1991) also pointed out apparent absence of any additional references to this practice. The coppicing ability and deep rooting system seem to enable the species to withstand heavy browsing pressure resulting from increasing livestock populations in the drylands. Goats, unlike cattle, were particularly observed to be a threat to Balanites regeneration (Plate 4.6).

Plate 4.6 Effects of cows and goats on Balanites in Adjumani district
Over-grazed Balanites site (a) and an over-browsed Balanites sapling (b) in Nyeu village

There have been claims that Balanites seed passes through the intestinal tract of livestock (goats, sheep, cows) (von Maydell, 1990; Hall and Walker, 1991) though von Maydell (1990) questioned passage by goats. Shanks and Shanks (1991) in their *B. aegyptiaca* extension manual assert that "another good way of collecting seed is to gather them from dung after they have been eaten by livestock". In this study, increased regeneration from seed was observed in animal resting places. Nevertheless, both cows and goats were observed not to swallow Balanites stones but regurgitated them after stripping off the mesocarp. This was confirmed true because the stones seen in goats, sheep and cattle resting places were always clean. Given that the major impediment to Balanites seed germination is the hard endocarp, what needs to be examined in future studies is whether livestock help in creating lines of weakness in the process of steeping the mesocarp. However, the results of this study also bring this line of thought into doubt since no cracks were observed on the stones.

Higher regeneration rates were observed in wild conditions in Adjumani than in Katakwi district. Higher intensities of annual bush fires were responsible for low regeneration in the wild in Katakwi district. The proportionately higher number of trees (ha^{-1}) than saplings on-farms in Adjumani district could indicate that farming activities were interfering with the regeneration. Farmers appeared to be discouraging further regeneration on the pretext that mature Balanites stocking levels were already adequate for farm conditions. This may be an appropriate management practice in the short-term since farmers have to balance the number of trees retained on farms and yields of associated agricultural crops.

4.5.3 Health status of *B. aegyptiaca* trees in Katakwi and Adjumani districts

Whereas only a few (7%) trees were lopped in Adjumani district mainly to provide fencing material and fodder in the dry season, most (70%) of the trees in Katakwi district were lopped for provision of leaf vegetable consumed in the dry season. Out of these, all branches had been lopped from 42% of the trees in Katakwi district. The 30% of the un-lopped trees in Katakwi district were those considered to have "bitter" leaves, thus not edible. Since trees with "bad" leaves were easily noticed in the field, they were always targets for cutting to provide fuelwood or fencing materials.

Over 78% of the trees in both districts had no signs of pests and diseases indicating that Balanites trees were generally healthy. However, among the 22% of the affected trees, the common diseases observed were leaf galls and blackening of leaves while two pests (defoliators) were observed on Balanites trees. Though trees in Adjumani district were more affected by leaf galls to varying extents, there was no noticeable effect in fruit yield since even the affected trees were heavily fruited. Studies are however, needed to determine the effect of leaf galls and other pests and diseases on the leaf and fruit yield of Balanites. Leaf galls affected the quality of leaves eaten as a vegetable and such trees were avoided during leaf harvesting in Katakwi district.

Over-harvesting of *B. aegyptiaca* leaves coupled with intense annual bush fires severely affected wild trees with some of them dying. This was particularly common in Katakwi district where increased flooding supported lush grass growth which in the dry season became fuel with deleterious effects on tree stems and crowns. Young and old trees with dry or rotten patches on stems were observed in the study areas and reported to be highly susceptible to such fires. During the course of this study, up to 6% of the trees started drying up due to bush fire in Ngariam sub-county, Katakwi district (Plate 4.7).

Plate 4.7 Effects of fire on wild Balanites trees in Katakwi district

(a) One of the dead Balanites trees – over-harvested leaves and burnt by fire.
(b) Over-accumulated fuel (grass) makes older trees highly susceptible to firet.

According to Hall (1992), established Balanites trees often survive bush fires because the fluted bole ensures that bark damage is not total. He also noted that in drier areas (mean annual rainfall of less than 600 mm), there is insufficient fuel for fires to be either intense or extensive. Fire also suppresses regeneration (Hall, 1992) but von Maydell (1986; 1990) stated that the ability to withstand fire in Balanites takes at least three years to develop. It may, therefore, be necessary to sensitize the local communities in Katakwi district about the dangers of uncontrolled bush burning on the Balanites which is the main source of edible leaves in dry season. In addition, there is a need to put in place mechanisms for regulating such a practice and managing grazing fields/pastures that are communally owned and used in the dry season when bush fires are very common.

4.5.4 Associated tree species

In all sites inventoried, Balanites was the pre-dominant tree species. It constituted 58 – 72% and 40 – 42% the tree individuals ≥ 10 cm DBH in Adjumani and Katakwi districts respectively. Hall (1992) reported that in sites where *B. aegyptiaca* is well-represented, it accounts for more than 20% of individuals exceeding 10 cm DBH. In Katakwi district, Balanites trees were retained on farms and grazing lands because the leaves are eaten as vegetables during the dry season and in Adjumani the fruits were used to produce oil. The value of Balanites fruits has been the main reason for their retention in Niger (Keay, 1959) and Senegal (Giffard, 1974). According to Adams (1967), logistical problems associated with removing the hard wooded and firmly rooted Balanites trees with small hand tools contribute to the species' persistence in some areas in Sudan where other tree species have been cleared.

A number of trees were associated with Balanites but common indigenous fruit trees found in Adjumani were *Tamarindus indica, Sclerocarya birrea, Ziziphus abyssinica* and *Z. mauritiana*. In Katakwi, one fruit tree (*T. indica)* was commonly associated with *B. aegyptiaca*. The study sites in Katakwi district experienced extended flooding thus making them unsuitable for other fruit trees except Balanites. Indigenous fruit trees (IFTs) in Katakwi and Adjumani districts were in different locations from water sources, such as rivers and swamps. Balanites tended to occur close to water points and followed by *S. birrea*, *T. indica* and *Vitellaria paradoxa* on well drained upland sites. *S. birrea* and *T. indica* were also associated with Balanites in other reports (Hall, 1992). Since all these are priority IFTs that can be integrated into dryland farming systems in Eastern Africa (Teklehaimanot, 2008), it presents an opportunity for development of an IFT strategy for the drylands of Uganda. Furthermore, since some advances have so far been made in the development of *V. paradoxa* including marketing of products both locally and internationally, improving the processing technology of *B. aegyptiaca* products would be a worthy venture.

CHAPTER FIVE: PHENOLOGY, FRUIT YIELD AND FRUIT CHARACTERISTICS OF *BALANITES AEGYPTIACA* IN UGANDA

Information on leafing, flowering and fruiting phenology, fruit yield and fruit characteristics of *Balanites aegyptiaca* in Uganda is presented in this chapter. Section 5.1 introduces the chapter and section 5.2 gives the objectives, hypotheses and research questions. Section 5.3 contains the methods used to collect and analyse data while section 5.4 has results presented under the following sub-sections: leafing, flowering and fruiting patterns (5.4.1), fruit yield (5.4.2) and fruit characteristics (5.4.3). The discussion is given in section 5.5.

5.1 Introduction

Phenology is defined as the study of relations between the periodicity of morphological and physiological phenomena of plants and that of ecologically active, particularly climatic variables (Lieth, 1974). Brearley, *et al.* (2007) noted that for plants, recurrent biological events include vegetative processes, such as, leaf flushing and shedding as well as reproductive events including bud formation, flowering and fruiting. The timing of many of these events is likely to represent trade-offs between resource availability, pollinator availability and competition, abundance of herbivores, suitable conditions for seed germination and establishment, and phylogenetic constraints (van Schaik *et al.*, 1993; Wright and Calderón, 1995). Plant species differ with respect to the timing, duration and frequency of leafing, flowering and fruiting. According to Bawa and Ng (1990), phenological patterns of tropical trees can be diverse and complex and so are the factors that regulate these patterns.

Unlike in the temperate regions where temperature and photoperiod are the key abiotic factors that are likely to affect phenological patterns (Molau *et al.,* 2005), there is less seasonality with regard to temperature and day length in the tropics but there is often greater diurnal than seasonal temperature variation. However, many tropical regions experience seasonality of rainfall, and phenological patterns are often related to this seasonality with peaks in fruit production occurring at the beginning of the rainy season (e.g. Justiniano and Fredericksen, 2000). Van Schaik *et al.* (1993) hypothesized this to allow the greatest chance for seedling survival as seeds are dispersed when soil moisture conditions are most favourable for seed germination and rapid seedling growth. A knowledge of phenological patterns is critical for successful management of tree genetic resources since such information can guide both in-situ and ex-situ conservation of a species. Information on flowering and fruiting patterns in tropical trees is also useful in indicating variation in resource availability for pollinators (Kearns and Inouye, 1993) and fluctuations in fruit production in time and space (Richards, 1996).

As the desire to domesticate Africa's priority IFT species increases, there is need for a clear understanding of species phenology. Some of the questions of importance in tree phenology include; what are the basic leafing, flowering and fruiting patterns in a species? Are there any relationships between leafing, flowering and fruiting and the environmental cues, such as precipitation, temperature and humidity? Are survival adaptations of the species related to the reproductive growth? Adler and Kielpinski (2000) pointed out that the first step in studying phenology is to identify spatial and temporal patterns; as such information is important in laying the foundation for identifying factors that underline those patterns.

Unlike tropical humid forest trees, phenological information on many savanna parkland trees such as *Balanites aegyptiaca* is scarce. Woody species of the savannas are reported to be dominated by deciduous species (Menaut and Caesar, 1979) and differences in timing of leaf fall, flowering and shoot expansion are often associated with soil moisture, inter-annual differences in rainfall patterns, and plant size (Whigham *et al.*, 1990). Chidumayo and Frost (1996) also reported that in addition to rainfall and temperature, the phenology of the miombo plants was influenced by seasonal variation in temperature. Documentation of the vegetative and reproductive phenology in *B. aegyptiaca*, and examination of the relationships between phenological events and environmental cues is one of the necessary steps in its domestication.

An understanding of potential fruit yield is important in guiding the selection, domestication and commercialization of any indigenous fruit tree. This can be more critical in cases where the fruit is a major product of interest. There is apparent lack of information on potential fruit yield from *B. aegyptica* in east Africa. Some of the records available from other regions/countries, such as West Africa and the Sudan may not be applicable in east Africa due to the variation in tree size. An assessment of the potential fruit yield from Balanites trees is necessary for guiding development of the tree products. Equally important is an understanding of the characteristics of Balanites fruits from different populations in Uganda with a view to guide the selection and subsequent domestication of the species.

5.2 Objectives, hypotheses and questions

The overall objective of the study was to assess phenological events in *B. aegyptiaca* and provide baseline information on the species' fruit yield and fruit characteristics to aid its promotion.

The objectives of the study were to;

i. Assess the leafing, flowering and fruiting patterns of *B. aegyptiaca* and their relation to environmental cues (rainfall, temperature and humidity);
ii. Determine potential fruit yield from *B. aegyptiaca* trees in different sub-regions and land uses; and
iii. Determine the characteristics of *B. aegyptiaca* fruits from different populations and land uses.

The study was guided by the following hypotheses;

i. There is no relationship between phenological events in *B. aegyptiaca* and environmental cues (rainfall, temperature and humidity),
ii. There is no relationship between Balanites fruit yield and the tree growth parameters and land uses,
iii. There is no significant variation in Balanites fruits characteristics within and among study populations and land uses

The study also pursued the following questions;

e) What are the basic leafing, flowering and fruiting patterns for *B. aegyptiaca* in different parts in Uganda?
f) What are the proportions of the different fruit parts (epicarp, mesocarp, stone and kernel) in *B. aegyptiaca* and what is their relevance to species domestication?

5.3 Materials and methods

The study was conducted in Adjumani and Katakwi districts in Uganda. One Balanites population with wild and on-farm sites in each of the two districts were selected for the study. Thus, two populations with four sites were studied.

5.3.1 Phenology

In each of the four sites, observations were made on 100 reproductive (mature) Balanites trees during peak flowering and fruiting over two years (2008 and 2009) to assess the ability of the trees to flower and fruit. Out of these, twenty trees with clearly visible crowns were randomly selected for assessing the timing and periodicity of leafing, flowering and fruiting. The selected trees were tagged and assessed for height, DBH and crown diameter. Leafing, flowering and fruiting were monitored over of period of 24 months beginning January 2008. According to Akpo (1997), observations made during one annual cycle at a single location cannot account for the phenology of the species in general. Phenology assessment was always done within the last three days of each month in all populations. In each of the two study districts, a trained field assistant made all observations of individual tree crowns to evaluate the phenological phases. Data was recorded based on a modification of phenology classification codes by Seghieri *et al.* (1995), Seghieri and Simier (2002) and Okullo (2004) (Table 5.1). A pair of binoculars was used for observing tall trees and a phenology record sheet (Appendix 5.1) was maintained for each tree.

Table 5.1 Phenological codes and associated events

Code	Leafing	Flowering	Fruiting
1	Flushing	Initiation/flower buds	Fruit setting
2	New leaf	Open flowers	Fully developed fruits
3	Shedding	Peak flowering	Ripening and fall
4	End of shedding	End of flowering	End of fruit fall

In addition, the proportion of the tree crown under different phenological events was visually assessed and recorded as; 1: < 25% (initiation); 2: 25%; 3: 50%; 4: 75% and 5: ≥80%. Any incidences of bush fires were also recorded since this was observed to influence phenological events in the study sites. Associated mean monthly values for precipitation, minimum and maximum temperatures and humidity for the respective nearest weather stations (Arua and Soroti) were also obtained from the Metrological Department.

5.3.2 Fruit yield

Total fruit count using contract farmers was used for Balanites yield assessment. A similar method was used for *Vitellaria paradoxa* and *Parkia biglobosa* in West Africa (Teklehaimonot, 2004). The farmers, all women, were given clear instructions and motivated through cash payments. In each of the two study districts, six fruited Balanites trees (three from wild and another three from farm) were randomly selected from the same sites used for phenology study.

The three trees in the respective land uses (wild and farm) were allocated to one contracted farmer who collected fruits over the ripening period. Fruits were kept in separate hessian bags and weighed using a spring balance on a weekly basis until the end of the fruit fall period. An estimate of the proportion of fruits which did not fall during the fruit fall period was also noted for each of the trees. Respective tree DBH, height, and crown diameter were measured and recorded.

5.3.3 Fruit characterisation

Balanites aegyptiaca fruits were collected from the four study sites during the 2008 ripening period. In each site, ripe fruits were collected from 30 trees during the peak ripening season. A minimum distance of 100 m was maintained between sampled trees to reduce chances of sampling from cross pollinated trees. Forty healthy, ripe and fallen fruits were collected from under each tree making a total of 1,200 fruits per site. Fruits were considered healthy if they had no visible insect damage or disease symptoms. From each site, 75 fruits were randomly selected and transported to the laboratory in cooler boxes. Individual fruits were then measured while fresh. Variables measured included; fruit weight (electronic balance), length, width and stalk length (vernier calliper).

In order to determine the proportions of the different parts of Balanites fruit, all the fruits were thoroughly mixed and 10 batches, each weighing one kilogram were randomly measured and used as starting samples. The number of fruits per kilogram was counted and then the fruit batches were shelled, de-pulped and kernels extracted by manually (Plate 5.1). At appropriate stages during the process, an electronic balance was used to take weights of shells (seed coat), pulp (mesocarp), stone (hard shell) and kernels (seed) contained in the starting one kilogram of the fruit sample.

A kilogram of ripe Balanites fruits

Fruit outer shell (epicarp)

Peeled fruits with edible pulp

Juice made from Balanites fruit pulp

Nuts (stone and kernel)

Kernels

Plate 5.1 Components of Balanites fruit

5.3.4 Data analysis

Phenology data was descriptively analysed in Microsoft Excel to reveal patterns which were used to generate phenograms for different sites over the 24-months monitoring period. The phenograms revealed the number of individuals in the different phenophases within a site over time. Pearson correlation coefficient (r) was used to investigate the relationship between environmental variables (mean monthly precipitation, temperature and relative humidity) and observed means of trees under different phenological events.

Data on fruit yield and fruit characteristics was first analysed descriptively using Microsoft Excel to generate tables and graphs. Data was then transferred and analysed in SPSS Version 16. Regression was used to investigate linear relationships between fruit yield and tree measured variables (DBH, height and crown diameter). ANOVA, with significance level determined at $\alpha \leq 0.05$, was used to investigate if there were significant differences in fruit characteristics due to study populations/districts and sites. For variables with significant differences, means were separated using Tukey's "honestly significant difference test" since sample sizes were similar between populations and land uses.

5.4 Results

5.4.1 Phenology of *B. aegyptiaca*

5.4.1.1 Description of sampled *B. aegyptiaca* trees

Results in Figure 5.1 show that all the Balanites trees in Adjumani district fruited in both study years (2008 and 2009) while in Katakwi district, some of the trees did not fruit. Within Katakwi district, fruiting was higher in the on-farm site with 82 and 73% of individuals fruiting in 2008 and 2009, respectively. In contrast, fruiting was low in the wild with only 30% and 10% of the trees fruiting in 2008 and 2009, respectively.

Table 5.2 presents the growth parameters for trees used in phenology monitoring. Trees used in the wild site in Adjumani were generally bigger than the rest. Although trees from on-farm site in Adjumani were smaller in DBH, they were taller and had bigger crown diameter than those from the two sites in Katakwi district.

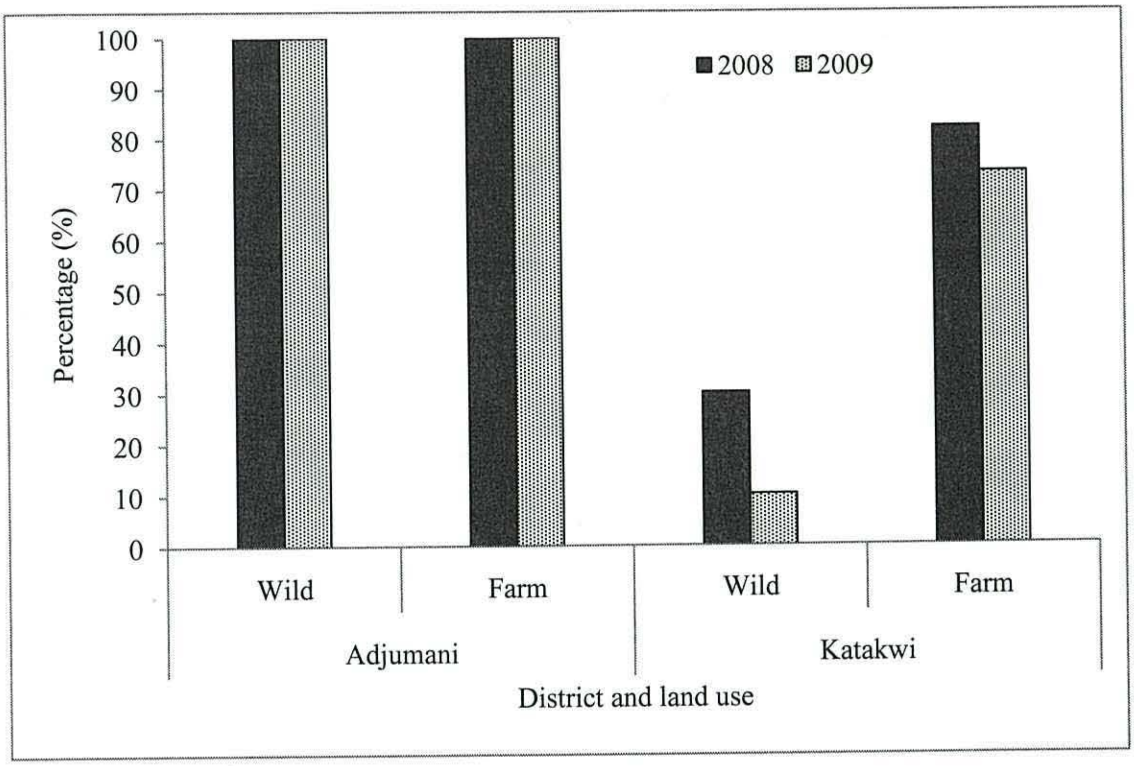


Figure 5.1 Percentage of fruiting trees in four sites in Adjumani and Katakwi districts *(n=100 for each site)*

Table 5.2 Growth parameters of Balanites trees assessed for phenology in four sites

Tree parameter	Adjumani district		Katakwi district	
	Wild	Farm	Wild	Farm
DBH (cm)	49.52	35.84	37.55	39.81
Height (m)	10.08	9.11	7.44	7.83
Crown diameter (m)	12.85	11.48	9.09	10.88

(n=20 for each site)

5.4.1.2 Leafing, flowering and fruiting patterns of *B. aegyptiaca*

Figures 5.2, 5.3 and 5.4 show the leafing, flowering and fruiting patterns of *B. aegyptiaca* over 24-months period. Balanites was found to be semi-deciduous; however, marked leafing generally began in October-November and peaked in December - February. Leaf fall also took place at the same time, starting in October, peaking around December – January and falling to minimal levels by February. New leaves were produced simultaneously as the old ones fell, except in a few cases where trees briefly remained leafless for 1 -2 months.

Trees flowered over an extended period; however, major flowering lasted from January to April with peak around February - March. Flowering in Katakwi sites was ahead of that in Adjumani sites by one month; hence peak flowering in Katakwi was reached in February while the same state was attained in March in Adjumani. Flowering was immediately followed by fruiting, starting around February with a peak in March. Just like it was observed in flowering, Adjumani sites lagged behind those in Katakwi sites by one month. Fruits developed for a period of 7 - 8 months (from March/April to November) and ripening and fruit fall started in November, peaked around in December-January in Katakwi and in February in Adjumani.

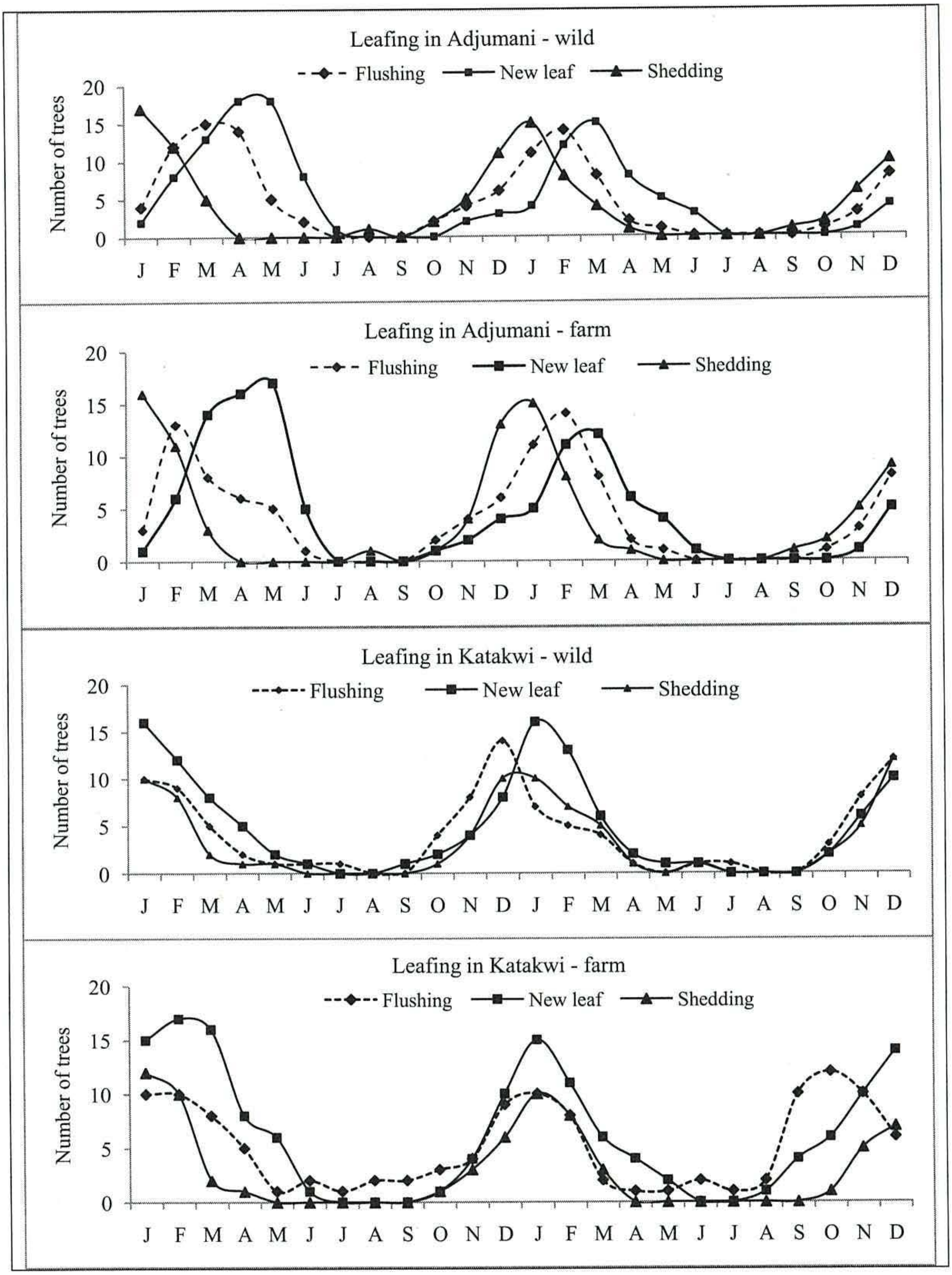


Figure 5.2 Leafing patterns in *B. aegyptiaca* under wild and farm conditions in Adjumani and Katakwi districts over 24 moths (Jan. 2008 – Dec. 2009).

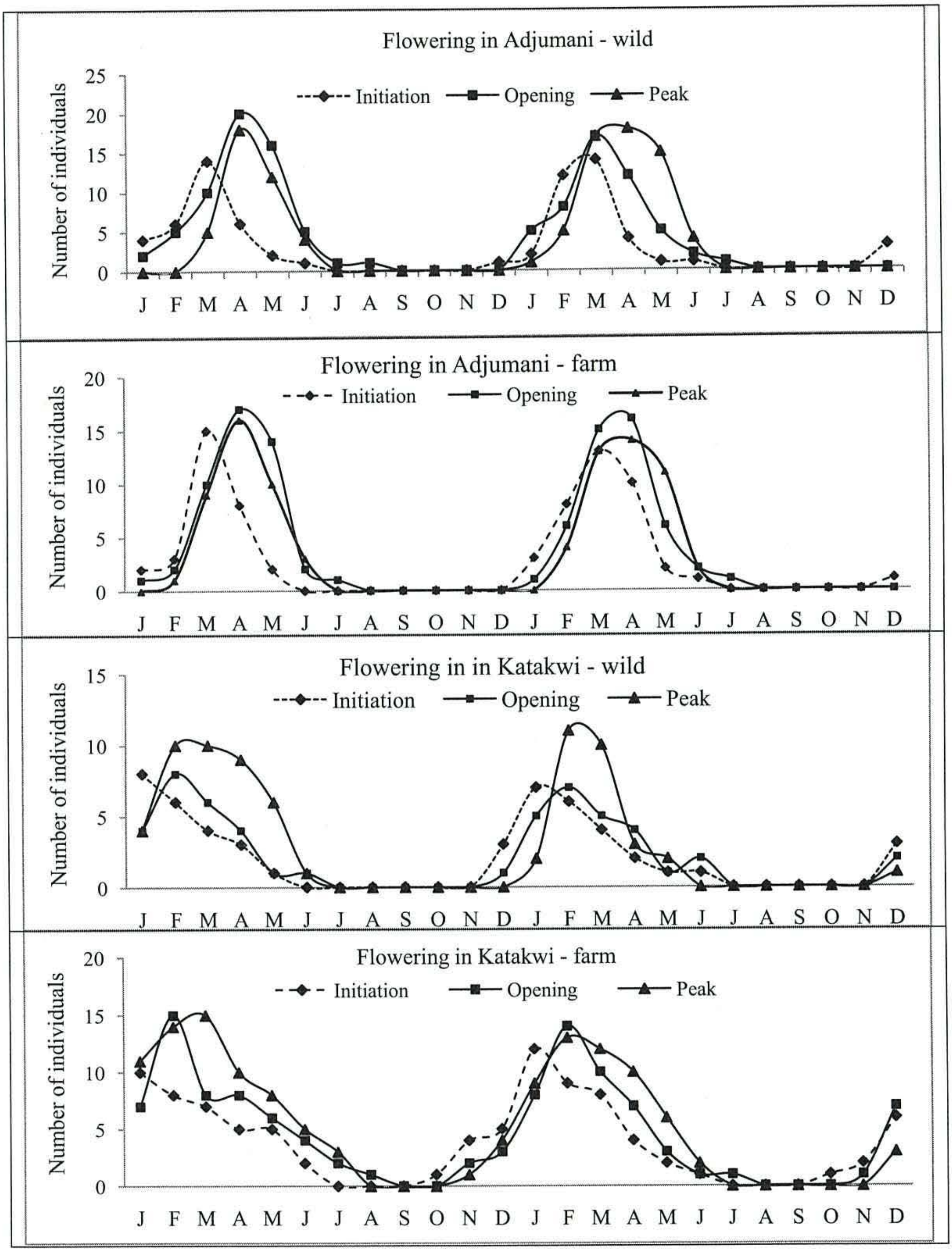


Figure 5.3 Flowering patterns in *B. aegyptiaca* under wild and farm sites in Adjumani and Katakwi districts over 24 moths (Jan. 2008 – Dec. 2009).

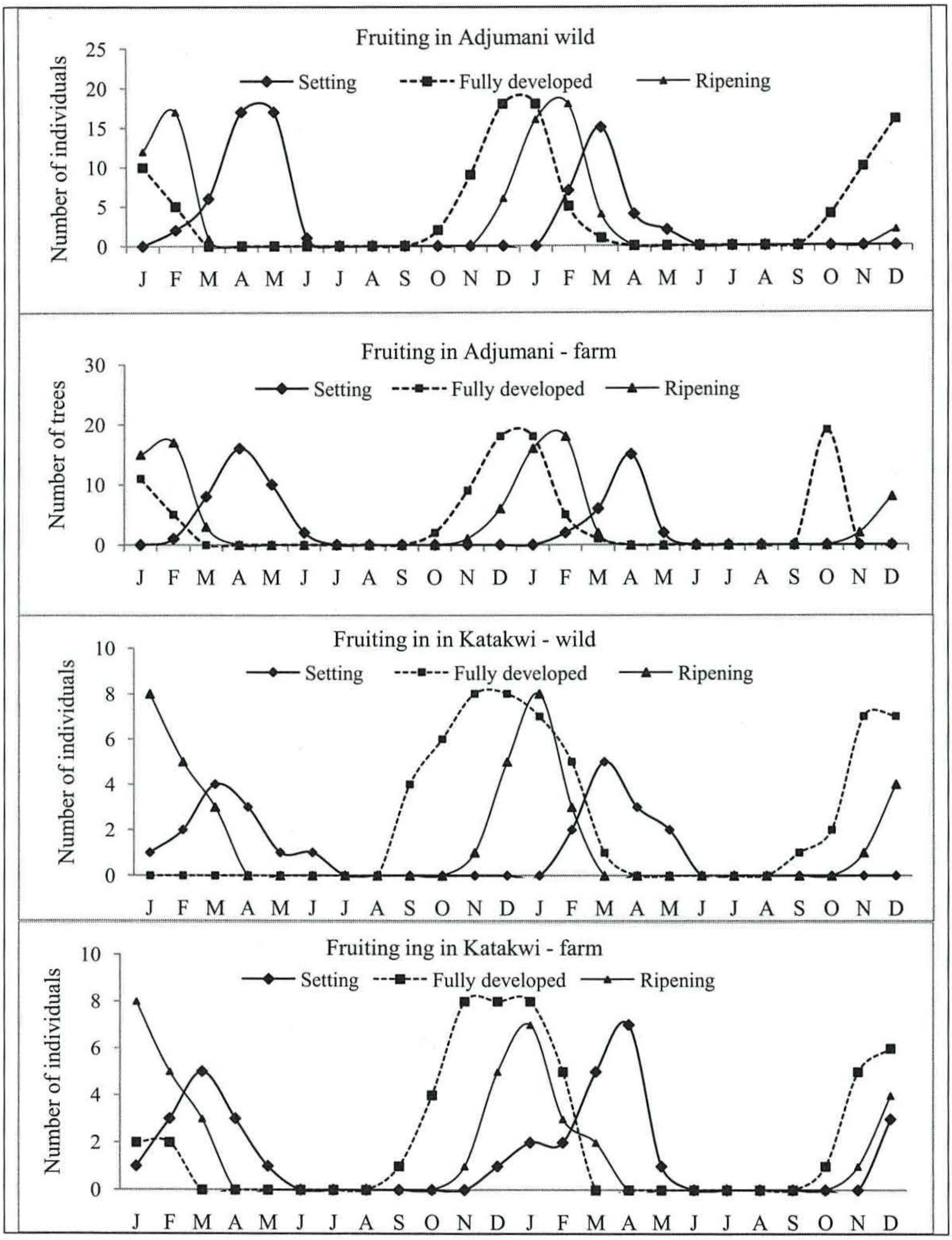


Figure 5.4 Fruiting patterns in *B. aegyptiaca* under wild and farm conditions in Adjumani and Katakwi districts over 24 moths (Jan. 2008 – Dec. 2009).

Due to prolonged fruiting and fruit setting periods, peak ripening was always reached but with some fruits still in either developing or fully developed phase (Plate 5.2a). At the end of the ripening period, some of the ripe fruits failed to drop and remained on the tree for an extended period and in some instances extending to the next season (Plate 5.2b).

Plate 5.2 Peak ripening in February (a) old fruits still attached to the tree (b)

5.4.1.3 Relationship between phenological events and environmental variables

The mean annual rainfall in Adjumani was higher (1,529 mm) than that in Katakwi (1,251 mm). On the other hand, mean monthly temperatures and relative humidity for Katakwi district were higher than those recorded in Adjumani (Table 5.3).

Table 5.3 Means of environmental variables for Adjumani and Katakwi

Variable	Mean	
	Adjumani	Katakwi
Annual rainfall (mm)	1,529	1,251
Monthly Max. Temp. (^{0}C)	29	31
Monthly Min. Max. Temp. (^{0}C)	17	19
Monthly average Temp. (^{0}C)	23	25
Monthly relative humidity (%) (0600GMT)	75	77
Monthly relative humidity (%) (1200GMT)	49	50

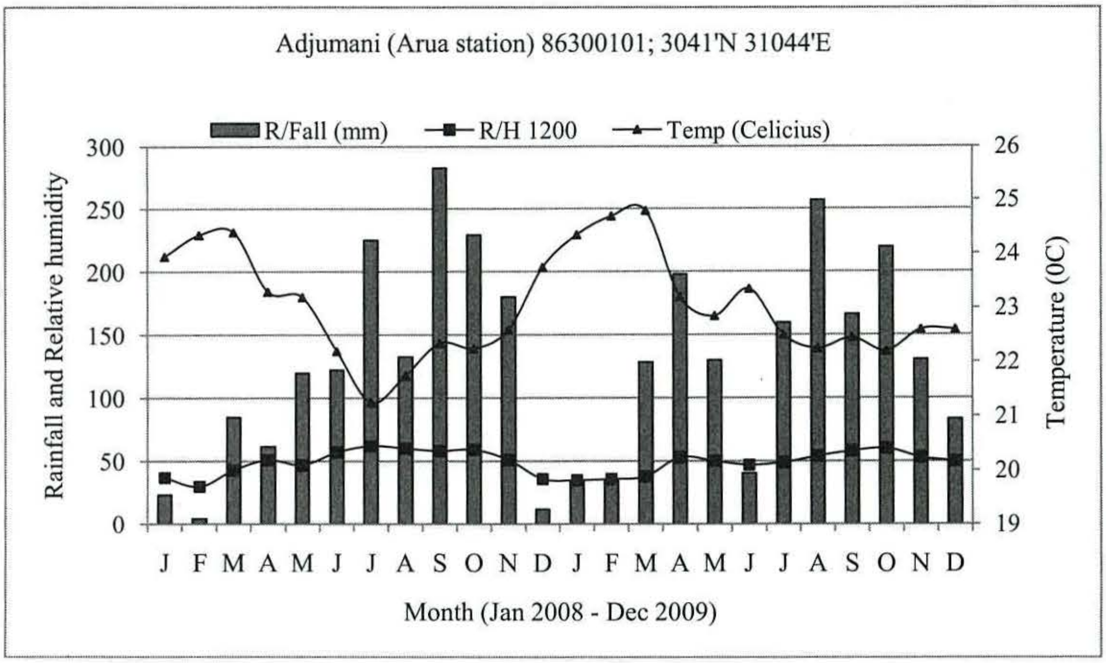
Environmental data for two years (January 2008 – December 2009)

Pearson correlation coefficients presented in Table 5.4 generally indicate that phenological events in Balanites in the two study districts were positively and strongly correlated with temperature and negatively correlated with rainfall and relative humidity. Thus, leafing, flowering and fruiting events in Balanites generally occurred with increased temperatures which also coincided with the dry season. In both districts, the long dry months ran from November – March and a short dry season was experienced in June (Figure 5.5).

Table 5.4 Pearson correlation coefficients (r) for phenological events in *B. aegyptiaca* in Adjumani and Katakwi districts, Uganda

Variables	Pearson correlation coefficient (r)	
	Adjumani	Katakwi
Leaf flushing and rainfall	-0.65 (0.001)**	-0.60 (0.002)**
Leaf flushing and temperature	0.77 (0.001)**	0.68 (0.001)**
Leaf flushing and relative humidity	-0.69 (0.001)**	-0.45 (0.026)*
New leaf and rainfall	-0.41 (0.045)*	-0.32 (1.26)ns
New leaf and temperature	0.60 (0.002)**	0.47 (0.022)*
New leaf and relative humidity	-0.42 (0.040)*	-0.47 (0.022)*
Shedding and rainfall	-0.66 (0.001)**	-0.51 (0.01)*
Shedding and temperature	0.60 (0.002)**	0.48 (0.019)*
Shedding and relative humidity	-0.75 (0.001)**	-0.68 (0.001)**
Flowering initiation and rainfall	-0.42 (0.39)*	-0.48 (0.018)*
Flowering initiation and temperature	0.79 (0.001)**	0.63 (0.001)**
Flowering initiation and relative humidity	-0.59 (0.003)**	-0.54 (0.007)**
Peak flowering and rainfall	-0.09 (0.68)ns	-0.43 (0.04)*
Peak flowering and temperature	0.34 (0.10)ns	0.53 (0.008)**
Peak flowering and relative humidity	-0.12 (0.59)ns	-0.27 (0.21)ns
Fruit setting and rainfall	-0.20 (0.34)ns	-0.09 (0.67)ns
Fruit setting and temperature	0.44 (0.03)*	0.48 (0.018)*
Fruit setting and relative humidity	-0.25 (0.24)ns	0.008 (0.97)ns
Fruit ripening and rainfall	-0.65 (0.001)**	-0.48 (0.017)*
Fruit ripening and temperature	0.71 (0.001)**	0.49 (0.015)*
Fruit ripening and relative humidity	-0.81 (0.001)**	-0.71 (0.001)**

***. Correlation is significant at the 0.01 level (2-tailed); *. Correlation is significant at the 0.05 level (2-tailed); and ns. Not significant at the 0.05 level*



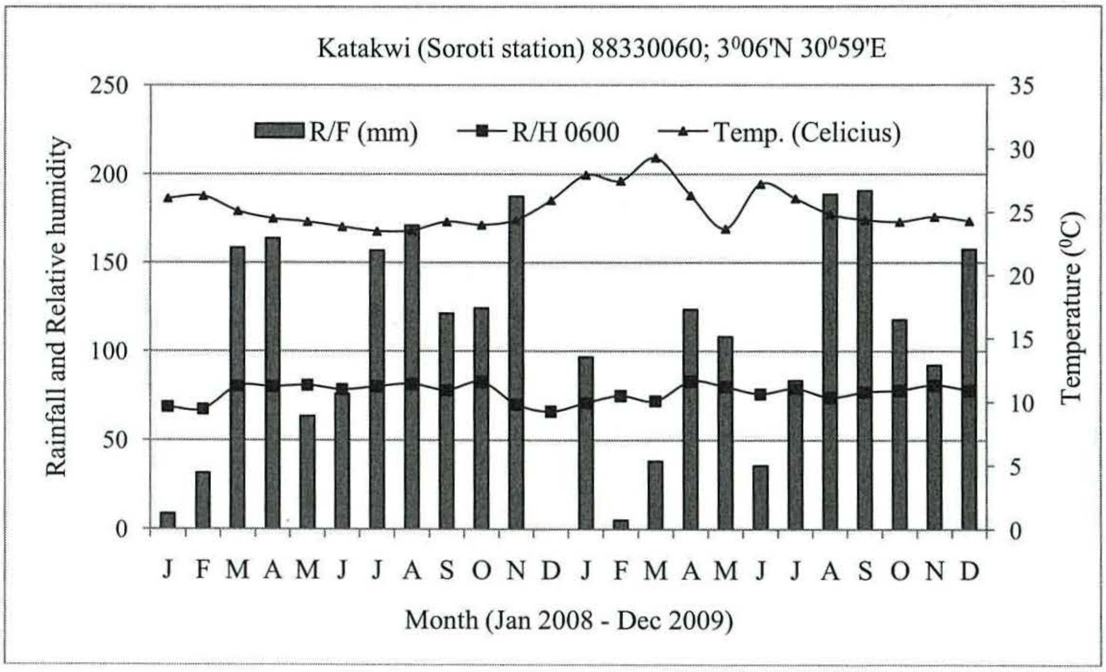


Figure 5.5 Mean monthly rainfall, temperature and relative humidity for Adjumani and Katakwi districts, Uganda

5.4.2 Fruit yield

5.4.2.1 Parameters of trees used for fruit yield assessment

Trees used for fruit yield in Adjumani district were generally bigger in DBH, taller and had bigger crowns than those used in Katakwi. However, the dimensions of trees in different land uses (wild and farm) within each district were more or less similar (Table 5.5).

Table 5.5 Means of *B. aegyptiaca* parameters used for fruit assessment in Katakwi and Adjumani districts, Uganda

Tree parameters	Adjumani		Katakwi	
	Wild	Farm	Wild	Farm
DBH (cm)	57.8	52.7	40.5	40.6
Height (m)	11.0	12.1	10.9	9.5
Crown diameter (m)	12.1	12.5	9.4	9.8

n = 6 for each land use

5.4.2.2 Balanites fruit yield by district

Average fruit yield per tree was 53 kg in Adjumani and only 14 kg in Katakwi (Table 5.6). Fruit yield was significantly higher in Adjumani district than in Katakwi (t = 4.13, 10 df, p = 0.002, 2-tailed). Similarly, the total number of fruits per tree was significantly higher in Adjumani than in Katakwi (t =3.97, 10 df, p = 0.003, 2-tailed).

Table 5.6 Mean of fruit parameters in Katakwi and Adjumani districts, Uganda

Parameter	Mean ±SE	
	Katakwi	Adjumani
Weight fruits per tree (kg)	13.5±1.98	53.1±9.36
Number of fruits per kg	130±1.26	126±1.84
Number of fruits per tree	1,757 ±252	6,679±1,214

Within the two districts, wild trees in Adjumani recorded higher yields (62 kg/tree) than on-farm trees (44 kg/tree). On the contrary, on-farm trees in Katakwi tended to produce more fruits (15.3 kg/tree) compared to wild trees (11.8 kg/tree). Fruit yield between land uses was significantly ($p<0.05$) different ($f= 6.16$. 3 df; $\alpha=0.018$) (Figure 5.6). However, separation of means revealed significant ($p<0.05$) differences in fruit yield between sites in the two districts but there was no significant difference in sites within each of the districts.

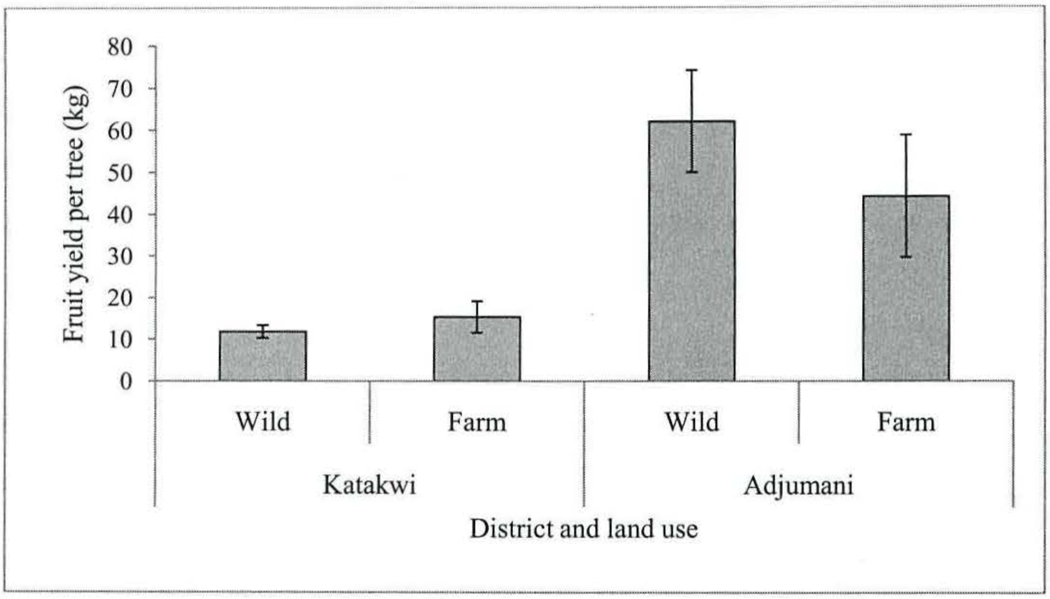


Figure 5.6 Balanites fruit yield (±SE) under different land uses in Katakwi and Adjumani districts, Uganda

5.4.2.3 Relationship between fruit yield and tree parameters

Figure 5.7 reveals that the DBH and crown diameter of Balanites trees was positively but weakly correlated with fruit yield while tree height showed a weak negative relationship. However, only DBH showed a strong positive relationship. When the correlations were performed by combining the trees assessed in the two districts and after removing one outlier, DBH still appeared to be a better predictor of fruit yield than crown diameter and height (Figure 5.8).

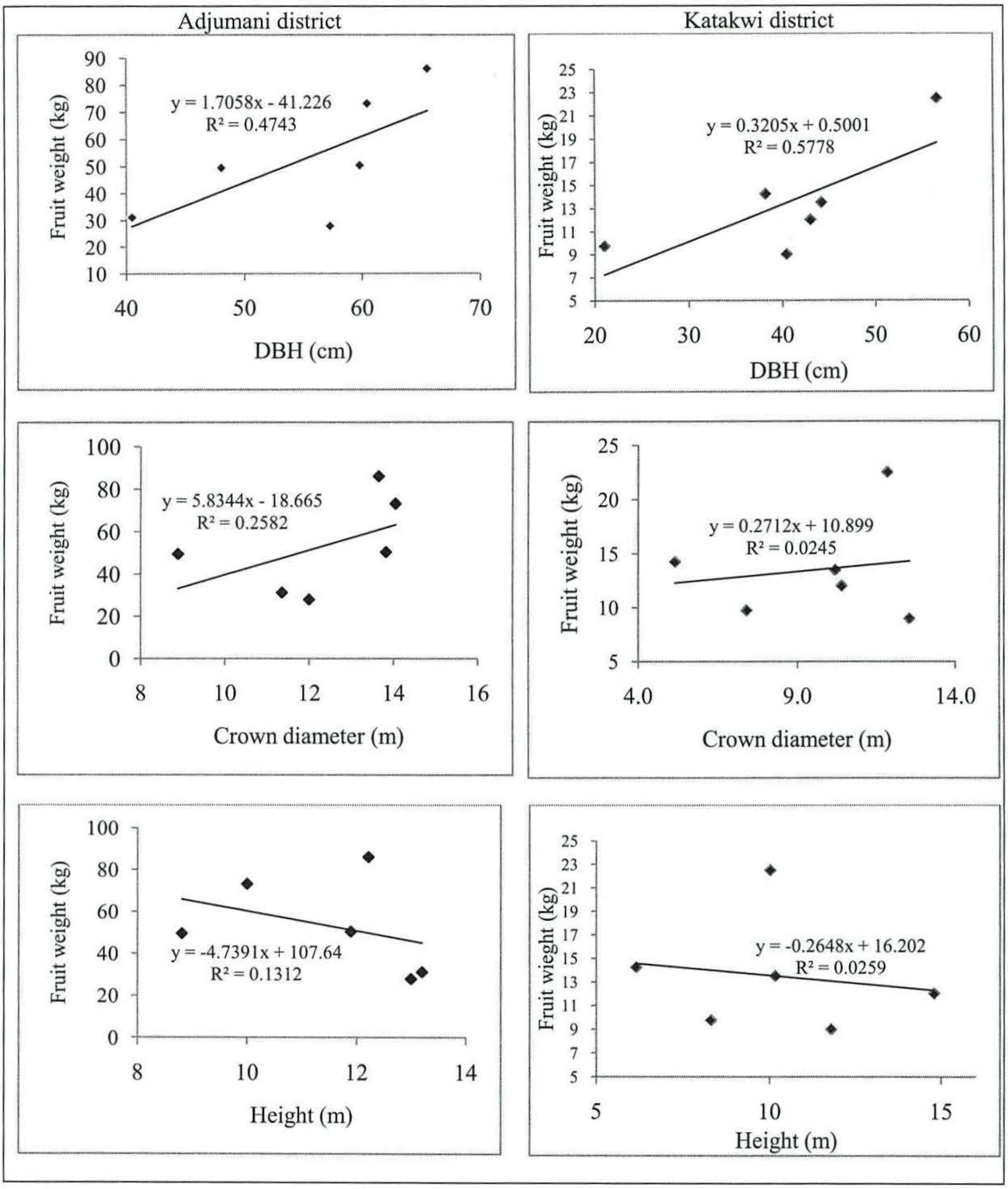


Figure 5.7 Relationship between fruit yield and Balanites tree parameters

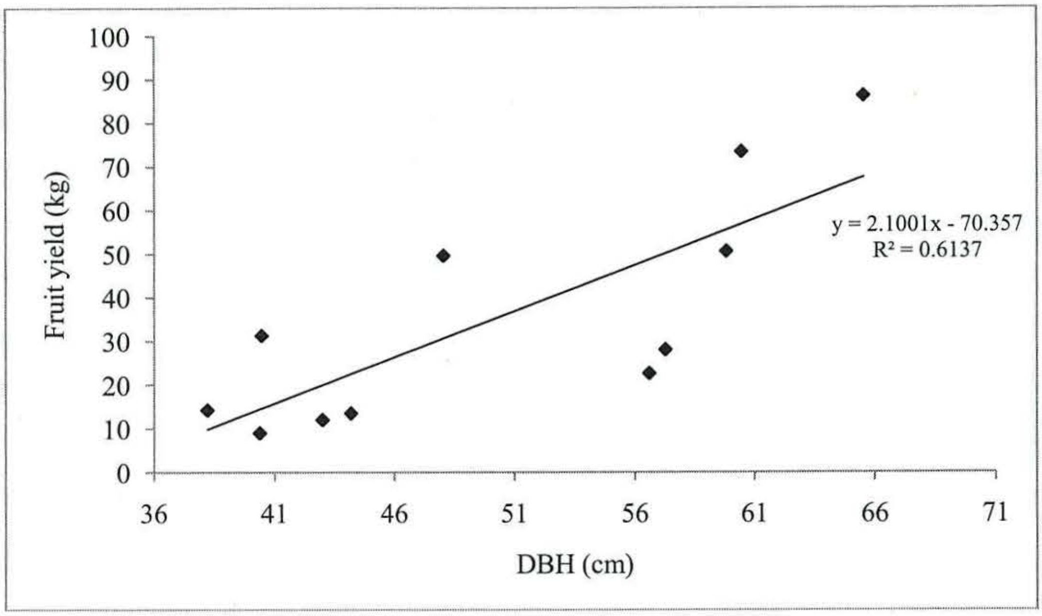


Figure 5.8 General relationship between Balanites fruit yield and tree DBH

Thus, Balanites fruit yield can be predicted using the following regression equation;

$y = 2.1x - 70.35$ where;

y = fruit yield in kg, and

x = DBH of the Balanites tree.

5.4.3 Fruit characterisation

5.4.3.1 Comparison of fruit parameters between Adjumani and Katakwi districts

Balanites aegyptiaca fruits were found to be long, narrow drupes. Mature fruits were greenish, turning yellow when ripe. Fruits had a mean weight, length, width and stalk length of 7.2 g, 3.2 cm, 1.6 cm and 0.4 cm, respectively. Shape of fruit and nuts varied considerably within the two districts. Fruits and nuts from Adjumani were generally spheroidal while those from Katakwi tended to be oblong (Plate 5.3a&b). Comparison of the means of tree parameters using independent sample t-test revealed that; fruit weight, length and width were significantly ($p<0.05$) different between the two districts (Table 5.8).

Adjumani *Katakwi*

Plate 5.3 Variation in shape and size of Balanites nuts obtained from Adjumani and Katakwi

Fruits from Adjumani district were generally heavier and wider than those from Katakwi district; however, those from Katakwi were longer. Fruit length/width ratio for Katakwi was 2.2 while that for Adjumani was 1.9. Fruits from the two districts were more or less similar in their stalk length though there was much variation in the Katakwi fruits (Table 5.7).

Table 5.7 Mean weight and dimensions of fresh *B. aegyptiaca* fruit, Uganda (n=300)

Parameter	Mean ±SD		
	Adjumani (n=150)	Katakwi (n=150)	Combined (n=300)
Fruit weight (g)	8.12±1.88	6.19±1.27	7.16±1.87
Fruit length (cm)	3.09±0.41	3.36±0.44	3.22±0.44
Fruit width (cm)	1.65±0.28	1.58±0.25	1.61±0.27
Fruit length/width ratio	1.91±0.33	2.20±0.52	2.06±0.43
Fruit stalk length of (cm)*	0.41±0.09	0.42±0.12	0.42±0.11

SD = Standard deviation
**Number of fruit stalks measured was low (69) as most of them broke off during transportation to the laboratory*

Table 5.8 Independent samples t-test for comparison fruit characteristics means

Parameter	t	df	Sig. (2-tailed)
Fruit weight (g)	10.45	298	0.005
Fruit length (cm)	5.74	298	0.005
Fruit width (cm)	2.34	298	0.020
Fruit stalk length of (cm)	0.47	67	0.676

n=150 for all parameters except stalk length where n=69

Effect size (Eta squared) was computed using the relationship; Eta squared = t^2/t^2+df; where t is the t-value obtained from the independent samples t-test and df is the degrees of freedom. The difference in district of the fruit origin contributed to 29.5%, 10% and 1.8% of the fruit weight, length and width respectively (Table 4.9).

Table 5.9 Effecet of district of origin on fruit parameters

Parameter	Eta squared
Weight of fruit (g)	0.295
Length of fruit (cm)	0.100
Width of fruit (cm)	0.018

5.4.3.2 Comparison of *B. aegyptiaca* fruit parameters between land uses

The means of the fruit parameters were compared using a one-way ANOVA with sites as a grouping variable and cases excluded analysis by analysis. Equality of variances, one of the assumptions for normality was tested using Levene's test. Results in Figure 5.9 and Table 5.10 show that fruit weight, length and breadth were all significantly ($p<0.05$) different between the four sites. However, stalk length did not vary significantly between the sites.

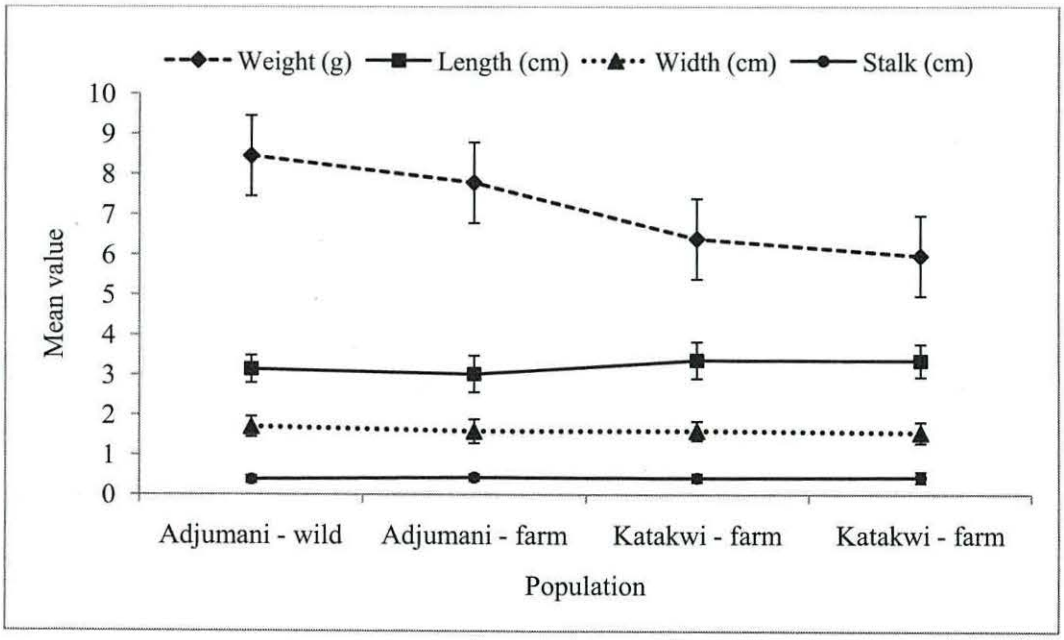


Figure 5.9 Mean (±SE) of Balanites fruit parameters across districts and land uses

Table 5.10 One-way ANOVA for comparison of means of Balanites fruit parameters between four sites

Variable	SS	df	MS	F	Sig.
Weight of fruit (g)	304.218	3	101.406	40.314	0.001
Length of fruit (cm)	6.38	3	2.127	12.088	0.001
Width of fruit (cm)	0.968	3	0.323	4.624	0.004
Length of fruit stalk (cm)	0.017	3	0.006	0.45	0.718

Separation of means (Table 5.11) showed that both wild and on-farm sites in Adjumani district were similar and likewise those from the two land uses in Katakwi district. Major variations were with respect to fruit weight and length. Wild site in Adjumani district had heavier and wider fruits while wild site from Katakwi had lighter and long fruits. There was little variation in fruit width, except for Adropi population which had significantly wider fruits than the rest. Fruit stalk length was similar in all the four sites.

Table 5.11 Separation of means of Balanites fruit parameters (Tukey's Test)

Population	Weight (g)	Length (cm)	Width (cm)	Stalk (cm)
Adjumani wild	8.45±0.21a	3.15±0.04a	1.71±0.03a	0.38±0.03a
Adjumani farm	7.79±0.22a	3.02±0.05a	1.59±0.03b	0.43±0.02a
Katakwi wild	5.98±0.14b	3.36±0.05b	1.55±0.03b	0.43±0.03a
Katakwi farm	6.40±0.15b	3.37±0.05b	1.60±0.03ab	0.41±0.02a

5.4.3.3 Relationship between Balanites fruit parameters

The relationship between fruit weight and fruit length was found to be negative and weak ($r = -0.13$; $p<0.024$), implying that, as fruit length increases, its weight decreases. In contrast; fruit weight and width were found to be positively and weakly related ($r = +0.15$; $p<0.008$), implying that as fruit width increases, so does the fruit weight. Fruit length however, accounted for only 4% of the variance in fruit weight. Figures 5.10 and 5.11 show the regression lines for the two relationships.

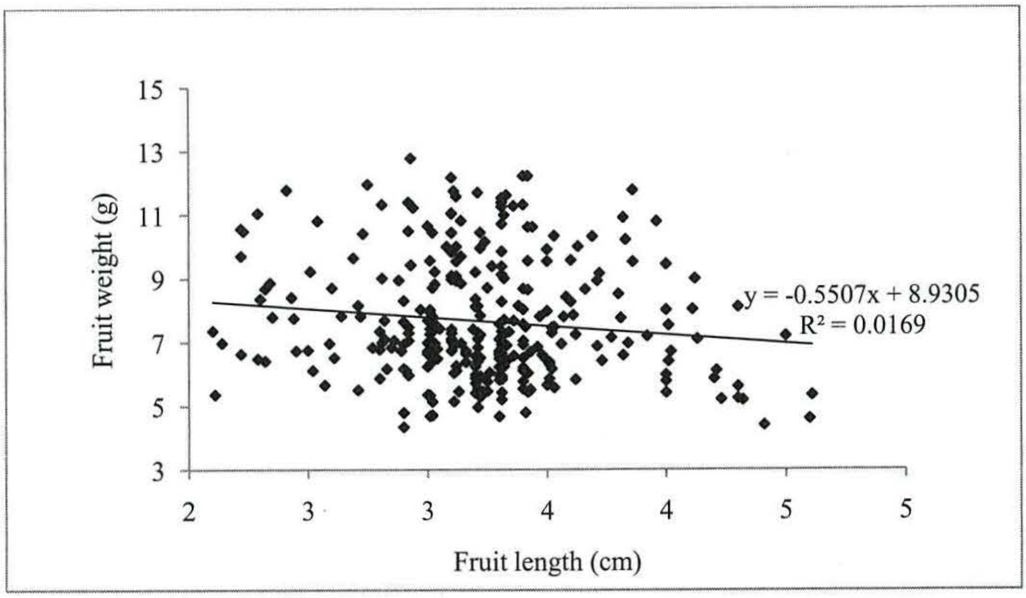


Figure 5.10 Relationship between Balanites fruit weight and fruit length

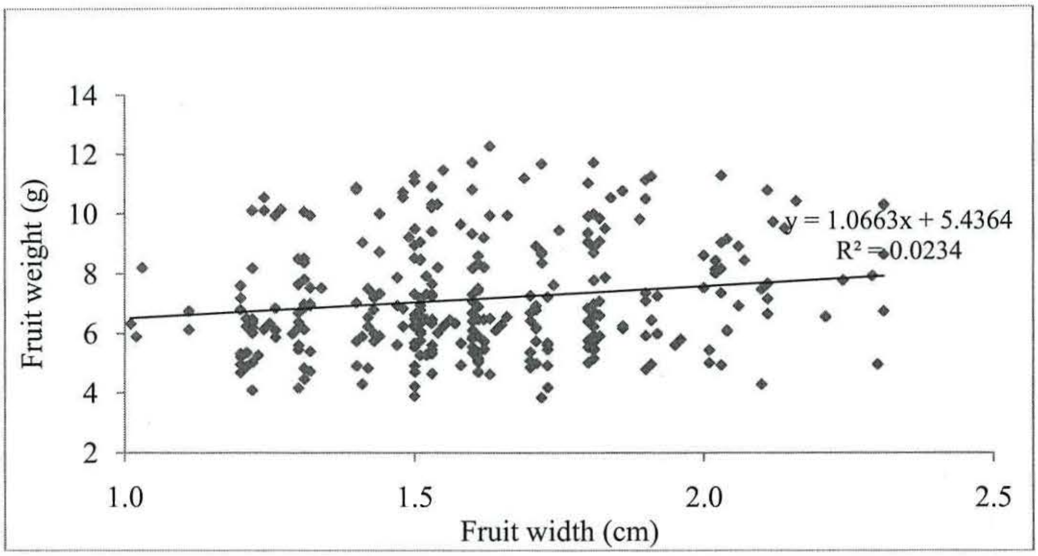


Figure 5.11 Relationship between Balanites fruit weight and fruit width

5.4.3.4 Proportions of the different parts of *B. aegyptiaca* fruit

A kilogram of ripe Balanites fruits was found to contain an average of 130±5 fruits. Proportionally, the fruit was composed of 17.3 % outer shell (epicarp), 22.7% pulp (mesocarp), 47.2% hard shell (endocarp/stone), and 12.4% kernel (Figure 5.12). The stone and kernel together made up to 60% of the fruit out of which 79% was the stone and only 21% was kernel

(Appendix 5.2). The fruit, and thus, nut size and shape from particular trees were found to be distinct and could be sorted out of a pile.

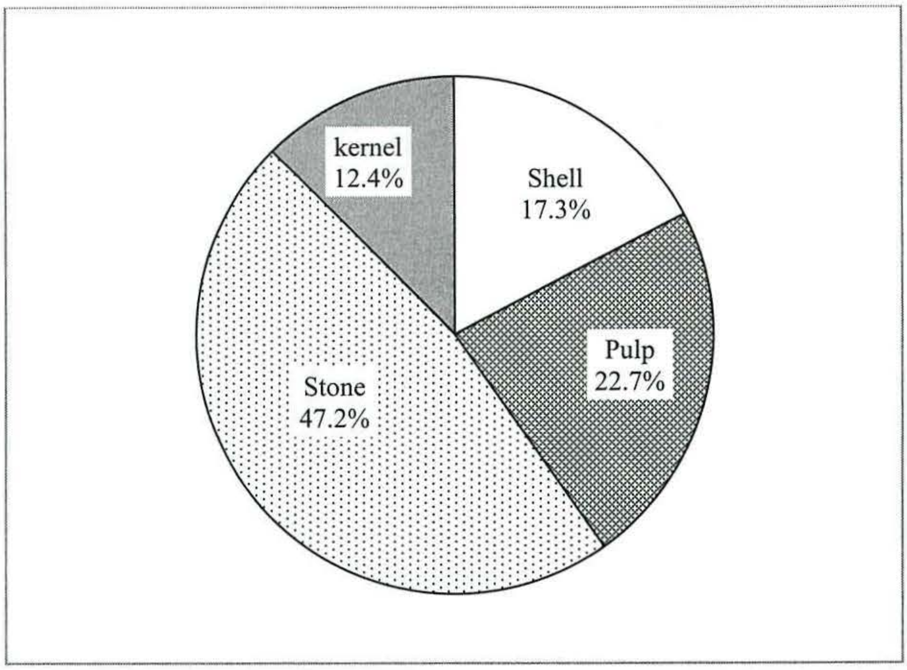


Figure 5.12 Proportions of different parts of *B. aegyptiaca* fruit

5.5 Discussion

5.5.1 Phenology of *B. aegyptiaca* in Uganda

The two year phenological observations revealed that *B. aegyptiaca* in Uganda is a semi-deciduous tree. Other reports (e.g. Hall and Walker, 1991) reported Balanites to be semi-deciduous however; in environments with limited precipitation (< 500 mm) the species may become leafless at the peak of the dry season (Ndoye *et al.* (2004). Balanites trees in this study only became leafless when scorched by the annual bush fires.

All the sampled trees in Adjumani district underwent reproductive activity on repeated annual timescale while in Katakwi some trees failed to fruit even after flowering. Similarly, Ndoye *et al.* (2004) in a study of the reproductive biology of *B. aegyptiaca* in Senegal reported that some trees due to their own situation and specificities failed to produce fruits after flowering. In this study, it is possible that increasing intensity of annual bush fires and repeated lopping of trees during leaf harvesting could be partly contributing to decline in fruiting. Local people reported declining fruiting over the years, and according to them, bush fires and old age of most trees could be contributory factors. Ndoye *et al.* (2004) reported high ratio of abortion in *B. aegyptiaca* in Senegal however, Tybirk (1991) pointed out that such high ratio of abortion is usual in the Sahelian (dry) environment where trees produce a great number of flowers to attract pollinators and after fertilization and according to resources allocated (Bawa and Webb, 1984), select the most competitive fruits for maturation. The situation in Katakwi was however, complicated by the fact that trees, for some reasons, aborted all the flowers and even fruits at the setting stage. Brearley *et al.* (2007) observed that failure to produce fruit after flowering may be due to a number of reasons including lack of pollinators, poor climatic conditions or insufficient carbohydrate reserves. It is probable that the high intensity of pollarding in search of Balanites leaves in Katakwi has had a negative effect on the reproductive phenology of the trees. The already low and decreasing proportion of trees that fruited over the two years monitoring period in Katakwi could be worrying as this may pose a regeneration threat. This data may however not be comprehensive enough to make conclusions on the reproductive success of Balanites in Katakwi district. There may be need to study effects of this phenomenon on plant health, flowering and fruiting over an extended time period. There were always flowers produced outside the main flowering season. These resulted in fruiting; however, fruits produced were inferior in quality. Such fruits were observed to be attacked by borers and fell before full development.

There were both strong negative and positive correlations between the phenological events in Balanites and environmental variables. The strongest negative correlations were found for leaf shedding, leaf flushing and fruit ripening with both rainfall and relative humidity. For instance, leaf shedding was strongly negatively correlated with rainfall in both Adjumani and Katakwi districts (r = -0.75 and -0.68; $P < 0.001$, respectively). Fruit development was the main phenological event observed to be associated with a rise in relative humidity, which was also closely associated with the rainy season. This occurred from late April to October. During this period the tree is able to provide adequate resources needed for development of initially long and narrow fruits.

On the other hand, leaf flushing and shedding, flowering, fruit setting and ripening were all strongly positively correlated with temperature. This implies that these phenological events occurred concurrently during the dry season, which lasted from around November to March. One of the recent studies on the reproductive phenology of trees over a 10-year period

(Brearley *et al.*, 2007) showed that temperature (drought) is a more important environmental cue than rainfall and relative humidity. Analysis by Sakai *et al.* (2006) showed that drought appears to be the cue for general flowering as it was the only climatic factor that was consistent in preceding four general flowering events in Sarawak between 1993 and 2003. In a study of 24 species in the Sudanian Savanna of Burkina Faso, Devineau (1999) found leaf flushing, flowering and fruiting to occur mostly in the dry season. Janzen (1967) attributed flowering in the dry season to the necessity for avoiding competition for physiologically active sites within the individual and to the availability of pollinators. In the current study, leafing and fruit setting occurred during the dry season but always continued into the early rainy season (April). However, leaf shedding and fruit ripening were restricted to the dry season.

In both Katakwi and Adjumani districts, bush fires were recorded during the dry months, especially from December to February. This also corresponds with fruit ripening period and such fire caused a considerable damage to Balanites fruits, thus, depriving communities of annual fruit collections. In some cases, fires were set just before the start of fruit ripening. Such fires were observed to cause drying and eventual leaf and fruit fall. However, some fruits (10 – 25%) always remained hanging on the tree probably due to high abscission and fell over an extended period of about six months. The use of fires in the savannas for regenerating pasture was found to induce a state of leaflessness 2 - 4 weeks after the fire and this was immediately followed by prolific leaf flushing. Besides pasture regeneration, fire was also used in Katakwi to trigger the growth of young succulent leaves that were harvested as a green vegetable at the peak of the dry season.

Some phenological events, especially, flowering, fruiting and fruit ripening in Katakwi district were a head of those in Adjumani by one month. This appeared to be related to the timing of seasons in the two districts. For instance, rains in Katakwi and Adjumani started in March and April respectively. In this scenario, peak flowering was observed in Katakwi in February while the same event was pushed to March in Adjumani. The trees appeared to have some kind of an early warning system which enabled them to reach peak flowering just before the start of rains. This seems to be an advantage to the plant since rains usually destroyed the small flowers probably before being pollinated. Fruit setting equally seemed not to be dependent on rain; however, adequate soil moisture was needed during fruit development stage. At this stage, the plant needs adequate resources for proper fruit development. Since flowering and fruiting occurred over an extended period, fruit ripening was more or less observed at the same time in the two districts. Nonetheless, fruit fall in Katakwi ended in February while it extended up to March in Adjumani.

Observations on phenological events in *B. aegyptiaca* as reported here are important in management of trees in the wild and can also help in guiding their integration in to agroforestry systems. For instance, prediction of leafing, flowering, fruiting, and fruit ripening times can be related to capture of environmental resources. Given that Balanites fruits and seeds are readily attacked by seed borers soon after fruit fall, an understanding of the fruit ripening period can be applied to plan for fruit/seed collection at peak ripening period (December – February).

5.5.2 Fruit yield from *B. aegyptiaca* trees

Fruit yield has a direct relationship with the size of a tree, especially its crown. It is therefore not surprising that bigger trees found in Adjumani district produced more fruit than smaller trees in Katakwi district. Besides, environmental differences, lopping of trees during the leaf harvesting and repeated bush burning tended to reduce the size of trees in Katakwi. The characteristic dropping nature of Balanites branches (Katende, *et al.*, 1995; Sands, 2001) can be easily seen in Adjumani trees while this has been virtually lost in most trees in Katakwi populations (Plate 5. 4).

Balanites trees in Adjumani district were always found along the River Nile. This could have ensured access to ground water given the deep rooting nature of Balanites trees (Hall and Walker, 1991). Trees in Katakwi were found along seasonally water logged areas with probably limited access to ground water at the peak of the dry season. In addition, over-grazing in Adjumani unlike in Katakwi ensured that there was less combustible fuel thus reducing the effect of bush fire on Balanites trees. The effect of bush fires in wild populations in Katakwi could have been one of the key factors for reduced fruit yield in the wild than on farm. In Adjumani, where there were less damaging bush fires, wild trees produced more fruit than on-farm trees due to the management practices applied to trees on farm lands, especially, pruning to reduce competition with associated crops.

Plate 5.4 Variation in Balanites tree crown in Adjumani and Katakwi

Balanites tree with characteristic dropping branches in Ege village Adjumani district (left), and with lower branches burnt by bush fires in Acoite village, Katakwi district (right)

Whereas fruit yield from Katakwi district was considerably low (13 kg per tree), yields from Adjumani district (53 kg per tree) compare well with those reported by Piot (1980) - 45 kg per adult tree. However, Abu-Al-Futuh (1983) reported higher yields of 100 -150 kg of ripe fruit per tree year^{-1}. The average number of fruits produced by individual Balanites trees in this study was 6,679 and 1,757 in Adjumani and Katakwi, respectively. Earlier accounts (e.g. von Maydell, 1986 and 1990) reported higher fruit yield of about 10,000 fruits per tree year^{-1}. As argued by Hall and Walker (1991), this could have been a heavy fruiting situation, and more likely for bigger sized trees.

It is difficult to directly compare the current results with those reported in earlier studies due to the fact that the average tree size and environmental conditions of the sites are not specified yet these are important determinants of fruit yield. Results from this study may also have a limitation due to a small number of trees used for yield estimation (12 trees- 6 per site). However, the present results give a fair estimate of Balanites fruit yield from the drylands of Uganda where there has been dearth of information. It is also important to bear in mind the challenges in determining fruit yield from Balanites trees, especially the thorny nature of the tree, extended fruit fall period and competition for fruit with animals.

The equation derived in this study for determination of fruit yield ($y = 2.1x - 70.35$) seems to be valid for larger diameter trees (DBH $\geq$ 36 cm). This could be attributed to the absence of small diameter trees in the fruit yield sample (Appendix 5.3). Thus, though the equation requires some improvements through increased sample size of different diameter classes, it provides a reasonable starting point.

5.5.3 Balanites fruit characterisation

The shape of Balanites fruit varied considerably in the two districts with fruits from Adjumani being spheroidal while those from Katakwi tended to be oblong. Whereas Aviara, *et al.*, (2005) referred to such differences in shape in a Nigerian sample to represent different varieties of Balanites, they could simply be a result of environmental modifications. Environmental data in this study shows that Katakwi district was drier than Adjumani. According to Sands (2001), Balanites fruits elongate markedly in early development and are very variable when mature. They could be sub-spherical or ovoid to ellipsoidal, rounded, truncate or sometimes sulcate at both ends and the apex tapering (Sands, 2001). A mixture of fruit types was observed in both districts; however, the proportion of long (oblong) fruits/nuts was higher in Katakwi. This will be important in selection for kernel oil yield. This is further supported by the observed positive relationship between fruit weight and fruit width.

The dimensions of Balanites fruits obtained in this study agree with those reported by Sands (2001) under his "revision of the genus Balanites". Except for the epicarp, the proportions of Balanites fruit (wet basis) obtained in this study closely agree with those reported by (Hall and Walker 1991; Chapagain *et al.*, 2009). While the epicarp is reported to constitute 5 - 9% of the fruit (Hall and Walker 1991), a higher value of 17.3% was obtained under the present study. The proportion of the kernel (12.4%) is higher than that reported in Sudan, 9 - 10% (Hussain *et al.*, 1949) but more closer to that reported in Israel - 12.7% (Chapagain *et al.*, 2009). The composition (dry basis) reported by Deshmukh and Bhuyar (2009) for India; 10–13% outer cover, 30–35% pulp, 35 – 40% shell and 15 – 17% kernel, appear to vary from the present findings. This could be due to various differences. The finding that fruits from Adjumani populations are heavier than those from Katakwi can be applied in selection of elite trees/fruits for propagation purposes. However, before this can be applied as a selection criterion, there is need to evaluate if higher fruit weight is positively correlated with pulp and/or kernel weight.

CHAPTER SIX: LOCAL PROCESSING AND MARKETING OF *BALANITES AEGYPTIACA* PRODUCTS IN UGANDA

This chapter documents the local processing of Balanites leaves, fruits and kernel oil and examines their market potential in two dryland sub-regions in Uganda. Introduction, objectives and methods used are covered in sections 6.1, 6.2 and 6.3, respectively. The results are presented in section 6.4. Sub section 6.4.1 is presented in such a way that it creates a link with chapter three (local knowledge), by first, highlighting the harvesting of Balanites products before detailing the processing techniques currently employed by the local people. Sub section 6.4.2 presents results on marketing of Balanites products while sub section 6.4.3 captures policy related constraints and opportunities for commercialisation of Balanites products in Uganda. The results are then discussed in section 6.5.

6.1 Background

Perennial tree crops play a fundamental role in the economies of many developing countries in the tropics where they occupy millions of hectares and few alternative agricultural enterprises exist (Omont and Nicolas, 2006). Indigenous fruits and other indigenous foods can be a major factor in local poverty alleviation since both local and international demand for their products continues to grow. According to Schreckenberg *et al.* (2006), a wide range of indigenous fruits can enable farmers to meet their varied household needs for food, nutrition, medicines and income. Indigenous fruits and vegetables are often part of the traditional diet and culture and there is accumulated time-tested local knowledge regarding their processing and trade. Collection, processing and marketing of these indigenous tree products can represent a significant portion of total household income particularly where farming is marginal (Scoones *et al.,* 1992).

There is evidence that IFTs can contribute significantly to household income in every region in the tropics and that they present an opportunity for asset-building for smallholder farmers (Roe, 2002; Ramadhani, 2002; Akinnifesi *et al.*, 2007; Leakey *et al.*, 2005; Schreckenberg *et al.*, 2006). Some popular examples of such species are; the marula tree (*Sclerocarya birrea)* in southern Africa (Shackleton and Shackleton, 2005), shea butter tree (*Vitellaria paradoxa*) in the west and east Africa (Boffa, 1999; Ferris *et al.*, 2001; Teklehaimanot, 2004; Okullo, 2004), the baobab tree (*Adansonia digitata*) in western, southern and eastern Africa (ICRAF, 1997; Hall *et al.*, 2002) and safou tree (*Dacryodes edulis)* in western Africa (Awono, *et al.*,2002). Based on the case of *Dacryodes edulis* and *Irvingia gabonensis* in Cameroon and Nigeria, Schreckenberg, *et al*., (2006) presented evidence for the contribution of indigenous fruits to poverty reduction and urged for key policy interventions to sustain and increase their already valuable contribution to poverty reduction.

While products from these species are used both locally and internationally, many other indigenous tree products, including those from the desert date (*Balanites aegyptiaca*) remain largely unexploited and with only localised importance. However, the desert date shares many attributes with other widely popular species. For instance, it is widely spread in Africa-occurring from Senegal to Sudan (Hall and Walker, 1991). Additionally, it has potentially novel products, e.g. oil, fruits and leaves that are critical in rural diets and trade. Reports on Balanites (e.g. Hall and Walker, 1991; NRC, 2008) have indeed revealed important nutritional, cosmetic and medicinal attributes of its products. According to von Maydell, (1990) and Teklehaimanot (2005), Balanites produces fruit even in unusually dry years. Local communities in the drylands of Africa heavily rely on its products both as food and trade (von Maydell, 1990; Cook *et al.,* 1998; Teklehaimanot, 2005 and 2008). The young leaves were reported to be the only vegetable available during the dry season in Katakwi district, Uganda (Teklehaimanot, 2008) and Niger (Cook *et al.,* 1998). This highlights the fact that Balanites products have a potential to join the list of novel wild tree products from African drylands. In this way, communities can improve their livelihoods and also conserve the trees that are currently abundant in the wild.

One of the bottle necks facing use and management of indigenous trees, such as Balanites is lack of access to information throughout the production to consumption pathway. According to Hughes and Haq (2003) marketing information and economics are essential in the successful commercialisation of fruit tree species. They further assert that indigenous fruit trees are now rediscovered after misguided and unbridled modernization which had relegated them to the shadows. Farmers, small-scale entrepreneurs, businesses and research institutions have expressed a need for access to current information on aspects of the production to consumption pathway with respect to indigenous fruit trees (Haq and Hughes, 2002). Evidence of this is also reflected through participatory research and regional meetings in Africa and elsewhere (Haq and Atkinson, 1999; Chikamai *et al.,* 2004, Chikamai *et al.,* 2005).

Local knowledge on processing and marketing of Balanites products needs to be harnessed and incorporated into the development of appropriate processing technologies that can be easily adopted by farmers and small and medium scale entrepreneurs (SMEs). Marketing of indigenous fruits plays an important though neglected role in the sustainable use of dryland tree resources (Shanley, 2002). Although it has been reported that fruits of some indigenous trees in Eastern Africa are traded locally and internationally, their trading is not known (Chikamai *et al.,* 2004, Teklehaimanot, 2008). Furthermore, their contribution to rural livelihoods and their processing and value addition are not documented. In order to enhance farmers' income from indigenous fruits, appropriate processing technologies for various products need to be developed. However, an understanding of local initiatives is needed to support development of such appropriate technologies.

Effective development and utilisation of indigenous fruit trees also requires identification and careful analysis of constraints and opportunities to their harvesting, processing and marketing; and implementation of actions to overcome the constraints and exploit available opportunities. Some SMEs dealing in indigenous fruits do not have clear understanding of business practices, including how to market their products, which are often of low quality (Haq, 2000) and thus fetch low prices (Vinning and Moody, 1997). There are also no promotional activities carried out in marketing of indigenous fruits. It has been argued that; for local farmers to be successful market participants in both local and international markets, they need to monitor the market demand and prices. They also have to engage in networking activities and seek strategic alliances in producer-industry partnerships (Koppell, 1995). For famers to engage in trade at all, they need information regarding the basic market structures, especially, stakeholders, trade channels and patterns of value-adding along the marketing chain. If left to market dynamics alone, the economic importance of indigenous fruit market (and with it the incentive to use indigenous tree resources sustainably) can be expected to remain weak (Statz, 2000). According to Teklehaimanot (2008) linking farmers to high-value and export markets is an important strategy for raising incomes and reducing poverty. Research has to play a key role in this process, especially in the analysis of current markets and prevailing marketing practices.

It has been reported that households gathering wild food plants can avoid hunger and boost rural employment and generate income (Mithofer, 2004) through processing and value adding (Saka *et al.*, 2004). Chikamai *et al.* (2004) noted that although the international market for oil from *B. aegyptiaca* is undersupplied by producer countries, no records of trade within eastern Africa are available. According to Sign and Roy (1984), one of the important subjects to be dealt with by the ever-increasing population is to find ways of adding value to local edible wild plants by processing them as part of rural poverty alleviation. This study therefore, aimed at documenting local methods used for collection and processing of Balanites products (fruits, nuts and leaves) and exploring their market prospects as a way of promoting their use and commercialization.

6.2 Objectives and research questions

The objectives of the study were to;

i. Document local methods for harvesting and processing of Balanites products
ii. Assess the market potential of Balanites products in Uganda, and
iii. Identify policy related opportunities and constraints for commercialization of Balanites products in Uganda.

The study sought to address the following research questions;

i. Which Balanites products are traded in Uganda?
ii. What quantities are collected and sold?
iii. How are the different Balanites products processed and stored?
iv. What are the marketing channels for Balanites products?
v. What are the prices and how are they determined?
vi. Which product attributes are considered important by buyers?
vii. What are the opportunities and constraints for marketing of Balanites products?
viii. How can the market for Balanites products be improved in Uganda?

6.3 Materials and methods

6.3.1 Data collection

In order to capture wider marketing issues on Balanites products, the study area was expanded to include two districts in each of the two study sub-regions. These included; Katakwi and Amuria districts in Teso sub-region and Adjumani and Moyo districts in West Nile sub-region. Information on local harvesting and processing of Balanites products was obtained through in-depth focus group discussions. Participants were selected purposively based on their involvement in either Balanites products processing and/or trade. Focus groups were comprised of 6-10 people and involved groups of men, women and children. A Rapid Market Appraisal (RMA) (Appendix 6.1) was conducted in both rural and urban markets (Februry – March 2008) to collect basic marketing information on Balanites products. RMAs are commonly used for analysing commodity markets using a combination of informal survey techniques, like, individual and group informal interviews, direct observations and participatory rural appraisal tools (Simons *et al.,* 1996). Holtzman *et al.* (1993) noted that RMA framework is best suited to research studies in which little previous work has been done before, it was poorly conducted or needs updating. The framework has flexibility to detect emerging issues, themes and opportunities facing a marketing system.

Market potential of Balanites products was assessed through two formal surveys with aid of semi-structured questionnaires. A traders' survey (Appendix 6.2) involved 45 respondents who were involved in selling Balanites products in both rural and urban/peri-urban markets in the two study sub-regions. Information collected included; products sold, pricing and pre-sale activities, storage and transportation of products, market information and market returns, and traders' perceptions and opinions regarding trading in Balanites products. The buyers survey (Appendix 6.3) covered 50 respondents who bought Balanites products in various market locations. The questionnaire explored such issues as; products bought and/or consumed, attributes considered when buying products, preferences on the products and willingness to pay.

Policy issues regarding Balanites and other indigenous tree products were identified and examined using local leaders' semi-structured questionnaire (Appendix 6.4). The key issues examined included; regulations on IFTs including Balanites, enforcement of these regulations and their effects, challenges faced by Balanites sellers in markets and local leaders' opinions on improving marketing of products from Balanites and other indigenous trees.

6.3.2 Data analysis

All the survey data were entered and analysed in SPSS Version 16. Analysis was mainly descriptive using percentage and means. Multiple response analysis was performed for cases where there where more than one possible response. Opinions and perceptions were summarised using a likert scale based on perception indices with the following scoring; strongly agree (6), agree (5), partly agree and disagree (4), do not agree (3), strongly disagree (2) and no answer (1). Results were mainly presented in form of tables and graphs. Information generated through focus group discussions and RMS was summarised and used to fill gaps in the questionnaire data. This information was also used in the discussion to explain various issues surrounding collection, processing and marketing of Balanites products.

6.4 Results

6.4.1 Local harvesting and processing of Balanites products

6.4.1.1 Harvesting and processing of Balanites leaves in Katakwi district

Leaf harvesting: Balanites leaves are harvested for use as a vegetable in Teso sub-region during the dry season (November – March). Harvesting is mainly done by women and children, most especially girls. The major tools used were a container (e.g. a winnower, basket, basin or sack), a machete "panga" and sometimes an axe. In some cases, especially where the trees are very tall and trunk difficult to climb, a locally made ladder was used to aid climbing (Plate 6.1a). Harvesters normally go in groups of at least three people, especially when collecting from distant areas for company and security reasons. After identifying a tree with "good" leaves (local knowledge – chapter three), harvesters climb and cut small branches and twigs. The leaves are plucked under the tree or at a convenient bulking point, usually under shade. In cases where the branchlets have few or no thorns, the leaves are plucked together with the associated flowers by pulling the branchlet between the palm and fingers. Balanites leaves picked this way were referred to as "ekuruta" in Teso (Plate 6.1b). Only the plucked leaves and flowers were carried home while the cut small branches were left behind. These branches would however, be collected on a later day for use as firewood. In a few instances, especially where the harvesting site was near and with scarcity of firewood, such branches were transported home on the same day.

Plate 6.1 Picking of Balanites leaves in Katakwi

(a) A village elder on a ladder improvised by leaf collectors for climbing tall Balanites trees during leaf harvesting.

(b) Cooked Balanites leaves picked with flowers referred to as "ekuruta" in Katakwi district (Ateso).

Leaf preparation and storage: The leaves collected are boiled within 24 hours after collection. Storage for more than one day after collection was reported to result in hardening of the otherwise young and soft leaves and/or loss of good taste (turning bitter). The women emphasized that if complete boiling was not possible on the same day, it is advisable to at least start the process and complete it the following day. The leaves are not washed prior to cooking as this was not considered necessary since they are presumed to be clean. Leaves are boiled in water preferably using a traditional pot for 2 - 3 hours. Though a saucepan is also used, a pot was more preferred due to minimum heat loses. The use of saucepan was reported to take 3-4 hours. The traditional pot therefore, saves both time and fuelwood. While boiling, water should be added whenever it reduces so that the leaves are kept submerged. The leaves are also turned at intervals during boiling. Leaf readiness is determined by tasting (chewing) a few leaves at intervals until they become soft. When ready, leaves are left to cool and the remaining water is squeezed out by pressing between hands. If remaining water is little, some cold water may be added to facilitate the squeezing. This was reported to reduce bitterness. The leaves were considered ready for sale after squeezing. However, before transporting leaves to the market, some cold water was added to keep the partially cooked leaves fresh. In this case, further squeezing was done at the time of measuring the leaves for buyers.

To further process the boiled leaves for eating, they are pounded using a mortar and pestle. In some cases they were even ground (using a grinding stone). To make sauce, pounded leaves are mixed with cold water (2:1 ratio) and then groundnut paste or sour milk is added. The mixture is boiled over a low fire for a short time (5-10 minutes) while being stirred. Very little salt is added since even without salt it was said to taste good. It was reported that some people, especially the elderly, preferred it cooked without salt. It was urged that cooking the leaves without salt was a better option since one can always add little salt at the table. This seems to emphasise the point that only very little amount of salt, if any, should be added. In some cases, the sauce was further spiced up with honey, milk, tamarind or mango fruit extract and sugar, and usually served with millet bread 'atap'- traditional food in Teso sub-region. The sauce was also reported to be popular with sweet potatoes, corn "posho", cassava, and other local staples.

Boiled leaves can only be stored for 1 – 2 days. Generally, storage of boiled leaves, unless under refrigeration, was said not to be advisable, as the leaves develop a bad smell and taste after two days. However, elderly women reported that pounded leaves can be dried and conveniently stored for up to 3-4 months. The leaf powder has to be stored in air tight pots, polythene bags, bowls, tins and saucepans. Leaf storage was reported to have been practised to a limited extent in past but has more or less been ignored, probably due to decreasing quantities of leaf collected, increasing family size, increased market demand and changing social setup.

6.4.1.2 Fruit/nut collection

Fruit/nut collection: Balanites fruits ripen during the dry season (December – February or early March). They are mainly collected after falling beneath the mother tree though tree branches may also be shaken with hooked sticks to enhance fruit fall. The latter was mainly used for collecting fruits for eating or sale while the former was used for obtaining fruits for further processing into oil. Fruits are mainly collected by women and children and carried in saucepans, basins, baskets and bags. Nuts used for oil processing were also collected under parent trees, around places where fruits have been eaten and in animal resting places. Goats and sheep were found to spit the nuts after stripping the epicarp and mesocarp while cows regurgitated them. This made animal resting places convenient nut collection points.

Fruits collected were first sorted by removing small sized, immature and diseased ones. Fresh Balanites fruits were reported to have a shelf life of five days under ordinary house conditions or up to 10 days under cool conditions – improvised by dampening the storage sack. Under this study, both whole and shelled fruits were stored under refrigeration for up to three months without any noticeable deterioration in taste and colour. Communities in Adjumani district reported that shelled fruits can also be dried and stored for 2 - 4 months under ordinary conditions. Such fruits were however, noted to require soaking (5-10 minutes) before eating in order to re-fresh the hardened fruit pulp.

De-pulping of the fruit was reported to be optional since the nut could as well be dried with pulp. However, de-pulped nuts were reported to be easier to crack compared to those dried with the pulp. The nuts collected separately were further dried to make cracking easier and to store for long. Dried nuts were reported to store for 3- 4 months under ordinary conditions or up to 12 months under airtight containers. Treatment with ash was also reported to increase storability of nuts to over 6 months. One of the constraints in nut storage was reported to be attack by nut borers (Plate 6.2). Any Balanites nut with a hole (sign of borer damage) should be removed since its kernel will have already been damaged by the insect.

Plate 6.2 Balanites nuts damaged by borer

6.4.1.3 Oil processing

There were a number of women actively involved in Balanites oil processing in Adjumani and Moyo districts. Oil was produced for both home consumption and sale. There was generally one local method used for oil processing and it involved about seven steps (Figure 6.1). In detail, the oil extraction process involves activities described below:

(i) ***Drying and sorting nuts:*** Nuts were placed on bare ground and dried under the sun for about 3 – 7 days, depending on their source and intensity of the sun. Nuts collected from animal resting places take shorter time to dry (3 - 5 days) while those obtained by manual de-pulping take longer (4 - 7 days). Proper drying helps to facilitate nut cracking. Sorting was done at this stage to eliminate inferior nuts that would otherwise lower the quality of oil. Inferior nuts were reported to cause development of bad smell in the oil.

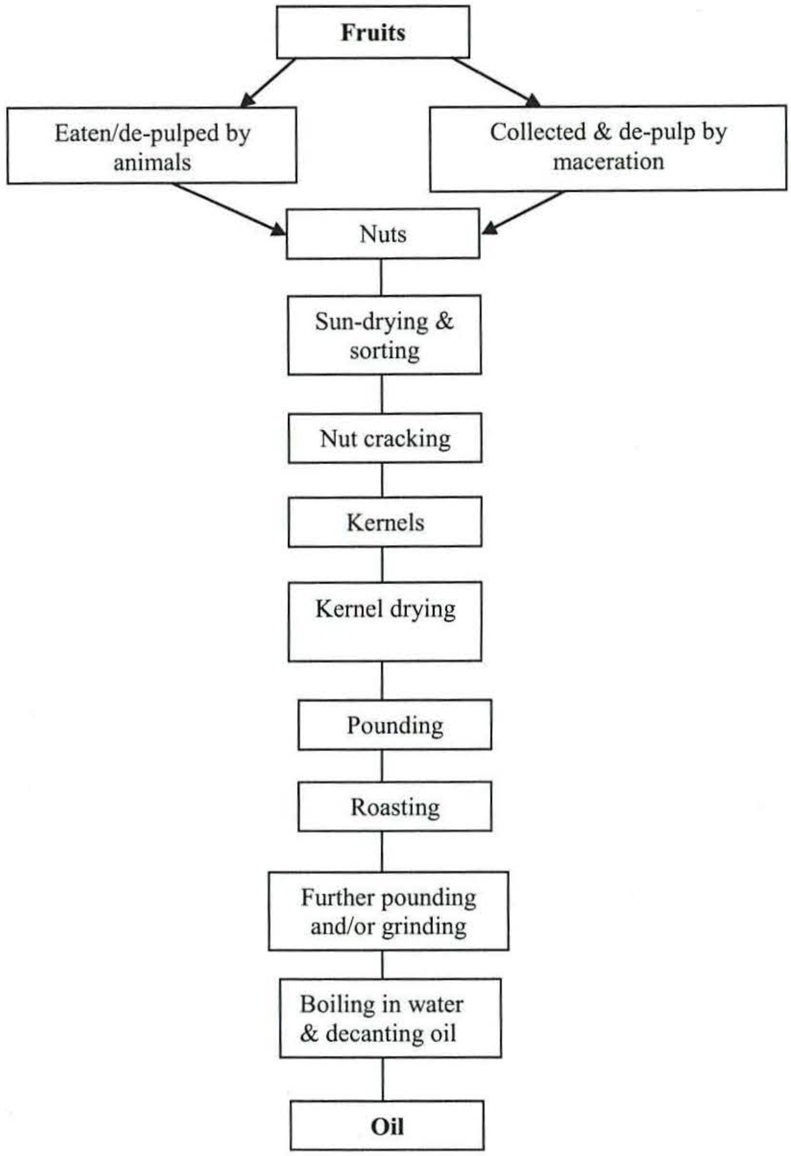


Figure 6.1 Local method used for processing Balanites oil in West Nile sub-region, Uganda

(ii) ***Cracking nuts to obtain seed kernels:*** nuts are cracked manually by hitting them between two stones, a bigger stone below and smaller one used as a hammer. The nut is first hammered horizontally to create cracks along its lines of weakness separating the five flagella. It is then hit vertically to open with the smaller pointed end up. The hard shell (endocarp) also referred to as 'stone' due to its extreme hardness, is then removed and the kernel extracted. If opening proves difficult to complete by hand, a

knife is used. The whole operation is delicate and needs to be performed with extra caution. Use of excessive force usually results in shattering of the kernel leading to low recovery. The first hitting (horizontal) is supposed to be light to avoid breaking the kernel while the second (vertical) is heavier but made directly at the pointed tip. This way, two leading lines of rupture will run along the flagella thus facilitating the opening of the nut and consequently removal of the kernel. For these reasons, men and boys were less interested in the nut cracking process, hence relegating it to women and young girls (Plate 6.3a). The thin layer covering the kernel (testa) was not removed. Experienced women extracted 2 – 3 kg of kernel per day.

(iii) ***Drying kernels:*** unlike the nuts that can be dried on bare ground, extracted kernels were always dried on a clean material, such as, winnower, polyethene sheet, smeared floor or mat. Any contact of the drying kernels with water was avoided as this was reported to lower the quality of resulting oil in terms of reduced shelf life. Under normal sunny conditions, kernels take 2 - 3 days to dry, and this facilitates the pounding and/or grinding of the kernels.

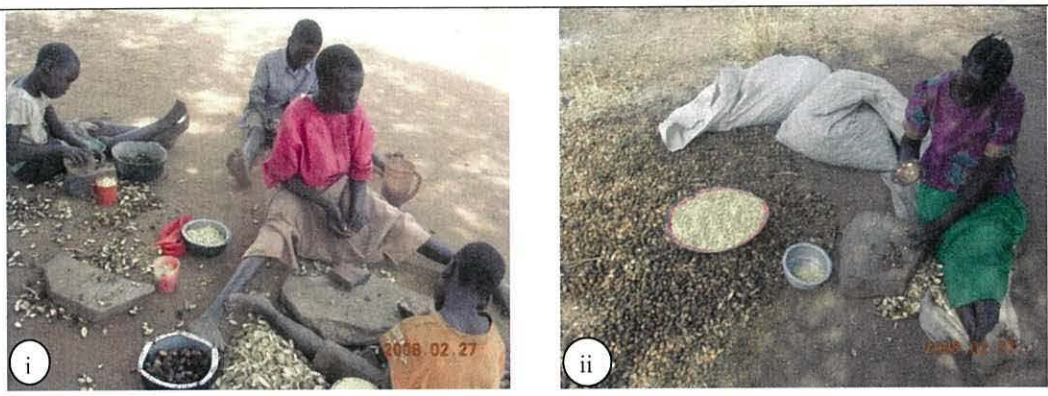
(iv) ***Pounding kernels:*** kernels were pounded into a rough powder using mortar and pestle. This first pounding was done to facilitate roasting.

(v) ***Roasting kernels:*** roughly pounded kernels were roasted for 20 – 40 minutes until they changed colour from yellowish to brownish. Roasting was said to improve oil yield and impart a pleasant smell and taste to the resulting oil. However, it also makes the otherwise light yellow oil become blackish in colour (Plate 6.4b). The roasted pounded kernels are cooled for about 5 – 10 minutes by spreading wide on a clean material.

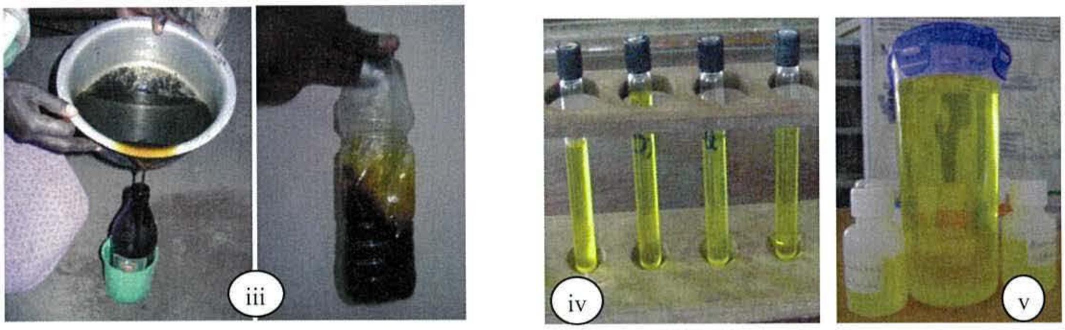
(vi) ***Grinding or further pounding of kernels:*** the roughly pounded and roasted kernels are made into powder or paste by grinding between two stones or further pounding with mortar and pestle. The resulting paste/powder was very oily. Grinding was most preferred since it produces a fine paste/powder in a shorter time. This was reported to increase oil yield and shorten the oil extraction process.

(vii) ***Oil extraction:*** oil was immediately extracted from the kernel powders in boiling water (hot water floatation). A saucepan was used for boiling. The oil processors (women) stated that the paste should never be stored as this leads to reduced oil yield. It was emphasised that one needed to put the water on fire as kernel grinding proceeded. Paste is added when water starts boiling in a paste to water ratio of about 1: ¾. As the paste is added, stirring with a stick should be done until the oil separates and settles on top. According to experienced processors, the quantity of oil extracted can easily be detected from the stirring stick. Once much of the oil has settled on top (extracted), the saucepan is removed from the fire and the oil decanted into another clean container. The oil extraction process was reported to take about 1 - 2 hours. The processors pointed out that only one round of oil extraction was sufficient since any further boiling and stirring will not always yield any reasonable additional oil. It was noted that this process has been perfected over years and is passed from mothers to their interested children, especially, girls. According to experienced oil processors in Adjumani district, about 2.5 kg of Balanites kernels are required to produce one litre of oil. This gives an estimated oil recovery of 40%.

Factors affecting oil quality: Extracted oil was stored in glass or plastic containers for example bottles, jars, jericans, and bowls. A few households stored the oil in saucepans, pots and tins. The use of a particular container depended on availability but clear/transparent ones are generally preferred for easy viewing. Oil was stored in appropriate places in a kitchen or main house. The shelf life for locally processed oil was reported to be about 4 - 6 months. Oil deterioration was detected through change in smell and taste.



(a) Children (i) and a woman (ii) cracking Balanites nuts in Ege village, Adjumani district, Uganda



(b) Traditionally extracted Balanites oil (iii), solvent extracted oil (iv) and machine pressed oil (v) – note the blackish colour of traditionally extracted oil compared to light yellow colour of solvent extracted and machine pressed oil – pressed oil was made by local women from Southern Sudan and was displayed during natural products workshop organised by ICRAF, Nairobi, May 2009.

Plate 6.3 Balanites Kernel oil processing in Adjumani district

The following factors were reported to affect the quality of Balanites oil during the processing;

- Exposure of kernels to water
- Delayed processing of kernels into oil after cracking
- Over-roasting (burning) of kernels
- Use of inappropriate ratio of water to paste during boiling
- Inadequate stirring while mixing kernel paste with boiling water
- Poor pounding or grinding (failure to make kernels into powder or paste)
- Poor decanting (presence of some water droplets in the oil)
- Prolonged boiling and repeated decanting.

On the other hand, the following factors were reported to affect the quality of Balanites oil after processing

- Dirty containers
- Uncovered containers - resulting in infestation by insects, especially small ants
- Storing near paraffin – gives the oil bad smell
- Prolonged oil storage (> 7 months)
- Storing close to cooking place - leads to contamination by smoke; affecting smell and taste
- Water droplets in the container.

6.4.2 Marketing of Balanites products in Teso and Adjumani sub-regions

6.4.2.1 Description of markets and characteristics of traders

Eleven markets were surveyed and a total of 45 traders were interviewed (Table 6.1). The major markets in Teso sub-region were Ochorimogin, Toroma, Acowa and Abarilela. Adjumani town council and Dzaipi were main markets in west Nile sub-region. Traders also reported existence of other formal and informal markets where they sold their products. Some of the informal markets included, town streets and outskirts, refugee or internally displaced peoples' camps, along highways and at landing sites. The products were reported to be sold in most weekly markets in the two sub-regions which mainly fell on Monday, Wednesday and Saturday (Figure 6.2).

Table 6.1 Markets covered in the different districts (n=45)

Sub-region	Market	Market days per week	Number of traders interviewed
Teso	Ochorimongin	1	6
	Toroma	2	6
	Ajelena	1	4
	Acuna	1	1
	Usuk Town council	1	4
	Abarilela	1	9
	Acowa	1	4
West Nile	Adjumani Town council	7	5
	Dzaipi	3	2
	Laropi	1	2
	Metu	3	2

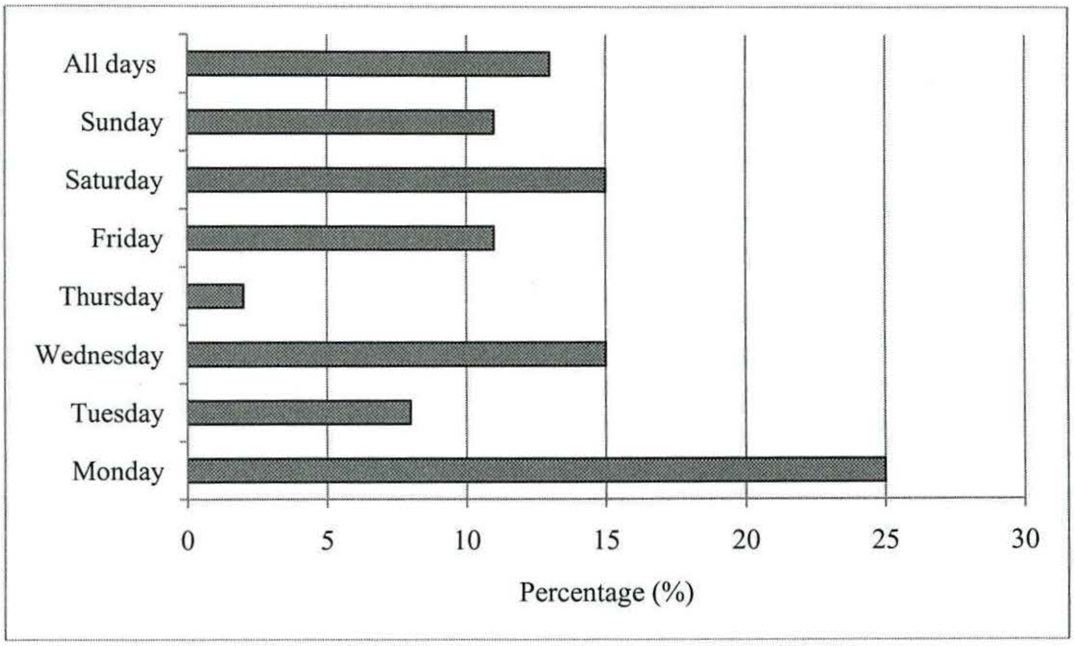


Figure 6.2 Market days in a week in Adjumani and Katakwi

Results presented in Table 6.2 show that, a majority (87%) of traders were female and represented different age groups. About 49% of the traders were married while those who were single and widowed were 27% and 22%, respectively. They generally attained low level of education with most (58%) having attained primary level and the rest (42%) with no formal education. About 60% of the traders come from large families (7 - 15 people) and were generally poor with 87% of them earning less than 1US$ per day.

Table 6.2 Characteristics of Balanites products traders

Variable	*% response*
Sex	
Female	86.7
Male	13.3
Age (years)	
< 20	20.0
20-35	37.8
36 - 50	26.7
> 50	15.6
Marital status	
Single	26.7
Married	48.9
Separated	2.2
Widowed	22.2
Education level	
No formal education	42.2
Primary	57.8
Family size (number of people)	
< 4	4.4
3-6	35.6
7-10	44.4
10-15	15.5
Annual household cash income (UGX)*	
<200,000 (USD 100)	40.0
200,000 - 400,000 (USD 100 – 200)	46.7
> 400,000 (USD > 200)	13.3

**1 USD = 2,000 UGX*

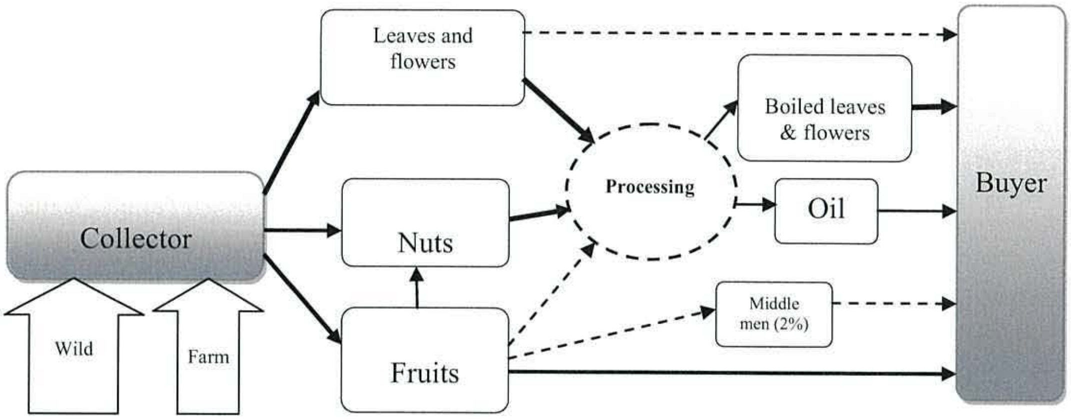
6.4.2.2 Marketing chain for Balanites products

The main Balanites products traded were leaves (67%) and fruits (30%) while oil was only traded at very low level (4.4%). All the traders operated at retail level. According to the traders, the main source of Balanites products was wild (89%) while only 11% came from trees retained on farms. Besides Balanites products, traders also sold other local vegetables, tamarind fruits, shea nuts and butter and mangoes. For a majority (82%), the distance to the market was less than 4 km, however there were some (9%) who travel 10 – 15 km to access markets (Table 6.3).

Table 6.3.Trading activities

Variable	% response
Balanites product sold	
Leaves	66.7
Fruits	28.9
Oil	4.4
Acquisition of Balanites products sold	
Collected	97.8
Bought (middle man)	2.2
Source of Balanites products	
Wild	88.9
Farm	11.1
Other products sold	
None (Balanites product only)	46.7
Local vegetables	31.1
Tamarind	8.9
Shea nuts	8.9
Mangoes	2.2
Shea butter	2.2
Distance to market (km)	
< 4	82.4
4 - 9	8.8
10 - 15	8.8

In both Teso and West Nile sub-regions, the marketing chain for Balanites products (Figure 6.3) was generally very short. A majority (98%) of traders were themselves collectors and/or processors. Only a few (2%) of the traders were middle men who bought Balanites products from collectors for retail sale to consumers. Even in such cases, the suppliers always had a close link with the middlemen, for instance, they resided in the same village, were extended family members or friends. Supply was dominated by women and children. Consequently, women were more knowledgeable about Balanites products value chain than their male counterparts. Whereas, Balanites fruits were consumed in Teso sub-region, there was no record of their trade. Oil was processed and sold in West Nile sub-region, but as its production was low and it was sold within the village or nearest trading centers, as such, it was difficult to capture information on its marketing.



Dotted arrows represent weak links

Collection, processing and marketing were all done by the same households

Figure 6.3 Marketing chain for Balanites products in Uganda

Unsold fruits were processed into nuts by maceration using water and dried for kernel extraction. Fruit buyers consisted of women (39%), girls (30%) and boys (23%) while women (40%), men (26%) and boys (20%) were the main leaf buyers (Figure 6.4).

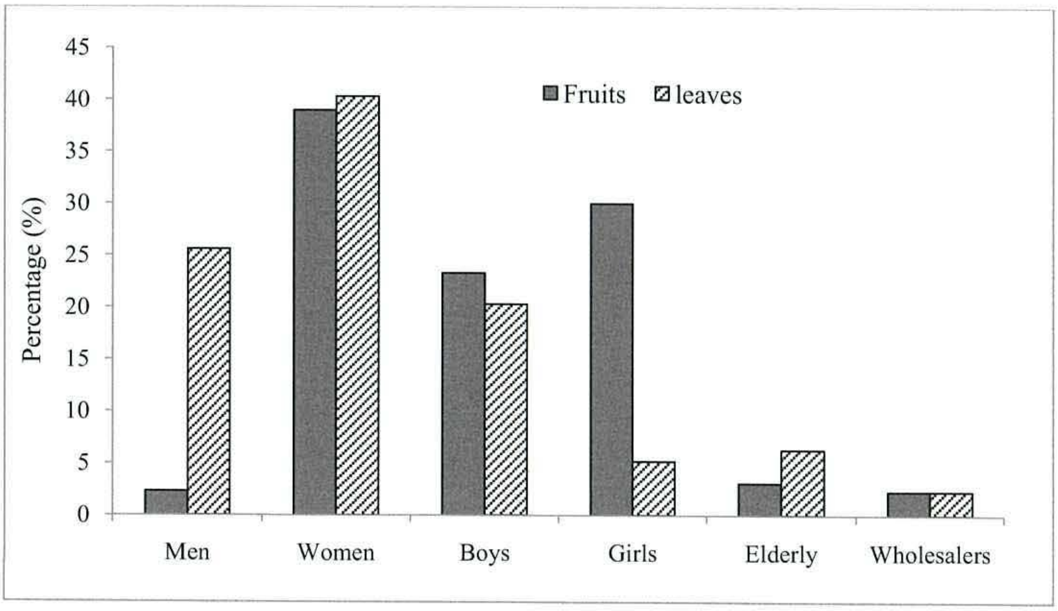


Figure 6.4 Balanites fruit and leaf buyers

Many traders were recent entrants but some reported having started selling Balanites products as early as 1980. There was generally an increasing number of traders who joined the trade from 2003 to 2009 (Figure 6.5).

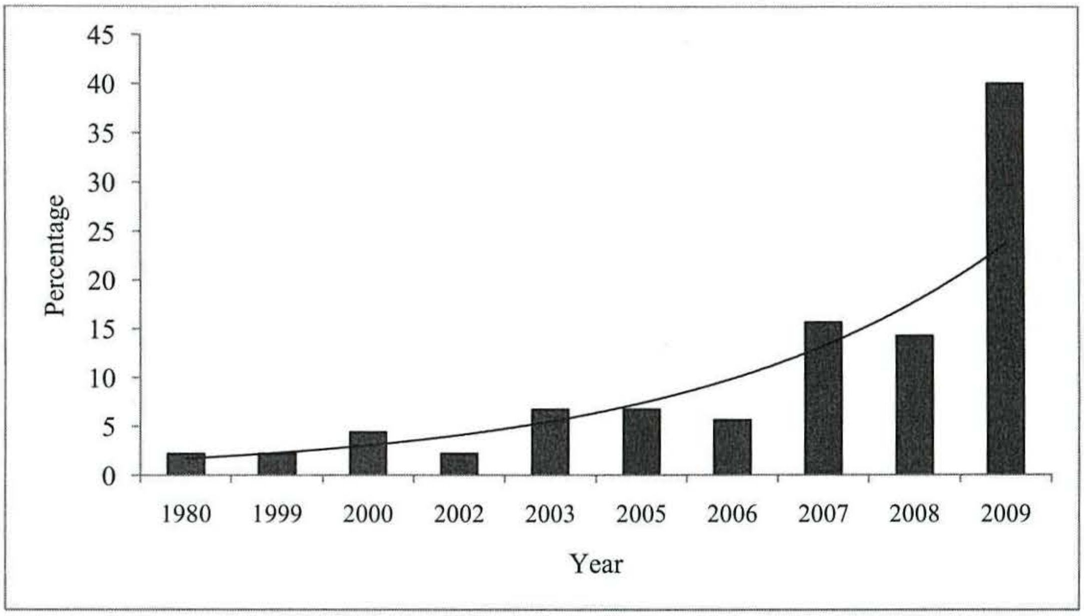


Figure 6.5 Year when started selling Balanites

6.4.2.3 Pricing and pre-sale activities

Pricing: Average selling prices for Balanites leaves and fruits were reported to have steadily increased from 2006 – 2009 (Figure 6.6). A kilogram of leaves in Teso sub-region rose from average price of UGX 174 in 2006 to UGX 400 in 2009 (1 US $ = 2,000 UGX). Similarly the average price for one kilogram of fruits in west Nile sub-region increased from UGX 160 in 2006 to 280 in 2009. Average price per litre of Balanites oil in West Nile rose from UGX 2,000 in 2006 to UGX 3,500 in 2009 (Figure 6.7).

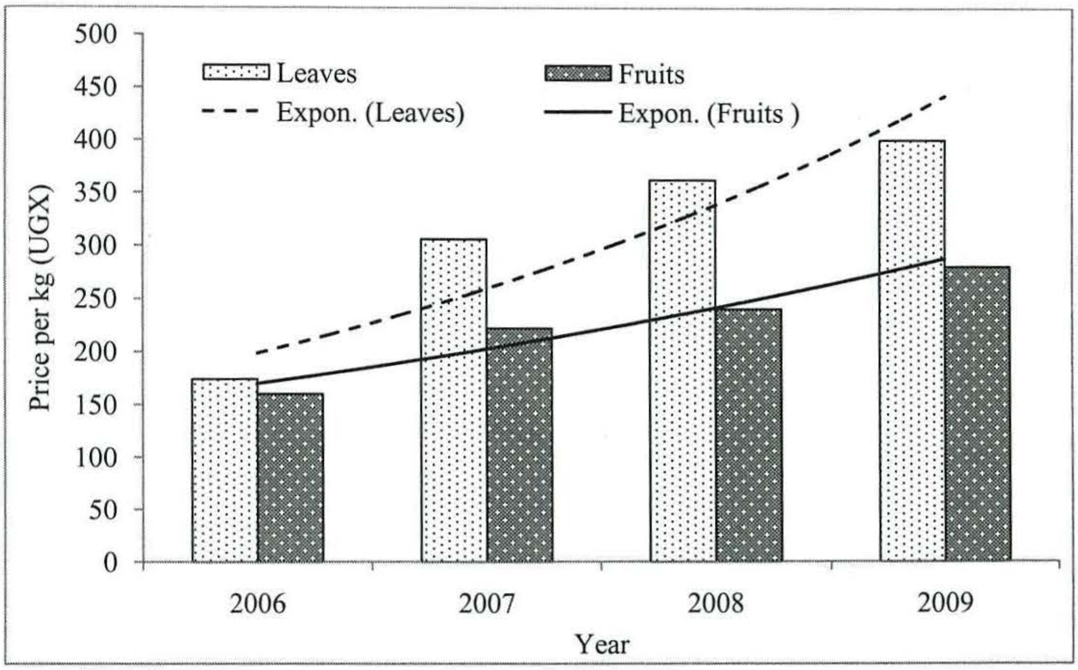


Figure 6.6 Average prices for Balanites leaves and fruits from 2006 to 2009

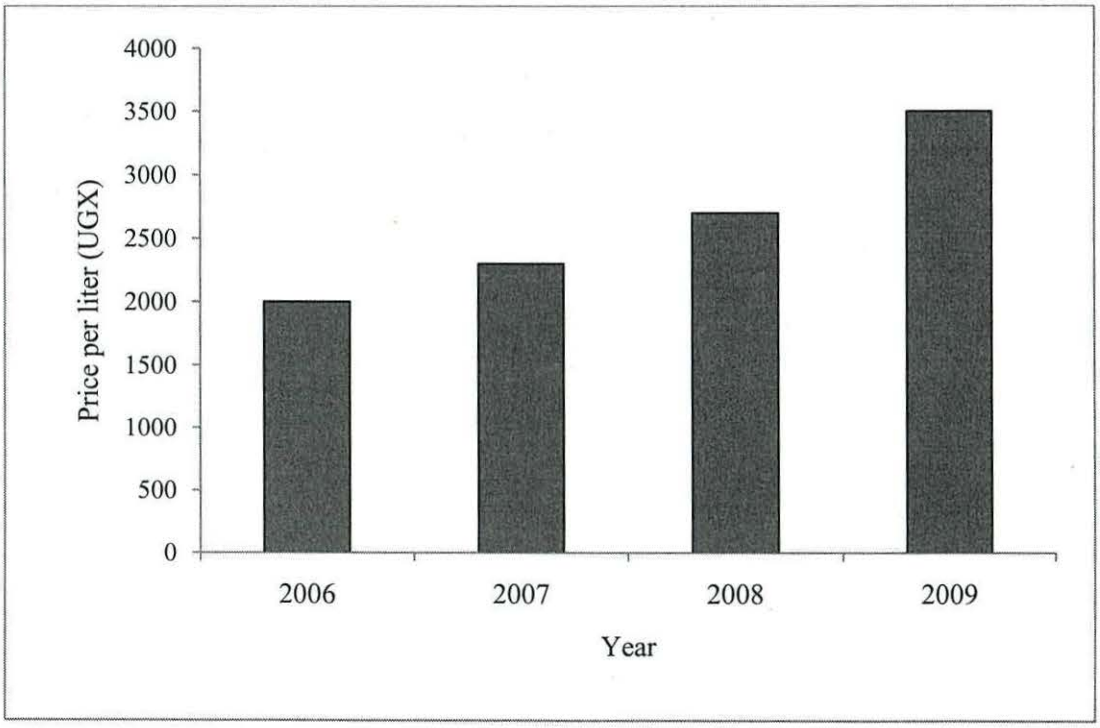


Figure 6.7 Increase in average price of Balanites oil from 2006 to 2009

Leaves and fruits were always tasted before being bought. The number of leaves given for testing ranged from 5 – 20 with mean of nine (Plate 6.4). Fewer fruits 2 – 4 (mean = 3) were allowed for tasting. Tasting was reported to result in losses since some market goers would only be interested in tasting without intentions of buying. Leaves were tasted for their readiness and level of bitterness. Soft or well boiled and sweet leaves were always preferred. Leaves with such attributes were reported to sell faster while hard and bitter leaves would sell slowly and were sometimes rejected by buyers, especially when there is plentiful supply. Fruits were tasted for ease of epicarp removal (peeling), freshness and sweetness of the pulp. Buyers were reported to prefer fruits that are easy to peel (by hand), with fresh pulp and sweet-bitter taste. Oil with pleasant smell and yellowish colour was preferred.

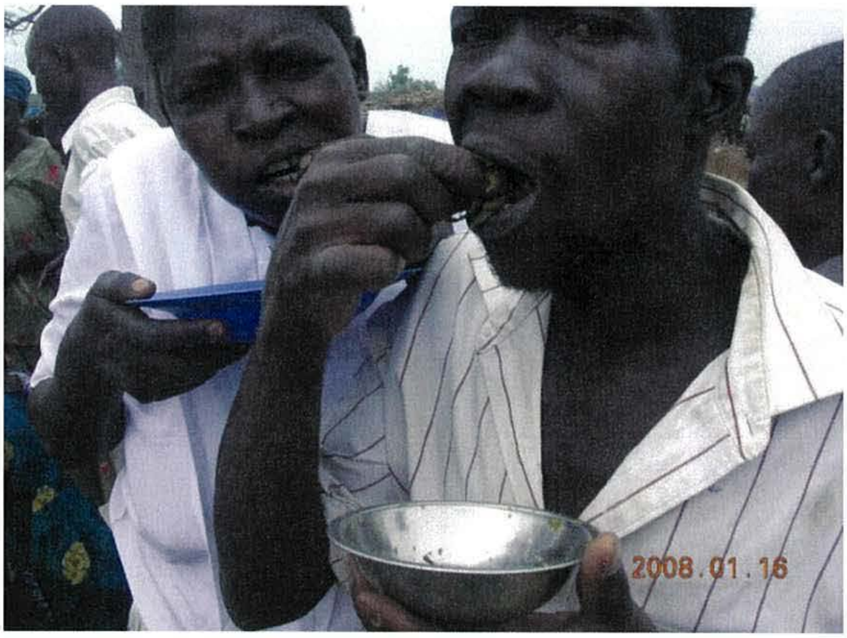


Plate 6.4 Testing Balanites leaves before buying in a local market, Katakwi district

Many (63%) traders reported selling all the fruits or leaves taken to the market even during peak season while 37% reported failing to sell some products during this season. This was attributed to plentiful supply since any member of the community was free to collect and sell the products. The method of payment was mainly cash (86%) although in a few instances products were reportedly bartered for food (13%). About 33% of the traders reported having sold less than 10% of their Balanites products on credit, nonetheless, the same price (92%) was used for credit sales. However, credit was only allowed when selling to known customers, especially residents of the same village, neighbours, friends and kin.

Prices for Balanites products were determined on the basis of previous season prices, demand for the product and quality of product supplied to a particular market (Figure 6.8). Many (67%) traders claimed not to be knowledgeable about the prices of respective products in other areas or markets while only 33% reported to be knowledgeable.

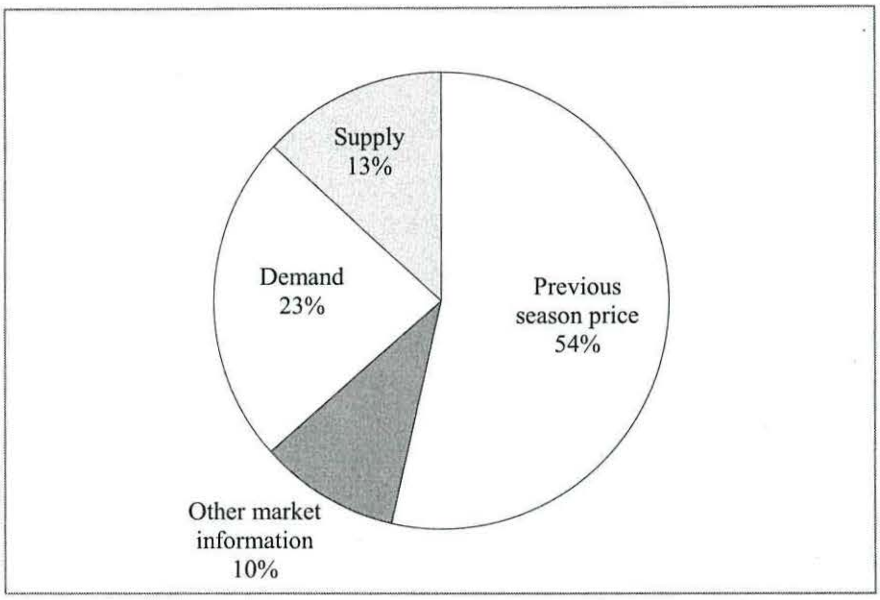


Figure 6.8 Price determinants for traded Balanites products

Pre-sale activities: Nearly all traders (95%) in Teso sub-region boiled Balanites leaves before selling (Plate 6.5). In West Nile sub-region, many (71%) traders reported conducting some pre-sale activities on Balanites fruits while some (29%) did not carry out any such activities. Pre-sale activities for fruits involved sorting (93%), washing (22%) and packing (6%). There was no price differentiation based on pre-sale activities, however, these activities were mainly carried out to; attract buyers (77%) and earn more money (26%). Fruit sellers who did not carry out pre-sale activities reasoned that such activities were; time wasting (60%) and not necessary (40%) since the fruits were already considered to be clean.

Plate 6.5 Boiled Balanites leaves being sold in a local market, Katakwi district, Uganda

Storage, shelf life and transport: A majority (93%) of the traders did not store Balanites leaves after initial boiling while a few (7%) stored them. On the other hand, 90% of the traders stored fruits while the remaining 10% delivered it to the market soon after collection. Table 6.4 shows the materials used for fruit and leaf storage. Fruits were mainly stored in basins and sacks while cooking pots and polyethylene bags were used for leaf storage.

Table 6.4 Materials used for storing Balanites leaves and fruits

Material	Leaves	fruits
Cooking pot	42.9	-
Polyethylene bag	28.6	-
Bucket	14.3	-
Sack	14.3	36.4
Basin	-	54.5
Basket	-	9.1

All the traders reported the shelf life for leaves to be short (2 days maximum) while fruits were noted to store safely for 4 – 7 days. Traders reported that the shelf life for leaves could be increased by washing (34%) and keeping on a little fire (22%). Other measures included refrigeration, storing in cold water, drying and keeping in air-tight containers (each 11%). Fruit shelf life was reported to be increased by storing in a cold place (57%) and sprinkling some water (43%). The main storage problems were the perishability of the products (79%), rodents (16%) and lack of storage materials (15%).

The commonly used means for transporting leaves and fruits to markets was head load (79%), while some (16%) used bicycles and only 5% used vehicles (Figure 6.9). Traders could not readily establish the cost of transport and many (70%) considered it to be negligible. However, further investigation revealed that traders' transport costs varied between UGX 1,000 – 2,000 (mean = UGX 1,500). Many (65%) of the traders claimed receiving market information relating to prices (71%) and product demand (29%) from neighbours who regularly visit markets.

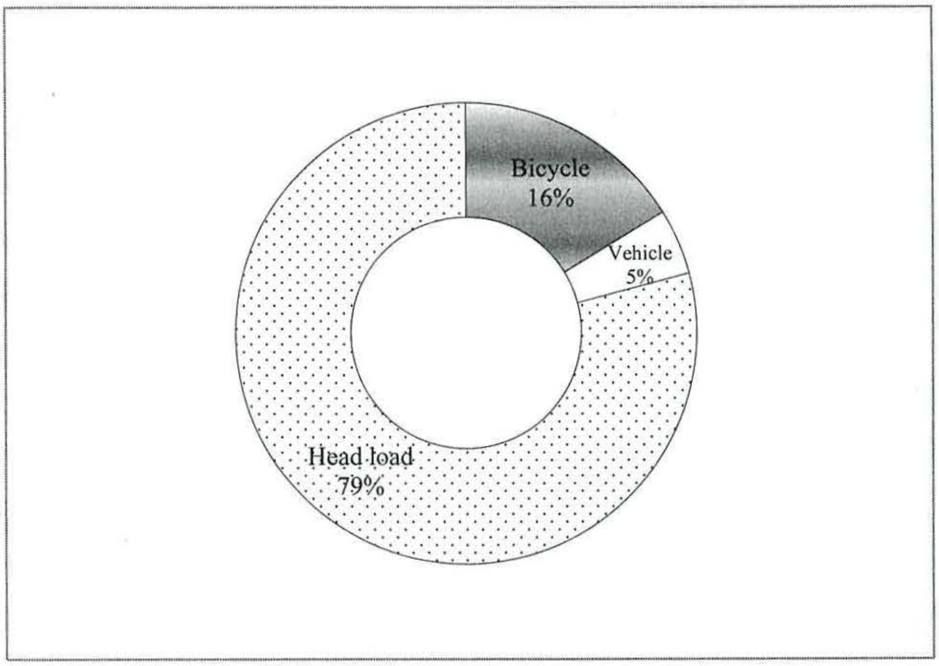


Figure 6.9.Means of transporting Balanites fruits and leaves to markets

6.4.2.4 Marketing costs and profit margins

Expenses paid at the market included; market fee (77.8%) and sweeping charge (31%). The daily total market expense was UGX 100 – 500 (mean = 200), depending on quantity of the product brought for sale. Leaf Sellers reported earning UGX 1,200 – 5,000 per market day while fruit sellers earned UGX 1,000 – 4,000 per market day. Conversely, both leaf and fruit sellers earned an average of UGX 3,000 per market day. Oil sellers received slightly higher returns of about UGX 5,000 per day (Table 6.5). However, oil was mainly sold at homes with unpredictable production and high demand within villages. Oil sellers claimed to earn an average of UGX 36,000 per year while leaf and fruit sellers earned an average of UGX 92,000 and 48,000, respectively (Table 6.6).

Table 6.5 Profit margins for Balanites products per market day

Product	Quantity	Unit price (UGX)	Costs (UGX)		Income (UGX)	
			Production & transport costs	Market expenses	Total	Net (profit)
Leaves	12 kg	400	1,500	300	4,800	3,000
Fruits	15 kg	280	1,000	200	4,200	3,000
Oil	2 litres	3,500	2,000	-	7,000	5,000

Table 6.6 Seasonal profit margins for Balanites products

Product	Qty sold/ season	Unit price (UGX)	Total income (UGX)	Total expenses (UGX)	Net income (profit)	
					UGX	US$
Leaves	240 kg	400	96,000	4,000	92,000	46
Fruits	180 kg	280	50,400	2,400	48,000	24
Oil	12 litres	3,500	42,000	6,000	36,000	18

Exchange rate: 1 USD = 2,000 UGX

Assumptions:
Leaves sold for five months a year
Fruits sold for 3 months a year
Four market days per month (once a week) for leaves and fruits
Oil is mainly sold in homes

Income received from sale of Balanites products was used for purchase of basic non-consumables (47%), food (36%), scholastic materials (12%) and health (5%). Some of the traders always sold other items alongside Balanites products, and these included; agricultural produce 72%, other wild fruits and vegetables (14%) livestock products (12% and fish (2%). All the traders reported spending 10 – 30% of their time on selling Balanites products.

6.4.2.5 Marketing opportunities and perceptions

Demand and supply: A number of demand and supply opportunities were reported to exist for both fruits and leaves. On the demand side, both fruits and leaves were reported to have willing buyers (73% and 69%, respectively). Other demand opportunities were; availability of the products during dry season, recurrent droughts and famine in the areas and medicinal values of the products. Conversely, the supply opportunity for both products was the abundance of trees in the wild (84% and 70% for fruits and leaves, respectively). In addition, increasing human population, product abundance at the peak of dry season and limited number of collectors/traders were considered to be supply opportunities. Much as oil was not commonly traded in markets, the same opportunities were reported to be applicable to its trade.

Perceptions and opinions: About 58% of the traders considered Balanites trees to be abundant in their localities while 42% thought the trees had become scarce. Many (78%) perceive selling of Balanites products to be worthwhile while a few (22%) were indifferent. According to the traders, the main challenges in selling Balanites products included; limited market information, lack of appropriate technology for processing and value addition, un-organised market and limited awareness on the nutritional values of the products (Table 6.7).

Table 6.7 Challenges in marketing Balanites

Challenges	Percent of Cases
Limited market information	66.7
Lack of appropriate technology for processing & value addition	64.4
Un-organized market structure	57.8
Low supply of the fruits/oil/leaves in some seasons	48.9
Limited knowledge of nutritional values of products	51.1
Low prices	15.6
Product perishablity	4.4
Long distances to the markets	2.2

6.4.2.6 Characteristics of Balanites products buyers

A total of 50 buyers with an equal number of males and females were interviewed in market settings across the two study sub-regions. About half of the buyers were aged 20 – 40 years and were mostly married (70%). Twenty percent of them had no formal education and only 10% had attained tertiary level of education while the rest attained primary and secondary education. Many (66%) traders obtained total cash income of less than UGX 400,000 (US$ 2,000) (Table 6.8).

Table 6.8 Characteristics of Balanites products buyers

Variable	Percentage
Sex	
Male	50
Female	50
Age	
< 20	6
20-40	50
> 40	44
Marital status	
Single	14
Married	70
Widowed	16
Education level	
No formal education	20
Primary	44
Secondary	26
Tertiary	10
Annual cash income(UGX)	
< 200,000	22
200,000 - 400,000	44
> 400,000	32

Exchange rate: 1US$ = UGX 2,000

6.4.2.7 Reasons for buying Balanites products

The main Balanites products bought in markets were leaves and fruits. Oil was reported to be rare in markets as it was always bought direct from producing households. The demand for oil was noted to be high but with limited production capacity. Reasons for buying Balanites products varied and depended on a given product. However, leaves, fruits and oil were commonly bought because of their ready availability during the dry season (77%), they were considered to be cheaper than exotics (75%), their long usage in the area (63%) and were perceived to be nutritious (58%). In addition, fruits were considered to be a good snack (92%). Most (80%) buyers in Teso sub-region highly regarded Balanites leaves as a traditional vegetable for the Iteso people while the oil was highly regarded among the Madi people in West Nile sub-region. Some buyers expressed that "our ancestors depended on these leaves/oil which means they must be good for us too". Buyers generally required; sweet and soft leaves, sweet and more fleshy fruits, and yellow and clear oil.

The products were generally bought once a week (in weekly markets) except in urban centres where they were available for 2 - 3 days a week. Many (71%) consumers bought leaves once weekly while the rest bought it 2 - 3 times a week. Most (85%) consumers bought 1kg of fruits per week, while 15% bought 1.5 – 2 kg of leaves per week.

6.4.2.8 Attributes considered when buying Balanites fruits and leaves

Several attributes were considered when buying fruits and leaves (Figure 6.10). However, the major attributes considered were price (97%), taste (92%), cleanliness (89%), colour (78%) appearance (77%) and size (71%). Packaging and grading, respectively were the least considered attributes. When these attributes were ranked, taste, cleanliness and price, respectively were considered to be very important (Table 6.9).

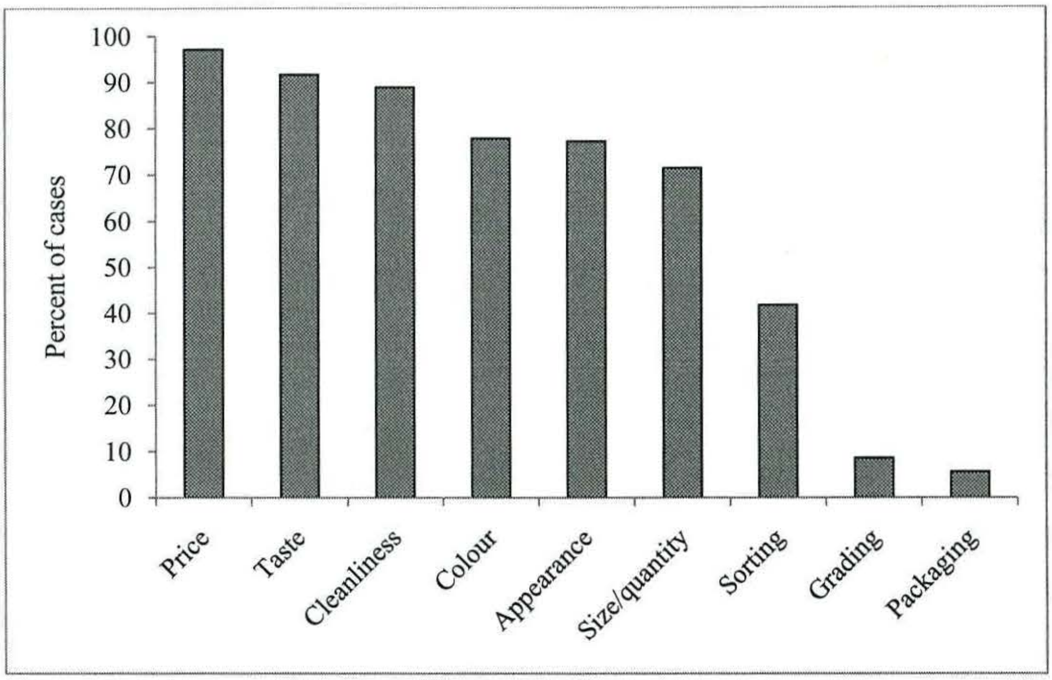


Figure 6.10 Attributes considered when buying Balanites leaves and fruits

Table 6.9 Relative importance of attributes considered when buying Balanites leaves and fruits

Attribute	Very important	Somewhat important	Not important	Not sure
Size/quantity	51.5	27.3	12.1	9.1
Colour	51.4	31.4	11.4	5.7
Taste	88.9	8.3	2.8	-
Price	73.5	20.6	2.9	2.9
Cleanliness	84.4	3.1	3.1	9.3
Appearance	41.9	41.9	6.5	9.7
Sorting	14.8	59.3	22.2	3.7
Grading	7.1	46.4	39.3	7.1
Packaging	59.3	37.0	3.3	-

Table 6.10 summarises the buyers' preference indices for the various fruit, oil and leaf attributes. Buyers generally preferred bigger sized fruits that are yellowish in colour. Packaging was also desirable to some extent while sorting and grading were on the border line between agreement and disagreement. Yellow oil packed in transparent containers was preferred while there appeared to be contention between locally processed and machine pressed oil. Green cooked leaves were preferred while dry, crushed and packed leaves were unpopular to buyers.

Table 6.10 Buyers' preferences for Balanites products in Teso and west Nile sub-regions

Preference	Preference index					
	Strongly Agree	Agree	Partly Agree/ Disagree	Don't Agree	Strongly Disagree	No Answer
(a) Fruits (West Nile & Teso)						
Big sized fruits against small sized fruits	18.0	55.0	-	-	-	-
Yellowish fruits against brownish ones	60.0	20.0	-	-	-	-
Packed fruits against un-packed ones	12.0	30.0	16.0	3.0	-	1.0
Sorted fruits against un-sorted ones	24.0	5.0	28.0	3.0	-	1.0
Graded fruits against un-graded ones	-	5.4	38.8	3.2	-	2.2
(b) Oil (West Nile)						
Yellowish oil opposed to blackish oil	71.1	10.8	-	-	-	-
Oil packed in transparent container opposed to packed in opaque container	12.9	48.4	8.6	-	-	-
Locally processed oil opposed to machine processed oil	-	16.2	34.4	3.2	2.2	-
(c) Leaves (Teso)						
Green leaves as opposed to yellowish leaves	71.9	21.8	8.8	22.9	19.7	-
Cooked leaves as opposed to raw ones	158.8	37.1	4.2	-	-	-
Dried, crushed & packed leaf powder as opposed to fresh un-packed leaves	12.7	15.8	8.5	44.5	27.5	-

Indices calculated based on the Likert scale (frequency x preference score)

6.4.2.9 Buyers' willing to pay for Balanites products

Buyers considered the normal price for a plate (0.5 kg) of leaves to be UGX 185. A price of UGX 167 was considered cheap while that of UGX 314 was assumed to be expensive. Similarly, a cup of fruits (0.5 kg) was considered normal, cheap or expensive if it cost UGX 100, 85 or 145, respectively. On the other hand, a bottle (0.5 l) of oil was considered cheap at UGX 1,165 and expensive at UGX 2,904 (Table 6.11). Many buyers expressed willingness to pay an expensive price for leaves (79%) and oil (50%). There was however, a reduced willingness to pay an increased price for fruits (Figure 6.11).

Table 6.11 Buyers perceptions on prices of Balanites products

Unit and Product	Price UGX		
	Normal	Cheap	Expensive
Leaves (0.5kg = plate)	185±34	167±43	314±55
Fruits (0.5kg = cup)	100±2	85±35	145±41
Oil (0.5 l = bottle)	1,962±262	1,165±176	2,904±582

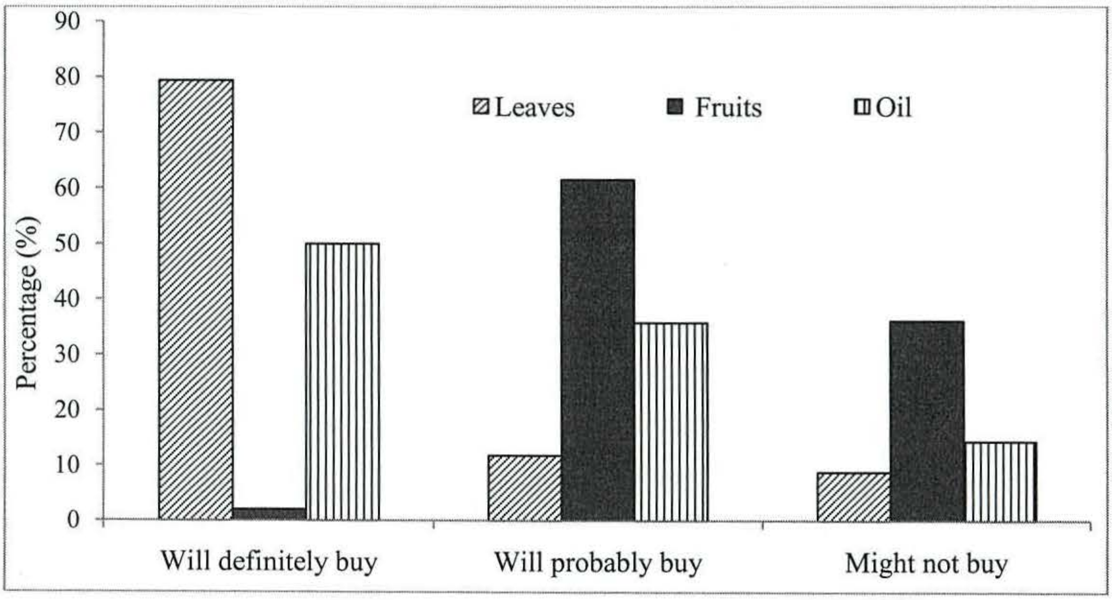


Figure 6.11.Buyers willingness to pay an expensive price for Balanites products

6.4.3 Policy related opportunities and constraints for commercialization of Balanites products

The policy assessment involved 45 out of the targeted 60 respondents (75% response). These were comprised of; Local Councils (LC1-3), sub-county and parish chiefs, sub-county extension staff, district secretaries for production, LC5 councillors, district Forestry, Environment and Wetland officers, and district natural resources coordinators. Most (75%) of the respondents were male and were aged 20 - 40 years.

6.4.3.1 Regulations on IFTs and their enforcement

Results in Table 6.12 show that, 62% of the respondents reported existence of some regulations regarding IFTs and these mainly seek to prevent destruction of IFTs either by cutting or bush fires, and ensuring that those cut are replaced by planting two or more trees. Other regulations reported by some respondents included; a need to seek for permission from local authorities before cutting IFTs, collection of fruits from own trees and collection of only ripe fruits from trees found in communal lands. The set of regulations varied from one administrative locality to another. These regulations were mainly aimed at protection of IFTs and protecting the environment in general. Regulations were reported to have generally led to the reduced cutting of IFTs and motivated some farmers to retain useful IFTs on their farms.

The major enforcers of IFTs regulations were local councils, sub-county administration (sub-county and parish chiefs), district forestry and environment office, local councils and clan leaders (Figure 6. 12). The common actions taken against offenders included; being fined, arrested and detained for a short time (<48 hours) and cautioning. Fines charged ranged from cash payments (79%) to tree planting (16%) and payment of goats/chicken (11%). These fines were determined by local environment committees (52.6%), sub-county or parish chiefs (52.6%) and local council committees (36.8%). Fines were mainly determined based on extent of damage (number of trees cut), income and physical ability of the offender and the tree attributes, including its type and size (Table 6.13). Collections from fines were either given to elders or used to implement some community activities, such as cleaning a water source.

Table 6.12 Regulation on IFTs

Variable	Percent (%)
Are there regulations on IFTs?	
Yes	62.2
No	37.8
Regulations on IFTs	
No cutting of IFTs	82.9
Plant two or more before cutting one	60.7
No bush burning	25.0
Seek permission from local authorities before cutting	15.6
Collect from own trees	10.0
Collect only ripe fruits	9.6
Aim of IFTs regulations	
Protection of trees	54.2
Environmental protection	41.7
Revenue generation	4.2
Effects of regulations	
Reduced cutting of IFTs	77.3
IFTs retained on farms	13.6
Scarcity of fuelwood	9.1
Some planting of IFTs	9.0

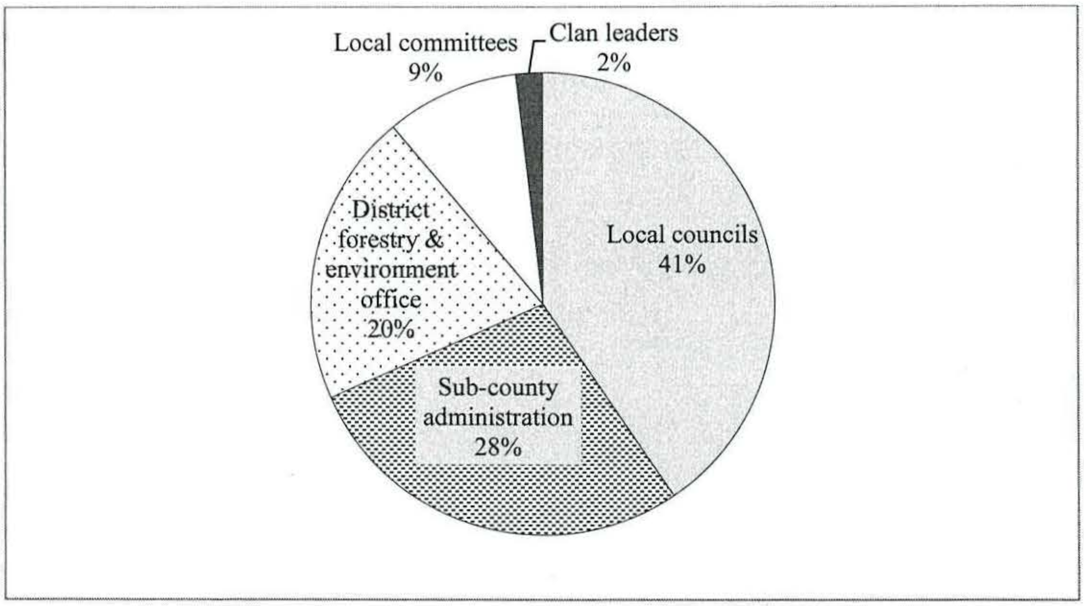


Figure 6. 12 Regulations enforcement organs

Table 6.13 Action against offenders and fines

Variable	Percent (%)
Actions taken against offenders	
Fined	63.0
Arrested and detained	33.3
cautioned	3.7
Kinds of fines	
Cash payments	79.2
Planting trees	15.8
Goats/chicken	10.5
Who determines fines? (% of cases)	
Local environment committees	52.6
Sub-county or parish chiefs	52.6
Local council committees	36.8
Determination of fines (% of cases)	
Extent of destruction (number of trees cut)	50.0
Income and ability of offender	27.8
Size of tree cut	16.7
Type of tree cut	16.7

Many (58%) respondents reported sensitisation as top role of the district and sub-county councils. However, their other roles included; passing of by-laws (25%), law enforcement (8%) and supporting tree planting activities (8%) (Figure 6.13).

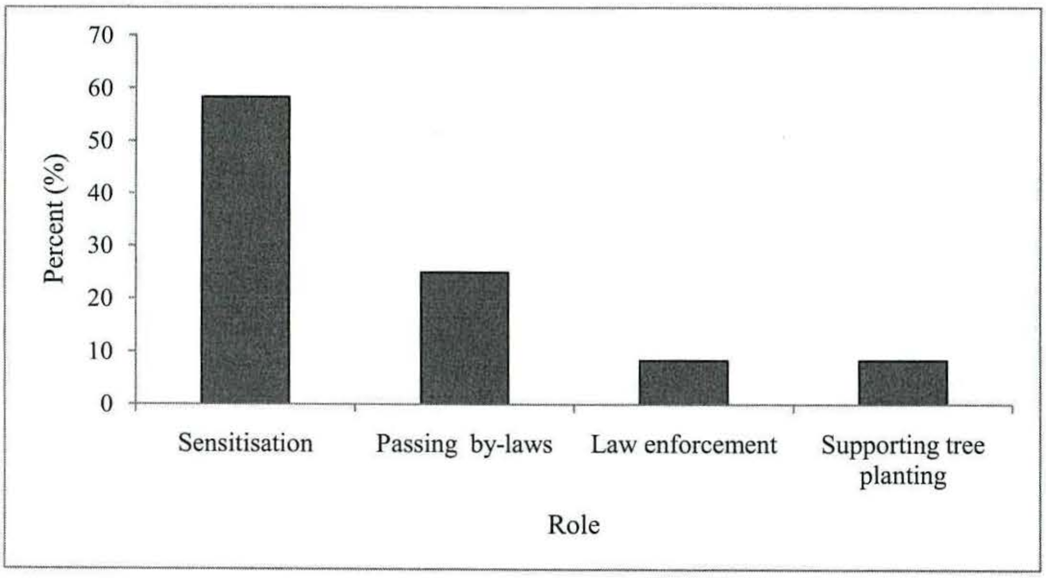


Figure 6.13 Role of district and sub-county councils

A majority (85%) of local leaders reported challenges in enforcing IFTs regulations. The key challenge was the high poverty levels (70.3%) while others included; lack of appropriate by-laws, limited enforcement capacity, limited sensitisation, agricultural expansion and unsecure land tenure in areas where IFTs are found (Table 6.14).

Table 6.14 Regulations on IFTs and their enforcement

Challenges in enforcing regulations	Percentage of cases (%)
High poverty levels	70.3
Lack of appropriate by-laws	60.4
Limited enforcement capacity	45.4
Limited sensitisation	40.6
Agricultural expansion	35.6
Unsecure land tenure	33.8

6.4.3.2 Local leaders' opinions and attitudes towards IFTs trade

A majority (88%) of the leaders interviewed perceived trade in Balanites and other IFTs to be worthwhile while only 11.6% were indifferent in opinion. However, more than half (55.6%) perceived Balanites trees to be becoming scarce in their localities while 44.4% reported that the trees were still abundant and could support increased trading activities.

The main constraints faced by people selling Balanites and other IFTs products included; un-organised market, lack of appropriate processing technology, limited market information, limited awareness on nutritional benefits of products (on the part of buyers) and poor access to urban markets given the remote locations of producing areas (Table 6.15). Against this background, local leaders strongly supported the idea of supporting farmers to plant selected IFTs including Balanites. They also supported establishment of community groups through which people engaged in collection, processing and marketing of IFTs products can be helped (Table 6.16).

Table 6.15 Constraints facing Balanites products trader as perceived by local leaders

Constraint	Percent of cases (%)
Un-organized market structure	95.6
Lack of appropriate processing technology	75.6
Limited market information	68.9
Buyers' limited knowledge on products' nutritional benefits	57.8
Poor access to urban markets	50.4
Low quantity of products supplied	42.2
Low prices/poor buyers attitude	17.8
Lack of storage facilities in markets	11.1
Seasonality of products	2.2
Accidents during harvesting	2.2

Table 6.16 Local leaders' opinions and attitude on IFTs

Statement	Attitude index					
	Strongly Agree	Agree	Partly Agree/ Disagree	Don't Agree	Strongly Disagree	No Answer
Farmers should plant Balanites or other IFTs for commercial purposes	135	88	14	4	0	0
Establish groups which will collect, process and sell fruits & other products	156	75	12	3	0	0
Issue licenses to individuals and groups who collect, process & sell fruits and other products	36	30	44	42	14	1
Support farmers to plant selected indigenous trees for commercial purposes	174	65	12	0	0	0

Table 6.17 presents options recommended by local leaders to address constraints facing sellers of Balanites and other indigenous tree products. Many (67%) of the respondents recommended improvements in processing of Balanites products. More than half (51%) suggested a need to support local groups involved in processing and marketing of Balanites and other indigenous tree products. Other suggestions included; a need to determine the nutritional and medicinal

values of Balanites products, promote planting of Balanites, provide marketing infrastructure and carry out wide community sensitisation.

Table 6.17.Community leaders' suggestions for improvement of Balanites products trade

Suggestion	Percent of cases (%)
Improve processing/value addition	66.6
Support groups involved in processing & marketing	51.1
Determine nutritional & medicinal value	35.6
Plant more trees on-farms	24.4
Provide marketing infrastructure	28.9
Community sensitization	34.2

Opinion indices in Table 6.18 reveal that local leaders strongly agreed on continued trading in Balanites fruits and oil and a need to select and plant good quality trees for increased supply of products. They were in agreement on the need to sell fruits in both rural and urban markets. They also concurred that; selling of Balanites fruits and oil can improve rural livelihoods, sensitisation is important for improving marketing of fruits and the need for all people to use Balanites leaves, fruits and oil for health reasons (Table 6.18).

Table 6.18 Local leaders' opinions on marketing of Balanites fruits and oil in West Nile sub-region, Uganda

Statement	Opinion index					
	Strongly Agree	Agree	Partly Agree/ Disagree	Don't Agree	Strongly Disagree	No Answer
(a) Fruits						
Traders should continue selling Balanites fruits	59.3	16.5	-	2.5	-	-
Selling of Balanites fruits will improve rural livelihoods	26.2	43.8	-	2.6	-	-
Sensitisation is important to improving marketing of Balanites fruits	-	43.8	17.5	-	-	0.9
Balanites fruits should be sold in all markets (village and urban)	10.5	35.0	14.0	5.3	-	-
Balanites fruits should not be sold - God given	5.2	8.8	10.5	23.6	1.7	-
Good quality Balanites trees should be planted to increase fruit supply	28.0	32.7	7.4	2.8	-	-
Children and pregnant women should be encouraged to consume Balanites fruits for health reasons	11.2	42.0	7.4	2.8	-	0.9
All people should use Balanites fruits for health reasons	6.5	53.8	-	-	-	2.2
Exotic fruits are more beneficial for our health than indigenous fruits	6.5	-	4.3	32.3	2.2	-
(b) Oil						
Traders should continue selling Balanites oil	42.0	30.0	-	-	-	1.0
Selling of Balanites oil will improve rural livelihoods	33.6	32.7	7.4	-	-	-
sensitisation is important to improving marketing of Balanites oil	6.5	32.3	25.9	-	-	-
Balanites oil should be sold in all markets (village and urban)	12.9	43.1	12.9	-	-	-
Good quality Balanites trees should be planted to increase oil production	45.2	32.3	-	-	-	-
Factory refined oils are more beneficial for our health than locally made ones	-	-	8.6	32.3	-	1.1
All people need to use Balanites oil for health reasons	-	28.0	33.6	-	-	-

Indices calculated based on the Likert scale

6.5 Discussion

6.5.1 Local harvesting and processing of Balanites products

6.5.1.1 Leaf harvesting, preparation and storage

Balanites leaves and flowers were only harvested and processed in Teso sub-region. Harvesting was mostly done by women and children using simple tools such as a machete and an axe. This is different from the case of baobab in Ghana where men have been reported to play an active role in leaf harvesting while women processed and marketed the products (Kranjac-Berisavljevic *et al.*, 2009). Young leaves and flowers of Balanites have also been reported to be harvested and processed in Burkina Faso though no mention is made of the gender involved (Guinko and Pasgo, 1992). In this study, harvesters improvised ladders to access tall trees with straight boles. Tree climbing was noted to pose a serious problem to harvesters and cases of accidents, though rare, were reported. The thorny nature of the tree and presence of small black ants on trees increases risks associated with Balanites tree climbing. Harvesters therefore expressed a need to grow shorter trees to make leaf harvesting easier.

Whereas one could view Balanites collection as a labour demanding activity, the collectors reasoned that it was beneficial and economically viable considering that it took place during the peak of the dry season with no alternative vegetables and with no or minimal agricultural activities. This meant that Balanites leaf collection took place when most family labour would otherwise be redundant, thus justifying its use in leaf collection to provide leaf for home consumption and excess for sale. The women also asserted that leaf collection for sale did not require any capital, hence it was viewed to be attractive option for the poor to earn income during the dry season when alternatives are few. It was further reported that leaf collection was a more productive use of the otherwise redundant people who would otherwise engage in drinking or other unproductive activities. Children too valued Balanites leaf collection as a way of raising money to buy clothing and scholastic materials. It has been noted that since many NTFPs are seasonal, they are important to household subsistence because of when they appear in the diet. In Benin (Schreckenberg, 1996) reported that NTFPs were available during the dry and early rainy season or 'hunger period' when cultivated crops are in short supply. This therefore makes their collection worthwhile.

Women were skilful in leaf preparation and this knowledge was passed from mothers to children though boys were always reluctant in learning the process. According to the boys, leaf preparation falls within the domain of women and girls. This may be explained by the traditional set up of the Iteso people where cooking is generally considered to be a woman's role. Squeezing of excess water from leaves after boiling was considered important because leaves and flowers are always collected from several trees. Although there is selection for sweetness in the field some of the bitter leaves could still mix up thus this squeezing helps to minimize any bitterness which may have resulted by collection from various trees. Additional cold water was added to keep the leaves fresh and make them attractive to buyers.

Many reports on Balanites only report of leaves being eaten with no account of how they are collected and/or prepared (e.g. von Maydell, 1990, Hall and Walker, 1991; Cook *et al.*, 1998; NRC, 2008; Teklehaimanot, 2008). The local method for Balanites collection and preparation among the Iteso people in Uganda has been documented in the present study. Leaf preparation involved two stages of cooking (i) pre-boiling – prepared the leaves for marketing and shortened the final cooking process and (ii) pounding and final short cooking where pasted groundnuts or milk was used. Use of little or no salt at cooking further illustrates the technical details that local people have developed for preparation of Balanites leaves. Balanites leaves were eaten with variety of local foods making it an integral part of the dry season diet. There was however, very minimal storage of leaves (up to 2 days) and this limited their use to just within 2 – 3 days after boiling. It also meant that leaves could not be stored for later use during the early rain season when other green vegetables were still rare. There is a need to explore ways of drying leaves and flowers either just after picking or after boiling. Alternatively, they could be dried after pounding. Though communities in Teso are currently not used to dry Balanites leaves, it is possible to change attitudes over time through awareness campaigns.

Whereas Baobab leaves are reported to be processed and stored in powder form for use in dry season in West Africa (Maranz *et al.,* 2008), Balanites leaves in Uganda are only partially boiled and used or sold within 2-3 days. However, in northern Nigeria, Lockett *et al.* (2000) reported that the fruits, leaves and nuts of 'aduwa' Balanites were sun-dried and used as sweeteners, or eaten fresh during cattle herding activities, while leaves were also sun-dried, pounded into a fine powder, and used to thicken soups. Furthermore, Lockett *et al.* (2000) reported that Balanites seeds were sun-dried, made into flour and used to prepare porridge (*dawwa*) while oil was also extracted and used. Such innovative processing and use of Balanites products was found to be currently lacking in Uganda and yet this could help in extending product shelf life and facilitate access to distant markets. These examples could be borrowed so that women in Teso can be able to sell Balanites leaves over an extended period thus earning more income.

6.5.1.2 Fruit/nut collection

Fruits for sale were mainly collected from under trees after fruit fall. Whereas most collectors considered such fruits to be clean, they could be susceptible to insect attack, especially in cases where collection is delayed. This method of commercial collection called for more work in sorting the fruits since in most cases; both fresh and old fallen fruits were all collected. There is need to improve on the collection method to ensure cleanliness of fruits. In areas with more livestock, there was competition for fruits between animals and humans. Much as this is not currently a big problem, it is likely to create a conflict if the collectors were to increase the scale of their activities in the event of market expansion. Cases of these conflicts were witnessed in Nyeu village, Adjumani district, where herdsmen were refusing to allow women to collect fruits from Balanites trees close to their kraals. In the drylands of Uganda, animals (cattle, goats and sheep) are usually not put in enclosures during the dry season since there are no cultivated crops at this time. Interestingly, ripe Balanites fruits fell more at night and in this situation, women and children competed with animals for ripe fallen fruits in the morning.

Women expressed a desire to have control over Balanites and other fruit trees, especially, shea tree (*Vitellaria paradoxa*) and Tamarind tree (*Tamaridus indica*). They urged that control of such tree resources which make a contribution to their livelihoods would enable them to increase production of tree products and generate more income. Unlike the leaves which could only be stored for two days, Balanites fruits had a shelf life of five days under ordinary conditions which could be extended to seven days by dampening the storage conditions. Refrigeration extended shelf life to over three months. However, storage of fruits under both ordinary and refrigerated conditions made peeling difficult. In the latter case, the outer covering becomes more brittle while in the former it becomes hardened and sticks with the pulp. Under these circumstances, it becomes difficult to separate the shell from the pulp, hence affecting the quality of the pulp. Therefore, only short-term storage of unpeeled fruits is advisable – 4 and 7 days under ordinary and refrigerated conditions, respectively. If long-term storage is required, the fruits should be peeled when fresh and either sun-dried and kept in air-tight containers or kept under cold conditions. Some collectors stored peeled dry fruits but such fruits had low marketability due to uncertainty about the cleanliness of peeled dry fruits. There is therefore a need to explore ways of building customers' confidence in the fruit peeling and drying process. This was compounded by the fact that fruits were not packed but rather carried in bulk, thus increasing chances of contamination.

In cases where fruits were collected mainly for extraction of kennels used in oil extraction, they were immediately macerated in water. This required soaking the unpeeled fruits (10-15 minutes) and rubbing then between hands or with aid of rough surfaces. The resulting nuts were then rinsed with water and sun-dried. This was only done in cases where more quantities of nuts were required within a short time. The common method was to collect nuts from animal resting places or areas where they have been disposed after eating the pulp. In a few instances, fruits burnt by fire (nuts un-burnt) beneath the mother trees were also collected and used for kernel extraction. Processing of Balanites fruits in Nigeria involves soaking them in cold water for three days or hot water for a day and washing off the pulp to obtain the nut. The nut is sun-dried for two days if cold water was used and for eight hours if hot water was used to soak the fruit (Mamman *et al.,* 2005). In this study animals (cows, goats and sheep) were heavily relied upon to de-pulp Balanites fruits leaving nuts that were used to obtain kernels. Nut storage was constrained by borers that damaged the kernels thus, lowering their storage time to 2 - 4 months. However, treatment of nuts with ash and keeping them in airtight containers increased their storage time to about six months. Similar storage time has been reported for Balanites nuts elsewhere (von Maydell, 1990; Hall and Walker, 1991).

6.5.1.3 Oil processing

Balanites oil processing was dominated by elderly women in Adjumani and Moyo districts. The steps in oil extraction were found to be more or less similar to those used for local shea oil extraction (Mbaguinam *et al.,* 2007; Omujal, 2008). After nut collection, the seven steps used in local processing of Balanites oil included; (i) drying and sorting nuts, (ii) manual cracking of nuts to obtain seed kernels, (iii) sun drying kernels, (iv) pounding kernels, (v) roasting kernels, (vi) Grinding or further pounding of kernels, and (vii) oil extraction in boiling water (hot water floatation). However, some of the exceptions in Balanites oil extraction process were;

- Unlike the shea nuts that can be cracked by light beating with a stick or even pressing between thumb and fingers, Balanites nuts were reported to be much harder, thus, requiring use of two stones.
- After sun-drying (stage 3), Balanites kernels were immediately pounded unlike shea kernels that can be stored or even marketed in this state (Omujal, 2008). Storage of Balanites kernels for more than five days was reported to cause rancidity and decrease in oil yield.

The techniques used in local processing of Balanites oil in Uganda are in agreement with the principles of oil extraction reported by FAO (1992), involving (i) decortication or dehulling (separation of the oil bearing part), (ii) breaking of the oil bearing part (kernel) into smaller pieces by pounding in a pestle and mortar or by manual or motorized grinding (iii) heating the oil bearing material, sometimes with addition little water, to assist in the rupture of oil bearing cells and in the liberation of oil, and (iv) oil extraction. Hot water floatation is reported to be the simplest method used in oil extraction stage and is used in many rural areas (FAO, 1992). In this study, oil processors place ground Balanites kernels in boiling water and the contents are boiled while being stirred until the oil settles on top. On removing from the fire and cooling, the floating oil is skimmed off. However, the final stage of heating the oil in a shallow pan to drive off the last traces of water (FAO, 1992) was not performed by Balanites processors. This is reported to improve the keeping quality of the oil as water has a catalytic role in the development of rancidity in oils (FAO, 1992). Balanites processing communities in Uganda should therefore be made aware of the need to add this last step so as to improve the shelf life of locally processed oil. Despite the generally low extraction efficiency of the hot water floatation method due to the formation of oil-water emulsions which makes the final separation difficult (FAO, 1992), experienced Balanites oil processors in Adjumani reported 40% recovery. In some cases salt is used to break such emulsions. For the case of shea butter in Uganda, this traditional method has been improved with use of manual oil press. If Balanites nut cracking is improved, it is possible that the shea oil press can be used or adapted for its oil processing.

Lack of an appropriate equipment to crack Balanites nuts to obtain the oil-rich kernels is widely documented as a major limitation to their use and popularity (FAO, 1992; Mamman *et al.;* 2005; Aviara *et al.;* 2005 and NRC, 2008), In Nigeria, the manual method used for Balanites nut cracking is similar to that used in Uganda. It involves cracking nuts with stone on top of another stone or metal and it is very slow and risky (Mamman *et al.*, 2005). Likewise, the process used in local extraction of Balanites oil in Nigeria appears to be similar to that used in Uganda (Mamman *et al.* (2005). The kernel meal was heated in a pan or pot containing some water over an open fire. While the manual crackers in Uganda regarded the operation to require extra care to avoid smashing the kernel, Mamman *et al.* (2005) similarly reported damage of kernels if cracking force used in the prototype machine was too high.

In an attempt to develop an appropriate machine for cracking Balanites nuts, Mamman *et al.* (2005) investigated effect of moisture content and loading position on the mechanical properties of Balanites nuts. They found a decrease in the mechanical properties of the nuts with increase in moisture content. This was attributed to the fact that Balanites nut is spongy and being a biological material, it becomes weaker and easier to fail as its moisture content increases. This would suggest that, to save energy, the nuts should be cracked at high moisture content. However, nut cracking at high moisture content crushes 40% of the kernels into small pieces. They concluded that, since product quality is very important, the nuts should be cracked axially at low moisture content so that intact kernels can be obtained. Despite this study, no machine has so far been successfully designed for improved cracking of Balanites nuts. NRC (2008) notes that a design of such a machine still awaits discovery for the befit of dryland communities who depend on Balanites oil processing.

Balanites oil processing was restricted to older women while other family members regard it as having lower returns to labour. There was a unique case of a blind old woman in Nyeu Village, Adjumani district who was involved in Balanites oil processing as her major source of income. She relied on children to collect nuts which she stored in bulk. Difficulty in cracking Balanites nuts is a hindrance to large scale oil production, thus very little oil is processed though the demand is high. Mamman *et al.* (2005) also noted that the most difficult and risky aspect of all Balanites oil extraction operations was the cracking of the nuts to obtain the kernels.

6.5.2 Marketing of Balanites leaves, fruits and oil

6.5.2.1 Selling and buying

Trade in Balanites leaves was dominated by females (86%) with only 13% males who were always young boys. The buyers were however balanced between men and women. Biggest number of both sellers and buyers were married people with low education levels and low annual cash incomes. While this seems to imply an association between Balanites trade and such group of people in society, the data may be insufficient for making any strong deductions. However, the results provide an indication of an active trade in Balanites products in the two sub-regions of Uganda.

Balanites leaves and fruits were sold in both urban and local markets but oil was mainly sold from within the producing households. The biggest market in Teso sub-region is Ochorimongin located in Katakwi district. This is a weekly market and it attracted an average of 2,000 people on every market day. It had the largest number of Balanites leaf sellers. Besides, the established weekly markets and daily markets in urban centers, Balanites leaves in Teso and fruits in west Nile sub-regions were sold on a daily basis in various informal markets, such as road sides and town outskirts. There were also a number of weekly markets in various locations (sub-counties). This was favourable for selling and buying of Balanites leaves since buyers could obtain a consistent supply by visiting several markets depending on market days. It was however noted that products were not taken to markets outside the producing sub-regions. Ham *et al.* (2008) note that long market chains for indigenous fruits often consist of collectors, whole sellers, retailers and customers. In this study, there were generally no middle men since the collectors and processors were also retailers selling direct to the final consumers. The volume of the products marketed by each trader was also generally low.

According to Hughes and Haq (2003), farmers' profit on their fruits depends on whether they market the fruits themselves, or sell through an intermediary. Despite the disadvantages of intermediaries, Schreckenberg *et al.* (2000), note that their role is often very significant in assisting farmers to market their produce to distant markets since they can bulk the products. Some farmers or community groups may however make the decision not to sell their produce to an intermediary, but to market their own products. Rice (2002) gives a clear illustration of this among the Ikalahan people, in the Philippines who after producing quality jams and jellies from locally gathered wild fruits decided to sell their products in local towns through help of local university and business school. This example provides a lesson on how institutions can work with communities to improve their livelihoods through local level processing and marketing of indigenous fruits.

However, marketing of Balanites products was noted to be an important income generating activity. In both study areas, the products become available at the peak of the dry season making them highly demanded since there were limited alternatives. Selling of fruits was dominated by children since it required no processing. On the other hand, leaf and oil trading required experience in their processing. There is a great deal of evidence that commercialization of certain non timber forest products, including indigenous fruits and vegetables, is typically characterised by low thresholds of entry with respect to capital and skills, are particularly important for poor people (Falconer, 1990; Schreckenberg, 1996). Gondo *et al.* (2002) also acknowledge that because of little capital requirements, most poor people often take up trading in NTFPs as a source of livelihood.

Besides being readily available during the dry season, the buyers attached significance to Balanites products due to their long usage in the areas and they were generally considered to be cheaper then alternatives such as exotic fruits and vegetables. Balanites leaves were considered a traditional dish among the Iteso people in Teso-sub-region. On the other hand, oil was highly valued among the Madi people in west Nile sub-region. Such strong cultural attachments to Balanites products present an opportunity for development of Balanites products. It was thought that, if processing was improved, Balanites products could find ready markets in urban centres with many people originating from the producing sub-regions. This is similar to findings by Awono *et al.* (2002) who reported that the short shelf-life of the fruit is undoubtedly the single greatest constraint faced by domestic safou traders in Cameroon and made it almost impossible to get fruit to the potential markets in other towns within the country where residents originally from producing areas were based.

Unlike other local products in Uganda with some established marketing chain, such as shea butter/oil (Ferris *et al.*, 2001), marketing for Balanites was found to be largely undeveloped. In almost all cases, collectors and/or processors doubled as sellers and were mainly women and children. Ramadhani and Schmidt (2008) reported similar finding in their study of marketing of indigenous fruits in southern African. There were however some particular exceptions in southern Africa such as commercialisation of marula tree (*S. birrea*) products for manufacture of alcoholic drinks. Fruits in this study were sold with no or little value addition. Unlike in some West African countries where Balanites nuts have been reported to be traded in markets (Guinko and Pasgo, 1992), no trade in nuts was found in the current study. However, nuts were used for oil extraction.

6.5.2.2 Pre-sale activities and pricing

A majority (95%) of traders boiled leaves before marketing while only a few sorted and sometimes washed the fruits. This can be explained by the fact that leaf boiling is a long process, taking over two hours, hence buyers preferred half prepared leaves so as to shorten the final preparation before eating. On the other hand fruits were considered to be clean since they fell on grass under mother trees, thus needing no cleaning. A more elaborate processing was however used in Balanites oil extraction.

Prices may generally be set based on total cost incurred, demand and competition (Panigyrakis, 1997). Results of this study concur with those for indigenous fruits trade in southern Africa (Ham *et al.*, 2008) and western Africa (Tchoundjeu *et al.*, 2008) where there was no consistent mechanism used by traders to set market prices. Even the simple approach of adding profits to costs (Ham *et al.*, 2008) was not used by Balanites products traders in Uganda. However, the major determinants of the selling prices were previous season's prices and demand for the product. Traders did not seem to value their labour, including transport. All products were mainly sold on cash basis. In a few cases where credit was allowed, it was restricted to known individuals such as neighbours, friends and relatives. Ramadhani and Schmidt (2008) attributed such tendencies to prevalence of short-term and more or less random contacts between sellers and buyers.

6.5.2.3 Transport and marketing costs

For all tradable commodities, transportation plays an important role in marketing. It even becomes critical when products marketed are highly perishable, as is the case with Balanites leaves. According to Jain (2009) transportation facilitates quick linkage between the producer and the final consumer who may be located far away. Most (79%) traders transported products to the market by head load. The use of walking or head-loads was also reported to be the predominant means for transporting indigenous fruits to markets in rural parts of southern Africa (Kadzere *et al.*, 1998; Ramadhani, 2002). The cost of transport in the present study was estimated based on the distance to the market and average transport cost for such a distance on a hired bicycle. In most cases, Balanites sellers avoided any transport cost as they always preferred to walk. In some instances, they used family bicycles. This highlights the fact that sellers were poor and were always desperate to minimize costs so as to increase their income.

Besides transport, the other key marketing cost was market fee. In urban markets these fees were collected at the entrance and depended on the quantity of the products while in village markets, market fees were collected within the market. In both market types, average market fee for sellers of Balanites products was UGX 200. In some instances, sellers were also charged sweeping or cleaning fee. This was always a point of contention since sellers considered this as double taxation. In one of the markets in Katakwi district, some of the sellers opted to sell their leaves in the outskirts of the market in protest to what they considered high market fees. Similar to a case of *Uapaca kirkiana* fruits in Zimbabwe (Ramadhani and Schmidt, 2008), intensive tasting of Balanites fruits and leaves in markets was considered a loss to sellers. This was particularly serious in cases where some people went on tasting products from various traders but could not buy from any.

6.5.2.4 Profit margins from sale of Balanites products

Average daily income from sale of either leaves or fruits was UGX 3,000 (US$ 1.5) while traders earned UGX 5,000 (US$ 2.5) from oil. When seasonal/annual projections were made, leaf, fruit and oil sellers earn about US$ 46, 24 and 18 respectively. Leaf sellers earn more because of the extended leaf collection period (5 months) while fruits were harvested over three months period. It could be possible to realise more income out of oil since the nuts can be stored and utilized over six months period or more; however, the major obstacle was nut cracking. Value addition to Balanites products is an important element that could greatly improve rural incomes. Sundriyal and Sundriyal (2004) reported that processing and value addition to indigenous fruits can increase income generated by farmers 3 – 4 times.

Income received through sale of Balanites products was used to buy household essentials, such as, soap, salt, paraffin and other food items. However, children used the proceeds to buy clothing and scholastic materials. They reported that sale of Balanites products had enabled them to acquire scholastic materials during holidays and thus contributing to their education. Primary education in Uganda is now free; however, some children are still unable to go to school because their parents/guardians cannot afford some basic requirements such as uniforms and books. Selling of Balanites products is therefore an attractive option for children who are eager to meet the cost of their scholastic materials.

Traders reported that there were willing buyers of Balanites products and the trees were still abundant in some localities. Availability of the products during the dry season also makes them to be highly demanded. As such most (78%) of the traders claimed that trading in Balanites products was a worthwhile venture. However, their challenges were limited market information, lack of appropriate processing technology and un-organised markets.

6.5.2.5 Buyers attributes, perception and willingness to pay

The buyers considered taste, cleanliness and price to be very important attributes considered when buying Balanites fruits and leaves. For the oil, colour was the most important consideration. Size, colour and appearance were also important for fruits while packaging was a demanded service for all products. In general buyers preferred; yellow, big-sized fruits that should be packed when being sold; green well-boiled leaves; and golden yellow oil packed in transparent containers. In order to improve the demand of indigenous fruits, Ramadhani (2002) noted the importance of analysing information on preferences and attitudes associated with the fruits. No price differentiation was reported for products with these desirable attributes. None the less, they present an opportunity for product development and future price differentiation. Ramadhani and Schmidt (2008) urged that there is need for research in order to develop measures to translate consumer preferences of indigenous fruits into price and profit increases for trades.

Given strong attachment to Balanites products, buyers were generally willing to pay increased prices for leaves and oil while many reported that they would probably not pay increased prices for fruits. This appears to be related to the fact that no value was added to fruits and there was therefore no justification for its price increase. Contrary to reports elsewhere, where many people believe that IFT products were inferior to exotics (e.g. Mithöfer and Waibel, 2008), buyers of Balanites products in Uganda considered them to occupy a special place that cannot easily be filled with exotics. This could be an opportunity for Balanites product sellers. It also presents an entry point for commercialization of Balanites products.

6.5.3 Policy related opportunities and constraints for commercialisation of Balanites products

6.5.3.1 Regulations on IFTs and their enforcement

Regulations on IFTs existed in many local areas. The most common were no cutting of IFTs, planting two or more before cutting one and no bush burning. These regulations were generally aimed at protection of IFTs and conserving the environment in general. Although environment committees (legal local entities) have been established at district, sub-county and village levels, most of them have remained largely non-operational due to technical and institutional constraints. As such, local councils, sub-county administration and district forestry and environment offices were the key agencies involved in enforcing IFTs regulations. The roles of district and sub-county administration were reported to be sensitisation, passing by-laws and enforcing them and facilitating tree planting activities.

There were however, a number of challenges faced by local agencies in enforcing IFTs regulations. Key among these was the high poverty levels in rural areas. It was noted that poor people with limited income options could not easily observe conservation regulations, such as no cutting of IFTs. Consequently, IFTs were sometimes cut for charcoal production since they provide good charcoal with high market value. In West Nile sub-region Balanites grows along the River Nile and it was found to be one of the species favoured by fishing communities for fish smoking. Its use for fish smoking was however considered less threatening due to small quantities of wood used by local people. Nevertheless, increasing firewood cutting for sale in urban and peri-urban areas could constitute a bigger threat to Balanites tree population in the near future.

Local leaders also pointed out lack of appropriate regulations and lack of capacity at lower government levels to enforce the existing ones as challenges to IFTs protection. It was noted, for instance, that a need to plant two or more trees before cutting one was difficult to enforce since a tree may be cut in the dry season when it would be difficult to plant others. It was also noted that Balanites and other IFTs, such as, shea butter tree could not be easily raised for planting. This means that trees cut would have to be replaced by planting other readily available seedlings. Similarly, there was a big challenge in controlling bush fires. Some community members; especially herders almost considered it a right to set the savanna grasslands on fire during the dry season to regenerate pasture. Herders were reported to have developed secretive ways of setting bush fires without any chances of being identified. For instance, they left glowing piece of charcoal covered with dry cow dung and grass in the bushes. This fire "bomb" would then be maintained and ignited by wind and eventually set the surrounding bush on fire several hours later. In this way, any evidence of associating the person seen in that site some hours later only becomes circumstantial. These examples serve to illustrate a need to re-examine and develop appropriate regulations for protecting IFTs.

Considering the role of fire in maintaining the dynamics of the savanna ecosystems, the 'no burn' regulation may probably need to be revisited to protective or early burning. This would serve the interests of both herders and IFTs collectors. It was also noted that the district environment and forestry offices had one official each. They also operated limited budgets and sometimes with no official means of transport. This shortcoming was expected to have been overcome with establishment of non-paid environment committees at local levels. These committees have unfortunately failed to take off in many localities. Compounding this is the communal ownership of most lands where Balanites and other IFTs grow. Given these circumstances, it may be necessary to explore other management options for IFTs in the drylands of Uganda. One such option is empowerment of community interest groups, such as IFTs collectors, processors and traders to form groups that work with government agencies to developed appropriate regulations. These interest groups would then take the lead in enforcing compliance and only seek technical support from the relevant government agencies.

6.5.3.2 Local leaders' opinions and attitudes towards IFTs trade

Despite the challenges of enforcing some of the regulations, local leaders reported that IFTs had received some level of recognition by local communities. This recognition however, varied from species to species depending on the products and/or benefits derived. For instance, the shea tree was highly regarded by local communities in both Teso and West Nile sub-regions because of the income derived from its products- nuts and oil/butter. In the same way Balanites was highly regarded in areas where communities derived more benefits. In Katakwi and Amuria districts in Teso sub-region, there was a gender dimension to protection of Balanites trees both on farms and in the wild. Trees with sweet leaves (identified by previous branch cuts) were conserved in all land uses. Women would protest any cutting of such trees (their vegetable source) and reported offenders to local leaders. Men seemed to have complied with the women's interests by only cutting trees with bitter leaves (indentified by lack of previous branch cuts). In some localities, only trees with lopped branches could be seen in the landscape. Inquiries among local elders revealed that both sweet and bitter leafed trees existed but the latter had been selectively cut over the years.

In West Nile sub-region, Balanites tree population was still high (17 – 30 trees ha^{-1}) hence the farmers selection pressure was not well evident for trees in the wild. Nonetheless, it was clearly seen on farms, where trees with bigger and sweet fruits were the majority retained when fields are open for cultivation. These cases appear to illustrate a classic case of farmer conservation through selection of trees with desired attributes. Farmers' interest in selection of Balanites trees can be of benefit to improvement and participatory domestication of the species. According to Teklehaimanot (2008), IFTs domestication should use 'plus-tree' selection criteria which incorporate local people's values, knowledge and priorities. Improvement of trees through selection and domestication of superior quality varieties is well documented in agroforestry literature (e.g. Simons, 1996; Leakey and Simons, 1998; Leakey *et al.*, 2003; Leakey, 2005). Selection is one of the steps of tree improvement and when combined with domestication, it can be a means of ensuring quality and supply of raw materials (Teklehaimanot, 2008).

Local leaders seemed to agree strongly with the need to establish and support interested farmer groups to plant Balanites and other IFTs of their choice. They also strongly agreed with the need to support community groups or enterprising individuals involved in collection, processing and selling of IFTs products. This supports the thinking that commercialisation of IFTs can contribute to poverty reduction. Such efforts can make a significant contribution in the drylands of Uganda where there are limited options for the rural poor, especially, women and the youth. For this to be realised, local leaders pointed out a need to improve the processing and value addition to Balanites products. In agreement with Balanites collectors and traders, local leaders prioritized the improvement of processing methods and value addition. Furthermore, local leaders recommended a need to determine the nutritional and medicinal benefits of various Balanites products. It was reasoned that such information would be vital in creating attitudinal change in favour of Balanites products through awareness campains.

CHAPTER SEVEN: NUTRITIONAL VALUE OF *BALANITES AEGYPTIACA* LEAVES, FRUIT PULP AND KERNEL OIL

The nutritional value of *B. aegyptiaca* leaves, fruit pulp and kernel oil are presented in this chapter. General introduction and background to the chapter are given in section 7.1, the aim, objectives and hypotheses are presented in section 7.2 while the study area and methods are described in section 7.3. The results are presented in section 7.4 under the following sub-sections: 7.4.1 Nutritional Composition of Balanites Leaves and Fruit Pulp, 7.4.2 Oil Yield and Physico-chemical Characteristics of Balanites Oil, and 7.4.3 Mineral Composition of Balanites Oil. The results are discussed in section 7.5.

7.1 Introduction

The nutritional composition of most indigenous fruits including *B. aegyptiaca* is largely unknown and this limits recommendations for their wider use or promotion. As noted by Grivetti and Britta (2000), there is a need to understand the nutritional status and value of the so-called 'edible weeds of agriculture' that are important in the traditional diets of many communities and contribute to their food and nutritional security. Balanites leaves, flowers, fruits and oil have been utilised for many generations by both rural and peri-urban communities in the drylands of Uganda and across the Balanites range in dryland Africa. In Uganda, the young succulent leaves are eaten as dry season vegetable by the Iteso while the fruits and oil are popular among the Madi, Lugbra and Karamojong ethnic groups (Katende *et al.*, 1995; 1999, Teklehaimanot, 2008). These products are also traded in both local and urban markets in Karamoja, Teso and West Nile sub-regions of Uganda (Katende *et al.*, 1999), thus providing an income and a source of livelihood to many rural households. The 2007/2008 floods in Teso sub-region of Uganda increased the consumption and trade in Balanites leaves.

Because of its hidden potential, *B. aegyptiaca* has been described as one of the underutilized indigenous fruit trees and also as a neglected and underutilized species in the drylands of eastern Africa (Chikamai *et al.*, 2004; Chikamai *et al.*, 2005 Teklehaimanot, 2005; 2008). A recent report by the National Research Council of US ranked *B. aegyptiaca* among the 24 priority lost "crops" of Africa and called for a concerted effort to develop its true potential using modern capabilities (NRC, 2008). The report indicates that although *B. aegyptiaca* produces the necessities of life in one of the world's most difficult zones of existence (drylands), its full potential has not been explored.

Understanding the nutritional value of Balanites leaves, fruits and oil that are commonly consumed and traded will most probably contribute to unlocking its hidden potential. This is essential in the current emerging efforts to promote increased use and commercialization of *B. aegyptiaca* and other wild food resources for poverty alleviation. If adequately exploited, Balanites products have a potential to reduce malnutrition, contribute to food security and reduce poverty among dryland communities. This will also help in understanding its nutritional value to households that are dependent on the products for up to five months every year.

According to the National Research Council of US, *B. aegyptiaca* products could provide raw materials for small and medium-scale enterprises (SMEs) otherwise inconceivable in the dry areas where it grows (NRC, 2008). In a study of the nutritional composition of wild food plants (including *B. aegyptiaca*) in West Africa, Cook *et al.* (1998) noted that nutritional information could widen the food choices for populations inhabiting the Sahel and other dryland regions of the world. They also reported that knowledge of the comparative nutrient values of wild edible plants could serve as a basis for creating awareness among governmental and non-governmental organizations about which plants to conserve for times of food shortage, and to propagate. Such information could be disseminated to increase knowledge of the nutritional worthiness of certain plants to households in rural areas where the health benefits would be most beneficial (Cook *et al.*, 1998).

7.2 Aim, objectives and hypotheses

The aim of this study was to determine the nutritional composition of *B. aegyptiaca* leaves, flowers, fruit pulp and oil so as promote their wider utilisation and conservation in the drylands of Uganda and to improve livelihoods.

The objectives were to:

i. Determine the nutritional composition of Balanites leaves, flowers and fruit pulp in terms of dry matter, ash, crude protein, fat, selected minerals (Na, K, Mg, Cu, Mn, Zn, and Fe,) and level of tannins.

ii. Determine the physico-chemical characteristics of Balanites kernel oil in terms of colour, refractive index, viscosity, iodine value, acid value, and saponification value.
iii. Assess the fatty acid profile of Balanites kernel oil.

The following hypotheses were tested:

i. There is no difference in the proximate and mineral composition between fresh and pre-cooked Balanites leaves.
ii. There is no difference in proximate and mineral composition of Balanites fruit pulp from different sub-regions of Uganda.
iii. There is no difference in fatty acid profile of Balanites kernel oil from different sub-regions of Uganda.

7.3 Study area and methods

7.3.1 Study area

Samples for laboratory analyses were collected from three sub-regions in Uganda, all located in the semi-arid belt where *B. aegyptiaca* is naturally growing. In each sub-region, one district was selected for the study and in each of these districts, study samples were collected from two villages/localities (Table 7.1).

Table 7.1 Areas in Uganda where Balanites leaf, fruit and oil samples were collected

Sub-region	District	Village/locality	Samples collected
Teso	Katakwi	Acoite and Abela	Leaf and fruit
Karamoja	Moroto	Moroto town and Moroto prison farm	Fruit
West Nile	Adjumani	Nyeu and Egge	Fruit and locally processed oil

7.3.2 Sample collection

Pre-determined quantities of samples were collected based on their accessibility and availability and in consultation with the district forestry officials and community leaders. The conceptual framework applied in the study is shown in Figure 7.1 and samples collected from each site are given in Table 7.1. Leaf samples were only collected from Katakwi district where they were being eaten as a leafy vegetable. Locally processed Balanites oil was collected from

Adjumani district where it was processed and utilized at the time of the study. Balanites fruit samples were collected from all the three study sub-regions.

Local people knowledgeable in the selection of superior quality leaf yielding trees helped to identify trees for leaf collection. About 2 kg of fresh leaves were then collected from each of the three randomly selected trees. Leaf samples from each tree were sub-divided into two equal portions and one portion (1 kg) was boiled in an earth pot with leaves fully submerged in water for three hours, the remaining water decanted and the boiled leaves left to cool, while the other portion was kept fresh. Only one of the trees selected for leaf sampling was heavily flowered and as such flowers that were found on the harvested twigs were collected as one of the samples. Boiled (pre-cooked) leaf samples sold in Toroma market in Katakwi district were collected from three randomly selected traders on a market day. All the leaf samples were doubled tagged and transported to the laboratory (Makerere University) in cooler boxes.

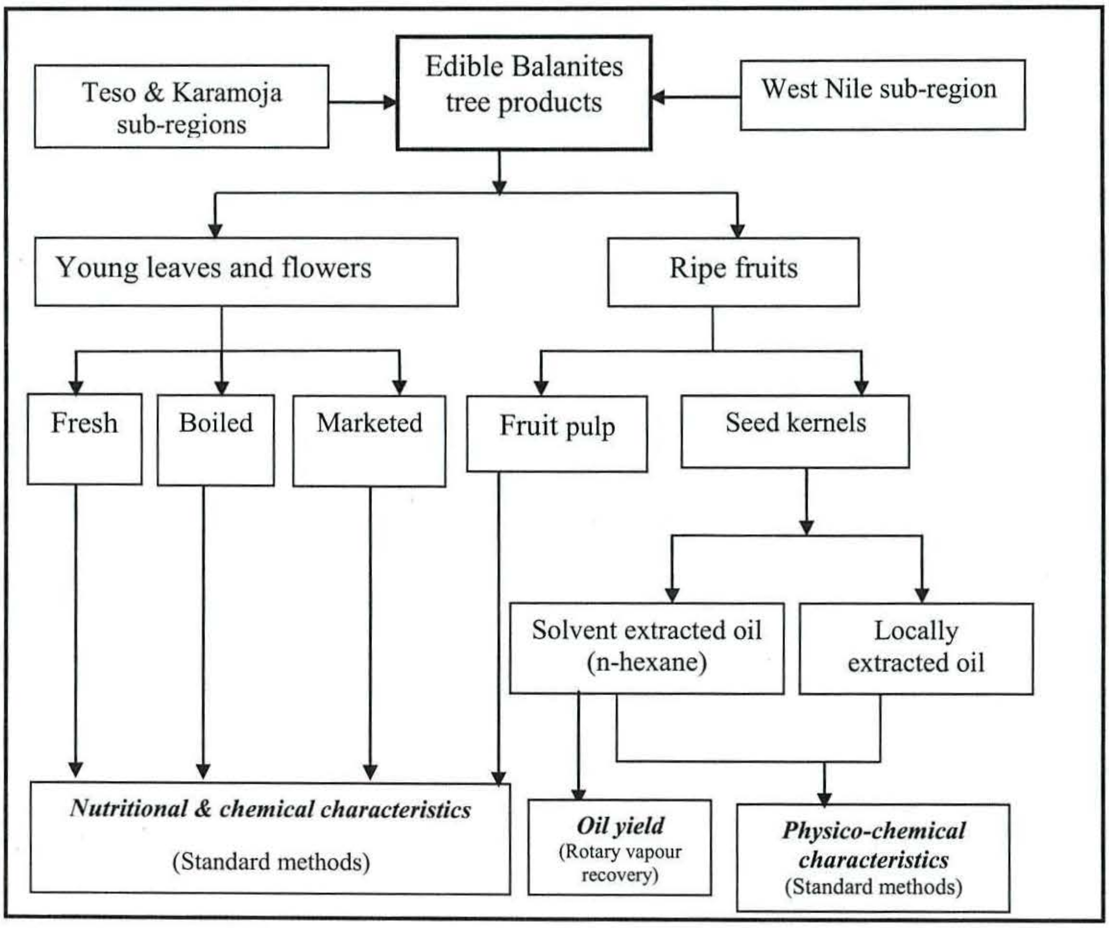


Figure 7.1 Conceptual framework for nutritional study of *B. aegyptiaca* in Uganda.

In each locality, ripe fruits were collected from under 10 randomly selected healthy trees after fruit fall. These were mixed and a sub-sample of about 3 kg obtained and double tagged. Three 300 ml samples of locally processed Balanites oil were bought from three farmers and placed in appropriate plastic containers. Both the fruit and local oil samples were transported to the laboratory (Makerere University) in cooler boxes.

7.3.3 Sample preparation

In the laboratory, Balanites leaf, flower, fruit and locally processed oil samples were stored in freezers. Fresh weight of the leaf samples was taken before drying. The epicarp was removed by hand and the mesocarp separated by peeling with a knife. Leaf and flower samples were then chopped, put on trays and dried in a forced drought oven (LEEC type Model FXC1) at 60°C for three days while the fruit pulp and nuts were dried at the same temperature for seven days. Dry leaf and flower samples were ground in a blender while the pulp was ground using a mortar and pestle due to its oily nature. Ground samples were kept in airtight containers and appropriate quantities drawn for laboratory analysis. At the same time, dried nuts were decorticated manually between a stone and mallet to extract the oil rich seed kernels. The kernels were dried at 60°c for three days, ground into powder using a mortar and pestle and stored in airtight containers under refrigeration to prevent deterioration.

7.3.4 Oil extraction and yield determination

The total weight (M_1) of each powder sample of kernel was determined using an electronic balance. Oil was extracted by leaching in soxhlet apparatus using *n*-hexane (analytical grade) as a solvent. The sample was then placed in a thimble and loaded into a soxhlet (Plate 7.1). Six runs of the condensing solvent (lasting 6-8 hours) were sufficient to extract oil from each sample. The process was stopped when the condensing solvent passing through the sample turned colourless.

The solvent/oil mixture was separated using a rotary vapourator (Buchi Rotavapor R-210, USA, Pump: Vacuubrand MZ 2C, Cooler: Huber Miniciller Ref 466.0010). The resulting Balanites oil was weighed (M_2) and oil content determined gravimetrically and expressed as percentage of the kernel powder weight using the formula: Oil yield = (M_2/ M_1) x 100%. The oil was stored under refrigeration (-20°C) until it was required for analysis.

Plate 7.1 Equipment used to extract Balanites oil from kernel powder.

7.3.5 Analysis of leaf, flower and fruit pulp

(i) Moisture content and dry Matter – the field samples were dried at 60°C, 2 g of each sample weighed in a clean dry crucible and put in forced drought oven (Thelco Precision Scientific model 29) at 105°C for 24 hours. Samples were removed, cooled in desiccators, weighed and loss in weight recorded as moisture content and residue as dry matter.

(ii) Total ash – about 2 g of each dried sample was weighed in a clean dry crucible and samples put in muffle furnace (Griffin Electric Furnace by Griffin and George Ltd) at 600^{0}C for 6 hours, removed and cooled in desiccators. The residues were weighed and recorded as total ash content.

(iii) Crude protein - micro-Kjeldhal method was used and results converted to protein content by using the conversion factor 6.25 (FAO/WHO, 1994). About 0.2 g of each sample was weighed in Kjeldah digestion tubes, two drops of a catalyst (copper sulphate, selenium powder and sodium sulphate mixture) was added followed by 5 ml of concentrated sulphuric acid.

Samples were heated on a block digester (Model 2040 Foss Tector) at 360^{0}C and digested until they were clear. After digestion, samples were left to cool and then distilled using a semi automatic Kjetec 2200 Auto Distillation Foss Tector machine. Ammonia was collected and titrated (using 50 ml Digitrate) with 0.02M hydrochloric acid.

(iv) Crude fat - About 2 g of each sample was weighed in a thimble. The flasks were weighed and 200 ml of petroleum ether added to the flask. The flasks were assembled with the condenser and holding unit and refluxed for one hour using soxtec (Model 2050 Foss) machine. The flasks were removed and dried in the oven at 105^{o}C for 30 minutes then weighed. Gain in weight was recorded as crude fat content.

(v) Mineral content - calcium, sodium and potassium were determined using a flame photometer (Jenway, UK) while magnesium, iron, cooper and zinc were determined using atomic absorption spectrophotometer (AOAC, 1984; Okallebo *et al.,* 2002). A digest was prepared by weighing about 2 g of each sample in 100 ml digestion tube and 5 ml of a digestion mixture was added. Samples were heated in the digestion block at 360^{o}C until they became clear, then cooled and diluted to 100 ml with distilled water. The samples were filtered through N0.1 filter paper and the filtrates used for mineral determination. Serial dilutions were required to bring the samples into the linear working range element detection. Sample concentrations of each element were determined by comparing absorbency to a standard linear regression curve containing a minimum of five standard points for each element.

7.3.6 Analysis of the physico-chemical properties of Balanites oil

The physical and chemical parameters of Balanites oil were analysed using standard methods described by AOAC (1984). Physical parameters analysed included colour, refractive index and viscosity and the chemical parameters investigated were acid, saponification and iodine values. Colour was determined using lovibond apparatus (Model E Tintometer L322/92E, UK), viscosity using a viscometer (Brookfield DV-11+Pro) at 40^{o}C and the refractive index using a refractometer (Bellingham + Stanley, No. A86006).

(i) Colour: Balanites oil sample (10 ml) was melted in a water bath, placed in a cuvet and analysed using lovibond. The red, yellow and blue colour units were adjusted until a perfect colour match was obtained. The value of the colour with the lowest unit was subtracted from the colours leaving two units which were then used to describe the colour of the sample. Colour was described using the colour nomenclature namely, red, orange (combination of red and yellow), yellow, green (combination of yellow and blue), blue and violet (combination of red and blue). In addition, the terms "bright" and "dull" were used to further describe a given oil sample.

(ii) Refractive index: Balanites oil sample (0.5 g) was melted at 25°C in water bath and analysed using Bellingham + Stanley refractometer, (Model No. A86006, UK).

(iii) Viscosity: Balanites oil sample (300 ml) melted at 40°C was placed in 600 ml beaker and the viscosity was determined using Brookfield DV-11+Pro programmable viscometer, USA, S.No. TR P6514911, model LVDV-11+P by inserting the spindle down to a depth of 1cm into the oil sample. Analysis was carried out with a spin code 61, RPM: 30 and temperature of 40°C. The viscometer was standardized using viscosity standard fluid from Brookfield. The values were read in centistokes (cst).

(iv) Acid value: Diethyl ether (25 ml), ethanol (25 ml) and 1% phenolphthalein (1 ml) were mixed and neutralized with 0.1M sodium hydroxide. Two grams of Balanites oil was dissolved in the neutral diethyl ether, ethanol and phenolphthalein solution. The solution was titrated with 0.1M sodium hydroxide until a pink colour that persisted for at least 10 seconds was obtained. Acid value was calculated using the equation: **Acid value (AV) = 56.1 x Mv/w**, where; M = molarity of KOH (0.1), v = volume of KOH solution (ml), and w = weight of the oil sample (2 g).

(v) Saponification value: 2 g of each of the Balanites oil samples were weighed into the different conical flasks and 25 ml of ethanolic potash was added. To another flask was added the same quality of the ethanolic potash but omitting the oil sample that was used as a blank. All the flasks were boiled in a water bath for 30 minutes and shaken frequently. Two drops of phenolphthalein indicator was added to each flask and titrated with 0.5M HCl with vigorous shaking to get the end point. The saponification value was derived from the equation: **SV = 56.1M (x – v)/w**, where; x = volume of HCl used in the blank titration, v = volume of the HCl used in the test titration, M = molarity of HCL and w = weight of the oil sample (2 g).

(vi) Iodine value (Hanus method): The hanus iodine reagent was prepared by dissolving iodine (13.2 gm) in glacial acetic acid (1litre) under heat and 3 ml of bromine added. The hanus iodine reagent was then kept in a bottle until the analysis was complete. Two grams of Balanites oil was weighed into a 500 ml conical flask and 10 ml of chloroform added. Using a pipette, 25 ml of Hanus iodine was added and left to stand in the dark for 30 minutes with occasional shaking. Fifteen percent potassium iodine was added and shaken thoroughly. One hundred millilitres of distilled water was added to rinse any iodine on the stopper. The solution was then titrated with 0.1N sodium thiosulphate until a yellow solution turned almost colourless (S ml). Three drops of starch indicator (1%) was added towards the end point and titration continued until the blue colour turned colourless. A blank determination was done and recorded (B ml). The iodine value was calculated from using the equation: **Iodine value (IV) = (B – S) X M X 12.69/w,** where; B = volume of $Na_2S_2O_3$ used for blank titration, S = volume of $Na_2S_2O_3$ used for oil sample, M = molarity of $Na_2S_2O_3$ (0.1), and 12.69 = constant (meq weight of iodine).

7.3.7 Analysis of fatty acids in Balanites oil

Five steps were followed to determine the fatty acid content of Balanites oil:

(i) ***Preparation of acidified anhydrous methanol:*** Dry hydrogen chloride (HCl) gas was bubbled into methanol placed in a bottle and immersed in an ice bath. Increase in mass of the methanol was checked periodically to monitor the concentration of hydrochloric acid. The hydrogen chloride gas was prepared by adding drops of conc. H_2SO_4 to conc. HCl in a stoppered round-bottomed flask using a dropping funnel. The ensuing hydrogen chloride gas (7.2 g) was dried by passing it through conc. H_2SO_4 and bubbled into methanol (100 ml) to make methanol/2MHCl solution.

(ii) Esterification of the fatty acids in the oil: About 10 mg of each oil sample was placed in 15 ml thick-walled glass tubes with teflon-lined screw caps to which acidified anhydrous methanol (1 cm^3) was added. The test tubes were securely capped and placed in an oven at 90^oC for two hours, removed and allowed to cool to room temperature. During the heating process, free and bound fatty acids reacted with the methanol and were converted to the corresponding fatty acid methyl esters (FAME).

(iii) ***Extraction of the fatty acid methyl esters (FAME):*** The resulting FAMEs were separated from the mixture by solvent extraction using a water-hexane solvent system (Grahl-Nielsen and Barnung, 1985). To achieve this, hexane (1 cm^3) and water (0.5 cm^3) were added to the resulting FAME mixture and after shaking for three minutes, the mixture was centrifuged at 1500 rpm for a further three minutes. The FAMEs were then obtained from the upper hexane phase of the partition by siphoning. A second extraction was performed after addition of hexane (1 cm^3) to the residual mixture and repeating the same procedure. The extracts were then pooled and stored under refrigeration until GC-MS analyses were performed.

(iv) GC-MS determination of fatty acid composition: Analyses of FAMEs was performed with Gas Chromatography-Mass Spectrometry (GC-MS) using an Agilent 6890N GC model equipped with a 7683B series auto-sampler, fitted with an electronic pressure control and mass selective detection ionizating energy of 70eV; source temperature was 300°C and a column of 25 m x 0.25 mm fused silica capillary with polyethylene glycol (PEG) as a stationary phase with a thickness of 0.2µm (CP-WAX 52CB) from chrompack. The temperature of the injector pot was maintained at 260^0C. The oven temperature was maintained at 90°C for four minutes, increased to 165 °C at 30°C per minute, and then increased to 225^0C at 3^0C per minute, and maintained at 225°C for 10 minutes. Helium gas was used as the carrier at 1.7 ml per minute at 40^0C. The fatty acids in the samples were identified by a standard FAME mixture, GLC-68D from Nu-Chek-Prep (Elysian, Minn., USA) and mass spectrometry. The combination of all the instruments above was operated by the Chemstation software to produce Agilent 6890N, gas chromatographs.

(v) Qualitative identification of the fatty acids: The chromatographic peaks of a reference standard mixture of FAME (GLC-68D from Nu-Chek-Prep (Elysian, Minn., USA), were identified by interpretation of their mass spectra, and by matching the spectra with an in-built library of spectra. Component chromatographic peaks of analytes were identified by correlating with individual peak retention times with the reference standard mixture of FAME. Matching the mass spectra with in-built CHEM PREP mass spectra libraries confirmed the identity of the components.

7.3.3 Data analysis

Data were entered in MS Excel and later transferred to SPSS Version 16 to generate means and standard errors. A one-way analysis of variance (ANOVA) was applied to compare means of nutritional values of products between the study sites and plant parts (leaves, fruit pulp and oil characteristics) with significance levels determined at $p \leq 0.05$. Where the null hypothesis was rejected in favour of the alternative, Scheffe's test (due to unequal sample size) was used to identify homogeneous subsets of means (Kleinbaum and Kupper, 1978). Results were presented in tables and graphs.

7.4 Results

7.4.1 Nutritional composition of *B. aegyptiaca* leaves, flowers and fruit pulp

7.4.1.1 Proximate composition of *B. aegyptiaca* leaves, flowers and fruit pulp

Results of the proximate analyses of *B. aegyptiaca* leaves, flowers and fruit pulp are presented in Table 7.2. The moisture content of leaves and flowers was lower (1.39 – 2.20%) than that of the fruit pulp (4.72 – 5.35%). Dry matter for all the samples was generally above 94%, varying from 94.7% in fruit pulp to 98.6% in leaves. The ash content in leaves, flowers and fruit pulp varied between 5.7 and 9.0% while the fat content in leaves and flowers was higher (2.0 – 2.7%) than in fruit pulp (0.37%). Fat content was highest in flowers (2.7%) and crude protein was highest in flowers (19.96%) followed by leaves (14.2 – 17.3%) and lowest in fruit pulp (5.4%).

A one-way ANOVA indicated significant ($p<0.05$) differences between plant part samples in all the parameters accessed (Table 7.3). Comparison of means using Scheffe's method at α = 0.05 (Table 7.2) revealed that dry matter, moisture content, fat and crude protein varied significantly ($p<0.05$) between the leaves/flowers and the fruit pulp. There were no differences in means between fresh and boiled and/or market leaves. The flowers however, had significantly ($p<0.05$) higher fat and crude protein than fresh leaves. There was no difference in the fruit pulp contents in all the study sites.

Table 7.2 Proximate composition of *B. aegyptiaca* leaves, flowers and fruit pulp

Site/sample	N	Mean ± SE				
		MC (%)	Dry matter (%)	Ash (%)	Fat (%)	Crude protein (%)
Leaves & flowers*						
Fresh leaves	6	1.76 ± 0.05^{a}	98.24 ± 0.05^{b}	8.69 ± 0.17^{b}	2.02 ± 0.05^{b}	14.24 ± 0.78^{b}
Boiled leaves	6	1.39 ± 0.14^{a}	98.61 ± 0.14^{b}	6.39 ± 0.14^{ab}	2.41 ± 0.18^{bc}	17.25 ± 0.39^{bc}
Market leaves	6	2.20 ± 0.28^{a}	97.80 ± 0.28^{b}	9.02 ± 0.84^{b}	2.00 ± 0.11^{b}	16.36 ± 0.77^{bc}
Fresh flowers	2	2.18 ± 0.12^{a}	97.82 ± 0.12^{b}	8.18 ± 0.01^{ab}	2.74 ± 0.15^{c}	19.96 ± 0.23^{c}
Mean		1.88	98.12	8.07	2.29	16.95
Fruit pulp						
Katakwi	4	5.35 ± 0.13^{b}	94.65 ± 0.13^{a}	7.26 ± 0.30^{ab}	0.43 ± 0.08^{a}	4.54 ± 0.16^{a}
Adjumani	4	5.10 ± 0.41^{b}	94.90 ± 0.41^{a}	7.90 ± 0.09^{ab}	0.30 ± 0.02^{a}	6.01 ± 0.30^{a}
Moroto	4	4.72 ± 0.95^{b}	95.28 ± 0.95^{a}	5.74 ± 0.08^{a}	0.37 ± 0.01^{a}	5.64 ± 0.68^{a}
Mean		5.055	94.94	6.97	0.37	5.40

Means for groups in homogeneous subsets are shown with similar letter (Scheffe's method, $\alpha = 0.05$).
SE = Standard error of the mean
**Leaves and flowers were only collected from Katakwi district*

Table 7.3 One-way ANOVA for comparison of means for proximate analyses

Parameter	Sum of Squares	df	Mean Square	F	P-value (α =0.05)*
Fat (%)	26.64	6	4.44	73.31	0.001
Crude protein (%)	962.60	6	160.43	84.30	0.001
Dry matter (%)	81.52	6	13.59	21.08	0.001
Ash (%)	43.27	6	7.21	7.57	0.001
Moisture content (%)	81.52	6	13.59	21.08	0.001

**All the parameters were significant at both $\alpha = 0.05$ and $\alpha = 0.01$; in all cases p-values were 0.001*

7.4.1.2 Mineral composition of *B. aegyptiaca* leaves and fruit pulp

Results of macro and micro mineral composition in different parts of *B. aegyptiaca* are given in Table 7.4. The amount of K in fresh leaves (24.59 mg g^{-1}) and flowers (28.67 mg g^{-1}) was higher than in boiled and marketed leaves, 12.78 and 12.10 mg g^{-1} respectively. The amount of K in the fruit pulp was high and comparable to that in the fresh leaves and flowers, ranging between 24.78 -29.84 mg g^{-1}. The Na content in leaves, flowers and fruit pulp ranged between

1.62 – 4.02 mg g^{-1} while the magnesium content was < 1.0 mg g^{-1} in fruit pulp and ranged between 1.15 – 1.35 mg g^{-1} in the leaves and flowers.

Iron was the most abundant among the micronutrients followed by manganese, zinc and copper in that order (Table 7.4). The iron content was less variable in the leaves, flowers and fruit pulp (427.05 – 493.92 mg g^{-1}). Manganese was highest in the leaves (61.50 – 72.58 µg g^{-1}) followed by flowers (45.30 µg g^{-1}) and lowest in fruit pulp (27.78 – 35.73 µg g^{-1}). The amount of zinc was highest in the leaves (39.73 – 50.13 µg g^{-1}) followed by fruit pulp (28.48 µg g^{-1}) and lowest in flowers (10.75 µg g^{-1}). Copper was higher in the leaves and flowers (23.25 – 28.97 µg g^{-1}) than in fruit pulp (18.92 µg g^{-1}). The amount of Cu in fruit pulp varied in the three study sites from 13.78 µg g^{-1} in Adjumani district, 17.78 µg g^{-1} in Moroto district to 25.20 µg g^{-1} in Katakwi district.

Tannins were higher in fruit pulp (6.02 – 20.84 mg g^{-1}) than leaves and flowers (0.61 – 3.40 mg g^{-1}). The amount of tannin was higher in the fresh leaves (3.4 mg g^{-1}) than in fresh flowers. Furthermore, the tannins content in boiled and market leaves was generally lower than that in fresh leaf and flowers (Table 7.5). Fruit pulp from Adjumani district had higher tannin content (20.84 mg g^{-1}) than that from Moroto and Adjumani districts (9.64 and 6.02 mg g^{-1}), respectively. Tannin content was significantly ($p<0.05$) higher in fruit pulp than in leaves. The tannin content of fruit pulp from Katakwi district was significantly ($p<0.05$) higher than those from Moroto and Adjumani districts.

Table 7.4 Macro and micro mineral composition of *B. aegyptiaca* leaves, flowers and fruit pulp

Sample	Mean ± SE						
	K ($mg\ g^{-1}$)	Na ($mg\ g^{-1}$)	Mg ($mg\ g^{-1}$)	Cu ($\mu g\ g^{-1}$)	Mn ($\mu g\ g^{-1}$)	Zn ($\mu g\ g^{-1}$)	Fe ($\mu g\ g^{-1}$)
***Leaves & flowers**							
Fresh leaves (n=6)	24.59 ± 0.99^{b}	3.26 ± 0.25^{a}	1.35 ± 0.03^{d}	24.82 ± 0.58^{a}	72.58 ± 6.55^{c}	39.73 ± 5.27^{bc}	436.58 ± 10.97^{a}
Boiled leaves (n=6)	12.78 ± 0.89^{a}	4.02 ± 0.39^{a}	1.23 ± 0.02^{cd}	24.92 ± 0.44^{a}	61.50 ± 6.04^{bc}	42.15 ± 2.79^{bc}	427.05 ± 29.74^{a}
Market leaves (n=6)	12.10 ± 1.34^{a}	3.66 ± 0.57^{a}	1.32 ± 0.04^{d}	28.97 ± 5.47^{a}	63.23 ± 4.17^{bc}	50.13 ± 3.97^{d}	473.05 ± 61.10^{a}
Fresh flowers (n=2)	28.67 ± 0.94^{b}	2.35 ± 0.31^{a}	1.15 ± 0.05^{bc}	23.25 ± 0.95^{a}	45.30 ± 3.30^{ab}	10.75 ± 0.45^{a}	472.15 ± 07.85^{a}
Mean	19.54	3.32	1.26	25.49	60.65	35.69	452.21
Fruit pulp							
Katakwi (n=4)	27.11 ± 0.99^{b}	1.62 ± 0.50^{a}	0.93 ± 0.09^{abc}	25.20 ± 1.40^{a}	27.78 ± 2.68^{a}	28.55 ± 4.14^{ab}	433.40 ± 26.21^{a}
Adjumani (n=4)	29.84 ± 1.16^{b}	3.20 ± 0.43^{a}	0.83 ± 0.11^{ab}	13.78 ± 0.58^{b}	35.73 ± 2.09^{a}	27.48 ± 1.26^{ab}	493.92 ± 49.29^{a}
Moroto (n=4)	24.78 ± 1.77^{b}	2.19 ± 0.18^{a}	0.73 ± 0.08^{a}	17.78 ± 2.18^{b}	30.28 ± 1.95^{a}	29.40 ± 2.46^{ab}	475.70 ± 50.16^{a}
Mean	27.24	2.34	0.83	18.92	31.26	28.48	467.67

**Leave and flower samples were only collected from Katakwi, where they are widely used and traded.*
Significantly different means within columns are shown with different letters in superscript (Scheffe's method, α = 0.05).

Table 7.5 Level of tannins in *Balanites* leaf and fruit pulp samples

Sample	N	Tannins ($mg\ g^{-1} \pm SE$)
Leaves & flowers*		
Fresh leaves	6	3.396 ± 1.38^{a}
Boiled leaves	6	1.307 ± 0.37^{a}
Market leaves	6	0.611 ± 0.07^{a}
Fresh flowers	2	1.865 ± 0.78^{a}
Fruit pulp		
Katakwi	4	6.023 ± 0.86^{b}
Adjumani	4	15.844 ± 1.42^{c}
Moroto	4	9.639 ± 2.54^{b}

**Leave and flower samples were only collected from Katakwi, where they are widely used and treaded.*
Means for groups in homogeneous subsets are shown with similar letter (Scheffe's method, $\alpha = 0.05$).

One-way analysis of variance (ANOVA) revealed significant ($p < 0.05$) differences between plant part samples in all the parameters assessed except iron (Table 7.6). Separation of means (Sheffe's method) (Table 7.4) showed that, among the macronutrients (K, Na and Mg), there was a significant ($p < 0.05$) difference in the amount of magnesium in the leaves and fruit pulp. The amount of potassium in the flowers and fresh leaves was significantly ($p < 0.05$) higher than in boiled and market leaves. The flowers had significantly ($p < 0.05$) lower amount of magnesium than all the leaf samples.

Separation of means for micronutrients (Cu, Mn, Zn and Fe) indicated that the amount of Mn was significantly ($p < 0.05$) higher in leaves than in fruit pulp. Fruit pulp from Katakwi district had significantly ($p < 0.05$) higher amount of Cu than that from Moroto and Adjumani districts. Magnesium was also significantly ($p < 0.05$) higher in fresh leaves than in fresh flowers. The Zn content of all types of leaves was significantly ($p < 0.05$) higher than that of the flowers. The tannin content of the fruit pulp from Adjumani district was significantly ($p < 0.05$) higher than that from Moroto and Katakwi districts (Table 7.5).

Table 7.6 One-way ANOVA for comparison of means for minerals

Mineral	Sum of Squares	df	Mean Square	F	Sig.
K (mg/g)	1592.525	6	265.4	37.96	0.001*
Na (mg/g)	20.266	6	3.4	3.85	0.007*
Mg (mg/g)	1.751	6	0.3	17.20	0.001*
Cu (µ/g)	721.6	6	120.3	3.01	0.024*
Mn (µ/g)	9218.8	6	1536.5	12.37	0.001*
Zn (µ/g)	3470.8	6	578.5	7.87	0.001*
Fe (µ/g)	18897.6	6	3149.6	0.38	0.888^{ns}
Tannin (mg/g)	793.025	6	132.171	19.12	0.001*

**Significant at p≤0.05*
ns =Not significant at p≤0.05

7.4.2 Oil yield and physico-chemical properties of *B. aegyptiaca* kernel oil

Up to 60% of the fruit was made up of nut (endocarp and kernel). The kernel constituted 18.1 – 23.2% of the nut with a mean of 19.57% while the rest was endocarp/stone (Table 7.7). The mean oil yield from *B. aegyptiaca* seed kernels was 44.5%. The highest oil yield was from Katakwi district (50.56%), followed by Adjumani district (44.37%) and Moroto district (38.53%) (Figure 7.2).

Table 7.7 Proportion of Balanites kernel powder in the nut

District	Village/locality	Kernel powder (%)
Adjumani	Egge	19.67
	Adropi	19.52
Katakwi	Aputon	19.92
	Abela	16.97
Moroto	Moroto town	18.10
	Moroto prison farm	23.24
Mean	Combined	19.57

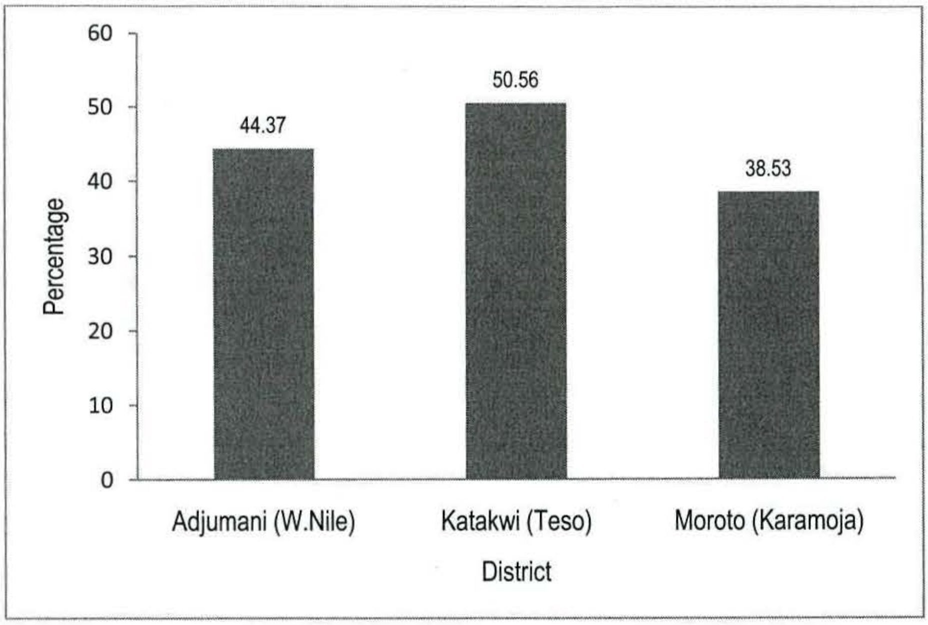


Figure 7.2 Balanites kernel oil yield from different districts/sub-regions in Uganda.

The physico-chemical characteristics of *B. aegyptiaca* oil are presented in Table 7.8. The oil obtained from Katakwi and Adjumani districts was light yellow while the oil from Moroto district was yellowish-orange.

Saponification value was highest in Katawi oil (192.80 mg KOH g^{-1}) followed by Adjumani oil (185.55 mg KOH g^{-1}) and Moroto oil (180.50 mg KOH g^{-1}). Acid value was highest in the Moroto population (1.954 mg KOH g^{-1}) followed by Katakwi (1.41 mg KOH g^{-1}) and Adjumani (1.33 mg KOH g^{-1}). Viscosity was highest in Moroto oil (23.04 cSt) followed by Katakwi oil (22.60 cSt) and Adjumani oil (18.94 cSt). The oil's refractive index was similar (1.46) in the samples from the three sites. The amount of Iodine ranged from 98.20 to 103.32 (I_2 g/100 g).

Table 7.8 Physico-chemical characteristics of *B. aegyptiaca* oil

Property	Katakwi district	Adjumani district	Moroto district	Mean
Physical				
Colour (degree of colour mixtures)*	Yel-Gr+9.9Y	Yel-Gr+9.3Y	Yel-Or+13.3Y	Yel-Gr+10.8Y
Refractive Index [25 °C]	1.461	1.460	1.464	1.46
Viscosity [40°C] (cSt)	22.60	18.94	23.04	21.53
Chemical				
Saponification Value (mgKOH/g)	192.80	185.55	180.50	186.28
Acid Value (mgKOH/g)	1.41	1.33	1.954	1.56
Iodine Value (I_2g/100g)	98.20	100.04	103.32	100.52

* Yel-Gr ≡ Yellow-Green, Yel-Or ≡ Yellow-Orange
Values and are means of duplicates

7.4.3 Fatty acid profile of *B. aegyptiaca* kernel oil

Balanites aegyptiaca oil had four major fatty acids in the range of C_{16} to C_{18} namely, palmitic (15.5%), stearic (19.01%), oleic (25.74%) and linoleic (39.85%) acids (Table 7.9; Figure 7.3). Small amount of α-linolenic acid (< 0.7%) was detected in some samples. The amount of unsaturated fats (oleic + linoleic) was higher (65.59%) than that saturated fats (palmitic + stearic) (34.41%) giving unsaturated to saturated ratio of 1.9.

Table 7.9 *B. aegyptiaca* fatty acid profile (n=42)

Fatty acid	Weight % ± SE
Palmitic	15.40±0.26
Stearic	19.01±0.29
Oleic	25.74±0.35
Linoleic	39.85±0.48
Saturated	34.41±1.80
Unsaturated	65.59±6.92
Unsaturated/saturated acid ratio	1.91

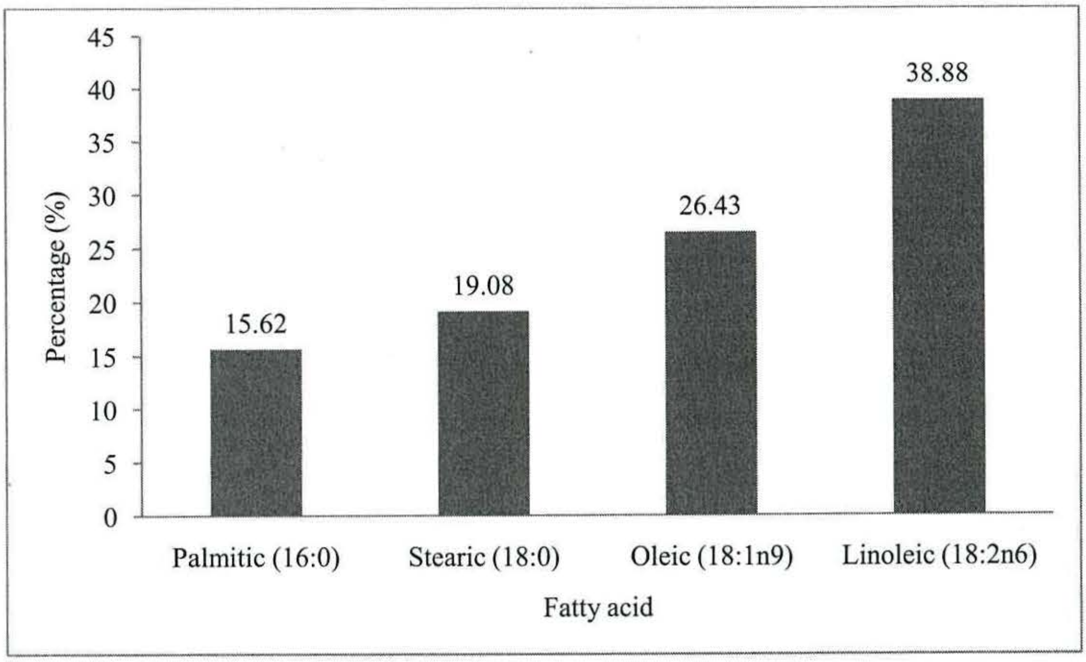


Figure 7.3 Average fatty acid content of *B. aegyptiaca* kernel oil (Uganda)

7.4.4 Variation in *B. aegyptiaca* oil from Adjumani, Katakwi and Moroto districts

Comparison of means (one-way ANOVA) showed significant ($p<0.05$) difference in the amounts of oleic acid only (Table 7.11). Separation of means revealed that *B. aegpytiaca* oil from Katakwi had significantly lower oleic acid content than oil samples from Adjumani and Moroto districts (Table 7.10). There were no differences in the fatty acid contents of oil locally processed from Adjumani district and the hexane-extracted oil (Table 7.10).

Table 7.10.Percentage composition of fatty acids in Balanites kernel oil from different study districts

Sample	N	Percentage fatty acid (Mean ± *SEM*)			
		Palmitic (16:0)	Stearic (18:0)	Oleic (18:1n9)	Linoleic (18:2n6)
Adjumani	16	15.73 ± 0.29^{a}	18.94 ± 0.32^{a}	26.22 ± 0.63^{a}	39.12 ± 0.63^{a}
Adjumani-local	6	16.23 ± 0.21^{a}	17.76 ± 0.18^{a}	26.61 ± 0.12^{a}	39.40 ± 0.27^{a}
Katakwi	11	14.89 ± 0.66^{a}	19.30 ± 0.19^{a}	23.99 ± 0.78^{b}	41.82 ± 1.44^{a}
Moroto	9	14.90 ± 0.75^{a}	19.61 ± 1.20^{a}	26.46 ± 0.12^{a}	39.03 ± 0.37^{a}
Mean (Uganda)	42	15.40 ± 0.26	19.01 ± 0.29	25.74 ± 0.35	39.85 ± 0.48

Values with the same superscript letter within a column are not statistically different ($p\leq0.05$). SEM= Standard error of the mean.

Table 7.11 One-way ANOVA of means of fatty acids in Balanites oil

Fatty acid	Sum of Squares	df	Mean Square	F	Sig.
Palmitic	10.978	3	3.659	1.277	0.296^{ns}
Stearic	13.678	3	4.559	1.301	0.288^{ns}
Oleic	46.57	3	15.523	3.611	0.022*
Linoleic	58.621	3	19.54	2.220	0.102^{ns}

**Significant at p≤ 0.05; ns = Not significant at p≤ 0.05.*

7.5 Discussion

7.5.1 Nutritional composition of *B. aegyptiaca* leaves, flowers and fruit pulp

7.5.1.1 Proximate composition of *B. aegyptiaca* leaves, flowers and fruit pulp

Although *B. aegyptiaca* fruit pulp had significantly higher moisture content (5.06%) than the leaves and flowers (1.88%) both can be considered to have lower moisture content when compared with other fruits and vegetables (Lockett *et al.,* 2000). The dry matter content of leaves, flowers and fruit pulp was generally high, ranging from 95% in fruit pulp to 98% in leaves and flowers. Dietary study in northern Nigeria by Lockett *et al.* (2000) revealed equally high dry matter content in *B. aegyptiaca* fruits (90.9%). High dry matter content has also been reported in some of the commonly consumed vegetable in rural areas (Dhello *et al.*, 2006).

The low moisture content and high dry matter in Balanites products is not surprising given the hardy nature of the Balanites tree. The low moisture content suggests that all the three Balanites products could have a long shelf life, implying that products could be dried under ordinary conditions and kept for longer periods by households. This however, was not observed in the study areas since the scarcity of vegetables during the dry season means that all leaves harvested were consumed thus leaving no extra for storage. The high dry matter contents make these products appropriate foods for dry season or famine time in reas where they are found. The quantity of Balanites leaves is not greatly reduced by cooking. During severe famine, Balanites leaves are eaten as a major source and such high dry matter content reduces the length of starvation.

The ash content of Balanites leaves and flowers was 8.07% while that of the fruit pulp was 6.97%. Kubmarawa *et al.* (2008) reported ash content of 9.26% in leaves while Lockett *et al.*

(2000) found higher ash content in leaves (12.27%) and a closely similar amount (7.42%) in fruit pulp. Hall and Walker (1991), citing several sources, reported an ash content of 2.4 – 6.9 % in fruit pulp of Balanites. This is closer to the ash content reported in other locally consumed leafy vegetables such as 4 – 5% in *Amaranthus hybridus* (Dhello *et al.*, 2006) although these are leaves of herbs and not trees. Since most fruits and vegetables tend to have an alkaline ash, the consumption of Balanites leaves, flowers and fruits can contribute to healthier diets by neutralizing the effect of other acidic foods. Snyderhealth (2003), recommended that a diet should consist of at least 70 to 80% basic foods and with no more than 20 to 30% acidifying foods in order to maintain a balanced pH in the blood and tissues.

The fat content of Balanites leaves (2.29%) was significantly higher than that in fruit pulp (0.37%). Lockett *et al.* (2000) reported slightly higher values in Adamawa State, Nigeria, namely 3.34 and 1.34% for the leaves and fruits respectively. Kubmarawa *et al.* (2008) also reported a similar fat content (2.9%) in *B. aegyptiaca* leaves collected from Adamawa State, Nigeria. In contrast, Cook *et al.* (1998) reported a much higher fat content in fruit pulp (14%) in Niger. Dougal *et al.* (1964) also reported a slightly higher fat content (6.6%) in Kenya while most of the earlier literature including, Abu-Al-Futuh (1983), Backer (1983) and Nour *et al.* (1985) reported the fat content of 0.1 – 0.7% in Balanites fruit pulp which are consistent with the findings of the present study. Dougal *et al.* (1964) and Backer (1983) reported a higher content of fat in the young shoots and leaves (1.5 – 4.2%) than in the fruit pulp, further supporting the results of the present study. Omujal (2008) found fat content of 1.5 – 3.5% in shea pulp which compares well with that found in Balanites leaves and both are dryland fruit trees. This indicates that Balanites leaves and flowers are better sources of fats than fruit pulp.

Importance of lipids in nutrition and health has been long known. Fats are a major source of energy for the body and aid in vitamin absorption and tissue development. They also play important role as antioxidants (NAS, 2005; Anhwange *et al.,* 2004). In order for a body to meet its daily nutritional needs while minimizing risk of chronic diseases, NAS (2005) recommended that adults should obtain 20 – 35% of their calories from fat. Though the quantity of fat in Balanites leaves, flowers and fruits are somehow low, this could still be vital as energy supplements during the dry season when alternatives are few. Moreover, their consumption could have a substantial cumulative effect thus sustaining rural diets. Cook *et al.*

(1998) found four fatty acids in the fruit pulp which were similar to those in the Balanites kernel oil but in smaller quantities (0.4 – 1.31 mg g^{-1} dry wt). These further add nutritional value to fruit pulp. It is also important to remember that Balanites fruits are mainly consumed by the nutritionally vulnerable members of the community (children, women and elderly) whose health could be more compromised in their absence.

Similarly, crude protein content was significantly higher in Balanites leaves and flowers (16.95%) than in the fruit pulp (5.4%). The crude protein value in the leaves reported in this study is close to that reported by Kubmarawa *et al.* (2008) who found 15.86% in Niger but higher than that reported by Lockett *et al.* (2000) [7.88%] in Nigeria. However, Dougal *et al.* (1964) reported much higher protein content (20.8 – 27.5%) in Kenya. The protein content in the fruit pulp reported in the present study (5.4%) is generally within the range reported by Dougal *et al.* (1964), Abu-Al-Futuh (1983), Backer (1983), Hall and Walker (1991), Cook *et al.* (1998) and Lockett *et al.* (2000) [3.2 - 8.5%]. These levels of crude protein in both Balanites leaves and fruits are within the range reported for most tropical vegetables and fruits (Saka and Monthi, 1994; Omujal, 2008; Kubmarawa *et al.,* 2008). Thus, Balanites leaves, flowers and fruits are generally good sources of protein and compare well with other tropical leafy vegetables.

Proteins play an important role in nutrition and diet since they are the major structural components of all body cells. They function as enzymes, membrane carriers, hormones and provide energy. According to NAS (2005), the recommended daily allowance (RDA) for proteins is 0.8 g kg^{-1} of body weight for adults and an increased value of 1.1 g kg^{-1} of body weight for pregnant and breast feeding women. WHO (2007) recommended a slightly higher protein value of 0.83 g kg^{-1} of body weight which translates to about 33 - 66 g/day for adults and about 16.2 – 59.9 g/day for boys and girls aged between 4 -18 years. Christian and Ukhun (2006) noted that protein quality and quantity are major concerns in human diets. Protein deficiency causes growth retardation, muscles wasting, oedema, kwashiorkor and abnormal collection of fluids in the body (Anhwange *et al.,* 2004). According to WHO (2004), there is inadequate protein consumption in many developing countries, including Uganda. Wide-spread consumption of Balanites leaves during the dry season in Uganda supplements other protein sources such as beans, peas and groundnuts that are rare at such times.

Balanites leaves and fruit pulp have been reported to have amino acids required by the body. Amino acids are the basic building blocks for proteins and according to NAS (2005) and WHO (2007) there are currently nine indispensable amino acids including histidine, isoleucine, leucine, lysine, methionine, cysteine, threonine, tryptophan and valine. Up to eight of these amino acids, excluding tryptophan, have been reported in Balanites leaves (Kubmarawa *et al.*, 2008) while four have been detected in fruit pulp (Cook *et al.*, 1998). Consumption of Balanites leaves and fruits can therefore be of high nutritional value to dryland communities in many parts of Africa where the species grows.

7.5.1.2 Mineral composition of *B. aegyptiaca* leaves, flowers and fruit pulp

The level of macronutrients was generally higher in the leaves and flowers than in fruit pulp in the order of K>Na>Mg with mean values of 19.54, 3.32 and 1.26 mg g^{-1} in leaves and flowers respectively. The corresponding mean values in fruit pulp were 27.24, 2.34 and 0.83 mg g^{-1} respectively. Amounts of Mg reported here are close to those reported by Lockett *et al.* (2000) as 2.96 and 0.81 mg g^{-1} in leaves and fruit pulp respectively. Reports on other minerals are rare in literature. In the present study, pre-boiling of leaves appeared to reduce the amount of potassium while Na and Mg remained the same. At the same time, the amount of potassium in fresh leaves and flowers was significantly higher. Origin/sub-region of fruit pulp did not significantly affect the macronutrient contents found in Balanites fruit pulp.

Macronutrients are important in human diet because of their various functions in the body. For instance, sodium is vital for maintaining fluid volume, osmotic equilibrium and acid-base balance. Its deficiency during hot weather is attributed to heavy work in hot climate (Christian and Ukhun, 2006). Magnesium functions as a cofactor of many enzymes involved in energy metabolism, protein synthesis, RNA and DNA synthesis and maintenance of electrical potential of nervous tissues and cell membranes (Al-Ghamdi *et al.*, 1994). Potassium is very important in the human body where along with sodium, it regulates the water balance and the acid-base balance in the blood and tissues. In the nerve cells, sodium-potassium flux generates the electrical potential that aids the nerve impulses. A low Na/K ratio is recommended in a diet. In the drylands of Uganda, this can be achieved through consumption of Balanites leaves and pulp since potassium level is significantly higher than sodium.

Iron was the most abundant micronutrient in the Balanites leaves, flowers and pulp. Micronutrients in leaves and flowers were in the order Fe>Mn>Zn>Cu with mean values of 452.21, 60.65, 35.69 and 25.49 $\mu g\ g^{-1}$ respectively. A similar trend was found in fruit pulp with mean values of 467.67, 31.26, 28.48 and 18.92 $\mu g\ g^{-1}$ for Fe, Mn, Zn and Cu, respectively. Lockett *et al.* (2000) also reported a higher level of Fe (579.3 $\mu g\ g^{-1}$) in Balanites leaves but with lower levels of other trace elements than reported in this study. The levels of Zn and Cu were as low as 22.7 and 11.0 $\mu g\ g^{-1}$ respectively. Furthermore, the two studies by Lockett *et al.* (2000) and Kubmarawa *et al.* (2008) reported much lower levels of Mn, Zn and Cu than found in this study. More notable is the great variability in the level of Fe, 58.0 – 120 $\mu g\ g^{-1}$ in fruit pulp compared to 579.3 $\mu g\ g^{-1}$ in leaves. In the present study, the level of Fe in pulp (467.67 $\mu g\ g^{-1}$) was closely similar to that in leaves and flowers (452.21 $\mu g\ g^{-1}$).

The role of trace elements, including those reported above, in human nutrition and disease control cannot be over-emphasized. Even though they form a small proportion of the nutrients required by the body and do not contribute to the energy value of food, they are of great physiological importance particularly in body metabolism (Schwart, 1975; Saura-Calixto and Canellas, 1982; WHO, 2004; NAS, 2005). Iron is a constituent of hemoglobin, myoglobin and a number of enzymes, which catalyze oxidation and reduction processes in body cells and its deficiency causes anaemia (Dallman (1986; Christian and Ukhun, 2006). Zinc is an essential component of many enzymes participating in the synthesis and degradation of carbohydrates, lipids, proteins and nucleic acids as well as metabolism of other micronutrients. Zinc also plays a central role in the immune system by modulating increased susceptibility to infection (Shanker and Prasad, 1998; Prasad *et al*, 2007; Aggarwal *et al.,* 2007). Due to this important role, Cook *et al* (1998) commended the consumption of Balanites fruits in Niger for provision of zinc and other nutrients. They further observed that for people who live in the Sahel and other dry areas, especially children who are at risk of many microbial and parasitic infections, consumption of Balanites fruits could provide useful amounts of this critical micronutrient (Zn) to maintain their immune systems and reduce vulnerability to diseases. Copper is essential in the human diet to help iron-rich foods make red haemoglobin in the blood and is also involved in the formation of collagen and other connective tissue and protective coverings for nerves. The role of copper in maintaining cardiovascular health is well established (WHO, 2004; NAS 2005). A much higher content of copper was found in Balanites pulp (18.92 $\mu g\ g^{-1}$) than that reported by Cook *et al* (1998) [2.4 μg g^{-1}]. Availability of a significant amount of iron in Balanites leaves, flowers and pulp is therefore of nutritional and health benefit to dryland communities since their consumption during the dry season helps in reducing incidences of anaemia or need for iron supplementation among pregnant women.

Barminas *et al*. (1998) noted that in many developing countries, frequent food shortages and high cost of cultivated green leafy vegetables results in frequent consumption of wild leafy vegetables especially in the rural communities. The vegetables supply calories and nutrients during dry season when there is shortage of cultivated green vegetables and other food resources. According to Baumer (1995), knowledge of nutritional composition of such wild foods could improve their utilization prospect. Kubmarawa *et al.* (2008) observed that *B. aegyptiaca* falls in the category of such plants yet it is popular among certain communities throughout its range in Africa. Understanding their nutritional and anti-nutritional composition permits better assessment of their importance to the well being of communities that consume them.

The findings of the present study indicate that Balanites leaves commonly consumed by the rural populace of Katakwi district and other areas are not inferior to the conventional Ugandan vegetables. There is a need, however, to determine the vitamins and minerals present in both fresh and boiled Balanites leaves, since they can easily be lost during preparation. According to Kubmarawa *et al.* (2008) nutrient loss is of great concern during blanching and cooking of vegetables. The present findings show that pre-boiling of Balanites leaves before selling or direct household consumption have no effect on the amounts of both macro and micronutrients, except potassium. It is possible that the level of vitamins, not determined in this study, could be significantly reduced during the pre-boiling and washing of leaves. The effect of pre-boiling and squeezing of Balanites leaves on vitamin availability needs to be investigated in order to provide a basis for minimizing loses.

Potassium was the most abundant macronutrient in the leaves, flowers and pulp. This is nutritionally significant because potassium plays a key role in neuro-muscular function. The high quantity of potassium, sodium, magnesium, iron, manganese, zinc and copper make Balanites leaves, flowers and fruit excellent sources of macro and micronutrients. Balanites leaves should constitute diets of individuals with low levels of these minerals.

7.5.1.3 Level of anti-nutritional factors in Balanites leaves, flowers and fruit pulp

One of the factors limiting wide use of many plants is occurrence of a range of anti-nutrients capable of causing harmful effects in humans (Kubmarawa *et al.*, 2008). The commonly reported anti-nutritional factors in vegetables and fruits include tannins, oxalates and phytates. In this study, tannin content was significantly ($p < 0.05$) higher in fruit pulp than in leaves and flowers. Tannin content in leaves was lower than that reported by Kubmarawa *et al.* (2008) in Nigeria and also for most vegetables, thus making Balanites leaves fit for human consumption. The amount of tannin was reduced by pre-boiling and decanting the water because the tannin content of boiled leaves from the market leaves was low. Large amounts of tannin reduces digestibility of nutrients (Kubmarawa *et al.*, 2008). Though Kubmarawa *et al.* (2008) also found low levels of phytic acid (2.97 mg/100g) and oxalates (75.0 mg/100g) in Niger, this may not necessarily be the case with the Ugandan populations. The amount of phytic acid and oxalates in Balanites leaves in Uganda also need to be examined. This is important since phytic acid has been reported to reduce the bioavailability of trace elements and minerals (Apata and Ologhobo, 1989). Oxalates are considered anti-nutrients as well as toxins since they render calcium unavailable by binding calcium ion to form insoluble calcium oxalate complex (Kubmarawa *et al.*, 2008). Lockett *et al.* (2000) also recommended detailed studies on nutrient bioavailability of edible wild plants so as to determine their nutritional value.

Though not determined in this study, Lockett *et al* (2000) reported that Balanites leaves and pulp contain 15.8 and 1.2 mg g^{-1} of calcium respectively. Cook *et al* (1998) also reported 10.5 mg g^{-1} in the fruit pulp while Kubmarawa *et al.* (2008) found 0.75 mg g^{-1} of oxalates in the leaves. It is therefore necessary to determine the possiblecombination of calcium and oxalate, which can accumulate in the kidney as calcium oxalate stones, the most common form of renal stone.

7.5.2 Oil yield and physico-chemical characteristics of Balanites kernel oil

7.5.2.1 Oil yield

Balanites kernels constituted 18.1 – 23.2% of the nuts with a mean of 19.5%. These values are close to those reported in the Borno State, Nigeria where Aviara, *et al.* (2005) found *B. aegyptiaca* kernels to constitute 22.6 - 24% of the nuts. Oil yield from the kernels varied from 38.53 - 50.56% with mean of 44.5%. This yield is within the range reported elsewhere.

Chapagain and Wiesman (2005) reported oil yield of 46.12%, 44.17% and 39.20% from Israel, Africa and India populations of *B. aegyptiaca* respectively. It has also been reported that oil yield is positively correlated with level of diosgenin in Balanites kernels. Since these parameters are desirable characteristics, the relationship may play a vital role in germplasm selection for future domestication of *B. aegyptiaca* (Chapagain and Wiesman, 2005). Other studies have reported variable oil yield from Balanites kernels, such as, 46% in Sudan (Hussain *et al.*, 1949); 45.0 - 46.1% in Sudan (Nour, *et al.*,1985); 40-46% in Sudan (Abdel-Rahim *et al.*, 1986); 45% in India (Jain and Banerje, 1988); 38.2% in Nigeria (Eromosele *et al.*, 1994); 48% in Cameroon (Kapseu *et al.*,1997); 49% in Sudan (Mohamed *et al.*, 2002); 39 – 46.7% in Israel (Chapagain *et al.*, 2009); and 45 – 47% in India (Deshmukh and Bhuyar, 2009).

From the available reports, it can be inferred that *B. aegyptiaca* kernels yield oil in the range of 40 – 50%. Oil yield obtained from Katakwi population therefore seems to be on a higher side than that reported in literature. However, the average oil yield of 44.5% reported in this study for Uganda compares well with that reported from other countries where *B. aegyptiaca* is found. Balanites oil content for Moroto population was relatively lower than that from Katakwi and Adjumani populations. These differences in oil yield could be explained by differences in environmental conditions between the sub-regions as well as genetic variation. Kapseu *et al.* (2007) and Omujal (2008) reported similar variations in shea oil yield, another dryland fruit tree found in Uganda. The good oil yield from Uganda coupled with high density of trees along the River Nile in West Nile sub-region (Madrama, 2006) and Teso and Karamoja sub-regions (Katende *et al.*, 1995) make the drylands of Uganda a potential niche for Balanites oil production for both local and external markets.

7.5.2.2 Physico-chemical characteristics of *B. aegyptiaca* oil

Physico-chemical characteristics of any oil are important for determining its nutritional quality and commercial value (Omujal, 2008; Chapagain *et al.*, 2009). Colour of hexane-extracted oil was light yellow; refractive index was 1.46 at 20°C while viscosity of the oil varied between 15.75 - 22.60 cSt at 40°C. Deshmurkh and Bhuyar (2009) described Balanites oil as golden yellow and Hussain *et al.* (1949) attributed the yellow colour in Balanites oil to presence of α-carotene. According to FAO/WHO (1994) and WHO (2004), carotenoids and their derivatives are responsible for the yellow colour of fruits, vegetables, cereals and some crude oils. The presence of carotene makes Balanites oil nutritionally important because carotenoids are highly unsaturated polyisoprene hydrocarbons that are lipid and are precursors for vitamin A (WHO, 2004). The light yellow colour of the oil also makes it visually attractive thus, along with other good attributes; this could make Balanites oil a viable and competitive market commodity.

Refractive index of 1.46 at 20°C is in line with that reported by Hussain *et al.* (1949) and Abdel-Rahim *et al.* (1986). However, Chapagain *et al.* (2009) reported a slightly higher value (1.51) for samples from Israel. Other kernel oils have been reported to have similar refractive indices, for instance, 1.46 for Jojoba in Jordan and India (Kaul *et al.*, 2008) and 1.48 for shea butter in Uganda (Omujal, 2008). Refractive index is an important attribute of oil quality (Omujal, 2008).

At the same temperature (40°C) Eromosele and Paschal (2003) in Nigeria and Deshmurkh and Bhuyar (2009) in India reported higher viscosities, 46.8 and 38.60 cSt, respectively. Similarly, Chapagain *et al* (2009) though without specifying the temperature reported higher viscosity (49 cP). Eromosele and Paschal (2003) also found the viscosity of *Balanites* oil showing a negative dependence on temperature increase thus suggesting potential application as lubricating oil base stock. According to Chapagain *et al.* (2009), viscosity is one of the quality parameters of oil. Other qualities of Balanites oil such as refractive index and specific gravity were very similar to those of soy oil, thus making it suitable and potential resource for biodiesel production.

The saponification value was 186.28 mg KOH g^{-1}- on average. Jain and Kenerjee (1988) and Chapagain *et al* (2009) reported slightly lower saponification values, 175.91 and 172.7 mg NaOH g^{-1}, respectively. Other earlier reports by Abu-Al-Futu (1983), Nour *et al.* (1985) and Abdel-Rahim *et al* (1986) indicated variable saponification values ranging from 177 to 204. Whereas some of the variations could be explained by differences in environmental conditions, improvements in the methods of analysis could explain some of the variance. The total acidity of the oil expressed as acid value was generally low (1.33 – 1.95 mg KOH g^{-1}) and agrees with that reported by Deshmurkh and Bhuyar (2009) and Abdel-Rahim *et al* (1986) although higher than that reported by Eromosele *et al.* (1994), and Nour *et al.* (1985) who found acid values of 0.11 – 0.5 mg KOH g^{-1}. Omujal (2008) reported a higher acid value of 3.18-6.92 mg KOH kg^{-1} for shea butter in Uganda. Iodine value ranged from 98.20 to 103.32 I_2 g/100g, which is within the ranges reported by Abu-Al-Futu (1983) and Chapagain *et al.* (2009). Eromosele *et al.* (1994) and Jain and Kenerjee (1988) reported lower values (76.2 and 56.5 I_2g/100g respectively). Acid, saponification and iodine values reported in this study are generally within the range of most edible oils that are suitable for food and cosmetics. The high saponification value suggests that Balanites oil is suitable for soap making. Since the physico-chemical characteristics of Balanites oil obtained in this study are more or less similar to those reported in other countries, it is possible to develop regional standards for Balanites oil before it is commercialized or widely traded like shea butter which has standards (RCT, 2006).

7.5.3 Fatty acid composition of *B. aegyptiaca* kernel oil

The fatty acid profile is important for determining the nutritional value of oils (WHO, 2005; NAS, 2005; Ajayi *et al.*, 2006). The fatty acid composition of Balanites oil revealed linoleic acid as the predominant fatty acid. Four major fatty acids in the order linoleic>oleic> stearic>palmitic were found in oils from the three study sub-regions, with small quantities of α-linolenic acid in some of the samples. The mean fatty acid contents in this study were; palmitic 15.40%, stearic 19.01%, oleic 25.74%, and linoleic 39.85%. Cook *et al.* (1998) also reported the same four fatty acids in fruit pulp though in smaller proportions of 0.5 - 1.31 mg g^{-1} dry weight. The four major fatty acids in Balanites oil constituted 99.2 – 100% of the total fatty acids. Chapagain *et al* (2009) found the same four major fatty acids to constitute 98 – 100% of total fatty acids for cultivated and irrigated *B. aegyptiaca* plants in Israel. They also found significantly higher levels of linoleic acid (31 - 51%) and correspondingly lower quantities of oleic and stearic acids than reported here. They further found the fatty acid profile of *B. aegyptiaca* oil to be very similar to soybean oil profile. When compared to the Uganda shea oil (Omujal, 2008), Balanites oil in this and other studies is about six times higher in the essential omega 6 linoleic acid. This also explains why Balanites oil remains liquid while shea oil turns solid at room temperature.

The values obtained in this study for the respective fatty acids are within those reported elsewhere by Hussain *et al.*(1949), Giffard (1974), Abu-Al-Futuh (1983), Jain and Banerjee, 1988, Muhamed *et al.* (2002), Deshmurk and Bhuyar (2009) and Chapagain *et al.* (2009). Minute quantities of α-linolenic acid <0.7% were detected in this study and in consonance with findings by Muhamed *et al.* (2002) and Deshmurkh and Bhuyar (2009) who reported higher levels of 1.7 and 7.2% % respectively. It appears that the difference in method of extraction used (hand press as opposed to solvent extraction) and improvement in the scientific equipment could have enabled detection of increased amounts of alpha linolenic acid in these studies. The presence of an omega 3, α-linolenic acid in some populations of *B. aegyptiaca* presents further opportunities for selection of superior races for propagation trials. Chapagain *et al.* (2009) also reported several other fatty acids but in smaller quantities. Deshmurkh and Bhuyar (2009) detected presence of palmitoleic acid (4.3%) in the Indian population which appears not to have been reported in the literature so far available. It appears that Deshmurkh and Bhuyar (2009) were able to detect additional fatty acids in Balanites kernels due to the more detailed analyses employed because they were interested in the fuel properties of this oil. Environment and tree genetic variations could also account for differences in fatty acid profiles in *B. aegyptiaca* oil.

Only oleic acid content was significantly lower in the Katakwi population, 23.99% than the overall mean of 25.74%. However, the oil also had slightly higher content of the omega-6 linoleic acid (41.82%) than the mean (39.85%). Since linoleic is an essential fatty acid [EFA] (Uauy, 2009), this could be used as one of the qualities for germplasm selection. Linoleic, undoubtedly one of the most important polyunsaturated fatty acids in human food because of its prevention of distinct heart vascular diseases (Omode *et al.*, 1995) was predominatly in oil from all the three study sub-regions. It is well known that dietary fat rich in linoleic acid, apart from preventing cardiovascular disorders such as coronary heart diseases and atherosclerosis, also prevents high blood pressure (Ajayi *et al.*, 2006). Furthermore, linoleic acid derivatives serve as structural components of the plasma membrane and as precursors of some metabolic regulatory compounds (Vles and Gottenbos, 1989). The presence of one of the three essential fatty acids in Balanites oil makes it nutritionally valuable and highly recommended for human consumption.

Monounsaturated oleic acid was the second most prominent fatty acid in Balanites oil. This gives higher percentage of unsaturated fatty acids [UFA] (65.59%) than saturated fatty acids [SFA] (33.41%) with UFA:SFA ratio of 1.91. Results by Deshmurkh and Bhuyar (2009) indicated UFA/SFA ratio of 3.03 and is of great nutritional significance. The polyunsaturated fatty acid (PUFA) content (linoleic) was also higher (39.85%) than that of other nonconventional oilseeds: avocado (15.5%), *Canarium schweinfurthii* (28.8%), *Dacryodes* *edulis* (25.2%) (Chalon, 2001; Dhellot *et al.*, 2006) and shea butter (6.9%) (Omujal, 2008). The UFA:SFA ratio makes it possible to classify Balanites oil as potentially linoleic/oleic oil having good nutritional properties. Thus, Balanites kernel oil could be a good source of essential polyunsaturated fatty acids. There are also traces of omega 3 alpha linolenic fatty acid with immensely positive nutritional and health properties.

Similarities between the locally processed and solvent extracted Balanites oil suggests that the traditional processing method does not have any detrimental effect on the fatty acid profile. However, the locally processed oil had a darker colour than solvent extracted oil (Plate 7.2). It is possible that there are differences in the physico-chemical characteristics of the oils extracted by the two methods, though it was not possible to perform most of the physico-chemical analyses on the locally processed oil simply because of this rather dull colour. Whereas elderly local people appreciated the taste of locally processed oil despite its dark colour, young people and the urban buyers felt otherwise. In order to capture the urban market and make the oil visually attractive to younger persons, there is a need to improve the processing method by the introduction of a hand press as already being done for shea butter in the drylands of Uganda. The same technology could be adopted for Balanites oil processing in Uganda.

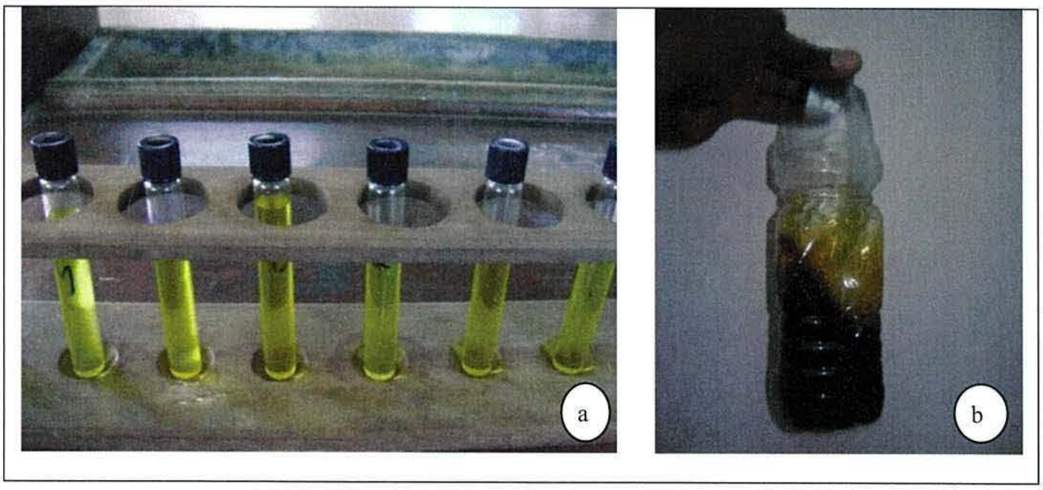


Plate 7.2 Solvent extracted (a) and locally processed (b) Balanites oil.

CHAPTER EIGHT: GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

This chapter is a synthesis of discussion of all the results already presented in various chapters. It has three sections: section 8.1 comprises a General Discussion based on the four major areas of the study, namely local knowledge, species ecology, local processing and marketing, and nutritional value of *Balanites aegyptiaca* products. The conclusions are given in section 8.2 and the recommendations are presented in section 8.3.

8.1 General discussion

8.1.1 Local knowledge of use, management and conservation of *B. aegyptiaca*

The drylands of Uganda are richly endowed with valuable trees that have potential for domestication. *Balanites aegyptiaca* is one of these valuable fruit and vegetable trees with enormous socio-economic, environmental and cultural importance. This study has revealed that *Balanites aegyptiaca* is highly valued in both Adjumani and Katakwi districts of Uganda. Communities in Adjumani value Balanites as a fruit tree while those in Katakwi district regard its leaves as a dependable dry season vegetable that supplements diets and contributes to food security. Given the varied preference of the major Balanites products, local communities in Adjumani district rank it as their first priority indigenous fruit tree although a majority are not aware of its use as a vegetable. The only exception of Balanites leaf use was noted among a few households in the Sudanese refugee camps in Adjumani district. Though food shortages in camps could have forced some households to consume Balanites leaves, the leaves were reported to be part of dry season diet for some communities originating from Southern Sudan. In Katakwi district, fruits are mainly eaten by children and women while leaves are consumed by all household members. Rural households use Balanites leaves about four times a week during the dry season. In both districts, women and children dominate the collection, processing and sale of Balanites leaves and fruits. However, women are more skilled in preparing leaves in Katakwi while in Adjumani, the women have special skills for extracting oil locally.

Priority ranking of *B. aegyptiaca*, reported in this study is specific to the study villages and/or sub-counties. It is possible that the species could be ranked differently in other regions of

Uganda where it occurs. This is because *B. aegyptiaca* is site specific while other IFTs are sparsely distributed over a wider area. Okia *et al.* (2008) found that *V. paradoxa* was a high priority IFT in Toroma sub-county (not one of the study sites) in Katakwi district. The manner in which local people prioritize IFTs is dependent on the species usage and abundance in a given area. IFTs usage in Uganda is closely linked to the culture and tradition of the local people in a particular area (Okia *et al.* 2008).

Katakwi and Adjumani districts lie in the semi-arid belt of Uganda and local communities in these districts often experience food shortages for at least three to four months a year. Local communities have an accumulated local knowledge about trees that have supported their survival in the challenging semi-arid environment for a long time although this is often undervalued. The drylands are generally characterized by low and unpredictable rainfall, low soil fertility, remoteness from markets and centers of decision-making (UNCCD, 1994; GLP, 2005, MEA, 2005, Reynolds *et al.*, 2007). As a result of these environmental challenges, it is hard to deliver social services efficiently, and institutional arrangements devised in other regions may be dysfunctional when imposed on drylands (Reynolds *et al.*, 2007). Consequently, dryland populations, including those in Uganda, tend to lag behind those in other parts of the world on a variety of economic and health indices (MEA, 2005). As noted by Khagram *et al.* (2003), dryland populations are among the most ecologically, socially, and politically marginalized on Earth due to a combination of biophysical and socioeconomic features that together constitute a "drylands syndrome." Balanites and other IFTs products play a big role in the livelihood of communities in the two dryland districts studied in Uganda. Over the years, local people have accumulated a wealth of knowledge on its use and management. Such knowledge needs to be integrated in modern management practices for trees in the wild and on-farm in order to increase the productivity of drylands.

All households in the study villages have used Balanites tree or its products in one way or another. Household members, especially women have immense local knowledge on the collection and preparation of Balanites products. This local knowledge has been documented in the present study and can be used for promotion of Balanites and other IFTs in the drylands of Uganda and elsewhere. According to Chambers and Longhurst (1986) communities' local knowledge about trees needs to be exploited for development of dryland resources. Reynolds *et* *al.* (2007) also noted that a much greater value must be placed on local environmental knowledge because its practice is central to the management of most drylands. Seen in this light, it can be said that the study of local knowledge on management and use of Balanites in Uganda has been timely because it has generated information hitherto unavailable for improved management of the species. Moreover, it has contributed to the existing body of knowledge about the species.

Consumption of Balanites fruits and leaves has a gender dimension (though not investigated in this study) because it was noted that its products are mainly eaten by women, children and the elderly. In many rural parts of southern Africa, Akinnifesi *et al.* (2006) reported the popularity of many indigenous plants to women, children and the elderly which corroborate this finding. They further stated that indigenous fruit snacks are especially important for children who need to eat more frequently than adults. Indigenous fruits are also important sources of the micronutrients that are often deficient in cereal-based diets commonly consumed in rural areas (Ruffo *et al.*, 2002). Iron, one of key micronutrients is high in all Balanites products. Consumption of such products therefore improves the nutrition and health of the local communities living in Uganda's drylands.

In Katakwi district, most households said they depend on Balanites leaves every year irrespective of the level of food crop harvest and/or drought incidence. However, Balanites leaf consumption tended to increase markedly in years of food shortage or famine. This observation is consistent with that of Akinnifesi *et al.* (2006) who noted that in times of drought and/or famine, wild foods are elevated from supplementary to principal source of food, thus fulfilling a much more substantial role in the diet of rural people. Furthermore, the consumption of Balanites leaves as a vegetable in Katakwi district was not undermined. This is contrary to some reports that indigenous fruits or vegetables are considered to be inferior to those grown on-farm (e.g. Barnett, 2001). Given the importance of Balanites reported in this study and elsewhere, it can be concluded that the species should be domesticated.

Earlier reports that Balanites trees are mainly found on communal savanna lands has been confirmed by the tree inventory undertaken as part of this study. Over 80% of the trees are found in the wild with almost no form of protection and being utilized as a common pool resource. The areas with Balanites used to be reserved for grazing only. However, human population increase has resulted in expansion of settlements into such areas. While a few trees are retained on farm during land clearance for cultivation, most of them are cut to avoid competition with agricultural crops. The local people reported that Balanites increases the yield of pulses (e.g. pigeon pea and cow pea) but reduces the yield of cereals (e.g. millet, maize and sorghum) and some tubers, especially, cassava and sweet potatoes. In West Africa the negative effects of some IFTs (e.g. *V. paradoxa and Parkia biglobosa*) have been minimized using tree management practices such as pruning (Teklehaimanot, 2003). In view of this, there is a need to explore appropriate management options for Balanites for possible integration with a range of dryland agricultural crops.

The results of the present study show that Balanites are rarely planted however, 51% of the farmers interviewed claimed that they retained naturally growing Balanites trees on their farms. Retention of valuable trees, especially IFTs, on farms is a common practice in the savannas of Africa (Clarke *et al.*, 1996; Shackleton, 2004; Okullo, 2004; Akinnifesi *et al.*, 2006). Most farmers are reported to nurture saplings of IFTs on their land, for example, in southern Africa most rural farmers manage self-seeded recruits of *S. birrea* while only while 30% planted the tree (Shackleton, 2004). However, the planting of *S. birrea* only started after its products had gained larger markets. Trees that remain in the fields are managed by pruning, lopping and pollarding in order to increase compatibility with agricultural crops and to provide firewood and building materials to households (Minae *et al.*, 1994).

The predominantly subsistence consumption of Balanites products noted in this study with limited markets have not been strong incentives for planting of the tree. Mithöfer and Waibel (2008) reported that farmers tend to plant or retain and manage IFTs when they notice: decline in production from off-farm tree stocks, growing demand for tree products, increasing need to secure rights of land tenure and use, and need to even out peaks and troughs in the seasonal flow of produce, income and seasonal labour demand. According to McGregor (1991), the reasons for active management of trees are twofold; first is growing scarcity (i.e. on-farm resources becoming more valuable). Second, commercialization and potential income that can be earned from trees motivate farmers to manage trees on-farm and in the wild. Like other tree resources, successful development of Balanites products will guarantee the species' conservation in the immediate and long-term. Participatory improvement and domestication can successfully conserve tree genetic resources (Cornelius *et al*., 2006) and this approach will be desired for conservation of Balanites in Uganda because its improved use will most likely encourage conservation.

Several methods are employed to harvest fruits from Balanites trees. These include picking fruits from the ground following abscission, climbing trees, throwing objects and shaking branches to dislodge fruits. Though no serious tree damage was observed in this study, Kadzere *et al*. (2002) noted that these crude methods of harvesting fruits not only damage the trees but also cause excessive bruising to fruits, thus reducing their shelf life, quality and market value. Producers of exotic fruits normally harvest their crops according to harvesting indices by observing optimum harvesting time. Horticultural fruits are harvested before they are fully ripe, and harvesting is timed so that fruits reach full ripeness when presented to the final consumer (Kadzere *et al*., 2002). For indigenous fruits, including Balanites, there is a need for better understanding of ripening patterns and to determine whether or not the technique of harvesting unripe fruit for postharvest ripening can be successfully applied.

The 150 households interviewed under this study harvested 19,680 kg of Balanites leaves, 50,400 kg of fruits and produced 204 litres of oil, thus earning about US$ 6,007 annually. This represents about 12% of the average household income in the study districts. In consonance with other reports on IFTs elsewhere (e.g. Akinnifesi *et al.,* 2008), Balanites products are collected, processed and sold during the dry season when agricultural activities are minimal, thus making it economically viable. According to de Ferranti *et al*. (2005), although rural communities have access to a wealth of natural resources, including IFTs, they face the highest levels of poverty, ill health and malnutrition and score low on other development indicators.

For a long time, millions of people dwelling in rural areas in the drylands of Africa have depended on trees for income, food and other livelihood and security options, through gathering and processing of tree products (Akinnifesi *et al.,* 2008). Indigenous fruits from the miombo woodlands are central to the livelihood systems of both rural and urban dwellers in southern Africa, especially during periods of famine and food scarcity (Campbell, 1987; Campbell *et al*., 1997; Mithöfer and Waibel, 2003; Akinnifesi *et al*., 2006; Mithöfer *et al*., 2006). Mithöfer (2005) noted that the miombo woodlands represent an important food supplement and cash income in better times for rural people. Studies have shown that 65–80% of rural households in Malawi, Mozambique and Zambia, lack access to food for as much as three to four months per year. A study by Akinnifesi *et al.* (2004), found that 26–50% of the rural households relied on *Uapaca kirkiana* and *Parinari curatellifolia* fruits when food was scarce. Similarly, Okia *et al.* (2008) found that about 83% of households in the drylands of Uganda did not harvest enough food in 2007 and 75% of them relied on IFTs, including *B. aegyptiaca*, as alternative or complementary food sources. In order to overcome the constraints to IFTs utilisation in the drylands of Uganda, there is a need to build the capacity of farmers in value addition through improved fruit harvesting, processing and storage. Market chains also need to be developed concurrently.

Indigenous fruits and vegetables remain one of the major options for coping with food shortages, nutritional deficiency, and poverty in the drylands of Africa. Harvesting fruits from the wild and also from the semi-domesticated trees growing on farms can boost rural employment and generate substantial income (Leakey *et al.*, 2005; Mithöfer, 2005), especially through processing and value addition (Saka *et al.*, 2004). Over, 94% of rural households in South Africa were reported using *Sclerocarya birrea* fruits for wine making (Shackleton, 2004).

Studies have shown that, rural people in developing countries have intimate knowledge of their natural environment and environmental processes (Saka *et al.*, 2008). Van Vlaenderen (1999) noted that building on local knowledge of resources reduces overdependence on development interventions and promotes rural economic development. Appreciation and promotion of local knowledge empowers rural people by increasing their self-reliance, confidence and capacity to utilize and manage their local resources (Saka *et al.,* 2008). According to Simons (1996) and Maghembe *et al.* (1998), gathering local knowledge from rural communities provides relevant information concerning opportunities for utilization of indigenous fruits. Local knowledge can therefore be important in formulating a strategy for promotion of indigenous tree resources. Effective utilization of local knowledge and rural community preferences are essential to domestication of trees and commercialization of their products (Kwesiga *et al.*, 2000).

8.1.2 Ecology of *Balanites aegyptiaca* (distribution, population, and phenology)

Balanites grows along water courses, such as along rivers and swamps in Katakwi and Adjumani districts as reported elsewhere (von Maydell, 1990; Hall, 1992; Katende *et al.* 1995; Hall, 2008). The altitude ranges from 600 to 1,370 m a.s.l. Mean annual rainfall is 800 – 1,500 mm and the average temperature is >25° C. Annual rainfall range recorded in this study is above that reported in the main Balanites range (400 - 1,000 mm). The high rainfall accounts for the tall and larger diameter trees encountered in this study. It also explains the high tree densities encountered. As would be expected, a higher population of Balanites should provide more products than a low population of scattered trees. Hall (1992) reported that the density of *Balanites aegyptiaca* can be high in areas with unrestricted access to ground water. The species also tolerates seasonal flooding (Hall and Walker (1991). This attribute makes *B. aegyptiaca* unique because it is found in sites where few IFTs would grow.

Balanites trees were also found in low lying areas with sandy clay soil that experience aquic moisture regime (i.e. soil being saturated by ground water). The top soil acidity was high to moderate (pH 4.5 – 5.2). Like in most dryland savannas, the soils were low in organic matter and nutrients. Farmers did not apply any soil amendments in their crop fields due to financial limitations. Low soil fertility due to low levels of organic matter is common in drylands (Reynolds *et al.,* 2007). Annual bush fires prevent accumulation of organic matter and expose soil in semi-arid areas to increased degradation during the dry season. Regulation of bush burning will help to maintain soil fertility in such areas.

Balanites was increasingly cut for firewood and charcoal. Cutting down of IFTs for fuelwood is a common practice in savannas, especially on communal lands. In South Africa, Shackleton (2004) observed that even in communities where as much as 94% of the rural people were benefiting from *S. birrea* fruit collection, trees were being felled for firewood because of fuelwood shortage. IFTs need to be domesticated to overcome the above problem because trees grown around homesteads tend to produce more fruits than in wild fruit trees (Shackleton, 2004).

The highest stocking density of Balanites trees was recorded in Adjumani district (17 - 30 trees ha^{-1}). Working with a small area, Madrama (2006) reported a high stocking density (39 trees ha^{-1}) in the neighbouring Moyo district. Average annual fruit yield in Adjumani district was 53 kg per tree implying that each hectare (30 trees ha^{-1}) could potentially provide an estimated 1,590 kg (1.6 ton) of fruits per year. Clearly, there is a huge potential for commercial Balanites oil production in Uganda if the species is managed both in the wild and on-farms. If the fruits are sold at current market price (UGX 280 kg^{-1}), a total annual monetary value of UGX 445,200 ha^{-1} would be realised. Alternatively, 191 kg of seed kernel could be extracted (kernel = 12% of fruit) and this would produce some 76 litres of Balanites oil (40% yield using local method). At current Balanites oil price (UGX 3,500), this translates to UGX 267,120. If the fruits are consumed within the oil producing areas, it will be possible to realize both revenues along the chain, though by different actors. Potentially, an annual revenue of UGX 712,300 (US$ 356) per hectare can be realised. These estimates can be used to guide the development of Balanites for improving rural livelihoods and conserving the resource base and biodiversity.

This study did not establish the total land area covered by Balanites trees in the study districts. However, such estimates can be obtained from data on species distribution and applying GIS computation techniques. This is possible because parish-level data on land areas are available in Arc GIS files. Such estimates enable determination of potential income for each district or sub-region, thus indicating potential economic value of Balanites in the drylands of Uganda. It is also important to remember that Balanites is always found in association with other valuable IFTs. Incorporation of potential incomes from such associated species would provide a more realistic indication of the economic potential of the drylands.

Adjumani and Katakwi districts are famous for abundance and widespread use of other IFTs, such as *Vitellaria paradoxa*, *Tamarindus indica*, *Borassus ethiopum*, *Vitex doniana*, *Sclerocarya birrea* and *Annona senegalensis*. However, it was observed that trees tend to occupy different niches in the landscape. *B. aegyptiaca* is abundant in lowland sites – along rivers and swamps. Ripening of the above fruits followed more or less similar trend. *S. birrea* fruits for instance; start ripening in March, corresponding to the end of fruit ripening in Balanites. The findings that *B. aegyptiaca* grew in association with other priority IFTs such as *V. paradoxa*, *T. indica*, *S. birrea* and *Ziziphus mauritiana* is of interest for development of a comprehensive strategy for promotion of a wide range of IFTs. Of particular importance would be adaptation of the technologies developed for processing other products, such as shea oil press, for processing other indigenous fruits.

Much as the regeneration of Balanites was high in Adjumani, it appeared to be inadequate in replacing the old trees. Increasing grazing pressure threatens regeneration. Goats in particular damage Balanites seedlings and saplings. On the other hand, Balanites trees are sparsely distributed in Katakwi district (2 - 8 trees ha^{-1}). The situation is worsened by low regeneration attributed to bush fires and over-exploitation of leaves as a vegetable. Intensive leaf harvesting in Katakwi can act as a strong motivator for women to plant Balanites. The coppicing ability of Balanites also offers prospects for development of "food banks", similar to innovations with baobab in West Africa (ICRAF, 2003). Information on Balanites propagation techniques is available (Shanks and Shanks, 1991). However, the palatability of Balanites leaves to livestock; especially goats clearly suggest that additional investment will be needed in protecting the planted trees, especially during the first three to four years. Furthermore, the trees will have to be pollarded at 1.0 – 1.5 m to keep foliage out of reach of goats. The distribution pattern of Balanites is random in all study sites. Comparison of wild and on-farm sites revealed that human activities have had little influence on the species distribution pattern.

About 22% of Balanites trees have signs of pest and disease infestation. The most common sign was leaf galls. Though leaf galls appear to have no observable reductions in fruit yield in Adjumani, they considerably affect leaf production in Katakwi. Blackening of leaves and leaf defoliators also affect leaf production and their suitability for use as a vegetable. These problems will have to be addressed in any future Balanites domestication programme in Uganda.

Balanites exhibits diffused phenology. All the major phenological events occur during the dry season. The results of the present study show a strong positive correlation between phenological events in Balanites with temperature. Thus, leafing, flowering and fruiting occur during the dry season (November – March) when temperatures are high. The emergence of flowers soon after leafing makes them available to leaf harvesters in Katakwi. Flowers are destroyed as the small branches with young leaves are cut. This hinders regeneration and reduces fruit load.

Some thorn-less Balanites trees were seen in Katakwi and Adjumani districts. Picking of leaves from such trees was easier and collectors reported that they could be picked directly from the tree crown. Such trees were, however, few and it is not clear whether this is a different variety of Balanites. It is probable that older trees lose thorns. Small branches that originated from lower stems were thorny. In addition, seedlings raised from seeds of thorn-less trees had thorns. There is a need to further investigate and confirm whether or not there is a thorn-less variety of *B. aegyptiaca* since this could offer opportunities for establishing vegetable gardens.

8.1.3 Local processing and marketing of *B. aegyptiaca* products

Women in Katakwi experienced challenges in collecting leaves from tall Balanites trees. Though this was always overcome by using improvised ladders, the thorns still made it hard to collect the leaves. Restricted access to some leaf collection sites, such as wildlife reserve in Katakwi left fewer trees available for leaf harvesting. In southern Africa (Mithöfer and Waibel *et al.,* 2008), such restriction motivated farmers to plant desirable trees. Though no planting of Balanites was reported, women in Katakwi expressed willingness to plant Balanites trees to provide a leaf vegetable. This means that planting materials will have to be made available to them.

The concurrent harvesting of leaves and fruits during the dry season is important to rural communities in the study districts because at this time, dryland communities have no alternative food sources, thus, Balanites leaves and fruits provide food safety net in such a situation. As pointed out in other reports (e.g. Falconer, 1990; Falconer and Arnold, 1991; Schreckenberg, 1996), some NTFPs such as fruits, are available during dry or "hunger" period when cultivated crops are scarce or not available. In addition, trading in such products is considered economically viable by the poor who have no capital and lack skills to engage in other livelihood activities. Shackleton and Shackleton (2004) noted that despite the small cash incomes from trade in NTFPs, they provide an important contribution that complements the diverse livelihood strategies within poor rural households. They further state that there are moreover some non-financial benefits of NTFPs trade that are commonly overlooked.

Elderly women have experience in processing Balanites oil but the production levels are low due to difficulties associated with nut cracking. Women are able to produce 2-3 kg of kernel per day that yield one litre of oil and fetch UGX 3,500. To increase oil production, women help each other and engage children to crack nuts. These activities are carried out during low farming period and off-farm hours. An income of UGX 3,500 per day is reasonably high in a rural setting where the average wage is UGX 2,000. Currently, about 5% of the nuts are used for oil production while the rest go to waste. Improvement in nut cracking could attract men and boys into oil processing activities, hence increasing oil production and household incomes. Oil processing is a long process and requires strict observance of hygiene along the value chain. Proper oil storage containers are required because households store oil in saucepans which expose it to moisture and other contaminants. Clean plastic containers could improve Balanites oil storage and facilitate delivery to markets. In agreement with other reports (e.g. FAO, 1992; Mannan *et al.*, 2005; Aviara *et al.*, 2005; NRC, 2008), information generated from the present study shows that lack of appropriate equipment for nut cracking has greatly limited the use of Balanites oil in Uganda.

Balanites leaves and fruits are sold in local and urban markets. Traders sell the products in small quantities due to difficulties in processing and transport to markets. The demand and prices have increased over the past three years. Traders in Adjumani district felt that prices of fruits (UGX 280 kg^{-1}) and oil (UGX 3,500 kg^{-1}) are reasonable. In Katakwi, the price of leaves (UGX 400 kg^{-1}) is considered to be lower than the production costs (if all activities are monetised). Leaf collection is considered to be the most demanding activity because of the long distance (3- 6 km) travelled to collection sites and difficulties in climbing the thorny trees.

The leaves and fruits are highly perishable and this limits their marketing. Thus, Balanites products are not transported to markets outside the production districts. There is a need to explore possibility of processing leaves into leaf powder and fruit pulp into juice, jam, and alcoholic drinks. Balanites leaf powder is sold in some countries such as Burkina Faso (Guinko and Pasgo, 1992) and baobab leaves are marketed in powder form in West Africa (Lockett *et al.*, 200; Maranz *et al.*, 2008). Some of the buyers encountered in this study indicated willingness to buy Balanites leaves and oil even if prices double. Most buyers (75%) said that Balanites products were cheaper than their alternatives. Improved production of Balanites oil will enhance its marketability and increase its acceptability by consumers. However, without value addition, many consumers may not be willing to pay premium price for Balanites products.

8.1.4 Nutritional value of *B. aegyptiaca* leaves, flowers fruit pulp and kernel oil

Balanites aegyptiaca leaves, flowers and fruit pulp that are consumed in Katakwi and other drylands in Africa contribute substantial amount of macro and micronutrients to human diet. Other studies have also reported presence of essential amino acids in leaves and fruit pulp. The level of anti-nutritional factors in Balanites products, such as tannins (determined in this study) and oxalates and phytic acid (Kubmarawa *et al.*, 2008) are lower than those reported in other traditionally consumed vegetables and fruits, thus confirming their safety for human consumption. There is, however, a need to understand bioavailability of nutrients in these products so as to guide their wider use and possible commercialization.

The results indicate that Balanites leaves, flowers and fruit pulp are not inferior to most vegetables and fruits consumed in Uganda and elsewhere. They are rich in crude protein, K, Fe, Mn, Zn and Cu. Oil yield is high (44.5%) with good physico-chemical properties and rich in polyunsaturated omage 6 linoleic acid and small quantities of omega 3 alpha linolenic acid, all essential fatty acids. The order of fatty acids is linolenic>oleic>stearic>palmitic> α-linolenic. Unsaturated fatty acids constitute 65.6% of oil making it nutritionally beneficial.

Nutritional information on Balanites leaves, flowers, fruit pulp and oil reported here should prove useful to nutritionists, policy makers, development agencies and the general public in Uganda and elsewhere where nutrition and health benefits would be most beneficial in the following ways: (1) it could provide communities living in the drylands where Balanites is found with a basis to continue and/or increase consumption of Balanites products (2) could be used to disseminate knowledge on the nutritional worthiness of Balanites products (3) it could assist in eliminating negative perceptions about consumption of Balanites products so that they become part of the normal diet rather than being considered as 'famine' or 'poor peoples' food; (4) information could also serve to educate government agencies and NGOs concerned with natural resources as well as dryland communities about the need to conserve indigenous plants such as *B. aegyptiaca* for multiple products and services.
Though some studies have demonstrated and recommended use of Balanites oil for biodiesel production (e.g. WIPO, 2006 a&b; Deshmukh and Bhuyar, 2009 and Chapagain *et al.,* 2009), this may not be a commercially viable option for Uganda in the short and medium term

because of technological and resource limitations. What appears to be feasible in the foreseeable feature is the need to equip rural communities with appropriate tools and techniques for increasing oil production hygienically. Improved processing of the leaves for use outside the producing areas and exploring other uses of fruit pulp, for instance for making wine or other beverages could provide more income to dryland communities. This could help in addressing the multifaceted challenges of improving nutrition, raising incomes and conserving Balanites trees in the wild and on-farm. Short of this, Balanites resource which is currently abundant in some dryland areas of Uganda may be depleted due to other competing uses such as charcoal production and firewood.

Wild fruits and vegetables have long been valued as buffer food resources in famines and during food shortages. Falconer (1990) noted that trees provide food resources in most seasons, in the form of edible leaves and fruits but it is at times when few cultivated varieties of food are available - during seasonal shortages and droughts - that they become recognised and most appreciated. In southeastern Nigeria, for example, the leaves of the forest trees *Pterocarpus sp., Myrianthus arboreus* and *Ceiba pentandra* are highly valued because they flush at the end of the dry season, providing a vegetable during this "hunger period". Similarly, the fruits of *Treculia africana, Chrysophyllum albidum,* and *Dacryodes edulis are* popular since they mature with the early rains during the crop planting season (Okigbo, 1975).

The seasonal contribution of NTFPs is especially important in arid regions where seasonal food supply fluctuations are acute. In the Ferlo region of Senegal, although there are as many as 150 wild plant foods available, only those products that are available during seasonal "hunger" periods are widely consumed. Of particular importance are the leaves and fruit of baobab *(Adansonia digitata),* the leaves, fruit and seeds of *B. aegyptiaca* and the fruit of *Ziziphus mauritiana* which are principally gathered (Becker, 1983, Falconer, 1990). Ostberg (1988) reported that *B. aegyptiaca is* highly appreciated in the semi-arid Pokot region of Kenya because it produces fruit even in drought years when few foods are available. In addition, the trees provide valued bee forage for honey production.

8.2 Conclusions

The following conclusions are drawn from this study:

The current findings reveal that *Balanites aegyptiaca* products form an integral part of dryland communities' diet whose usage increases significantly during drought and/or famine periods due to their ready availability and affordability. Communities are endowed with gender specific knowledge on used of Balanites. This knowledge and skills has been passed on over generations. Balanites is a highly valued tree in both Adjumani and Katakwi districts; however, while communities in Adjumani prioritize it as a fruit tree, those in Katakwi highly regard its leaves as a dependable dry season vegetable. In addition, communities in Adjumani process edible oil from Balanites seed kernels. Balanites is also used as a remedy for various health ailments including; skin infections, stomach-aches, joint pains and intestinal worms. About 80% of Balanites products collected are consumed within a household while 20% are sold, generating 12% of the household income.

There are regulations on management and conservation of Balanites and other IFTs in both study sites however, such regulations lack effective implementation. There is a break down in traditional tree management institutions yet local government institutions lack the capacity to manage IFTs and/or do not recognize their contribution to household nutrition and income. Cutting of Balanites trees for fuelwood or sheer destruction during land clearing are leading to increased loss of trees.

Balanites aegyptica in Uganda is mainly found in semi-arid areas of Karamoja, Teso and West Nile sub-regions. There are however, other occurrences outside these areas but they are characterized by low tree densities. The species generally occurs along rivers and swamps on moderately acidic sandy clay soil. Population density of Balanites trees is higher in Adjumani district (17 – 30 trees ha^{-1}) than in Katakwi (2 – 8 trees ha^{-1}). Nonetheless, the species occurs over large areas in both districts.

Balanites are found in both the wild and on-farm and for all the sites studied, the stocking levels were similar between wild and farm conditions. The high stocking levels, such as those found in Adjumani can provide sufficient products, especially fruits that can support establishment of rural-based, small scale enterprises. Most of the Balanites trees in both districts are however old and the rate of natural regeneration is apparently insufficient to ensure replacement. Although Balanites is rarely planted; many famers reported retaining and managing naturally growing trees on their farms. Balanites is the most dominant tree species in both study districts making up to 72% and 42% of the trees in Adjumani and Katakwi respectively. In both districts, Balanites occurs in association with other locally valuable IFTs, such as *Tamarindus indica, Sclerocarya birrea* and *Ziziphus abyssinica.*

Leafing and flowering in Balanites take place during the dry season (November –March) while fruiting starts in the dry season but continues into the early rain season (April - May). Fruits develop for 7 – 8 months, and also ripen during the dry season (December – January). There is a strong positive correlation between phenological events in Balanites and temperature. The reproductive phenology of wild Balanites trees in Katakwi district has been greatly affected with up to 90% of the trees failing to fruit in some sites. Annual bush fires and intensive leaf harvesting are possible major contributory factors to this phenomenon.

Balanites fruits from Katakwi district are generally elongated but smaller in diameter while those in Adjumani are slightly shorter but bigger in diameter. These attributes will be important in participatory selection for future domestication of Balanites. Trees in Adjumani are generally taller and bigger in diameter than those in Katakwi, thus trees from Adjumani produce more fruit (53 kg per tree) than those from Katakwi (13.5 kg per tree). About 130 fruits are contained in one kilogram and a fruit contains 22.7% pulp and 12.4% kernel while the rest is a 'stone' and outer shell.

Balanites products are mainly collected, processed and traded by women and children. During the dry season, the products are common trade items in both village and urban markets. Leaves are traded in Katakwi while the fruits and oil are sold in Adjumani. Demand for Balanites oil is generally high but the production is low. Increasing number of rural people are engaging in trading Balanites fruits and leaves due to minimal start up costs involved. Although the income is still low, it is considered critical because of its timing in the dry season when there are no alternatives. For some products, especially the oil, there is a large unsatisfied market, hence,it is feasible to increase the contribution of Balanites products to rural income by developing appropriate processing techniques, especially for nut cracking. Improved processing and marketing of Balanites products can provide a number of opportunities to improve household income and nutrition among dryland communities in Uganda and elsewhere.

Local method of Balanites oil extraction yields about 40% while solvent extraction attains 45% yield. Locally extracted oil is dark in colour due to roasting of nuts which masks its otherwise golden yellow colour. Though preferred by the elderly, dark coloured oil is disliked by the young and urban consumers. Balanites leaves, flowers and fruit pulp are good sources of proteins, Fe, K, Mn, Zn and Cu. However, leaves and flowers are nutritionally superior to fruit pulp. Local extraction method used in Adjumani appears to have no effect on the chemical and fatty acid characteristics of Balanites oil. The resulting oil is generally composed of four major fatty acids in the order; linoleic>oleic> stearic>palmitic with a high content of nutritionally beneficial unsaturated fats (65.6%). All Balanites products can therefore be used to supplement cereal-dominated dryland diets.

8.3 Recommendations

8.3.1 Recommendations for improved management and productivity of Balanites

Based on the findings of this study, the following recommendations are made for improved management and productivity of *Balanites aegyptiaca* in Uganda:

i. There is a need to improve local methods currently used through training community groups on improved harvesting, processing and value addition. Community groups also need to be provided with incentives, such as, village credit schemes and local facilities for processing, storage and value addition.

ii. Ways of ensuring rural people with secure ownership of Balanites and other IFTs should be explored so that they can sustainably manage them and harvest products for their own benefit. District and village community groups need a strong collaboration in enforcing existing by-laws, especially on cutting IFTs and control of bush burning. Effect of annual bush fires on both regenerates and trees could be minimised through adoption of managed early burning, which would be beneficial to both herders and groups dependent on Balanites products.

iii. Integration of Balanites into dryland agroforestry systems in form of scattered, boundary or other appropriate planting arrangement should be promoted in order to sustain the resource base. This also calls for application of farmers''plus' tree selection attributes for leaf and fruit for identification and collection of propagation materials. Appropriate farmer level propagation techniques will be needed to avail farmers with quality planting materials and reduce the long juvenile phase, reported to be seven years.

iv. There is a need to introduce Balanites oil processing in Katakwi district and likewise, communities in Adjumani district should be introduced to Balanites leaf preparation and consumption. This can be achieved through inter-regional exposure visits or training and video documentaries. There is also a need to explore inter-regional trade in Balanites products since different ethnic groups prefer different products.

v. Efforts should be made towards expanding markets for Balanites products beyond sub-regions of production through organising collectors, processors and traders into associations to create economics of scale. This should be backed up with mass awareness creation based on nutritional and medicinal values of Balanites products. Additionally, production of a range of products, such as, jams, juices and alcoholic drinks from fruit pulp and packaging of dry pounded leaves targeting high income urban markets should be explored.

8.3.2 Recommendations for future research

i. A systematic and comprehensive inventory of Balanites should be conducted in other parts of Uganda where it occurs to establish its stocking levels and regeneration capacity.

ii. Detailed study of Balanites fruit yield is needed to determine potential fruit production from various populations.

iii. Impact of leaf harvesting and annual bush fires on the reproductive biology of Balanites, especially in Teso sub-region should be investigated. Studies are also needed to determine the effect of leaf galls and other pests and diseases on the leaf and fruit yield.

iv. Effect of fruit size on pulp content and oil yield should be investigated as a basis for elite germplasm collection for participatory domestication. Furthermore, factors responsible for 'sweetness'- a preferred attribute in both leaves and fruit pulp as well as lack of thorns in branches and twigs should be explored.

v. Effect of pre-boiling on the vitamin content of Balanites leaves should be investigated.

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APPENDICES

Appendix 3.1: Sample questionnaire: Local knowledge on use and management of Balanites in Uganda

Interview date.................................... Name of interviewer.................................District.............................
Sub county.. Parish:... Village::............................

SECTION A: RESPONDENT INFORMATION

1. Household Number/Code					
2. Sex	1. Male	2. Female			
3. Household head	1. Mother	2. Father	3.Child	4. Others (specify):	
4. Age (approximate)	1. >20	2. 20–35	3. 36-50	4. 51– 65	5. > 65
5. Marital status	1. Single	2. Married	3. Divorced	4. Widowed	
6. Number of people in household	Adults:	Youth:	Children:		
7. Education level attained	1. None	2. Primary	3. Secondary	4. Tertiary	
8. Duration settled in the area (yrs)					
9. Place of origin	District:	S/county:	Village:		
10. Tribe	1. Iteso	2. Madi	3. Lugbara	4. Acholi	5. Other.............
11. Major occupation (livelihood source)	1. Farmer	2. Employed	3. Business	3.Livestock keeper	5.Others (specify)
12. Land size (acres)					
13. Main food crops (Ranked)	1.	2.	3.	4.	
14. Main cash crops (Ranked)	1.	2.	3.	4.	
15. Land aquisition	1. Inherited	2. Allocated (Resettled)	3. Bought	4. Borrowed	5. Hired
16. Household annual income (approx)	1. <100,000	2. 300,000-400,000	3. 400,000- 700,000	4. > 700,000	

SECTION B: KNOWLEDGE OF INDIGENOUS AND EXOTIC FRUIT TREES AND VEGETABLES

1. What are your five (5) priority indigenous fruit trees in terms of fruits and vegetables?

Fruit tree name	**Use**	**Vegetable name**	**Use**
1.		1.	
2.		2.	
3.		3.	
4.		4.	
5.		5.	

2. Which of these tree species have you planted?

Indigenous trees planted	**No. planted**	**When planted (Year)**	**Source of planting materials**
1.			
2.			
3.			
4.			
5.			

3. Which of these tree species have you retained on farm?

……………………………………………………………………

4. Which exotic/improved fruit trees have you planted?

Exotic fruit tree planted	**No. planted**	**Source of planting materials**
1.		
2.		
3.		

5. Which green vegetables do you grow in your household?

Vegetable name	Period grown (range of months)	Source of planting materials
1.		
2.		
3.		
4.		
5.		

6. Which green vegetables do you collect from the wild?

Vegetable	When collected (range of months)	Use (1=household 2=Sold 3=Both)
1.		
2.		
3.		
4.		
5.		

7. What major constraints do you face in vegetable growing? (tick those that apply

i. Lack of material (seed) ii. Lack of knowledge on propagation iii. Drought iv. Others ………………………

8. What general constraints do you face in tree growing? (tick those that apply)

i. Lack of seed ii. Lack of seedlings iii. Lack of knowledge on propagation iv. Drought v. Termites vi. Others ...

SECTION C: UTILISATION OF *BALANITES*

1. Give the local names of the following:

English name	**Local name**
a) Balanites tree	
b) Balanites leaves	
c) Balanites fruit	
d) Balanites seed	
f) Balanites oil	

2. What are the three (5) main uses of *Balanites* in your household?

Main use (in order)	**Part used** *1. Leaves 2. Fruits 3. Nuts 4. Others ....*	**Persons using in household** *1. Men 2. Women 3. Children 4. All*	**Period when used** *(Range in months 1 – 12 = Jan-Dec)*	**No. of times used per week** (During use period)
1.				
2.				
3.				

3. What are the other uses of *Balanites* in your household?

Other uses	**Part used** *1. Leaves 2. Fruits 3. Nuts 4. Bark 5. Roots 5. Wood 6. Others (specify)..............*
1.	
2.	
3.	
4.	
5.	

4. What is your favourite Balanites product? 1. Fruits 2. Leaves 3. Oil 5. Others (specify)........................

5. What is the main source of Balanites product (s) 1. On-farm 2. Wild 3. Fallow land 4. Others.........

6. How far is the main source of Balanites from your home? (i) <1 km (ii) 1-2 km (iii) 3-6 km (iv) 7-10 km (v) >10 km

7. How far was the main source located 10 years ago (i) <1 km (ii) 1-2 km (iii) 3-6 km (iv) 7-10 km (v) >10 km

8. What has been the main reason for change in location of Balanites source?

i. Increased demand ii. Harvesting of balanites trees for other uses iii. Land clearance for farming iv. Poor harvesting methods v. Others ....

9. During which period of the year are Balanites products collected?

Part collected/harvested	Duration of collection period *(Range in months 1 – 12)*	Persons who collect *1. Men 2. Women* *3. Children 4. All*	Main pourpose 1. Home consumption 2. Sale 3. Both
1. Leaves			
2. Fruits			
3. Nuts			

10. What is the frequency of collecting Balanites products?

Part collected/harvested	Collection frequency *(No. of times per month)*	Approx. quantity collected per month *(A given measure, e.g. basin, cups – converted to kgs)*
1. Leaves		
2. Fruits		
3. Nuts		

11. How are the Balanites products collected/harvested in your household?

Balanites product	Method of collection/harvesting from on-farm trees 1. After falling on the ground 2. Cutting Branches/twigs 3. Climbing tree 4. Shaking branches on ground 5. Other (specify).................	Method of collection/harvesting from wild trees 1. After falling on the ground 2. Cutting Branches/twigs 3. Climbing tree 4. Shaking branches on ground 5. Other (specify).............................
1. Leaves		
2. Fruits		
3. Nuts		
4. Others.........		

12. If harvested by cutting young branches/twigs, explain why?..

13. What tools are required for harvesting the various products?

Part collected/harvested	Tools required
1. Leaves	
2. Fruits	
3. Nuts	

14. What effect does harvesting by cutting of young branches/twigs have on the Balanites tree?

Attribute	Observable effect 1. Increases 2. Decreases 3. No effect 4. Other (specify).........................
Tree vigour	
Yield of leaves	
Yield of fruits and nuts	
Other (specify).........	

SECTION D: PLANTING AND MANAGEMENT OF BALANITES TREES

1. How do you establish Balanites trees?
i. Planting ii. Retaining natural regeneration iii. Do not grow iv. Others (specify)..........................
2. Which planting material do you use to plant Balanites trees? (i) Seed (ii) Seedlings (iii) Cuttings (iv) Wildlings
3. Where do you get the planting material? [i] Wild [ii] friend, [iii] local nursery [iv] research station
[iv] Other (specify..
4. In which sites (niches) do you normally plant Balanites trees ?
(i) Near home (ii) Farm boundary (iii) Scattered in garden (iv) In a block (v) Other
(specify)..........................
5. In which sites do you normally retain the naturally growing Balanites trees?
(i) Near home (iii) Farm boundary (iii) Scattered in garden (iv) Others
(specify)..
6. What is the effect of the on-farm Balanites trees on agricultural crops?
(i) No effect (ii) Decrease in yield (iii) Increase in yield (iv) Don't know
7. How have you minimised the negative effects of Balanites trees on agricultural crops?
....
8. What major problems/constraints do you encounter in growing Balanites trees? (tick those that apply)
i. Lack of seed ii. Lack of seedlings iii. Lack of knowledge on propagation iv. Drought v. Termites vi. Others ......
9. What could be the possible solutions to overcome the above problems? ....
10. What is your opinion on commercial growing of Balanites trees? (i) Worthwhile (ii) No need (iii) Don't know
11. Who controls access to Balanites trees:
a. In the wild (savanna woodlands)? ....
b. In individual farmer fields?...
c. Around homes?..

12. What indigenous/local management practices are applied to Balanites trees?

Location of trees	Management practice
Wild (savannah woodlands)	
On-farms	
Around homes	
Others (specify).....................	

Codes for management practices: (i) No management ii. Slashing iii. spot weeding iv. Benefits from weeding associated crops v. Pruning vi. Pollarding (vii) Spraying (viii) Bush fires (ix) others specify.....................

14. How many Balanites trees can you conveniently leave on one acre of your agricultural land? ....
13. Who has a right over trees in your household?

Right to: (tick where appropriate)	Man	Woman	Children
Plant trees			
Harvest leaves			
Harvest fruits			
Cut trees			

SECTION E: SELECTION OF HIGH QUALITY *BALANITES* TREES

1. What attributes/characteristics do you use for selecting good quality Balanites trees?

Attribute	Indication of good quality *(a brief description may be used)*
Tree height	
Stem size	
Branches	
Leaves	
Fruits	
Nuts	
Other (specify)..........	

2. Have you been using these good quality attributes for selecting the Balanites tree planting materials?
   1. Yes 2. No
3. Which factors are responsible for determining the good quality of the Balanites tree products?..................
4. Which group of people have a good knowledge for selecting good quality Balanites trees?

(1) Men (2) Women (3) Children (4) All

5. Why is the knowledge of these good quality attributes restricted to the group you have chosen above?

....

6. What would you like to be improved about the Balanites tree?

Characteristics to be improved	Desired state ***(e.g. taller, shorter, bigger, smaller, remain same, more, softer, sweeter, etc ......)***
Tree height	
Stem size	
Branches	
Leaves	
Fruit pulp size	
Fruit pulp taste	
Nut size	
Kernel hardness	
Other features (Specify)...............	

7. How long does Balanites tree take to produce its first fruits? .... years
8. To what duration should Balanites fruiting period to be reduced? ....years

SECTION F: PROCESSING AND MARKETING OF BALANITES PRODUCTS

1. What are the main Balanites products produced in your household?

Product *(Include local name)- oil, leaf vegetable, etc.*	**Who processes** *1. men 2. women 3. children 4.All*

3. Which Balanites products are marketed in this area?

Product *(From one above)*	Marketability within village (1) No market (2)Low (3) moderate (4) High	Marketability outside the village (1) No market (2)Low (3) moderate (4) High

4. Who in your household markets Balanites Products?

Product	Marketing person in a household *1. Men 2. Women 3. Children 4. All*	Approximate quantity marketed per month

7. Where is the market(s) for Balanites products

Product	Name of market (If applicable)	Distance to market place (km)

8. What were the selling prices of Balanites products in the last season?

Product *(include local names derived earlier)*	Unit quantity of measurement	Unit price *(For a given measure)*
Leaves		
Fruits		
Nuts		
Oil		

9. How has the income derived from sale of Balanites products helped your household? ....

10. What are three (3) major constraints to marketing of Balanites products?

Constraint	Possible solution
1.	
2.	
3.	

SECTION G: INSTITUTIONAL CONSTRAINTS AND OPPORTUNITIES

1. What are the constraints to managing and conserving Balanites trees in this village?..
2. Which institutions are currently involved in guiding communities on the management/conservation of fruit trees in this locality?

Traditional institutions	**Government intuitions**	**Civil Society institutions/organisations**

3. What practices were used in the past to management/conserve of Balanites trees in this locality?....................
4. Which government regulations/laws are you aware of regarding the management and conservation of indigenous fruit trees? ....
5. Which by-laws have been put in place in this area to protect Balanites /indigenous fruit trees?...........................
6. What penalties are in place for the offenders?..
7. How effective have the by-lays been in conserving the Balanite trees/other trees in this area?
 (1) Effective (2) Somehow effective (3) Not effective
8. In your opinion what by-laws do you think should be put in place to promote the growing and conservation of Balanites in this locality?
....
9. What opportunities are in this locality that can help in sustainable management and utilisation of Balanites?
....
10. What cultural believes do you attach to Balanites trees in this locality? ....
11. In your opinion, how best can Balanites trees be managed in this locality? ....
12. Any additional comments you feel are important about Balanites? ....

End

Appendix 3.2: Interview guide focus group interviews and key informants

Local knowledge on use and management of *Balanites egyptiaca* in Uganda

1. What are the main indigenous fruit trees in the village?
2. Rank the priority three or five species (pair-wise ranking)
3. Explore reasons for the position of Balanites in the priority list
4. Historical perspective on use and management of Balanites in the village
5. What are the current main uses and other uses?
6. Explore the parts used, persons utilizing then (men, women children), periods in a year when utilized, and frequency of use e.g. per week or month.
7. Availability of the Balanites trees in the village now compared to 10 years ago
8. Any attempts in the village to grow/domesticate Balanites?
9. How is it propagated? Planting or retention on farm
10. What planting materials are used and from which sources?
11. Any constraints to growing of Balanites on farm?
12. What could be done to encourage more planting of Balanites?
13. What management practices are currently applied to Balanites both on-farm and in the wild?
14. What management practices were used in the past for management of Balanites?
15. Who controls access to Balanites trees on farm and in the wild?
16. What is the favourite Balanites product in this village and why?
17. What are the attributes of a good quality Balanites tree for the above product?
18. How are the different Balanites products processed? - Brief description
19. How are raw materials and final products stored?
20. Who does the processing?
21. What is the shelf life of the key products?
22. What are the main challenges/constraints in processing Balanites products?
23. What can be done to improve the processing of Balanites products?
24. Where are the Balanites products markets located? No. and distance from village
25. Explore any marketing chain for Balanites products.
26. How many times in a year do Balanites trees flower and produce fruits in this locality?
27. What are the leafing, flowering, fruiting periods for Balanites trees in this locality?
28. What are the factors that influence the sequence of events you have given above?
29. When are bush fires experienced in the village?
30. What is the effect of bush fires on the Balanites trees?
31. How does grazing affect the regeneration of Balanites in this village?
32. How does cultivation affect regeneration of Balanites in this village?

Appendix 4.1: Data sheet for Balanites tree inventory

District:……………………Sub-county……………………….. Village…………………..…..……Population:………………………..

Data entered by:…………………………… Date:………………………Plot No…………….…… GPS Reading:…………………...

Brief site description:……..

Note: For 100 Balanites treesa ≥ 5 cm dbh in each sample – Use additional datasheets for same plot

Tree No.	GPS Reading (Northings)	GPS Reading (Eastings)	DBH (cm)	Height (Total) (m)	Height (1st Branch) (m)	Crown Diameter (N-S) (m)	Crown Diameter (E-W) (m)	Crown damage (code)*	Pest/disease incidence (code)**

***Crown damage:** 5= No sign of lopping, 4= Only 25% of crown lopped, 3= 50% of the branches lopped , 2 = 75% branches lopped & 1= All branches lopped

****Pest/disease incidence:** 5= Healthy, 4= Only leaves affected, 3= Leaves & branches affected , 2= Leaves, branches & stem affected/starting to dry, and 1= Dry/dead

Appendix 4.2: Field data sheet for assessing regeneration of Balanites

District:........................Sub-county.............................Village.........................Population:..............................

Data entered by:.................................Date:............................Plot No..............................Sub-plot...................

Brief site description:...

No. of Balanites saplings in units of 40 x 40 m					Total
C unit	N unit	S unit	E unit	W unit	
Regeneration mode		Tally			Total
Seed					
Coppice					
No. of Balanites seedlings in sub-units of 20x 20m (use two sub-units per unit below - Tally)					Total
C unit	N unit	S unit	E unit	W unit	
1.					
2.					
Regeneration mode		Tally			Total
Seed					
Coppice					

<u>**Note:**</u>
Plot size = 200 x 200 m, Divide into forty sub-plots of 40 x 40m units.
Saplings *< 5 cm DBH ≥ 1m tall; select 5 units of 40 x 40 m (C, N,S,W&E)*
Seedlings *< 1 m tall; use 20 sub-units of 20 x 20m (nested within the five 40 x 40 m sub-units)*

Appendix 4.3: Field data sheet for recording other tree species associated with Balanites

District:........................Sub-county........................... Village.........................Population:...........................

Data entered by:... Date:..................................Plot No....................................

Brief site description:..

Note: For a plot of 100 Balanites trees, only enumerate other tree species that are ≥ 5 cm

Tree No.	Species name or local name	Tally	Total

Appendix 4. 4: Areas (parishes) where Balanites is found in Uganda

Parish	Parish
Aakum	Legu
Acowa	Lia
Agu	Loa
Airabit	Lokoreto
Ajeleik	Magoro
Ajugopi	Malera
Akisa	Nyeu,
Akum	Obalanga
Akwamor	Odoot
Aleles	Olilim
Aliakameri	Omi
Alimu	Omodoi
Angolebwal	Ongongoja
Apeitolim	Orwamuge
Arinyapi	Oyuwi-Ukusijoni
Awach	Pachara
Awuvu	Pakwero
Bugondo	Pakwinyo
Butiaba	Palorinya
Dufele-indridri	Pawor
Dzaipi	Ragem
Eramva	Toroma
Ewanga	Waka
Gogonyo	Akimenga - Serere
Iriiri	Kamawat
Kamaiba	Loleto
Kapir	Lopuyo
Katakwi	Kacheri
Kateta	Loputui
Katine	Achocor
Kobuin	Mogoth
Kwili	Lopei
Laropi	

Appendix 4.5: Basic soil properties in Balanites growing sites in Adjumani and Katakwi districts, Uganda

Site[1]-Horizon[2]	pH	N	O.M	P	K	Ca	Mg	Na
		(%)	(%)	(ppm)	(me/100g)	(me/100g)	(me/100g)	(me/100g)
AD-H1	5.3	0.06	0.66	*64.69	0.43	5.23	1.31	0.05
DZ-H1	5.1	0.07	1.58	9.86	0.16	4.68	1.17	0.17
KA-H1	5.3	0.05	1.08	0.73	0.08	2.75	0.69	0.5
NG-H1	4.6	0.04	0.83	0.73	0.04	1.38	0.35	0.16
Mean	**5.08**	**0.06**	**1.04**	**3.77**	**0.18**	**3.51**	**0.88**	**0.22**
AD-H2	5.4	0.06	1.08	*119.97	0.45	5.5	1.38	0.06
DZ-H2	5.5	0.08	1.25	1.02	0.33	6.33	1.58	0.1
KA-H2	5.6	0.04	0.91	0.15	0.33	6.88	1.72	0.96
NG-H2	4.6	0.03	0.5	0.58	0.06	2.2	0.55	0.4
Mean	**5.28**	**0.05**	**0.94**	**0.58**	**0.29**	**5.23**	**1.31**	**0.38**
AD-H3	5.9	0.04	0.5	*121.83	0.63	4.95	1.24	0.06
DZ-H3	6.1	0.05	1.16	0.58	0.86	6.33	1.58	0.09
KA-H3	6	0.03	0.33	0.29	0.27	4.95	1.24	0.8
NG-H3	5	0.05	0.83	0.29	0.22	5.78	1.45	1.24
Mean	**5.75**	**0.04**	**0.71**	**0.39**	**0.50**	**5.50**	**1.38**	**0.55**
AD-H4	6.1	0.03	0.33	*144.58	0.63	6.88	1.72	0.1
DZ-H4	6.6	0.06	0.66	0.15	0.93	7.7	1.93	0.09
KA-H4	6.7	0.03	0.25	1.31	0.32	8.53	2.13	1.24
NG-H4	6.7	0.04	0.5	0.29	0.35	9.63	2.41	1.91
Mean	**6.53**	**0.04**	**0.44**	**0.58**	**0.56**	**8.19**	**2.05**	**0.84**
Overall mean**	**5.66** (0.64)	**0.05** (0.01)	**0.78** (0.27)	**1.33** (1.63)	**0.38** (0.18)	**5.61** (1.93)	**1.40** (0.48)	**0.50** (0.26)

[1]*AD = Adropi, DZ= Dzaipi, KA= Katakwi, NG= Ngariam*
[2]*H1 to H4 = Soil horizons 1 – 4 in a particular profile pit*
**Values of phosphorus in the AD samples were exceptionally high thus considered outliers and excluded from computations of the mean.*
***Values in parentheses are standard deviations of the mean*
[Critical limits - low if less than: pH - 5.5, OM - 6.0%, N – 0.2 %, P – 15 me/100g, Ca – 4.0 me/100g, K –0.2, Mg – 0.5, Na – 1.0]

Appendix 5.1: Sample of phenological monitoring data sheet

District:.......................................Sub-county:............................Village:........................ Land use:...

Tree No:...GPS Reading..

DBH.. Height. .... Crown diameter.....................

Monitoring date	Definition of phenological events (indicate proportion of the phase in brackets (1= <25%; 2=25%; 3= 50%; 4= 75; 5= 80+)			Remarks- e.g. Incidence of bush fires, etc
	Leafing	Flowering	Fruiting	

Phenological codes and associated events

Code	*Leafing*	*Flowering*	*Fruiting*
1	*Flushing*	*Initiation/flower buds*	*Fruit setting*
2	*New leaf*	*Open flowers*	*Fully developed fruits*
3	*Shedding*	*Peak flowering*	*Ripening & fall*
4	*End of shedding*	*End of flowering*	*End of fruit fall*

Appendix 5.2: Proportions of B. aegyptiaca fruit

1 kg batches	Number of fruits	Fruit component proportions (%) Shell	Pulp	Stone	Kernel
1	127	17.76	22.41	46.53	12.64
2	132	17.45	22.60	46.63	12.40
3	121	17.20	22.85	46.61	11.90
4	129	17.20	20.47	48.38	12.13
5	126	17.62	23.59	47.52	12.66
6	134	17.56	23.01	47.28	12.71
7	132	17.46	22.46	47.55	12.73
8	135	16.95	22.29	46.95	13.09
9	138	17.13	22.30	46.97	12.35
10	127	16.76	22.30	47.79	11.26
Mean	130(5)	17.31(0.3)	22.43(0.8)	47.22(0.6)	12.39(0.5)

For each of the batches (1-10), 1kg of fresh fruits was used as a starting sample. Figures in parentheses as standard deviations

Appendix 5.3: Balanites fruit yield in Katakwi and Adjumani districts, Uganda

District	Tree No.	Land use	DBH (cm)	CD (m)	Height (m)	Fruit yield (kg)	No. fruit/kg	No. fruits/tree
Katakwi	1	Wild	38.2	5.15	6.2	14.25	128	1,824
Katakwi	2	Wild	43.0	10.4	14.8	12.0	130	1,560
Katakwi	3	Wild	40.4	12.6	11.8	9.0	135	1,215
		Mean	**40.5**	**9.4**	**10.9**	**11.8**	**131**	**1,533**
Katakwi	4	Farm	44.2	10.2	10.2	13.5	133	1,796
Katakwi	5	Farm	21.0	7.4	8.3	9.8	127	1,245
Katakwi	6	Farm	56.6	11.9	10.0	22.5	129	2,903
		Mean	**40.6**	**9.8**	**9.5**	**15.3**	**130**	**1,981**
Adjumani	7	Wild	48.0	8.9	8.8	49.5	117	5,792
Adjumani	8	Wild	59.8	13.8	11.9	50.4	130	6,552
Adjumani	9	Wild	65.5	13.7	12.2	86.1	128	11,021
		Mean	**57.8**	**12.1**	**11.0**	**62.0**	**125**	**7,788**
Adjumani	10	Farm	40.5	11.4	13.2	31.2	125	3,900
Adjumani	11	Farm	60.5	14.1	10.0	73.2	127	9,296
Adjumani	12	Farm	57.3	12.0	13.0	27.9	126	3,515
		Mean	**52.7**	**12.5**	**12.1**	**44.1**	**126**	**5,571**

Appendix 6.1: Guiding questions for Rapid Market Appraisal (RMA) -Marketing of *Balanites aegyptiaca* products in Uganda

Variable	Components
Market structure and institutional arrangements	• Number of sellers and buyers • Product differentiation including existing pre-sale activities e.g. grades, assortments, processed products • Existence and role of contracts and co-operatives if any • Central government involvement in markets of *B. aegyptiaca* through rules, by-laws and regulations on prices, etc. • Rates, taxes, subsidies, barns, and licenses • Local government and traditional leadership influence on *B. aegyptiaca* marketing through taboos and customary laws • Property and user rights of *B. aegyptiaca* products and trees • Marketing stages involved (from the source to the end user)
Market conduct and performance	• Activities on assembly, transportation and distribution • Perishability, storage, handling, processing, packaging • Trend of prices at farm-gate, wholesale and retail levels • Price determination and mode of payment at all marketing stages • Price variations across markets • Quality price differentials (prices of graded as against un-graded) • Close substitutes and complements of *B. aegyptiaca* products • Sources, uses and distribution of marketing information • Marketing costs and selling prices at all market levels
Buyers behaviour	• Exotic and indigenous fruits consumed, sources, habit of consuming *B. aegyptiaca*, change of habit over the years, frequency of consumption, amounts consumed, attributes of indigenous fruits preferred
Market infrastructure	• Market location, size and change of the market size over the years • Storage facilities • Transport, communication, electricity and water supply
Constraints and opportunities	• Constraints, opportunities, comments and suggestions for improvement at different levels of the market chain

Appendix 6.2: Marketing of *Balanites aegyptiaca* products in Uganda: Sample questionnaire for traders' survey

Date... Interviewer..Qn. code........................

A: Market description

1. Market name :...District.............................. Parish.....................
2. Market type (1) Rural (2) Urban center
2. Frequency of marketing operations? (1) Daily (2) Few days a week (List.................................)
   (3) Once a week (name the day ....)
3. Estimated number of people per market day ....

B. Respondent information

1. Sex (1) Male (2) Female
2. Age (years) (1) < 20 (2) 20-35 (3) 36 – 50 (4) > 50
3. Marital status (1) Single (2) Married (3) Separated (4) Divorced (5) Widowed
4. Education level (1) No formal education (2) Primary (3) Secondary (4) Tertiary
5. How many people are in your household? (a) Children (under 18 years) ....Adults.............
6. To which tribe do you belong? (1) Iteso (2) Madi (3) Lugbar (4) Acholi (5) Other......................
7. Household annual income (approx) (1) <200,000 (2) 200,000-400,000 (3) >400,000
8. Level of trading activity (1) Retail (2) Wholesale (3) Both
9. Balanites product traded (1) Fruits (2) Oil (3) leaves

C. Buying and selling

1. Which Balanites products do you normally sell **(Tick)** (1) fruits (2) leaves (3) oil (4) other........
2. How do you obtained the Balanites product you sell (1) Collect (2) Buy
2. If collected, from where do you collect them? (1) Wild (2) Farm (3) Other...................
3. If bought, where do you buy it from? (1) Homes (2) Settlement camp (3) Village markets
   (4) Trading center (5) Urban market
4. If bought, who are the major sellers to you (1) Men (2) Women (3) Boys (4) Girls (5)Elderly
5. Apart from Balanites, which other indigenous/local products do you usually sell?....................
6. When did you start selling indigenous/local products? (year)..

7. At what prices (average) do you buy Balanites fruits/oil/leaves per unit?

Unit and Product	Average buying price (UGX)		
	2006	2007	2008
0.5kg of leaves (small plate)			
0.5kg of fruits (cup)			
0.5 litre of oil (bottle)			

7. Apart from this market where else do you normally sell Balantes products?.................................

Product	Name of other Market (s)	Distance (km) from your residence	Quantity sold 2007 Indicate unit (kg or ltrs)	Price per kg	Demand 2006-2008 1=increased 2=decreased 3=constant
Fruits					
Oil					
Leaves					

8. Who are your main buyers/customers?

Product	**Main buyer (tick)**				
	1= Men	*2= Women*	*3 = Boys*	*4=Girls*	*5=Elderly*
Fruits					
Oil					
Leaves					

9. Which other traders do you sell to? (1) Middlemen (2) Retailers (3) Wholesalers (4) Others.............

D. Pricing and pre-sale activities

1. At what prices (average) do you sell the following Balanites products per unit?

Unit and Product	Average price (UGX)		
	2006	2007	2008
0.5kg of leaves (small plate)			
0.5kg of fruits (cup)			
0.5 litre of oil (bottle)			

Note: Fill in the appropriate line

2. What is the allowable quantity of Balanites product a customer can freely taste before buying? Leaves (No.) ....; Fruits (No.).....................and Oil.................. mls.

3. Do you normally sell all the fruits/leaves you have bought/collected during peak season?

1. Yes 2. No

4. Apart from cash, which other forms of payment do you normally charge for Balanites products? (1) Food (2) Others ....

5. Do you sell some of the products on credit? 1. Yes 2. No

If NO GO TO 8

6. If yes, what percent of your sells do you sell on credit? (1) <10% (2) 10-30% (3) 32-50% (4) >50%

7. When crediting, do you charge higher prices, interest or neither?

(1) Higher prices (2) Interest (3) Neither (4) Others...

8. How do you determine prices of the fruits/oil/leaves you sell? (1) Previous season price

(2) Total cost (3) Other market information (4) Demand (5) Others...

9. Do you know the price of this product in other areas/regions? 1. Yes 2. No

10. Do you conduct any pre-sale activity on the product? 1. Yes 2. No

IF NO GO TO 13

11. If yes, which ones? (1) Washing (2) Sorting (3) Grading (4) Packing (5) Others.....................

12. Why do you practice those pre-sale activities? (1) Attract customers (2) Earn more money (3) Store for long (4) Other ....

13. If Not, why don't you practice pre-sale activities? (1) Not necessary (2) Time wasting

(3) No added value (4) others ....

E. Storage, transport and shelf life

1. Do you store the following balanites products for sell later in the season? **(Tick)**

(1) Fruits	(2) Oil	(3) leaves

2. If yes, do you think it pays to store them during peak season and sell later on? 1. Yes 2. No

3. What storage materials/facilities do you use for storage of Balanites products

Product	Storage materials/facilities E.g. sacks, bottles, etc.
Ripe fruits	
Oil	
Uncooked leaves	
Cooked leaves	

4. For how long can Balanites products be safely stored?

Product/unit of time	Shelf life (duration before getting spoilt)
Ripe fruits (days)	
Oil (Months)	
Uncooked leaves (days)	
Cooked leaves (days)	

5. How can the shelf life of Balanites products be increased?

Product	One major way to increase shelf life
Ripe fruits	
Oil	
Uncooked leaves	
Cooked leaves	

6. Which problems do you experience in storage?..

7. Which transport means do you use to the selling point? (1) Bicycle (2) Motorcycle (3) Vehicle

8. How much do you pay to transport 10kg (Basin -fruit/leaves) or 10 ltrs (oil) to the market? ....
9. Do you experience any other transport problems? 1. Yes 2. No
10. If yes, which problems? (1) Delays (2) Damage (3) Other ....

F. Market information, market expenses and revenue

1. Do you get any market information in advance? 1. Yes 2. No
2. If yes, which information do you get (1) Prices (2) Demand (3) No. of traders in market (4) Other ....
3. Which expenses do you pay at the market? (1) Market fees (2) Storage fee (3) Others ....
4. How much in total do you pay as market expenses per day? UGX...
5. How much in total do you earn in sales per market day? UGX..
6. How do you use the money obtained from selling Balanites fruits/oil/leaves? (1) Consumables (food) (2) Basic non consumables-soap, paraffin etc (3) Education (4) Health (5) Other.................
7. Is selling of Balanites fruits/oil/leaves your only occupation throughout the year? 1. Yes 2. No
8. If no, which other business are you involved in? (1) Agric produce (2) Livestock (3) Alcohol (4) Shop (5) Other...
9. Which percentage of your time do you spend in selling Balanites products during their season? (1) <10% (2) 10-30% (3) 32-50% (4) >50%
10. Do you export Balanites products? (1) Fruits (2) Oil (3) Leaves
11. If yes, where? (1) Neighbouring country (name...........................) (3) Others............................

G. Perceptions and opinions

1. What is your perception on trade in Balanites products? (1) Worthwhile (2) Not worthwhile
2. What is your perception on availability of Balanites products (1) Abundant (2) Scarce (3) Don't know
3. What are the major two demand and supply opportunities for Balanites products?

Product	Demand opportunities	Supply opportunities
Fruits	1.	1.
	2.	2.
Oil	1.	1.
	2.	2.
Leaves	1.	1.
	2.	2.

4. What challenges/constraints do you face in marketing Balanites fruits/oil/leaves
   - (i) Un-organized market structure (No fixed market location)
   - (ii) Low supply of the fruits/oil/leaves in some seasons
   - (iii) Limited market information
   - (iv) Limited knowledge of nutritional uses of products
   - (v) Lack of appropriate technology for value addition to products
   - (vi) Others ....

End

Appendix 6.3: Marketing of Balanites products in Uganda: Sample questionnaire for buyers' formal survey

Date.. Interviewer...Qn. code............

A. Respondent information

1. Sex (1) Male (2) Female
2. Age (years) (1) < 20 (2) 20-40 (3) > 40
3. Marital status (1) Single (2) Married (3) Separated (4) Divorced (5) Widowed
4. Education level (1) No formal education (2) Primary (3) Secondary (4) Tertiary
5. How many people are in your household? (a) Children (under 18 years) ....Adults............
6. To which tribe do you belong? (1) Iteso (2) Madi (3) Lugbar (4) Acholi (5) Other..................
7. What is your estimated income per year/month/day? (1) < 200,000 (2) 200,000-400,000 (3) > 400,000.

B. Consumption of Balanites products

1. Do you usually consume the following Balanites products?

Product	Consume?	How do you get them? (Tick)		
	1=Yes, 2=No	1 =Own collection	2 =Given for free	3 = Buy
Fruit				
Oil				
Leaves				

2. If you don't consume any of the above why? ....
(If not consumed go to question 7 on...., If consumed continue from question 3)

3. If the answer to any of the above is yes, why do you consume them?

Product	Reasons for use (Tick)					
	As a snack	Satisfy hunger	Said to be nutritious	Other people are consuming	My ancestors used them	Other reason? ....
Fruit						
Oil						
Leaves						

If bought continue from question 4 - 6, If not bought, go to question 7.
BUYERS ONLY

4. If bought from the markets, why do you buy them?

1 Because they are cheaper than exotic ones 2. Just because they are available in markets
3. Because other people are buying 4. Others (specify)..

5. When *Balanites* was in season (2007 season), how frequently in a week did you buy its products?

Product	**Number of times bought in a week** *1= Daily 2= 2-3* *3=Once times 4= Not sure*	Quantity (kg) bought per week (approx)
Fruit		
Oil		
Leaves		

6. When buying *Balanites* fruits/oil/leaves, which of the following attributes/characteristics do you, consider important?

Characteristic/ attribute	**Consider** *1= considered* *2= not considered*	**Can you rank them** *1. Very important, 2. Somewhat important,* *3. Not important, 4. No answer/not sure*
Size		
Colour		
Taste		
Price		
Cleanliness		
Appearance		
Sorting		
Grading		
Parking		

7. Which products are sold in this area as substitutes to indigenous products?

Product	**Substitutes** (List the major two in each case)
Fruit	1.
	2.
Oil	1.
	2.
Leaves	1.
	2.

8. Do you agree with the following statements?

Regardless of taste, I would buy Balanites products:

Statement	Level of agreement/disagreement					
	Strongly Agree	*Agree*	*Partly Agree/ Disagree*	*Don't Agree*	*Strongly Disagree*	*No Answer*
(a) Fruits						
Big sized fruits as against small sized fruits						
Yellowish fruits as against Brownish ones						
Packed fruits as against un-packed ones						
Sorted fruits as against un-sorted ones						
Graded fruits as against un-graded ones						
(b) Oil						
Yellowish oil as opposed to blackish oil						
Oil packed in transparent container						

opposed to that packed in opaque (dark) container						
Oil processed by local method (roasting and boiling) opposed to one processed by pressing using some machine						
(c) Leaves						
Black leaves as opposed to yellowish leaves						
Cooked leaves as opposed to raw ones						
Dried, crushed & packed leaf powder as opposed to fresh un-packed leaves						

9. During this season (2008), which prices (UGX) will you consider normal (average), cheap and expensive for the following quantities of Balanites products?

Qty/Product/Unit used	Normal price (UGX)	Cheap price (UGX)	Expensive price (UGX)
0.5kg of leaves (small plate)			
1kg of leaves (big plate)			
0.5kg of fruits (cup)			
0.5 litre of oil (bottle)			

10. How likely will you buy these products at the expensive price you have mentioned above?

Qty/Product/Unit used	Expensive price (UGX) from above	**Willingness to buy** *1. I will definitely buy 2. I will probably buy 3. I Might or might not buy 4. I will probably not buy* *5. I will definitely not buy*
0.5kg of leaves (small plate)		
1kg of leaves (big plate)		
0.5kg of fruits (cup)		
0.5 litre of oil (bottle)		

10. Do you agree with the following opinions?

Statement	Level of agreement/disagreement					
	Strongly Agree	*Agree*	*Partly Agree/ Disagree*	*Don't Agree*	*Strongly Disagree*	*No Answer*
(a) Fruits						
Traders should continue selling Balanites fruits						
Selling of Balanites fruits will improve rural livelihoods						
Sensitisation is important to improving marketing of Balanites fruits						
Balanites fruits should be sold in all markets (village and urban)						
Balanites fruits should not be sold - God given						
Good quality Balanites trees should be planted to increase fruit supply						
Children and pregnant women should be encouraged to consume Balanites fruits for health reasons						

All people should use Balanites fruits for health reasons						
Exotic fruits are more beneficial for our health than indigenous fruits						
(b) Oil						
Traders should continue selling Balanites oil						
Selling of Balanites oil will improve rural livelihoods						
Advertisement is important to improving marketing of Balanites oil						
Balanites oil should be sold in all markets (village and urban)						
Good quality Balanites trees should be planted to increase oil production						
Factory refined oils are more beneficial for our health than locally made ones						
All people need to use Balanites oil for health reasons						
(c) Leaves						
Traders should continue selling Balanites leaves						
Organized sale of Balanites leaves will improve rural livelihoods						
Sensitisation is important to improving marketing of Balanites leaves						
Balanites leaves should be sold in all markets						
Balanites leaves should not be sold - God given						
Good quality Balanites trees should be planted to increase leaf supply						
Children and pregnant women should be encouraged to consume Balanites leaves for health reasons						
All people should use Balanites leaves for health reasons						
Exotic vegetables like...are more beneficial for our health than indigenous ones						

Note: only fill in the appropriate section only.

11. What would you like to be improved in order for you to enjoy Balanites products?

Product	**Required improvement** (List the major two in each case)
Fruit	1.
	2.
Oil	1.
	2.
Leaves	1.
	2.

End

Appendix 6.4: Marketing of Balanites products in Uganda: Policy Assessment Questionnaire

Date............................ Interviewer.......................... District.......................... Qn. Code.............

A. Respondent information

1. Title/Designation..
2. Administrative level (1) District (2) Sub-county (3) Village
3. Sex (1) Male (2) Female
4. Age (years) (1) < 20 (2) 20-40 (3) > 40
5. Education level (1) No formal education (2) Primary (3) Secondary (4) Tertiary

B. Market Issues

1. Which Balanites products are traded in this area? **(Tick)** (1) fruits (2) leaves (3) oil

2. Are there any regulations with respect to:

(i). Indigenous Fruit Trees 1. Yes 2. No

If yes, what do they say? ....

(ii). Collection of indigenous fruits 1. Yes 2. No

If yes, what do they say? ....

(iii). Sale of indigenous fruits 1. Yes 2. No

If yes, what do they say? ....

(iv). Planting of indigenous fruits trees 1. Yes 2. No

If yes, what do they say? ....

IF THE ANSWER TO ANY OF (i – iv) IS YES THEN CONTINUE WITH QUESTION 3, IF NO TO ALL GO TO QUESTION 18.

3. Are there any objectives of such regulations? 1. Yes 2. No

If yes, which ones?...

4. Are there any effects of the regulations at the local level? 1. Yes 2. No

If yes, which effects?..

5. Who is responsible for enforcing/implementing the regulations?...

6. Is there any problem in making people to obey the regulations? 1. Yes 2. No

7. What will happen if someone breaks the law? ....

8. Do they pay fines? 1. Yes 2. No

9. If yes, which sort of fines?

Type of fine	Which law? e.g. cutting a tree?, selling IFs?

10. Who set the fines?..

11. How are they determined?..

12. Do people pay the fines? 1. Yes 2. No

13. Who collects the fines? (1) Special local committees (2) LCs (3) Local government chiefs (4)other................

14. Which steps are to be taken for those who don't pay?..

15. Does the district council help in enforcing the regulations? 1. Yes 2. No

16. If yes, how?...

17. If No, why?..

18. What is your perception on trade in Balanites products (1) Worthwhile (2) Not worthwhile

19. What is your perception on availability of Balanites trees (1) Abundant (2) Scarce (3) Don't know

20. What challenges/constraints do sellers face in marketing Balanites Products?
    (i) Un-organized market structure (No fixed market location)
    (ii) Low supply of the products
    (iii) Limited market information
    (iv) Limited knowledge of nutritional uses of products by consumers
    (v) Lack of appropriate technology for value addition to products

21. To what extent do you agree with the following statements?

In order to promote or develop the marketing of indigenous tree products especially fruits, the following should be done;

Statement	Level of agreement/disagreement **(Tick)**					
	Strongly Agree	*Agree*	*Partly Agree/ Disagree*	*Don't Agree*	*Strongly Disagree*	*No Answer*
Farmers should plant Balanites or other IFTs for commercial purposes						
Establish groups which will collect, process and sell fruits & other products						
Issue licenses to individuals and groups who collect, process & sell fruits and other products						
Support farmers to plant selected indigenous trees for commercial purposes						

22. What are your personal opinion about the selling of indigenous fruits and vegetables?...........

End

Appendix 7.1: Nutritional content of Balanites leaves, flowers and fruit pulp

Sample	*Fat (%)*	*Cp (%)*	*K Mg/g)*	*Na (mg/g)*	*Mg (mg/g)*	*Cu (µg/g)*	*Mn (µg/g)*	*Zn (µg/g)*	*Fe (µg/g)*	*Tanins (mg/g)*
leaff	2.119	14.046	2.267	0.316	0.14	25.9	73.1	17.7	458.3	0.787
leaff	2.097	15.773	2.321	0.246	0.14	26.4	74.3	42.8	446.1	0.754
leaff	1.977	12.021	2.795	0.313	0.12	23.1	55.7	35.4	442.8	0.125
leaff	1.834	12.084	2.692	0.299	0.14	23.1	52.6	37.9	450.2	0.173
leaff	2.116	16.716	2.190	0.433	0.13	24.8	89.9	53.0	438.6	0.150
leaff	1.980	14.803	2.490	0.349	0.14	25.6	89.9	51.6	383.5	0.047
leafc	2.948	16.718	1.161	0.434	0.12	25.9	62.7	37.7	538.3	0.032
leafc	2.586	16.914	1.143	0.512	0.12	24.2	68.0	52.6	426.8	0.042
leafc	2.689	18.068	1.575	0.226	0.13	25.9	41.3	48.9	398.7	0.161
leafc	2.510	18.661	1.537	0.412	0.12	24.3	48.9	37.3	485.2	0.087
leafc	1.903	17.111	1.079	0.389	0.13	25.8	83.2	39.7	362.0	0.253
leafc	1.853	16.024	1.170	0.438	0.12	23.4	64.9	36.7	351.3	0.210
leafmkt	1.731	18.541	0.984	0.361	0.14	41.0	60.2	59.8	683	0.067
leafmkt	1.703	17.818	1.060	0.376	0.14	41.0	65.9	63.2	503.5	0.042
leafmkt	2.026	17.598	1.686	0.129	0.13	25.3	81.5	49.7	427.8	0.080
leafmkt	1.980	15.394	1.575	0.328	0.14	13.7	55.0	38.0	230.8	0.079
leafmkt	2.364	13.830	0.964	0.460	0.12	39.6	63.7	47.3	547.3	0.044
leafmkt	2.216	14.992	0.992	0.539	0.12	13.2	53.1	42.8	445.9	0.055
flower	2.586	19.734	2.773	0.204	0.12	24.2	48.6	10.3	464.3	0.264
flower	2.890	20.194	2.961	0.265	0.11	22.3	42.0	11.2	480.0	0.109
katplp	0.220	4.558	2.933	0.195	0.12	26.6	32.2	25.0	409.4	0.462
katplp	0.383	4.094	2.824	0.019	0.09	26.6	32.2	25.0	409.4	0.499
katplp	0.538	4.799	2.550	0.252	0.08	21.0	25.3	23.3	402.9	0.606
katplp	0.584	4.701	2.536	0.183	0.08	26.6	21.4	40.9	511.9	0.843
adjplp	0.249	6.583	3.060	0.442	0.11	15.4	37.2	28.9	449.3	1.779
adjplp	0.284	5.173	3.278	0.307	0.09	12.7	40.7	30.2	641.7	1.550
adjplp	0.351	6.024	2.802	0.246	0.06	13.3	34.0	26.1	442.6	1.196
adjplp	0.333	6.259	2.796	0.284	0.07	13.7	31.0	24.7	442.1	1.813
mortplp	0.381	4.421	2.285	0.253	0.08	22.5	32.1	36.6	623.6	0.430
mortplp	0.372	4.626	2.087	0.172	0.08	20.3	24.5	27.3	418.2	0.638
mortplp	0.377	6.274	2.689	0.210	0.05	15.2	33.0	28.1	409.0	1.479
mortplp	0.342	7.241	2.851	0.240	0.08	13.1	31.5	25.6	452.0	1.308

Leave and fruit sample were taken only from Katakwi district – where they were widely utilized
Leaff = fresh leaves
Leafb = boiled leaves
Leafmkt = leaves sold in local market
Katplp = fruit pulp from Katakwi
Adjplp = fruit pulp from Adjumani
Mortplp = fruit pulp from Moroto